**Projects, Management, and Protean Times:
Engineering Enterprise in the United States, 1870-1960**

by

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Submitted to the Program in Science, Technology, and Society
in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy in the History and Social Study of Science and Technology
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Abstract

In this dissertation, I trace methods for organizing skilled workers engaged in creative, limited-term projects in the United States between the nineteenth century and the 1950s. Examining eras of system building in technical fields—civil engineering in the nineteenth century, laboratory administration in the 1910s and 1920s, aircraft design in the 1930s, and electronics in the 1950s—I show that recent discourse on the management of innovation and change is a manifestation of a cyclically recurring conversation. This story complicates prevalent views of management theory and practice before World War II by recovering a thread obscured by emphasis on the organization of integrated, divisional companies and operative labor within them.

Applying ideas from recent work in organization studies to distill common aspects of the management problems and labor processes individuals have confronted and theorized, I find common patterns: managers of construction firms, engineering departments, and research laboratories have again and again theorized the fast-moving, knowledge-intensive, relational organization, doing so long before these terms were available. Such thinking has been driven both by practical needs and because external pressures have forced explanation of seemingly uncontrolled, irrational work.

Practically, the transferability of management techniques among settings such as construction and research has reflected kinships between labor and communication processes: each has involved skilled workers producing complex artifacts in uncertain physical, technical, and social environments. The need to explain such work, though, has been as much about external representation as internal control. From origins in government oversight of appropriations and military use of *esprit de corps* to cohere organizations under stress, tools used to manage project-based enterprises have been applied in response to the speed, scale, and complexity of the work itself. At the same time, engineers have explained the management of their work to deflect pressures to apply the logics of factory production and Taylorist scientific management to the organization of skilled labor. As explanations of the differences between building and operating and as delineations of points and terms of physical and cultural contact, representations of engineering work in schedules, budgets, organization charts, and narratives have both controlled and insulated work.

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Preface and Acknowledgements

This is not the dissertation I intended it to be. When I started this study, it was with the working title, "A History of Project Management, 1940–1970." As I saw it then, this would be a neatly defined look at the development of techniques for organizing large technical projects during World War II and the Cold War. My work would complement recent studies of operations research, systems analysis, and other mid-twentieth century applications of engineering science to management problems. From my initial literature search, I believed that project management was a recent phenomenon with an origin and lineage in the unprecedented complexity of military projects during the 1940s and after. These qualities would make it a tidy dissertation. Filling a niche in a developing literature, I could work with records of the large government projects that had given rise to this new kind of management.

Further research unraveled my preconceptions. As I dug, I found nagging references to earlier precedents. The term 'project management' quickly proved to be a red herring, pulled across my path by its familiarity and relatively recent popularization. As I read through dusty engineering journals, descriptions of the positions of the 'project engineer' and the 'project office' appeared further and further back. Terms such as 'case,' 'job,' and 'problem' often appeared where 'project' would appear in today's usage. Moreover, I found these words used in less and less exceptional circumstances. Having at first extended my research to include big civil works such as the Hoover Dam and the Panama Canal, I soon found similar ideas associated with modest construction jobs of decades earlier. Making the story still more complicated, it was not just engineers who talked about these issues. I found similar discussions associated with a broad spectrum of creative occupations—from construction contracting to film making to industrial research.

Most unexpectedly, I stumbled on articles in which engineers, accountants, and managers explicitly theorized organizational forms that would today be called "post-modern" or "neo-industrial." Explaining problems associated with getting their work done, individuals in the late nineteenth and early twentieth century raised issues close to those that can be found in current literature on the management of creative work—issues such as organizing for flexibility, speed, team coherence, and "brain work." But unlike evidence of formal project-based contracting and accounting practices, which I could find in the earliest efforts to control government appropriations in the United States and still further back in British and French precedents, these theoretical ponderings grew less frequent as I worked backwards. Having decided to limit my scope to the organization of engineering and scientific work in the United States, I slowly perceived a dynamic to these explanations.

The speed, scale, and complexity of technical projects had increased over the 1800s and 1900s and had driven formalization of working relationships and the application of ever more elaborate management systems to engineering work, but basic logics stayed constant. Whether in laying track, designing aircraft, or putting together computers, engineering and research management was always about disaggregating and then integrating work carried out by skilled, at least partly self-directed individuals and groups. More clearly new toward the end of the nineteenth century was a need to explain the organization of such irregular tasks. Some of the theorizing I found had evident practical motivations: coping with new technologies and new working relationships, and interested in professional self-definition, individuals wrote about how they did their jobs to share how-to knowledge and participate in occupational communities. But there was a further, defensive aspect to much of the evidence I gathered. Against a developing science of machine regulation and factory operation, most obviously in the form of Taylorism and scientific management, organizers of creative work

had had to explain how they went about managing irregular, often inscrutable tasks. Pressures to drive out variance in the interest of efficiency and system appeared in various guises—after scientific management in the 1910s came mass production in the 1920s, Keynesian economics in the 1930s, and automation in the 1950s—but each renewed a basic opposition between building and operating.

In response to these recognitions, I shifted both the nature and the object of this study. Instead of a detailed historical study of a few decades, I pursued a broader, more sociologically minded consideration of how, why, and when the management of creative, system-defining work has mattered. I downplayed the huge undertakings that had seemed the natural objects of my study, considering the stories of the Panama Canal and the Manhattan Project as equals to long-forgotten accounts of much less awe-inspiring projects. Attention to modest, seemingly mundane projects allowed an easy debunking of some of the exceptionalism and managerial heroic attached to big, “unprecedented” undertakings. More importantly, this shift forced me to find new bases for structuring my study, which in turn led me to think about patterns and connections over time.

The downside of this changed focus was that the topic grew beyond anything I could hope to tackle in a dissertation. There are too many jumps in time and space to make this a coherent, richly peopled history. At the same time, faced with shifts in language and context, I have not yet attempted to provide consistent measures of the phenomena I observe. Instead I offer excerpts from half-heard conversations, filtered by my efforts to understand why people said what they did and how and why they used the tools they chose. The patterns I suggest are based on understanding developed through reading page after page of trade periodicals and engineering reports rather than on quantified data. Having reached conclusions based on this inductive approach, I can suggest directions for further research that might support or contradict the ideas I put forth, which I do in the conclusion.

For allowing me to follow this hazardous course, I owe a great debt to my home department, MIT’s Program in the History and Social Study of Science and Technology (HSSST), and to my dissertation committee, Professor M. Roe Smith of my department and Professors JoAnne Yates and Paul Carlile, both of the Sloan School of Management. HSSST gave me a measure of diplomatic immunity as I followed my evidence across disciplinary boundaries. At the same time, Roe and JoAnne made sure that I was not straying too far afield and repeatedly reminded me that this is, after all, just a dissertation. Paul graciously agreed to join my committee at a late stage in the process, as I recognized that my thinking had migrated far enough into the world of organization theory that I needed further guidance. Though timing issues prevented his formal participation on my committee, Professor Michael Tushman of Harvard Business School offered thoughts and advice that proved basic to my ability to focus my ideas.

While just a dissertation, this document carries many debts. Paging through it, I see influences that long predate my time at MIT as well as vital contributions that are just days old. These notes are inevitably shallow relative to the depth of my gratitude for the help of many individuals and institutions. In addition to the just-mentioned individuals, many faculty and fellow students have prodded me to clearer thinking and pointed me to sources. Lumping people from different times and places together obscures the particulars of contributions, but it emphasizes the degree to which their influences circulate throughout what follows.

William Baldwin, Stephen Barley, Pablo Boczkowski, William Duncan, Deborah Fitzgerald, Brendan Foley, Hugh Gusterson, Roger Horowitz, Anders Houltz, Kendall Hoyt, Stephen Johnson, Richard Krauss, Richard Lester, Rolf Lundin, Theresa Lynch, Robert Martello, Carlos Martinez, Christopher McKenna, Christophe Midler, David Mindell, Peter Morris, Wanda Orlikowski, Connie Perin, Erik Rau, Heinrich Schwarz, Maureen Scully, and Timothy Wolters have offered inspiration and ideas along the way.

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Material support for this research and related activities has come from the MIT Industrial Performance Center, the Dibner Institute for the History of Science and Technology, the Hagley Center for the History of Business, Technology, and Society, the Linda Hall Library for Science, Engineering, and Technology, the MIT Program in the History and Social Study of Science and Technology, the MIT Graduate Student Council, and the Kelly-Douglas Fund of MIT. People associated with several of these organizations have made research and writing a pleasure. I am grateful for the hospitality and assistance of Roger Horowitz, Carol Ressler Lockman, and Marjorie McNinch at the Hagley Center and of Bruce Bradley, Cindy Rogers, Bill Ashworth, and Kathy Alshouse at the Linda Hall Library. In Cambridge, Trudy Kontoff, Carla Chrisfield, and Rita Dempsey of the Dibner Institute and Anita Kafka and Scott Shurtleff of the Industrial Performance Center made long days more bearable. Far from least, Chris Bates, Debbie Meinbresse, and Judy Spitzer of my home department provided vital support.

In an era of electronic communications, many transactions that once would have been accompanied by names and faces—or at least voices—instead occur anonymously. The wealth of resources provided by the MIT and Harvard Libraries made obtaining source material a matter of clicks. I am indebted to the people who make this possible.

The text and footnotes show my debts to authors past and present, but Arthur Stinchcombe deserves special mention. His "Bureaucratic and Craft Administration of Production: A Comparative Study" led to the *aha!* moment that eventually turned a loose set of questions and curiosities into this thesis.¹

My wife, Regan McDonald, and our sons, Lachlan and Colin, have tolerated the privations that go with having a husband and father in graduate school. For their good humor and support I am eternally grateful.

Cambridge, Massachusetts
May 2001

¹ *Administrative Science Quarterly* 4 (1959): 168–187.

“The organization of a research laboratory has many problems in common with those of bricklaying. The principal problems in each case are not those which are most obvious.”

George R. Harrison to Karl T. Compton, September 20, 1946²

² Accession AC4, box 165, folder 11, Institute Archives and Special Collections, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Introduction

Bricklayers and Research Scientists: From the Culture of Construction to the Sociology of Projects

The management of innovative work in high-technology fields has been a hot topic in recent years. In fields including innovation management, product development, organization design, corporate strategy, economic sociology, organizational economics, engineering management, and knowledge management (to name but a few), studies have examined topics ranging from the sociology of creativity to the boundaries of firms in networked industries. The larger political, economic, and social characteristics of work in information-intensive industries have similarly occupied political scientists and economists. The implications of contingent work, outsourcing, globalization, and the demise of the one-company career have been remarked in studies concerned with issues from regional and national competitiveness to the evolution of labor markets and the social contract. Articles and books in the popular business press have trumpeted “nimble” and “virtual” organizational forms required by unprecedented conditions while scholarly essays have addressed the management of relentless change, the option-based valuation of inter-firm networks, and knowledge in relation to organizational boundaries.¹

¹ The noted literatures are vast, partially overlapping conversations. Some loose measures of interest in the theory and practice of managing innovation can be found in the membership rolls of professional societies, the formation of specialized journals, and business school curricula. The Project Management Institute grew from under 8,000 members in 1990 to near 55,000 in 1999. The Technology and Innovation Management section of the Academy of Management grew from its founding in 1987 to 1,100 members in 2000. New or refocused academic journals include *Technology Management* (1994), *The Journal of Engineering and Technology Management* (1989), *New Technology, Work and Employment* (1986), the *Journal of Product Innovation Management* (1984), as well as a slew of popular business publications such as *Wired* (1993), *Fast Company* (1995), *Red Herring* (1993), and *Business 2.0* (1998). A longer-standing journal, The Institute of Electrical and Electronics Engineers's *Transactions on Engineering Management*, raised its annual page count by 160% between 1985 and 2000 to accommodate growth in the number of publishable submissions it received. Existing business periodicals and management reviews also became forums for articles on information technology and electronic commerce in the 1990s, adding columns and sections devoted to technology and the ‘new economy.’ MBA and executive education programs in technology management, entrepreneurship, and ‘e-business’ have been created at many business schools.

On regional and national competitiveness see, among others, Annalee Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (Cambridge: Harvard University Press, 1994) and Richard Lester, *The Productive Edge: How U.S. Industries are Pointing the Way to a New Era of Economic Growth* (New York: W.W. Norton,

Some of the earlier part of this wave of interest appeared in response to a crisis in U.S. productivity during the 1970s and 1980s, when industries from automobiles to semiconductors seemed to have lost their competitive edge to more able and agile foreign competitors.² More recent writing has appeared partly in response to problems associated with managing individuals and organizations involved in crafting technologies during a period of intense capital investment and shortages of skilled labor. Spending on information technology boomed during the 1990s, driving demand for workers ranging from telephone linemen to software engineers. In this as during other periods of technical ferment, new divisions of labor and new means of doing business developed as part of coping with and exploiting technical possibilities. In basic terms, the very different crises of the 1970s and 1990s both forced confrontation with the distinctions between building and operating.

Though no business activity is ever purely about building or purely about operating, there are basic distinctions between these kinds of work; the labor and communication processes required to build effectively are not the same as those needed to operate efficiently. Builders work in environments that are being defined in great part by their own actions. People who manage builders must rely on the skills of their employees not simply in carrying out tasks but in judging how to proceed and what to communicate as conditions unfold. This emergent and iterative quality can be found equally on blue-collar construction sites, in the cubicles of software start-ups, and at the laboratory benches of biotechnology companies. In this light, a wide range of occupations should be

1998); examples of work on the evolution of labor markets include Paul Osterman, *Securing Prosperity: The American Labor Market: How It Has Changed and What to Do about It* (Princeton: Princeton University Press, 1999) and Richard Locke, Thomas Kochan, and Michael Piore, eds., *Employment Relations in a Changing World Economy* (Cambridge: MIT Press, 1995). More firm-oriented treatments include Thomas Malone and Robert Laubacher, "The Dawn of the E-lance Economy," *Harvard Business Review* 76 (Sept.-Oct. 1998): 145-152; Clayton Christensen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* (Cambridge: Harvard Business School Press, 1997); Michael Tushman and Charles O'Reilly, "The Ambidextrous Organization: Managing Evolutionary and Revolutionary Change," *California Management Review* 38 (Summer 1996): 1-23; Shona Brown and Kathleen Eisenhardt, "The Art of Continuous Change: Linking Complexity Theory and Time-Based Evolution in Relentlessly Shifting Organizations," *Administrative Science Quarterly* 42 (March 1997): 1-34; Bruce Kogut and Nalin Kulatilaka, "Operating Flexibility, Global Manufacturing, and the Option Value of a Multinational Network," *Management Science* 40 (January 1994): 123-139; and, Susan Helper, John Paul MacDuffie, and Charles Sabel, "Pragmatic Collaborations: Advancing Knowledge While Controlling Opportunism," originally prepared for "Make versus Buy: The New Boundaries of the Firm" conference, Columbia Law School, May 1998 (revised 2000), available at <http://www.law.columbia.edu/sabel/papers.htm>.

² William Abernathy, *The Productivity Dilemma: Roadblock to Innovation in the Automobile Industry* (Baltimore: Johns Hopkins University Press, 1978); Michael Piore and Charles Sabel, *The Second Industrial Divide: Possibilities for Prosperity* (New York: Basic Books, 1984); and, Michael Dertouzos, Richard Lester, and Robert Solow, *Made in America* (Cambridge: MIT Press, 1989).

thought of as construction work and, notably, metaphors from the world of hard-hats are common in high-technology businesses. Programmers have been called the “bricklayers of the information age” and during the 1990s consulting firms claimed to be “architecting the new economy.”

Kinships among such seemingly diverse occupations extend to how they can be managed. The output of a carpenter or mason may be less malleable than that of a software designer or scientific researcher, but organizing for construction work (broadly defined) presents similar constraints across industries: complete description and observation of planned work is inefficient (if even possible) and tasks are irregular. In common, engineering firms, research laboratories, and programming departments tend to adopt flat, decentralized structures to cope with the nature of the environments in which their employees operate. Planners, engineers, and managers do their best to project the future in timelines, drawings, and budgets, but these are working documents and subject to revision in the uncertain light of future developments. Discussing relationships among uncertainty, skill, and decentralization, sociologist Arthur Stinchcombe has noted that in the building industry,

“It is construction foremen who adjust the amount of labor the firm hires to the amount of work there is to do. It is construction workers as well as foremen or managers who coordinate the work of different crafts. There is no particular ‘buffering’ of the work of the skilled workers in their routines to take out the uncertainty; after all, the firm hired skilled construction workers in the first place because it was in an uncertain work environment.”³

Though the relative instability of tasks, occupations, and organizations may vary, in industries where these conditions are found employment is irregular, firms are often short-lived, and careers rely on extra-firm social and professional networks. In common, construction industries and industries under construction adopt project-based organizing principles to identify objectives, coordinate resources, and establish communication among individuals and teams, both within and between firms. A recent study of “neo-industrial organizing” typified production in the late 1990s as increasingly “projectized.”⁴ Walk the cubicles of a technology or service firm and a common question is “what project are you on?”

³ Arthur Stinchcombe, *Information and Organizations* (Berkeley: University of California Press, 1990), 5.

⁴ Eskil Ekstedt, Rolf A. Lundin, Anders Söderholm, and Hans Wirdenius, *Neo-Industrial Organising: Renewal by Action and Knowledge Formation in a Project-Intensive Economy* (London: Routledge, 1999).

Sociologists of craft labor have noted similarities among workplaces characterized by project-based organization, uncertainty, and the employment of skilled workers. One study of construction work has commented,

Many characteristics in 'postindustrial' growth areas, such as professional services (e.g. the social organization of health care, legal services, and education), are more similar to the construction industry than to the auto industry. Labor process theory must explain more than the decline of craft organization; it must explain its persistence and even reemergence.⁵

Discussing shifting social contracts between employer and employed and accompanying increases in job switching and contract work in the late 1990s, *The Economist* has remarked,

"What on earth is happening? The broad answer is that it depends on where you live and what you do. The 'insecurity' that is suddenly so frightening to a *sarariman* in Tokyo has long been normal for a construction worker in Dallas..."⁶

Despite these and similar observations and the still-flourishing literature on the management of high-technology businesses, there has been little consideration of historical precedents for the problems of managing work under conditions of uncertainty or the tools used to solve them.⁷ Nor has there been any acknowledgement that recent transformations in the American workplace and in management theory may reflect that an unusually large and conspicuous number of people have recently been employed as builders of one kind or another. Between the neologisms of the new economy and a perceived second industrial divide, basic kinships and continuities have been

⁵ Thomas L. Steiger and William Form, "The Labor Process in Construction: Control Without Bureaucratic and Technological Means?" *Work and Occupations* 18 (August 1991): 251–270, quote 269.

⁶ "Career Evolution," (January 29, 2000).

⁷ For similar observations, and in addition to the several just-mentioned sources, see Robert Eccles "The Quasi-Firm in the Construction Industry." *Journal of Economic Behavior and Organization* 2 (1981): 335–357; Walter Powell, "Hybrid Organization Arrangements: New Form or Transitional Development?" *California Management Review* (Fall 1987): 67–87; and, Rolf A. Lundin and Christophe Midler, eds., *Projects as Arenas for Renewal and Learning Processes* (Boston: Kluwer Academic, 1998). Lundin and Midler cite the construction business as the "archetypal context" for the use of project management and suggest that the method is associated with "development periods" such as the New Deal and the Cold War, but do not expand on this. On construction, see Arthur Stinchcombe, "Bureaucratic and Craft Administration of Production: A Comparative Study," *Administrative Science Quarterly* 4 (1959): 168–187; Herbert A. Applebaum, *Royal Blue: The Culture of Construction Workers* (New York: Holt, Rinehart, and Winston, 1981) and "Construction Management: Traditional Versus Bureaucratic Methods" *Anthropological Quarterly* 55 (Winter 1982): 224–234; and, Jeffrey W. Riemer, "Worker Autonomy in the Skilled Building Trades," in P.L. Steward and M.G. Cantor, eds., *Varieties of Work* (Beverly Hills: Sage Publications), 225–234, and *Hard Hats: The Work World of Construction Workers* (Beverly Hills: Sage Publications, 1977). There is no history of the management of construction work, but work in construction history includes case studies that touch on the topic. See Brown, Joyce, series ed., *Studies in the History of Civil Engineering* (Aldershot: Ashgate Publishing, various dates).

obscured.⁸ In recent years there has been a developing interest in the history and persistence of craft and specialty production in the twentieth century United States, but the history of management theory remains blinkered.⁹ Histories of management have been written almost entirely about controlling the operation of production systems rather than about organizing their making,¹⁰ and the canonical bookshelf of management literature through the 1950s is almost wholly populated by works on factory administration and variations on the sociology of the organization man.¹¹ Similarities between

⁸ The latter term comes from Michael Piore and Charles Sabel, *The Second Industrial Divide*.

⁹ Literature on "flexible" or "specialty" production developed following the economic crises of the 1970s in the United States. After the oil crisis, the Vietnam War, and stagflation during the 1970s deflated both the stock market and the American management mystique, scholars looked abroad—especially to Japan and Europe—to examine paths not taken by U.S. firms. They returned with stories of Japanese quality circles, Italian industrial communities, and Catalan cooperatives. The seminal article in the historical branch of this literature is Charles Sabel and Jonathan Zeitlin, "Historical Alternatives to Mass Production: Politics, Markets, and Technology in Nineteenth Century Industrialization," *Past and Present* 108 (August 1985): 137–177. See also Michael Piore and Charles Sabel, *The Second Industrial Divide* and Michael Best, *The New Competition: Institutions of Industrial Restructuring* (Cambridge: Harvard University Press, 1990). Recent studies that show the history of alternative forms in the United States include Philip Scranton, *Endless Novelty: Specialty Production and American Industrialization* (Princeton: Princeton University Press, 1997) and *Proprietary Capitalism: The Textile Manufacture at Philadelphia, 1800–1885* (Cambridge: Cambridge University Press, 1983); Charles F. Sabel and Jonathan Zeitlin, eds., *World of Possibilities: Flexibility and Mass Production in Western Industrialization* (New York: Cambridge University Press, 1997); and, Donald Sull, Richard S. Tedlow, and Richard S. Rosenbloom, "Managerial Commitments and Technological Change in the U.S. Tire Industry," *Industrial and Corporate Change* 6 (1997): 461–501.

¹⁰ In *Strategy and Structure*, Alfred Chandler marked off the origins of modern business enterprise in the United States by explicitly distinguishing the operation of railroads from their construction. In Chandler's account, railway timetables were the original objects of management rationalization and train scheduling had mandated the creation of hierarchical organizations, a development subsequently extended to managing throughputs in mass production industries. See *Strategy and Structure: Chapters in the History of the American Industrial Enterprise* (Cambridge: MIT Press, 1962) and *The Visible Hand* (Cambridge: Harvard University Press, 1977). Chandler's explicit setting aside of construction appears in *Strategy and Structure*, 21. Histories of management theory include Joseph Litterer, "The Emergence of Systematic Management as Shown by the Literature of Management from 1870–1900" (Ph. D. dissertation, University of Illinois, 1959) and "Systematic Management: The Search for Order and Integration," *Business History Review* 35 (Winter 1961): 461–476; Daniel Nelson, *A Mental Revolution: Scientific Management Since Taylor* (Columbus: Ohio State University Press, 1992); Daniel Wren, *The Evolution of Management Thought* (4th ed., New York: John Wiley and Sons, 1994); Mauro E. Guillén, *Models of Management: Work, Authority, and Organization in Comparative Perspective* (Chicago: University of Chicago Press, 1994); Steven Waring, *Taylorism Transformed: Scientific Management Theory Since 1945* (Chapel Hill: University of North Carolina Press, 1991); and Yehouda Shenhav, "From Chaos to Systems: The Engineering Foundations of Organization Theory, 1879–1932," *Administrative Science Quarterly* 40 (1995): 557–585. See also David Hounshell, *From the American System to Mass Production, 1800–1932* (Baltimore: Johns Hopkins University Press, 1984) and JoAnne Yates *Control Through Communication: The Rise of System in American Management* (Baltimore: Johns Hopkins University Press, 1989), which blend close inspection of practices with awareness of broader developments in business administration.

¹¹ Management theory is routinely traced to Frederick Winslow Taylor, though Litterer, Yates, and others have shown its longer lineage (Litterer, "The Emergence of Systematic Management as Shown by the Literature of Management from 1870–1900"; Yates, *Control Through Communication*). While academic programs in industrial engineering and business administration predate the 1950s, the post-World War II and then Sputnik-inspired boom in higher education was a defining period for the field, and particularly for the integration of sociological theory into management education. *Administrative Science Quarterly*, the *Journal of the Academy of Management*, *Industrial Management Review* (now *MIT Sloan Management Review*), *California Management Review*, and *Business Horizons* were all started within five years of each other beginning in 1956. For students of organizations in the 1950s, large-scale production and mass society were defining

boom-bust cycles during periods of industry formation are commonly remarked, but these observations have not been extended to include patterns in management theory.¹² The 1990s were not the first era of system building, nor were they the first time that managers, policy makers, and academics grappled with how to know, explain, and control construction work during a period of social and technical change.

This dissertation is a history of management theory and practice during periods of industry formation. To typify the basic activity during these periods, I adopt Thomas Hughes's term 'system building.'¹³ This expression helps capture the fact that during such times it is not just products and processes that are being defined, but larger configurations of relationships. Though project-based organization is a constant in fields from construction to film making, attention to eras of system building and technological change helps draw out aspects of why certain labors are so organized.¹⁴ I focus on engineering and scientific work in the United States between the late nineteenth century and the 1950s and the bulk of my evidence comes from articles on management written by engineers and scientists. The loosely bounded case studies that structure the chapters that follow—railroad engineering in the 1800s, municipal infrastructure construction at the turn of the century, laboratory administration in the 1910s, aircraft design in the 1930s, and electronics in the 1950s—show that

problems. See the early content of these journals as well as books such as Robert Merton, et al., *Reader in Bureaucracy* (Glencoe: Free Press, 1952), Chris Argyris, *Personality and Organization: The Conflict Between System and the Individual* (New York: Harper and Row, 1957), Rensis Likert, *New Patterns of Management* (New York: McGraw-Hill, 1961), and, in more popular form, William H. Whyte's *The Organization Man* (New York: Simon and Schuster, 1956). This period coincided with the heyday of the human relations approach to organizations and social psychology, an approach applied to longer-standing questions of how to reconcile individual expression with the logics of large-scale organization. Charles Perrow has commented that rational choice models of human behavior were correct for social scientists of the mid-twentieth century, a period "when large, mass production organizations with worldwide market control were fine-tuning bureaucracy." Charles Perrow, "Pfeffer Slips!" *Academy of Management Review* 19 (April 1994): 192. Georg Simmel had asserted in 1903 that a fundamental dynamic of modern life was the resistance of the individual to being swallowed up in the "social-technological mechanism" ("The Metropolis and Mental Life," 1903).

¹² Most studies of the business cycle and innovative activity focus on more clearly measurable phenomena such as laboratory formations or employment of technical staff.

¹³ *Networks of Power: Electrification in Western Society* (Baltimore: The Johns Hopkins Press, 1983).

¹⁴ Filmmaking and other creative industries are outside of my scope. See Robert R. Faulkner, "Short-Term Projects and Emergent Careers: Evidence from Hollywood," *American Journal of Sociology* 92 (January 1987): 879–909; Wayne E. Baker and Robert R. Faulkner, "Role as Resource in the Hollywood Film Industry," *American Journal of Sociology* 97 (September 1991): 279 – 309; Richard Caves, *Creative Industries: Contracts between Art and Commerce* (Cambridge: Harvard University Press, 2000); Robert DeFillippi and Michael Arthur, "Paradox in Project-Based Enterprise: The Case of Film Making," *California Management Review* 40 (Winter 1998): 125–139.

recent attention to the management of creative, emergent, and iterative work is a manifestation of a cyclically recurring conversation.

This exercise complicates prevalent views of management before 1950. Because historians looking at business and management before the Cold War have emphasized the development of hierarchical, divisional, professionally managed corporations and the control of operative labor within them, management practices in other settings have been almost entirely obscured. Historians of technology have applied theories of social construction to open the “black boxes” of seemingly immutable past technical choices, complicating progressive views of technological change, but have not synthesized the history of efforts to manage change.¹⁵ There is no history of the pre-World War II management of engineers as opposed to that of management by engineers, and business histories typically follow project management, systems engineering, matrix organization, and other management ideas associated with organizing complicated engineering projects only as far back as the 1950s.¹⁶ Similarly, complex, “hybrid” or network organizations and theories of such forms are

¹⁵ Wiebe Bijker, Thomas P. Hughes, and Trevor Pinch, eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge: MIT Press, 1987) served as a clarion call for these approaches. See also Bruno Latour, *Science in Action: How to Follow Scientists and Engineers through Society* (Cambridge: Harvard University Press, 1987). Many of the fine-grained case studies that fall into this literature have touched on management, but tend to do so only briefly and at the broad level of organizational structure rather than at that of the actual directing of work. Thomas and Agatha Hughes’s recent *Rescuing Prometheus* (New York: Pantheon, 1998) consists of case studies of major projects from the 1950s to the present but only briefly mentions precedents for this form of organization. Studies of transformations accompanying industrialization in the nineteenth century have richly illustrated the efforts of individuals and communities to cope during times of change on a case-by-case basis. Examples include Anthony Wallace, *Rockdale: The Growth of an American Village in the Early Industrial Revolution* (New York: Knopf, 1978); Merritt Roe Smith, *Harper’s Ferry Armory and the New Technology: The Challenge of Change* (Ithaca: Cornell University Press, 1977).

¹⁶ See, particularly, Stephen Johnson, “Three Approaches to Big Technology: Operations Research, Systems Engineering, and Project Management,” *Technology and Culture* 38 (October 1997): 891–919; Thomas Hughes and Agatha Hughes, eds., *Systems, Experts, and Computers: The System Approach in Management and Engineering, World War II and After* (Cambridge: MIT Press, 2000). Also of note are Glenn Bugos, *Engineering the F-4 Phantom II: Parts into Systems* (Annapolis, Md.: Naval Institute Press, 1996); Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge: MIT Press, 1990); and John Lonnquest, “The Face of Atlas: General Bernard Schriever and the Development of the Atlas Intercontinental Ballistic Missile, 1953–1960” (Ph.D. dissertation, Duke University, 1996). The literature on project management offers limited aid in identifying pre-war practice. Most writing in the field consists of present-minded prescriptives peppered by case studies of recent projects. Where the history of the field is acknowledged, the links are either taken only as far back as the 1950s or they are extended in a few quick sentences to cover all of history. Two recent books do, though, address the history of project management in some detail. Peter Morris’s *The Management of Projects* (London: Thomas Telford, 1994) provides an international perspective on the development of the field since 1955, relating this to both earlier practices and current debates in management theory. J.-P. Boutinet’s *Anthropologie du projet* (Paris: Presses Universitaires de France, 1996) offers a consideration of the history of the idea of projects, focusing on the cultural and political implications of these ideas in France. Several authors associated with the International Research Network on Organizing by Projects (IRNOP) have examined the underlying social bases of project-type work and the proceedings volumes produced from IRNOP conferences offer valuable insights. Selected essays from two IRNOP

often seen as phenomena of the 1990s. Though many current authors acknowledge studies of temporary organizations, project-based enterprises, and systems thinking dating to the 1940s and 1950s, most treat World War II as a watershed.¹⁷ Sociologist Charles Perrow has commented that “no one [he has] ever read before 1955 even hinted at matrix structures, spinning off subsidiaries, creating one’s environment, radical decentralization of some functions, premise control, [and] multiple stakeholders with multiple performance indicators...”¹⁸ Management scholar Jay Galbraith began a 1971 article by noting that,

“Each era of management evolves new forms of management as new problems are encountered. Earlier generations of managers invented the centralized functional form, the line-staff form, and the decentralized product division of structure as a response to increasing size and complexity of tasks. The current generation of management has developed two new forms as a response to high technology. The first is the free-form conglomerate; the other is the matrix organization, which was developed primarily in the aerospace industry.”¹⁹

By leaving the beaten paths of management history to consider journals such as *Industrial and Engineering Chemistry* in the 1910s and *Aero Digest* in the 1930s as repositories of theory and evidence of practice, I have discovered that these ideas and forms have longer histories. Moreover, past explanations of such forms have revolved around many of the issues that occupy recent organization theory—speed, flexibility, internal and external relationships, and reliance on people once called “brain workers” and now known as “knowledge workers.” Such theorizing has appeared and reappeared as new technologies, divisions of labor, and social networks have developed as part of nascent industries.

A further quality becomes evident through consideration of how and why theories and tools have been used in project-oriented settings. The better-known history of business administration before the Cold War is that of a science of regulation developed from the governance of steam engines and

conferences have been published in the *Scandinavian Journal of Management* 11 (Fall 1995) and Rolf A. Lundin and Christophe Midler, eds., *Projects as Arenas for Renewal and Learning Processes* (Boston: Kluwer Academic, 1998).

¹⁷ Diverse examples of recent studies that reinforce the perception of World War II as a watershed include Bruce Kogut, “The Network as Knowledge: Generative Rules and the Emergence of Structure,” *Strategic Management Journal* 21 (March 2000): 405–425; Thomas Hughes, *Prometheus Rescued* (New York: Pantheon Books, 1998); Thomas and Agatha Hughes, eds., *Systems, Experts, and Computers*; and, Harold Kerzner, *Project Management: A Systems Approach to Planning, Scheduling, and Controlling* (New York: Van Nostrand Reinhold, 1992).

¹⁸ Charles Perrow, “Pfeffer Slips!” *Academy of Management Review* 19 (April 1994): 192.

¹⁹ “Matrix Organization Designs: How to Combine Functional and Project Forms,” *Business Horizons* 14 (February 1971): 29–40, quote, 29.

transportation networks and extended to monitoring throughputs in processing and manufacturing industries.²⁰ The history of the management of projects is by contrast one of tools for planning and scheduling tasks that would never yield the flows of operating data that could be used to control engines and assembly lines. On construction sites and in research laboratories alike, managers have done their best to approximate the detailed tracking possible on factory floors, to routinize parts of the work, and to apply data gathered on one project to planning for the next. At the same time, they have repeatedly had to explain the work under their direction by contrast to the flow-oriented logics of factory administration. In this regard, management tools in project-oriented settings have historically served representational as well as instrumental purposes. Managers of construction firms, engineering departments, and research laboratories have theorized project-based work *against* systematic management as defined in and for factory settings. To put it another way, only with the emergence and refinement of a science of operation did the irregularities of creative work require justification.

In this light, as explanations of differences between building and operating and as delineations of points and terms of physical and cultural contact, tools used to manage projects have at once ordered and insulated work. Engineering drawings, timelines, and budgets have served as go-betweens, mediating between working cultures at boundaries within and between projects, firms, institutions, and professional communities.²¹ Similarly, people with titles such as “construction expeditor,” “project manager,” and “liaison engineer” have worked at the interstices of organizational and technical relationships.²² The words, tools, and roles of managers in such settings have served as means by which iterative, uncertain work could be set apart, explained, and protected. To capture their twin intents of isolation and connection, I consider these tools and roles as *insulative*

²⁰ This emphasis is particularly drawn out in James Beniger, *The Control Revolution: Technological and Economic Origins of the Information Society* (Cambridge: Harvard University Press, 1986).

²¹ Sociological approaches to technical environments have adopted ideas of “boundary objects” or “linguistic hybrids” to describe the mix of translation and transfer that happens in exchanges. Examples include Susan Leigh Star and James R. Griesemer, “Institutional Ecology, ‘Translations,’ and Boundary Objects: Amateurs and Professionals in Berkeley’s Museum of Vertebrate Zoology, 1907–39,” *Social Studies of Science* 19 (1989): 387–420; Paul Carlile, “A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development,” unpublished manuscript, August 15, 2000; Peter Galison, *Image and Logic: A Material Culture of Microphysics* (Chicago: University of Chicago Press, 1997). I discuss some of these ideas further below.

²² Within the canonical organization theory literature, Tom Burns and G.M. Stalker provide an early discussion of importance of translation and liaison in managing innovation in *The Management of Innovation* (London: Tavistock Press, 1961), 155–173. Burns’s introduction to the 1994 edition of this book provides a sense of how the study of innovation was new territory in the minds of sociologists in the late 1950s (Oxford: Oxford University Press, 1994), vii–xx.

technologies. Project-based forms can be seen as setting knowable communication patterns and temporal dynamics in the absence of certain work processes and outcomes.²³

To summarize, understanding when and where the management of technical work has become a matter of particular interest is a matter of recognizing interference patterns between cycles of system building and the longer arc of the development of operating logics. On one hand, attention to issues in the management of innovative activities has tracked the ebbs and flows of eras of technological change. Faced with circumstances in which the speed, complexity, and scale of work have tested the limits of existing divisions of labor and knowledge, people have used project-based tools to order uncertain work. On the other, such attention has followed developments in the science of routine operations. Efficiency crazes—Taylorism in the 1910s, mass production in the 1920s, automation in the 1950s, process engineering and quality management in the 1980s and 1990s—have focused attention on the irregularities of building work. In the light of micro- and macro- political and economic theories of regularity and balance, irregular labors and clunky capital movements have needed smoothing in appearance if not actuality. Neither projects nor their management began in the 1800s, but the need to formalize and explain working relationships took on new dimensions over the course of the period covered here in response to practical needs and under the increasing glare of the flow-oriented logics of systematic management defined in and for operating contexts.

The epigraph to this dissertation comes from a letter written in the summer of 1946 by George R. Harrison, a physicist who was then head of MIT's School of Science, to Karl Compton, President of the Institute. Harrison wrote in reply to a request from Compton, who was soliciting opinions on research management from academics, industrialists, and managers. Compton planned to use the responses in a book to be titled "The Organization of Research."²⁴ The full paragraph containing the quoted sentences reads as follows:

²³ In the body of this study I adopt the term 'genre' from Wanda Orlikowski and JoAnne Yates, who use it to type communications that share formats and purposes. The history I track can be seen as one of elaborations of certain communicative genres. "Genre Repertoire: Examining the Structuring of Communicative Practices in Organizations," *Administrative Science Quarterly* 39 (1994): 541–574. As regards pacing, the role of projects in creating and anchoring dynamics where outcomes and relationships are uncertain can be seen in light of Deborah Ancona and Chee-Leong Chong's application of biological notions of "entrainment" to organizational phenomena. In their present-day ubiquity, projects act as time givers that help individuals adjust as they move between firms and tasks. "Entrainment: Pace, Cycle, and Rhythm in Organizational Behavior," *Research in Organizational Behavior* 18 (1996): 251–284.

²⁴ Never published.

“The organization of a research laboratory has many problems in common with those of bricklaying. The principal problems in each case are not those which are most obvious. The non-bricklayer is likely to suppose that all bricks are alike in shape and size, and that the tricks in bricklaying involve knowing how to arrange the bricks in various patterns which will best bind the mass of bricks together and produce a suitably shaped chimney or wall. Actually, no two bricks are alike. Some are overburned and are smaller than those which have been fired at a low temperature, and all are likely to be irregular in shape. The main problems of the bricklayer come in selecting each brick so that the assembly of irregular and dissimilar units will grow into symmetrical and neat-appearing whole. The main problem of the research director is to assemble a group of dissimilar, asymmetrical, and irregular personalities, each of whom is likely to be not more than 90% perfect if looked at from an angle not specially selected, into such an assembly that the qualities of each will contribute to the group, while the deficiencies, irregularities, and other sources of difficulty are hidden within the mass of the group.”²⁵

Harrison further stated that a research director should have “stability of outlook, so that he can to a certain extent insulate his staff from the variations in the outside world and protect them from undue economic and other fluctuations...”²⁶ The pages that follow are in essence about efforts to obscure the deficient, irregular, and not-more-than-90% perfect in the whole of the work. They are also about cycles in how, why, and when this has mattered. The story I tell is largely one of repetition and recycling, but in tracing efforts to explain and understand such work I also observe a trajectory from a culture of construction—a world of informal, unremarked and unremarkable arrangements—to a sociology of projects—a world of theorized and designed working relations.

The balance of this introduction further introduces perspectives and literatures that inform this study. In doing so, it provides a framework for understanding projects and their contexts as forms of production and elaborates the periodization that structures the body of this document. Subsequent chapters are based around episodes in the development and articulation of management theory and practice by engineers and scientists during periods of system building. The first chapter examines the contemporary development of railroading and civil engineering in the mid-1800s and sets a prototype for later chapters in all respects but one—until after the Civil War, no one had anything against which to explain project-based organization. Chapters 2, 3, and 4 are the core of this study, showing the explicit theorization of project-based organizing as opposed to the systematic management of

²⁵ Accession AC4, box 165, folder 11; Institute Archives and Special Collections, Massachusetts Institute of Technology, Cambridge, Massachusetts (hereafter MIT Archives).

²⁶ Ibid.

operating routines during the first decades of the twentieth century. These middle chapters form a cluster of overlapping and interconnected conversations, individually centering on discussions of construction engineering, laboratory administration, and product development. Chapter 5 looks at the post-World War II definition of project management as part of a constellation of systems engineering ideas, emphasizing the continuity of these forms with earlier practices. The conclusion briefly treats more recent history and suggests directions for further research.

A Comment on Methods and Theories

As noted in the preface, my preconception of this study was as a detailed investigation of the development and dissemination of project management during and after World War II. Only as my scope expanded and I began to perceive common qualities and patterns in my accumulating evidence did I start to search for frameworks that would help me explain what I had found. After my first year of research, having massed hundreds of journal articles and considerable archival material, I could see that project-based organization had become a matter of particularly intense discussion in periods associated with industry growth, and I could also see a set of common issues in each discussion I found.²⁷ In order to draw connections, I sought means by which to typify common themes and dynamics. Thinking about underlying issues at the levels of both labor process and organizational form helped me understand common aspects of the working conditions individual managers had confronted and theorized. Tracking patterns in the creation and content of professional discourses enabled me to describe long-term dynamics. In essence, I arrived at the hypotheses and frameworks stated here inductively.²⁸ The theories and literatures discussed below were basic to helping me sort out these issues, but the reader could skip the balance of this introduction and return only after reading the body of the dissertation—doing so would more closely approximate the manner by which I perceived the relevance of these ideas.

²⁷ In sum, I looked at approximately 40 technical periodicals with particular study of about 1,500 articles. I also examined archival materials of a number of corporations and institutions; these are set out in the bibliography.

²⁸ Work in sociology sometimes proposes the use of “grounded theory”—that is, research carried out with no theoretical presuppositions that might distort the gathering of evidence. I cannot claim such an approach in that at any given point in my research I thought I knew what I was looking for, but the result has some of this quality. Barney G. Glaser and Anselm L. Strauss, *The Discovery of Grounded Theory* (Chicago: Aldine Publishing Company, 1967).

Conversations and Periodization

The history of theories and practices in project-based organizing is the underlying object of this study, but conversations among scientists, contractors, engineers, and managers provide the lenses through which this object is seen. This unit of analysis reflects practical problems in gathering evidence as well as the nature of projects as form of production. The boundaries of both individual projects and larger cycles of system definition are not confined to individual firms but rather happen in ill-bounded exchanges of people, ideas, and things in technical communities.²⁹ I call these exchanges 'conversations' to emphasize that they play out over time. While traces of conversations can be found in the records of individual firms and projects, they are more evident in technical journals and the proceedings of professional conferences. By looking for evidence of when and where articles and papers in otherwise technical discourses have turned to management issues, I have used these forums to help identify when organizing has become such a problem for a given community that it got in the way of getting work done. Conversations thereby permit drawing connections between management theory, organizational form, and technological change.

Between Craft and System: Projects as an Organizational Logic

Sociological studies of technical work have recently coalesced around notions such as "communities of practice" or "epistemic cultures" and around the iterative, social construction of things and facts.³⁰ These concepts have an antecedent in the work of Ludwik Fleck, whose 1935 *Genesis and Development of a Scientific Fact* used notions of "thought collective" (*Denkkollektive*)

²⁹ The ill-bounded and irregular nature of project-based production partly explains the relative neglect of such forms in the historical literature. Notably, Chandler based *Strategy and Structure* on a sample of American firms from those holding the largest assets in 1909 and 1948, 3–6. In equating bigness and business success with assets and longevity, Chandler excluded firms in industries in which carrying assets brings hazardous economic exposure and neglected enterprises that do not leave lasting institutional forms.

³⁰ Edward Constant uses the term "community of practitioners" in "The Social Locus of Technological Practice: Community, System, or Organization?" in Wiebe Bijker, Thomas Hughes, and Trevor Pinch, eds., *The Social Construction of Technological Systems* (Cambridge: MIT Press, 1987): 223–242. "Communities of practice" is used by Jean Lave and Etienne Wenger in *Situated Learning: Legitimate Peripheral Participation* (Cambridge: Cambridge University Press, 1991) and has been taken up by many, notably Paul Duguid and John Seely Brown, "Organizational Learning and Communities of Practice: Toward a Unified View of Working, Learning, and Innovation," *Organization Science* 2 (1991): 40–57. Karen Knorr-Cetina uses "epistemic cultures" to capture a similar idea in *Epistemic Cultures: How the Sciences Make Knowledge* (Cambridge: Harvard University Press, 1999). While there are important shadings among various articulations of these ideas, in essence they share an understanding of facts, things, and knowledge as socially constituted.

and “thought style” (*Denkstil*) to capture the social aspects of cognition.³¹ In Fleck’s scheme, ideas acquire truth-value in circulation, and people using an idea can be classed according to their relationship to core, generative communities of users. He used the terms ‘esoteric’ and ‘exoteric’ to refer to expert and popular circles, respectively. Fleck further acknowledged that an individual belongs to multiple thought collectives and that the movement of ideas among collectives is important to knowledge creation, but he resisted reduction of these relationships into Venn diagrams or simple networks, noting that “even the simple communication of an item of knowledge can by no means be compared with the translocation of a rigid body in Euclidean space.”³² Following Fleck’s analysis, membership in a thought collective enables “directed perception” that both makes possible and structures interpretation of the world.³³ Fleck’s ideas are consonant with theories of cognition, knowledge, learning, and identity in organizations that, in common, treat these as mutually constitutive.³⁴ Fleck’s emphasis on directed perception enabled through participation in thought collectives is particularly useful because it emphasizes the social nature of interpretation.³⁵

The relevance of these theories to this study derives from the nature of project work. Projects have been the typical basis of organization in emergent and uncertain environments, and during such periods individual allegiances and identities have attached as much to loose thought collectives as to firms or clearly defined non-firm institutions. During the electronics boom of the 1960s, Victor Thompson observed that the nature of the workers employed in innovative activities made firms porous settings. “Professional loyalties will be stronger relative to organizational or bureaucratic

³¹ Ludwik Fleck, *Genesis and Development of a Scientific Fact*, originally 1935, trans. by Thaddeus Trenn (Chicago: The University of Chicago Press, 1979). Thomas Kuhn—whose work popularized the idea of paradigm shifts—knew Fleck in its German original (and wrote the introduction to its English translation), but Fleck’s work was widely discovered in the United States only following its appearance in English. It found ready acceptance among historians and sociologists of science and technologists in the 1980s for its compatibility with “social constructivist” and “socio-technical systems” approaches then ascendant. See Thomas Kuhn, *The Structure of Scientific Revolutions* (Chicago: The University of Chicago Press, 1962) and Wiebe Bijker, Thomas Hughes, and Trevor Pinch, eds., *The Social Construction of Technological System*. Fleck is not widely known to students of management. An exception is Deborah Dougherty, “Interpretive Barriers to Successful Product Innovation in Large Firms,” *Organization Science* 3 (1992): 179–202.

³² Fleck, *Genesis and Development of a Scientific Fact*, 111.

³³ *Ibid.*, 98.

³⁴ In addition to the sources cited in preceding footnotes, see notably Karl Weick, *Sensemaking in Organizations* (Thousand Oaks: Sage Publications, 1995). Weick traces studies of “organizational sensemaking” to William James’s pragmatic philosophy, 64–69.

³⁵ Relative to Herbert Simon’s idea of bounded rationality, this notion emphasizes that rationality depends on boundaries—that is, Simon’s terms are redundant. Simon, “A Behavioral Model of Rational Choice,” *Quarterly Journal of Economics* 69 (1955): 99–118.

ones,” Thompson wrote, and “the innovative organization will be characterized by structural looseness generally.”³⁶ This looseness had direct value to the organization, in that belonging to multiple groups would “increase the amount and diversity of ideas and stimulation.”³⁷ In a 1932 article, a construction manager similarly noted that “the allegiance of the employee is to the industry rather than to the employer.”³⁸ In times of change, firms have used employees both for their direct contributions to tasks and as links to ambiguously defined communities. In hiring a skilled construction worker or an esteemed research scientist, managers have sought the directed perception of the individual, which, in turn, has existed by virtue of his or her acculturation in a particular style of thought and participation in collectives external to the firm. This basically different orientation has distinguished the exploration of new opportunities from the exploitation of existing capabilities.³⁹

Though applied conspicuously to large technical tasks during and since World War II, the use of ‘project’ has long been routine in organizing and describing engineering work.⁴⁰ Whether an engineering scheme, a military campaign, or a social program (or some mix of these), projects have been imaginations of future states of affairs and formulations of means by which to achieve objectives. As a way of thinking about work, projects have had a singularity that distinguishes them from other kinds of production; overall processes are never repeated at the same location and under the same conditions. There may be kinships between one project and another and repetitive tasks within a project but these are partial; the object being created and the organization creating it develop in tandem. Lacking the fixedness and repetition found on a factory floor, the tasks required to meet an

³⁶ “Bureaucracy and Innovation,” *Administrative Science Quarterly* 10 (1965): 1–20, quotes, 13, 14.

³⁷ Ibid.

³⁸ R.C. Marshall, Jr., “Construction—Industry Nobody Knows,” *Engineering News-Record* 108 (February 3, 1932): 170–171, quote, 171.

³⁹ James March uses exploration and exploitation, respectively, as I use building and operating. See “Exploration and Exploitation in Organizational Learning,” *Organization Science* 2 (February 1991) reprinted in Michael D. Cohen and Lee S. Sproull, eds., *Organizational Learning* (Thousand Oaks: SAGE Publications, 1996), 101–123.

⁴⁰ The word came to English by way of the French *projet*, which derived from the Latin *proicere* or *projicere* and *project-um*, for the act or object of throwing forth or out. Used in English since the fifteenth century, the term has been applied to the projection of political, scientific, and military plans as well as the physical act of throwing. *Oxford English Dictionary*, on-line edition. The term generally refers to some form of directed action. The *OED* notes the ironic exception of “projecting” used in the American South in the for idle scheming or trifling, as in this sentence cited from the *Charlottesville Daily Progress* in 1957: “It beats all get-out how some people are always tinkering and ‘projecting’ on how to do things different from the way most people do them.” In the nineteenth century engineering literature, the term “projectors” can be found used both directly and ironically, in the latter case as a derogatory term roughly equivalent to speculators or touts.

organization's objective cannot be specified to the same degree because working conditions cannot be as well known in advance.

Given these conditions and contexts, project-based organization has been and can be conceptually opposed to factory or mass production.⁴¹ As with factory production, pressures of speed, complexity, and scale motivate formal organization in project environments. A project is managed rather than left solely to craft organization and informal networks.⁴² A construction manager writing in 1924 observed this simply: "No effective results can be obtained in building construction by haphazard methods. The necessity for controlling and co-ordinating the numerous elements which are interdependent is essential."⁴³ Purely craft-based organization relies on informal working relationships and tacit allocations of work, which take time to develop and time to operate. As the need to specify points of contact between different aspects of work in both space and time increases—whether because of innovation-driven destabilization of known divisions of labor or because time is precious—informal organizations fail. But unlike factory production, projects lack the visibility and repetition that conceptually and practically make routine-oriented management possible. The output of the individual involves mental activity and group interactions that are unspecifiable as a consequence of uncertain conditions. Because the work is at best only partly predictable, task definition can include the object hoped for and time of completion desired, but it cannot fully set out the steps to be taken. Uncertainty encourages decentralization of decision-making and makes the manager a facilitator of horizontal communication more than a top-down director of work.

Though mass and project production are both complicated processes in which time is a driving factor, they differ in that labor processes organized by project-based logics are non-repetitive and inscrutable. Mass production is an assembly of tasks performed by special-purpose machines and *operative* labor running those machines—Adam Smith's pin factory and all its subsequent elaborations. Project production is an organization of tasks assigned according to the *craft* knowledge

⁴¹ For further discussion of this conceptual opposition see Rolf A. Lundin and Christophe Midler, eds., *Projects as Arenas for Renewal and Learning Processes*, and Eskil Ekstedt, Rolf A. Lundin, Anders Söderholm, and Hans Wirdenius, *Neo-Industrial Organising*.

⁴² Robert Eccles, "Bureaucratic versus Craft Administration: The Relationship of Market Structure to the Construction Firm," *Administrative Science Quarterly* 26 (1981): 449–469.

⁴³ W.J. Lynch, "How a Contractor Schedules Operations for a Large Office Building," *Journal of the Western Society of Engineers* 29 (June, 1924): 265.

and skills involved—assemblies of people hired because of their identities as carpenters or Java programming experts. Given these distinct building blocks and acknowledging that organizations do not exist in pure forms, these factors can be used to locate projects and mass production relative to each other on several dimensions (figure 0.1).

Figure 0.1 –Project-based organizing mapped in relation to factors in the working environment. Intermediate forms such as job-shops and batch-production processes could be located in the space shown but are omitted for clarity.

This analysis helps isolate an important aspect of project-oriented fields. The tools and organizations used to manage projects can be thought of as efforts to locate, isolate, and cope with uncertainties in time, space, and organization. Gantt charts and their elaborations in Critical Path Method, Program Evaluation and Review Technique, and Design Structure Matrix (CPM, PERT, and DSM, respectively) diagrams all aim at disaggregating and coordinating work. They are projective, controlling, and linearizing. At the same time, they are just educated guesses that help locate and connect activities that cannot be further taken apart. Projects are thus working plans for the terms of exchange between component parts of work—their essence is in setting up communication protocols and control points, usually according to technical interfaces.⁴⁴ Mapping the research, development, and production process against the nature and volume of communication involved helps draw out a crucial aspect of this dynamic (figure 0.2).⁴⁵

⁴⁴ On communication patterns and structures as shapers of organizations see Wanda Orlikowski and Daniel Robey, “Information Technology and the Structuring of Organizations,” *Information Systems Research* 2 (1991): 143–169, and Wanda Orlikowski and JoAnne Yates, “Genre Repertoire.”

⁴⁵ The process represented in figure 0.2 should be recognized as idealized, but it nonetheless provides a useful foil. See Trevor J. Pinch and Wiebe E. Bijker, “The Social Construction of Facts and Artifacts: Or How the Sociology of Science and

Figure 0.2—The research, development and production process, seen in terms of applicability of different modes of control and shifts in the mode of communication.

Basic investigations involve individuals, small groups, and modest, largely informal volumes of communication. These are craft processes, with identities and skills shaping how the work gets done. As a product or process passes into development, more people join the work and the volume of communication increases. Technical relationships multiply. In order to organize and manage interactions, the work is taken apart and people are assigned to distinct tasks. At this stage, requirements can be set for when, between whom, and in what form communication should take place, but these can only be loosely defined and the content of communication remains unforeseeable. Conferences and progress reports allow for timed but open-ended interactions. As the nature of the artifact under construction and the organization producing it stabilize, more interactions can be specified. With full, “mature” production, most communication becomes routine exchange of operating data, disrupted only by unanticipated maintenance and incremental improvements to the process. These transitions between proposal, building, and operation within the development of an individual product also operate over longer cycles of industry emergence and definition.

Schumpeterian Swarms: Indices for Eras of System Building and Social Definition

Expanding Joseph Schumpeter’s idea of entrepreneurial “swarms” to embrace the establishment and content of periodicals, the formation of non-firm institutions, and theorizing on organizations helps link economic cycles to the nature of the work being done, associating theories of project-based forms with periods of technical and industry tumult.⁴⁶ In Schumpeter’s scheme, with technical

the Sociology of Technology Might Benefit Each Other,” in Bijker, Hughes, and Pinch, eds., *The Social Construction of Technological Systems*, 17–50; and, Edward Constant, “The Social Locus of Technological Practice,” same volume, 223–242.

⁴⁶ The idea of swarms is in Joseph A. Schumpeter, *The Theory of Economic Development*, translated by Redvers Opie (Cambridge: Harvard University Press, 1934), 223–236.

innovation new firms emerge to challenge existing companies, exploiting new possibilities and redefining markets. Responding rhetorically to the question, “why is it that economic development in our sense does not proceed evenly as a tree grows, but jerkily; why does it display those characteristic ups and downs?” Schumpeter answered:

“The answer cannot be short and precise enough: exclusively *because the new combinations are not, as one would expect according to the general principles of probability, evenly distributed through time*—in such a way that equal intervals of time could be chosen, in which the carrying out of new combination would fall—but *appear, if at all, discontinuously in groups or swarms.*”⁴⁷

During swarms, it is not simply products and processes immediately at hand that are emergent, but also larger networks of relationships. With innovative turmoil, social and technical structures and allegiances develop or reform simultaneously at the levels of the project, firm, industry, and profession as new divisions of labor bring about new working relationships and identities. As a consequence, there are larger volumes of unspecifiable communication during swarming periods than at other times. This helps locate and interpret conversations related to project-based organizing. Statistics on capital flows, rates of business formation, and miles of railroad track or fiber-optic cable laid provide potential markers. Swarms can also be found by dating the establishment of professional associations, looking for clusters in the formation of technical and management journals, and, within journals and the records of businesses and associations, tracking content—in other words, by looking for activity around new technologies and divisions of labor akin to that evident in the new economy discourse of the 1990s. The pattern that emerges from this search is one of sector-specific booms in project work and theorizing about that work. I have been able to find and interpret the evidence in the following chapters by looking for such periods.

Given these relations between communication and technical uncertainty, the ponderings of individual managers can be located against patterns in industry evolution or the innovation cycle. By adding further labels to the diagram introduced above, shifts in dominant organizational logic can be plotted in terms of an industry’s passage from an era of inventors and enthusiasts through a period of system building, then to coalescence around standards and technologies, and finally to operation and incremental innovation (figure 0.3).

⁴⁷ Ibid., 223, italics in original.

Figure 0.3 – Industry cycles, suggesting shifts in the mode of control, volume and type of communication, and the institutional settings in which discourses take place.

Just as the nature of communication and the identities of the communicators stabilize over the course of an individual project, divisions of labor and professional identities and institutional affiliations fix in the course of industry emergence. Figure 0.3 thus helps locate different industries in relation to ‘maturity,’ showing that while some businesses or industries systematize and move to the right, others reach steady states short of mass production. The construction industry and laboratory research can be seen as constrained by the persistence of uncertainty and consequent unspecifiable communication in their work. Industries characterized by short product cycles because of the vagaries of fashion or technology similarly churn somewhere in the middle part of the diagram.⁴⁸

Stinchcombe asserts that organizations develop structures in response to the sources of risk and uncertainty in their environment.⁴⁹ This ties the logic of construction to that of innovation and the

⁴⁸ Work on “high-velocity” companies or rapidly changing industries can be seen as stories about industries cycling somewhere short of standardization. Shona Brown and Kathleen Eisenhardt, “The Art of Continuous Change: Linking Complexity Theory and Time-Based Evolution in Relentlessly Shifting Organizations”; Clayton Christensen, Fernando Suárez, and James Utterback, “Strategies for Survival in Fast-Changing Industries,” *Management Science* 44 (December 1998): S207–S220. See also Clayton Christensen, *The Innovator’s Dilemma*; Clayton Christensen and Richard Rosenbloom, “Explaining the Attacker’s Advantage: Technological Paradigms, Organizational Dynamics, and the Value Network,” *Research Policy* 24 (1995): 233–257.

⁴⁹ *Information and Organizations*. Stinchcombe reanalyzes Chandler’s *Strategy and Structure* in more explicitly information-processing terms than originally employed by Chandler. Chandler comments on Stinchcombe’s work as part of a review symposium in “History and Organizational Sociology,” *Contemporary Sociology* 20 (May 1991): 340–342.

dynamic of the individual project to that of overall industries. Stinchcombe notes that “the administrative problems posed by innovation are of the same sort that skill and decentralization ordinarily solve,” and that, “innovations should tend to create pressures for divisional decentralized administration, such that the innovation has a separate but integrated news-collecting, information-processing, and decision-making structure.”⁵⁰ In essence, he observes that research departments should look like construction firms. Indeed, both have historically relied on project-based rather than operating logics. Recent studies highlight the need to insulate innovation from operation and the difficulties of integrating both activities within single organizations.⁵¹ With Stinchcombe’s comments and the preceding diagram, the degree to which different parts of an organization need to be insulated from one another will follow from distinctions in their information-processing structures that, in turn, reflect the uncertainty (or immaturity) of the environments in which they operate.

At the industry scale, Michael Tushman and Lori Rosenkopf have proposed a “sociopolitical dynamic” associated with technology cycles.⁵² Similarly, Trevor Pinch and Wiebe Bijker have focused on “interpretive flexibility” in “relevant social groups” over the course of the development of new technologies, a process that reaches rhetorical “closure and stabilization.”⁵³ Seeking to recognize the relative influence of chance events, social processes, and individual agency at different stages of industry definition, Tushman and Rosenkopf build their dynamic on a cyclical model of variation, selection, and retention in the adoption of technologies.⁵⁴ In this scheme, “technological discontinuities” unseat established “dominant designs,” leading to “eras of ferment” during which social and stochastic processes impinge on the selection of a new dominant design. With this winnowing comes an “era of incremental change” that is characterized by refinements and elaborations of the agreed-to design. This lasts until another discontinuity comes along.

⁵⁰ Stinchcombe, *Information and Organizations*, 24.

⁵¹ For example, Tushman and O’Reilly, “The Ambidextrous Organization: Managing Evolutionary and Revolutionary Change.”

⁵² “Organizational Determinants of Technological Change: Toward a Sociology of Technological Evolution,” *Research in Organizational Behavior* 14 (1992): 311–347.

⁵³ Pinch and Bijker, “The Social Construction of Facts and Artifacts.”

⁵⁴ This cycle is developed in Michael Tushman and Philip Anderson, “Technological Discontinuities and Organizational Environments,” *Administrative Science Quarterly* 31 (1986): 439–465; and Philip Anderson and Michael Tushman, “Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change,” *Administrative Science Quarterly* 35 (1990): 604–633.

The important point in connecting these discussions to patterns in the theorizing of project-based forms is that the construction of a technology is a social process that is *more* social at some times than at others.⁵⁵ There is more communication about more relationships at some times than at others. In other words, there is a socio-managerial dynamic associated with technology cycles. Tushman and Rosenkopf's cycles of social influence can be set against patterns in organizing logics (figure 0.4).

Figure 0.4—Cyclical patterns in the volume and nature of communication set against Tushman and Rosenkopf's scheme for understanding the relative influence of social factors in the course of technology cycle. The lower portion of this illustration is adapted from Tushman and Rosenkopf, "Organizational Determinants of Technological Change," 339.

Recognizing the social, political, and organizational dynamics that shape technology, Tushman and Rosenkopf refer to "technology as community." In construction work (again, as I broadly define it), the productive unit or technology cannot be neatly equated with a bounded entity such as a plant any more than it can with a firm. To recognize the relationships and tools that together make up a productive unit in a project-oriented environment is to see the communities of participants that surround projects. Inverting Tushman and Rosenkopf's phrase, community can be seen as technology. Or, in Fleck's terms, a thought collective is both product and producer of its technical objects.⁵⁶

Tracy Kidder has described the reaction of an engineer at computer company Data General on seeing the insides of rival Digital Equipment Corporation's VAX minicomputer. Looking into the

⁵⁵ Tushman and Rosenkopf argue that the selection process will be more or less social according to the complexity of the product. That is, simple, non-assembled products can be distinguished on technical grounds more easily than can complex assemblies of component technologies. See "Organizational Determinants of Technological Change."

⁵⁶ These patterns can also be interpreted using Thomas Kuhn's language of paradigm shifts as set out in *The Structure of Scientific Revolutions*.

machine, the engineer “imagined he saw a diagram of DEC’s corporate organization.”⁵⁷ The chapters that follow show that this relationship between organizational configurations and product architectures is a basic fact of engineering management. Further, in project-oriented industries, the innards of the technology betray the organization of both the immediate project and of constellations of external relationships. Gantt or CPM charts represent nested black-boxings inscribed in products, which at the same time echo larger social configurations. Management in project-oriented settings effects both these boxings and the terms of communication between them. At an industry scale, conversations help produce dominant industry and product architectures.⁵⁸

Projects, Business History, and the History of Technology

The diagrams discussed in the preceding section help position this study in relation to divergent approaches to business history and the history of technology. Alfred Chandler’s expositions of the establishment and refinement of systems are studies of industries progressing toward full maturity in the sense of routinized information processing associated with volume production for multiple markets—the classic multidivisional corporate form. Authors who focus on system building or the social construction of technology typically take snapshots of industries earlier in their period of definition.⁵⁹ This observation supports Chandler’s central thesis that strategy begets structure, emphasizing that Chandler studied *operating* structures.⁶⁰ Where high-speed throughputs of information can be used to drive uncertainty out of a system, large, integrated organizations make sense if there is no reliable external source for equivalent information. By contrast, project-based organizing helps coordinate irregular and disparate communications as best as can be managed. David

⁵⁷ *The Soul of a New Machine* (New York: Avon Books, 1982), 32.

⁵⁸ The foregoing analysis helps articulate why “architectural innovation” is hard for operating organizations. Rebecca Henderson and Kim Clark use this term to refer to changes in products that affect the *relationships* among component parts whereas radical innovation defines entirely new products while incremental innovation improves performance by refining existing components and connections. Architectural innovation forces existing organizations backward along the above curves, tearing at established technical and human relationships and routines. Rebecca Henderson and Kim Clark, “Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms,” *Administrative Science Quarterly* 35 (1990): 9–30.

⁵⁹ See David Hounshell, “Hughesian History of Technology and Chandlerian Business History: Parallels, Departures, and Critics,” *History and Technology* 12 (1995): 205–224.

⁶⁰ Chandler puts forward his central thesis most directly in *Strategy and Structure*, 13–14.

Hounshell has observed, "social constructivists have a key to understanding the behavior of young systems; technical determinists come into their own with the mature ones."⁶¹

Cyclical relationships between organizational logics and technological dynamics provide the most important general quality to be discerned from the evidence presented in the chapters that follow, but these patterns cannot be fully understood without reference to more traditional periodizations of mainstream management discourse and, broadly, the development of systematic management. The two dynamics interfere. Overviews of the history of management theory typically identify a trajectory from organic forms of solidarity to more mechanical and bureaucratic structures.⁶² Informed by ideas from Max Weber and Emile Durkheim, these distinguish the bonds of fealty found in pre-industrial societies from the bureaucratic governance of atomized individuals trapped in the "iron cage" of capitalism.⁶³ Studies that extend developments to the present sometimes find a shift back to more normative forms of workplace control with the rise of human relations approaches to individuals and groups since the 1930s, but put this in the context of a long arc of refinements to scientific approaches to organizing.⁶⁴ When Reinhard Bendix considered management ideas in the United States over the course of industrialization and up to the 1950s, he found that:

"Thus, over the past two hundred years, managerial ideologies in Anglo-American civilization have changed from the 'theory of dependence' to laissez-faire, to Social Darwinism, and finally to the 'human relations' approach."⁶⁵

Extending and updating Bendix's approach, Mauro Guillén similarly identifies in the United States,

"... a historical process by which the ideological justification of managerial and organizational practices shifted from religious and paternalistic grounds to scientific

⁶¹ "Hughesian History of Technology and Chandlerian Business History," 215.

⁶² The classic treatment is Reinhard Bendix, *Work and Authority in Industry: Ideologies of Management in the Course of Industrialization* (New York: John Wiley and Sons, 1956), reprinted with a new introduction (Berkeley: University of California Press, 1974).

⁶³ Max Weber, *The Protestant Ethic and the Spirit of Capitalism*, trans. by Talcott Parsons (New York: Scribners, 1958); Emile Durkheim, *The Division of Labor in Society*, trans. by George Simpson (New York: The Macmillan Company, 1933). The "iron cage" metaphor comes from Weber.

⁶⁴ Daniel Wren, *The Evolution of Management Thought*; Stephen Barley and Gideon Kunda, "Design and Devotion: Surges of Rational and Normative Ideologies of Control in Managerial Control." *Administrative Science Quarterly* 37 (1992): 363–399; Mauro Guillén, *Models of Management: Work, Authority, and Organization in Comparative Perspective* (Chicago: The University of Chicago Press, 1994).

⁶⁵ This quote appears in the conclusion to the 1974 edition of *Work and Authority in Industry*, 436. The conclusion to the 1974 edition is a revised version of a 1959 lecture, "Industrialization, Ideologies, and Social Structure," originally printed in *American Sociological Review* 24 (October 1959).

ones, including the extensive influence of engineering science between the world wars and of social and behavioral science after 1945.”⁶⁶

Mapping the relationships among these ideas, Guillén locates strains of thought according to whether they were primarily religious or scientific in their orientation and relative to several historical watersheds, which he identifies with, first, the broad bureaucratization of workplaces and the professionalization and unionization of workforces near the end of the nineteenth century, second, labor unrest and the increasing application of social-psychological approaches to management after 1945, and third, economic stabilization and corporate diversification in the 1960s. Suggesting an alternative periodization, Stephen Barley and Gideon Kunda have traced “surges of rational and normative discourse” in management theory, identifying five distinct eras or waves in the United States since 1870—industrial betterment in the late 1800s, scientific management in the early 1900s, welfare capitalism and human relations in the interwar period and up to the mid-1950s, systems rationalism from the 1950s to about 1980, and organizational culture in the last two decades. In Barley and Kunda’s analysis, these waves reflect “less a progression than a continued wrestling with counterpunctual themes.”⁶⁷ With simplification, Guillén’s strains of thought can be overlaid on Barley and Kunda’s cycles (figure 0.5).

Figure 0.5 – Patterns in mainstream management discourse. Developed from Mauro Guillén, *Models of Management: Work Authority, and Organization in Comparative Perspective* (Chicago: University of Chicago Press, 1994), figure 2.1, 31; and Steven Barley and Gideon Kunda, “Design and Devotion: Surges of Rational and Normative Ideologies in Managerial Discourse,” *Administrative Science Quarterly* 37 (1992), table 1, 364. Note that relative to this illustration, Guillén’s original diagram provides a richer sense of the oppositions and connections between competing models and that Barley and Kunda also emphasize conflicts between different views.

Barley and Kunda observe the broad acceptance of the general scheme they describe, noting that “despite serious theoretical and political differences, scholars have converged on a common vision of

⁶⁶ *Models of Management*, 30.

⁶⁷ “Design and Devotion,” 364–365.

how American managerial thought has evolved.”⁶⁸ These and other histories of management theory share a focus on a coterie of individuals who themselves focused on understanding large, hierarchical organizations. Guillén uses content analysis of major management journals to quantify the adoption of paradigms promoted by individuals including Frederick Taylor, Henry Gantt, Elton Mayo, Kurt Lewin, Peter Drucker, and Herbert Simon, among others. Bendix, Barley and Kunda, and other historians of management theory refer to this same set of actors.⁶⁹

A basic contention of this dissertation is that widely held but ultimately partial perceptions of management history in the U.S. reflect this focus on a limited cast of characters, but these are nonetheless accurately the individuals who dominated management discourse in their days. Managers of engineering work who participated in less prominent conversations had to contend with the mainstream. More pointedly, with the development of a science of machine regulation and its extension to industrial administration, organizers of projects were forced to manage both with and against such ideas. To summarize, vogues in management theory and shifts in organizational logic interfered to shape the tools available and the problems at hand. There remains the task of more closely specifying how I have mustered evidence to support these contentions.

Vade-mecum, Journal, and Textbook Engineering as Indices and Objects

Hunt's Merchant's Magazine and Commercial Review, a New York publication that ran from 1839 to 1870, represented itself as “a perfect *vade mecum* to the merchant, the manufacturer, and the Banker, as well as to the Statesman, Commercial lawyer, and Political Economist.”⁷⁰ The term ‘vade-mecum,’ from Latin for ‘go with me’ is typically treated as equivalent to ‘handbook,’ in the sense of a compendium of facts usefully kept at hand. In this regard it is equivalent to the use of ‘magazine’ to qualify a publication as a storehouse of information, but in present-day use a magazine is a *news* journal appearing at frequent intervals whereas a handbook presents both old and new information in editions issued in an annual or longer cycle. In *Genesis and Development of a Scientific Fact*, Fleck distinguished these two classes of publications and added a third to describe the types of literatures

⁶⁸ Ibid., 363.

⁶⁹ In addition to the noted works, see Wren, *The Evolution of Management Thought*; Waring, *Taylorism Transformed*.

⁷⁰ Issue of June 1849, cited in Frank Luther Mott, *A History of American Magazines*, Vol. 1, 1741–1850 (New York: D. Appleton Press, 1930), 697.

that develop in and through the activities of thought collectives. In Fleck's use, vade-mecum science is how-to literature addressed to practitioners—codifications of laboratory procedures, tabulations of reference data, and the like, as in the cases of the reference handbooks used today in chemistry, physics, and other fields or of engineers' pocket books popularized in the nineteenth century. Journal science similarly serves the esoteric circles of a collective, but where handbooks capture established, assumed facts, journals report on the application of a discipline's rules and assumptions in new endeavors. Fleck's third class of literature, textbook science, serves exoteric, popular audiences and helps in the induction and acculturation of new members into an expert community.

Each system-building boom has generated literatures that can be classed following Fleck's scheme. Railroading in the 1850s and electronics in the 1950s alike generated handbooks, magazines, and texts. Attention to the formative periods of each of these industries reveals a dynamic in the development of these literatures, particularly evident in the nature and content of journals and professional proceedings. Journals help constitute markets for information. Alongside other new business combinations, journals appear in swarms associated with technological and entrepreneurial ferment. In such periods, professional associations form and establish their own publications, hoping for sustenance from emergent communities. Government periodicals often precede commercial journals, appearing as part of the work of agencies and offices funded to abet technologies in the public interest. Agricultural research, aircraft engineering, and electronics engineering were each aided in their formative periods through government-funded publication of technical serials.

Because they echo the communities they serve, trade and industry periodicals offer indices to technical and social coalescence. Many of the serials started in the heady early days of an emergent industry fold or consolidate as the industry or profession they serve moves from expansion to stability or decline. As publications disappear and combine, the nature of their content shifts. In a given industry, the earliest publications serve promoters, speculators, and hobbyists. With growth, new publications appear and older ones shift to serve system builders and investors. Many fail for lack of readership. Those journals that survive generally shift to serving operators and providing business data rather than technical intelligence. Hence, compiling bibliographic data on trade and professional publications for a given industry helps locate when and where system building and the management of uncertain work have mattered. With frequent mergers, absorptions, and splinterings compounded

by title changes, following the family trees of technical journals is a laborious task.⁷¹ Nonetheless, even incomplete trees reveal a pattern related to the craft-project-system dynamic mapped in the preceding section. Figure 0.6 shows the growth of the periodical literature in several industries.

Figure 0.6 – Number of journals serving selected engineering industries, 1825 – 1960. The data underlying this illustration is not exhaustive and hence this illustration should be seen only as suggestive. Further detail of the nature and content of the magazines counted in this image appears in following chapters.

The relevance of these patterns to the history of management theory is simple: finding theorizing on the management of builders requires looking for builders' discourses. These, like projects and project-oriented businesses, have been fleeting, but combing through journals in periods when they have been proliferating in a given industry brings to light rich veins. For the 1910s, the *Journal of Industrial and Engineering Chemistry* provided the most important forum for theories of research management. For the 1930s, *Product Engineering* and *Aero Digest* should be recognized as important forums for management theory. In similar fashion, for the early 1950s the Institute of Radio Engineers's *Transactions on Engineering Management* registered the search of a rapidly growing profession for organizational principles. In some cases, journals that survived only briefly are useful

⁷¹ Aids to this undertaking include *The Engineering Index*, published from 1895 with retrospective coverage extending back to the 1870s, the *Industrial Arts Index*, and printed and on-line union lists. Frank Luther Mott's five-volume *A History of American Magazines* (Vol. 1, 1741–1850, New York: D. Appleton Press, 1930; Vols. 2 through 5, covering 1850–1865, 1865–1885, 1885–1905, and 1905–1930, respectively, Cambridge: Harvard University Press, 1938, 1938, 1957, and 1968) includes some coverage of commercial and trade magazines. The first two volumes briefly cover early commercial and trade publications, 696–698 and 78–83, respectively. Volume 2 includes *American Railroad Journal* among its sketch portraits of magazines, 297–300. The third volume is particularly valuable for covering the “mania of magazine-starting” after the Civil War but before the coverage of modern indices begins, 5. This volume also covers technical and trade journals at some length, 104–136. Roger Burlingame's semi-popular history of McGraw-Hill, *Endless Frontiers: The Story of McGraw-Hill* (New York: McGraw-Hill, 1959), is useful for the first half of the twentieth century. There is no study of the several other technical publishing houses of the early 1900s.

markers for cresting discourses. *Research Laboratory Record* in the early 1930s and *Innovation* in 1969 and appeared at apogees of interest in organizing for innovation. The relationships between the discourses of builders and operators in periodicals follow a pattern similar to that of unspecified and specified communication within projects and industries developed above. Discussions of building crest and then wane as operating literatures coalesce in relation to maturing industries.

More than Ideology and Honor: Professional Cultures and Getting Work Done

A second marker for the emergence of new thought collectives can be found by dating the establishment of professional and trade associations. Historical studies of the professionalization of engineering have emphasized struggles over ideology, social position, and power.⁷² Ethnographic studies of technical work share this perspective in part, focusing on coincident divisions of labor and power.⁷³ Edwin Layton refers to the founding the American Society of Civil Engineers as reflecting a profound “desire for moral independence” and Raymond Merritt emphasizes the “cosmopolitanism” and “*noblesse oblige*” of engineering elites. Layton sees the story of the professional development of engineers as a “search for personal dignity, independence, and social responsibility in a corporate age,” a battle he sees as ultimately lost.⁷⁴ David Noble views the rise of industrial laboratories as “the development of the institutions necessary for the production of both scientific knowledge and knowledgeable people, and the integration of these institutions within the corporate-based system of science-based industry.”⁷⁵ But there was more to it.

⁷² Monte A. Calvert, *The Mechanical Engineer in America, 1830–1910: Professional Cultures in Conflict* (Baltimore: Johns Hopkins Press, 1967); Edwin Layton *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession* (Cleveland: The Press of Case Western Reserve University, 1971); and David Noble, *America by Design: Science, Technology, and the Rise of Corporate Capitalism* (Oxford: Oxford University Press, 1971). More balanced views are Daniel H. Calhoun, *The American Civil Engineer: Origins and Conflict* (Cambridge: MIT Press, 1960) and Raymond Merritt, *Engineering in American Society, 1850–1875* (Lexington: The University Press of Kentucky, 1969).

⁷³ This is an oversimplification, but essays such as those collected in Stephen Barley and Julian Orr, eds., *Between Craft and Science: Technical Work in U.S. Settings* (Ithaca: ILR Press, 1997) and Peter Meiksins and Chris Smith, eds., *Engineering Labour: Technical Workers in Comparative Perspective* (London: Verso, 1996) do emphasize class and status issues. See also Peter Meiksins, “The ‘Revolt of the Engineers’ Reconsidered,” *Technology and Culture* 29 (April, 1988): 219–246; R. Zussman, *Mechanics of the Middle Class: Work and Politics Among American Engineers* (Berkeley: University of California Press, 1985); and Peter Whalley, “Negotiating the Boundaries of Engineering: Professionals, Managers, and Manual Work,” *Research in the Sociology of Organizations* 8 (1991): 191–215. On professionalization and the division of labor see also Charles Sabel, *Work and Politics: The Division of Labor in Industry* (Cambridge: Cambridge University Press, 1982) and Andrew Abbott, *The System of Professions: An Essay on the Division of Expert Labor* (Chicago: University of Chicago Press, 1988).

⁷⁴ *The Revolt of the Engineers*, ix.

⁷⁵ David Noble, *America by Design: Science, Technology, and the Rise of Corporate Capitalism*, 6.

As Merritt observes, professional societies also served practical roles for their memberships. In the first issue of the *Transactions of the American Society of Civil Engineers* in 1868, William J. McAlpine observed that the engineer who failed to keep abreast of technical developments could “rest assured that sooner or later *he* will be shelved.”⁷⁶ Though not a U.S. example, when Britain’s Institution of Electrical Engineers issued a “Standard of Professional Etiquette for Consulting Electrical Engineers” in 1902 that forbade solicitation of employment verbally, in writing, or through an agent and then further prohibited its members from responding to advertisements, it was mocked in the engineering press.⁷⁷ Professional association involved ideology, jurisdiction, and power, but it also provided markets for professional services, forums for communication about evolving technologies, and sanctions that helped define social structures and norms on job sites.

The development of social networks around esoteric knowledge has served a coordinating function for other kinds of labor as well, but in engineering these networks have been disproportionately important because of the shifting, often itinerant nature of the work. Engineering societies have served as businessman’s clubs and hiring halls. Growing, branching, and specializing bodies of technical knowledge have presented problems for both suppliers and purchasers of engineering skills, and engineers have needed means to develop and keep abreast of working knowledge while employers have needed means by which to identify qualified personnel. In this light, professional associations reflect divisions of labor in relation to the technical systems with which they codevelop and are, ultimately, part of these systems, echoing their architectures and workings.⁷⁸ Like swarms in the establishment of new technical and trade magazines, the appearance of new professional associations marks efforts to organize in relation to emergent technologies.

Some sense of the branching and size of different disciplines comes from census records. Categorization in the decennial U.S. census lags actual divisions of labor, but because discussion of

⁷⁶ William J. McAlpine, “Presidential Address, *Transactions A.S.C.E.* 1 (1868): 48. Quoted in Merritt, *Engineering in American Society*, 28.

⁷⁷ *The Engineering Magazine* noted that the document failed to include “a clause forbidding any member to permit such a thing as professional work to be mentioned to him at all, but requiring him to accept commissions only under compulsion of bodily injury, making it necessary for him to be sought out by the keen scent of bloodhounds and dragged from his carefully hidden lair and haled to work by force.” “The Regulation of Engineering Practice” 24 (1902): 604–605.

⁷⁸ Abbott, *The System of Professions*.

management in technical communities tends to come with growth, this complements other markers for conversations (figure 0.7).

Figure 0.7—Divisions of labor marked by the decennial U.S. census. Figures are numbers in thousands; "N.E.C." stands for not elsewhere classified. Source: U.S. Bureau of the Census, *Historical Statistics of the United States*, CD-ROM edition, Series D245–264.

The take-off or branching periods marked in professional associations, periodical literatures, and census figures together help identify periods when builders have had to become managers.

Historically, a significant proportion of trained engineers have become managers, not just of engineering work but also of larger businesses. In his 1963 introduction to Thorstein Veblen's 1921 *The Engineers and the Price System*, Daniel Bell set the development of the engineering profession in the context of an historical search for an autonomous class of expert administrators stretching back to Saint-Simon and other syndicalists and up to the "managerial revolution."⁷⁹ Of 600 graduates of the Stevens Institute between 1872 and 1896, 230 were in executive positions in 1900.⁸⁰ In an editorial comment introducing a 1901 article on engineers as managers, *The Engineering Magazine* noted that

⁷⁹ (New York: Harcourt, Brace and World, Inc., 1963), 3–4.

⁸⁰ William D. Ennis, "The Industrial Management of Engineering Works," *Engineering Magazine* 22 (1901): 241. Both Merritt and Layton cite similar statistics.

“the vast material progress of the last half century has been the direct result of entrusting more and more of the executive management of enterprises to the engineer.”⁸¹ Within given fields, transitions from technical to administrative problems have accompanied the growth and complexity of the work.

Summary and Structure to Follow

By examining published and archival evidence of efforts to understand and represent the management of creative activities in engineering and scientific disciplines in the United States over the course of industrialization, this dissertation illuminates a hitherto obscure aspect of the history of management theory. In doing so, it draws on and complements historical and present-minded studies of business operation and management (figure 0.8).

	Past		Present	
	Factory/ Mass	Flexible/ Project	Efficient Operations	Effective Innovation
Management Theory	Bendix (1956), Litterer (1959), Barley & Kunda (1992), Wren (1994), Guillén (1994)		Process Reengineering Quality Management	Social Construction Communities of Practice Interpretation/Boundary Objects Relational Networks
Business Practice	Chandler (1962, 1977) Hounshell (1984)	Sabel and Zeitlin (1985, 1997), Scranton (1997)	Process Reengineering Quality Management	Option-Based Networks “Ambidextrous Organizations”

Figure 0.8—The location of this study, mapped in relation to studies of management theory and practice, past and present. Only representative authors are cited for the historical literature. For more present-minded studies, representative concepts are indicated; it should also be recognized that the boundaries between reflective theorizing and positive prescription are inexact for these literatures.

The historical patterns set out in this introduction can be overlaid and used to locate the conversations that form the basis of the organization of this study (figure 0.9).

⁸¹ Introduction to *ibid.*

Figure 0.9—Conversations around problems in project-based organization, located in time and in relation to professional discourses.

In this illustration, each of the dark gray figures approximately marks the periods and occupations in which project-based organization has become a topic of heated discussion in response to both external pressures and internal complexity. Bullets mark the foundation dates of significant professional societies. Individual arrows mark approximate take-off periods for occupation-specific conversations, based on patterns in journal formation. In bridging across occupations, conversations reflect the integrative quality of the management of projects and mark historical connections by way of inter-occupational exchanges. Gaps do not mark the absolute disappearance of project-based organization as a problem, but rather periods in which discussions around this form of organization have waned and which have helped make project-based organizing appear novel when next discovered.

Chapter 1

The Economy of the Section:

Technical and Administrative Relations in Engineering Practice before 1890

“The origin... we must seek, not in variability, but in the uncertainty that results from it. Variability is an objective fact; uncertainty is a state of mind, and as such is the parent of extensive derangements of Economic Production.”¹

The beginning is not a beginning so much as a bifurcation. Before clocks and steam engines and factory whistles, most employments were irregular. Flexibility could be a problem only once there were inflexible production systems. Building could be opposed to operating only once the latter existed. Uncertainty could only derange Economic Production once there was such a thing. So, this chapter does not begin with the beginning of project-based accounting and organization. Rather, it starts in the period in which this kind of organization started to be something different, something that would later require explanation by virtue of acquired oddity. In the United States, this change took place over the course of the nineteenth century, particularly with the spread of the steam engine and the continuously operating systems it powered—most significantly railroads and factories.² From

¹ Edward A. Ross, “Uncertainty as a Factor in Production,” *Annals of the American Academy of Political and Social Sciences* 8 (September 1896): 92–119, quote, 111.

² Factory production did not of course begin with steam power but with waterpower. Samuel Slater’s mill at Pawtucket, Rhode Island, built in 1790, was the first factory in the United States. Subsequent developments at Waltham and Lowell, Massachusetts, in the 1810s and 1820s elaborated systems that embraced not just production processes but also workers’ lives and local economies. While factories radically altered daily and seasonal patterns for workers and surrounding communities, through the first half of the 1800s the distinctions between factory work and other forms of labor were less marked than they later became. In the early 1800s, factory production was only somewhat regular. Employment was often seasonal—governed by the availability of waterpower and willing workers, and hence exposed to weather and the cycles of agricultural employment. Textile and grain mills most nearly approximated continuous production, but the work experience at these factories remained passing. Over time, many goods that had been produced one at a time or in discreet batches or lengths increasingly approximated flows. Jonathan Prude, *The Coming of Industrial Order: Town and Factory Life in Rural Massachusetts* (Cambridge: Cambridge University Press, 1983); Louis C. Hunter, *A History of Industrial Power in the United States, 1780–1930* (3 vols., Charlottesville: University Press of Virginia, 1979–1991); E.P. Thompson, “Time, Work-Discipline, and Industrial Capitalism,” *Past and Present* 30 (1967): 56–97; David Landes, *Revolution in Time* (Cambridge: Harvard University Press, 1983).

efforts to manage the operation of these machines and systems, the theory and practice of business management developed as part of a science of regulation—a science of formulas for optimal rates, pressures, and efficiencies fed by flows of operating information from the gauges, indicators, and, later, cost-accounts of steam-powered systems. Split from and defined in relation to this emerging discipline, a loose kit of tools for managing irregular, one-off projects formed through engineers' efforts to coordinate the building rather than the operation of increasingly complex technical artifacts.

This split was not fully recognized or articulated in the period covered here, and so this chapter prepares the stage for later developments. In doing so, it uses railroad construction as a prototypical case. The construction of transportation infrastructure in the 1800s was bound up with the emergence of new divisions of labor, new professions, and new markets for goods and services. It also reflected longer-standing practices. Early railroads involved the use of military personnel and government accounting systems in private enterprise, the expression of physiocratic and laissez-faire approaches to engineering and government, and the definition of civil from military engineering. Of particular import to the history of management, the steam engines that powered railroads embodied the ideal of self-governing systems while also marking their failures—the continued hand of the engineer was required to prevent explosions, collisions, and other derangements. Railroads are further useful as an introduction to how technical and administrative logics mix in engineering work. Their planning and construction wrote large basic management issues that are constant across settings in this and subsequent chapters, if more complex in later instances. The small size of the communities and literatures that developed in the early days of railroading help make plain dynamics that are more involved in later cycles.

In addition to showing that what is now called project management was already commonplace in the nineteenth century, the intents of this chapter are several. It first rehearses the story of steam-powered systems as the generative force behind the development of modern business administration. Second, it locates a conceptual and practical split between building and operating. And third, it introduces early practices in the graphic representation of engineering work, establishing early representations of engineering projects and organization as precedents for later abstractions. In establishing these points of departure for episodes to follow, this chapter's organization also sets a pattern. It begins with a sketch of general historical developments, here several engineering booms of

before 1890. It then turns to more particular consideration of discussions of railroad construction in the nineteenth century. Finally, two cases provide a sense of how social and technical logics mixed in engineering practice and provide a more intimate sense of engineering conversations.

Internal Improvements and the Emergence of Engineering Discourse

There were two great engineering booms in the United States before the Civil War. Marked by the start of work on the Erie Canal in 1817, the first of these peaked in the early 1830s.³ This era saw a competitive rush to build ‘internal improvements’—canals, roads, and railroads—that pitted states and sections against each other in their hopes of dominating trade routes to the North American interior. Entrepreneurial legislatures and business interests promoted works while Federal involvement in infrastructure creation increased as politicians and military officers argued for transportation networks in support of interstate commerce and national defense. Typical in its mingling of local and national purposes, an 1831 report of the President of the Baltimore and Ohio Rail Road Company, to the Governor of Maryland, asserted that, “the establishment of an efficient, speedy and economical means of intercommunication between the different sections of our country, had for a long time been deemed of such importance as to involve, not only the well being, but perhaps the very existence of our social compact.”⁴ He followed this with a description of the great problems that his company had encountered in establishing the first sections of its railroad and an entreaty that, “she [the state of Maryland] should continue her patronage to this great enterprize and she will certainly secure to herself the full development of all the advantages which her geographical position gives her in relation to the vast and rapidly increasing commerce of the west.”⁵

³ The Erie Canal was completed in 1825. There were earlier canals, but the Erie marked the start of a general wave of transportation development. On the Erie, see Carol Sheriff, *The Artificial River: The Erie Canal and the Paradox of Progress, 1817–1862* (New York: Hill & Wang, 1997). General information in this section is culled from Colleen Dunlavy, *Politics and Industrialization: Early Railroads in the U.S. and Prussia* (Princeton: Princeton University Press, 1994); Daniel Calhoun, *The American Civil Engineer: Origins and Conflict* (Cambridge: Technology Press, 1960), Carter Goodrich, *Government Promotion of American Canals and Railroads, 1800–1890* (New York: Columbia University Press, 1960) and Forest G. Hill, *Roads, Rails, and Waterways: The Army Engineers and Early Transportation* (Norman: University of Oklahoma Press, 1957).

⁴ Philip Thomas, reproduced in *American Railroad Journal* 1 (January 7, 1832): 18. The Baltimore and Ohio—the first commercial road started in the United States—had been under construction only since 1828 and would not reach the Ohio River for two more decades. On the Baltimore and Ohio see James D. Dilts, *The Great Road: The Building of the Baltimore and Ohio, the Nation's First Railroad, 1828–1853* (Stanford: Stanford University Press, 1993).

⁵ *Ibid.*, 19.

Following a recession that bottomed in the early 1840s, infrastructure construction—predominantly of railroads—renewed with greater intensity in the 1850s. Not all of the early canal and railroad schemes had been successful and many had depleted state treasuries, limiting public enthusiasm for further direct subsidy, but government support through land grants contributed to the economics of railroad construction. From the late 1840s, telegraph lines paralleled many of the rails. By 1860, extensions west from the Pennsylvania Railroad reached to St. Louis and from the New York Central to beyond Chicago. More importantly, these lines existed as part of an increasingly dense network of transportation infrastructure, with a weave of branch lines linking up to main trunks.

Figures 1.1 and 1.2 show these early cycles. As can be seen in figure 1.2, railroad construction reached still more frenzied levels after the Civil War. By the time of this later boom, though, the nature of a railroad as a technical system was no longer in its experimental stage—the configuration of physical and social arrangements around railroading had been set though railroad systems continued to expand. The technical and administrative definition of railroading in the United States occurred in the 1830s through 1850s, with the refinement of steam locomotives, acceptance of a standard gauge, and protocols for interline transfers of cars, freight, and passengers. Divisions of labor also settled, with the roles of locomotive engineers, brakemen, ticket masters, and so on configuring in relation to railroad operation. Industry-level routines would set further in the 1870s and 1880s, with the formation of societies and unions in relation to divisions of work, but there was by 1860 a dominant industry architecture. Operating departments were by the post-bellum period generally distinct from engineering or construction operations.⁶

⁶ Chandler, *Strategy and Structure, The Visible Hand*.

Figure 1.1—Canal Investment in the United States, 1815–1860. Source: data from H. Jerome Cranmer, “Canal Investment in the United States, 1815–1860,” *Trends in the American Economy in the Nineteenth Century* (Studies in Income and Wealth, 24, Princeton: 1960), 547–564. Cranmer’s data is also partly reproduced in Carter Goodrich, *Canals and American Economic Development* (New York: Columbia University Press, 1961), 208–209, and in U.S. Bureau of the Census, *Historical Statistics of the United States*, CD-ROM edition, Series Q559–564.

Figure 1.2—Miles of Railroad Built in the United States, 1830–1879. Source: data from *Historical Statistics of the United States*, CD-ROM edition, Series Q329.

These early booms in infrastructure construction were bound up with developments in the broader industrialization of the United States and with the emergence of engineering as a profession. The spread of factory production concentrated and regularized output in a variety of processing and manufacturing industries. The contemporary growth of transportation and communication networks in turn allowed the wide and coordinated distribution of raw and finished materials. The combination of these processes of concentration and integration had practical and conceptual consequences. At the beginning of the nineteenth century, manufactures and commerce in the United States were largely coastal, contract based, and craft produced. Limits to transportation and communication made local markets and exchanges within them relatively discrete. As transportation projects opened new markets and linked these together and, in turn, trade and the distribution of goods and information over roads, rails, and canals increased, the sources of administrative problems shifted. Businesses

faced new difficulties managing output and traffic over ever-growing and faster-moving systems. As Chandler has emphasized, revolutions in the speed of systems and in the managerial coordination of information flows went hand in hand.⁷

The American Society of Civil Engineers did not permanently form until after the Civil War, but 'civil engineer' as a role and identity was brought into being through canal and railroad projects. The slow split of civil from military engineering and the former's loose definition as a community of practitioners will be taken up further after first establishing some of the conceptual and practical problems around which this community coalesced.

Physiocracy and Steam

The progress of the steam engine as motive power and metaphor captures much of physical and conceptual redefinition of work, business, and economy that occurred with industrialization in the United States. While continuities between earlier, water-powered systems and those driven by steam should not be lost, steam did increase the engineer or mechanic's control over the inputs and outputs of the engine. Attached to shafts and belts, steam engines freed factories from dependence on waterpower. Set on wheels, steam power "annihilated space and time."⁸ In and with the steam engine, technical and intellectual currents from British and French engineering and political philosophy mixed to shape ideas of systems and their regulation.⁹ The gauges and indicators of the steam engine complemented the newly mass-produced precision pocket watches and provided new ways of measuring work. Theoretical determinations of potential output against which realized force could be tested gave new meaning to the term 'efficiency.'¹⁰ But behind these generalities and abstractions were operating problems that distinguished steam-powered systems from their predecessors. Steam

⁷ Ibid.

⁸ The phrase comes from an Alexander Pope couplet, "Ye Gods! annihilate but space and time, And make two lovers happy," from *Martinus Scriblerus on the Art of Sinking in Poetry*, chap. xi. On its adoption to describe the action of steam railroads on mental maps, see Leo Marx, *The Machine in the Garden: Technology and the Pastoral Ideal in America* (New York: Oxford University Press, 1964), 194; and William Cronon, *Nature's Metropolis: Chicago and the Great West* (New York: W.W. Norton, 1991), 198.

⁹ On steam engine regulation as a shaper of mental outlooks, see Otto Mayr, "Adam Smith and the Concept of the Feedback System," *Technology and Culture* 11 (1971): 1-22 and *Authority, Liberty, and Automatic Machinery in Early Modern Europe* (Baltimore: Johns Hopkins Press, 1986); and David Mindell, "'Datum for Its Own Annihilation': Feedback, Control, and Computing, 1916-1945," (Ph.D. dissertation, MIT, 1996), especially 15-21.

¹⁰ The *Oxford English Dictionary*, on-line edition, dates this use to the mid-nineteenth century.

engines tended to explode. Steam trains collided with each other at high speed. When steam-powered systems failed, they often did so catastrophically. Canals, waterwheels, and roadways required tending and maintenance, but there was less need to formally coordinate their use or constantly monitor their behavior. Relative to railroads, these earlier systems were loosely coupled in their making and operation. Traffic volumes were modest, wagons or boats could nudge onto the shoulder or against the bank to give way, and rough consistency in vehicle size sufficed to ensure compatibility. The greater coordination needed to run a steam engine or railroad drove a basic shift in the role of engineering from facilitation to governance, a shift that complicated physiocratic and laissez-faire notions of the place of engineers and governments.

Physiocratic and laissez-faire ideology, like other aspects of early U.S. political philosophy, had origins in the Enlightenment social theory. While there are important differences between classical political economy as espoused by Adam Smith and other Scots and Englishmen and physiocratic theories associated with French circles around François Quesnay, these theories shared belief that the wealth and health of nations were matters of productive capacity and free circulation rather than of holdings.¹¹ The influence of both of these lines of thinking on political and economic theory in the early United States is widely evident and acknowledged. In the case of engineering it traveled especially through the defining role of French theory carried from the *Ecole des Ponts et Chaussées* to West Point by instructors and administrators.¹² In an 1825 report on canal construction, two ranking Army engineers explained the goal of national improvements in explicitly physiocratic terms:

“This system will contribute essentially to the great end of rendering the means of our government more efficient; for, by reducing the time necessary for communication, it will reduce, in fact, the great distances which divide the sections of our vast empire from each other, and will enable us easily and promptly to transfer the means and produce of one climate to another; it will give a new value to the agricultural and mineral riches of our soil, and a new life and activity to our manufacturing industry, by facilitating their circulation. Without a free and constant circulation, the political, as well as the human body becomes paralyzed and benumbed in its operations.”¹³

¹¹ There are significant differences between these schools. A general overview of differences and debts can be found in T.W. Hutchison, *Before Adam Smith: The Emergence of Political Economy, 1662–1776* (Oxford: Basil Blackwell, 1988).

¹² On eighteenth century French engineering thought see Antoine Picon, *French Architects and Engineers in the Age of Enlightenment*, trans. by Martin Thom (Cambridge: Cambridge University Press, 1992) and *L'invention de l'ingénieur moderne : l'Ecole des ponts et chaussées, 1747–1851* (Paris: Presses de l'Ecole nationale des ponts et chaussées, 1992).

¹³ Report of General Barnard and Colonel Totten, February 25, 1825, quoted in Hill, *Roads, Rails and Waterways*, 66–67. Notably, Barnard was a Frenchman.

Complaining of the limited number of trained engineers available for employment in the construction of improvements, the *National Journal* of October 23, 1825, noted that "either the spirit of this great system must be checked for want of men of science qualified for these employments, or superficial and incorrect surveys must be made..."¹⁴ Albert Gallatin, Secretary of the Treasury under Jefferson, authored a report on roads and canals in 1808 in which he advocated a national plan of improvement in the form of an interconnected system of roads and canals.¹⁵ Introducing this document, Gallatin noted that in the sparsely populated United States, canals could not "be undertaken with a view solely to the intercourse between the two extremes of, and along the intermediate ground which they occupy." Rather, they would become productive only when connected up with other improvements.¹⁶ Though typical early U.S. engineering projects had local and immediate objectives—a canal connected two markets or a stretch of rail brought coal from a particular seam to a particular river—they were conceived and engineered in relation to the body of the nation. In common, these approaches held that engineering work served an enabling function, freeing circulations of natural riches to find their own level.

An expression of the engineer's aim in building systems that would need no attendance in operation can be found in a treatise on the engineering of the Long Island Railroad written in the late 1830s. In this, an anonymous engineer offered several pages on the operation of the line as this influenced the engineering, with his aim being to eliminate operating problems through the initial layout.¹⁷ Having rejected installing two tracks over the full length of the line, the author explained his method for determining how many turnouts would be needed for "the accommodation of the greatest amount of long business on the road, or the non-interference of the trains, by regulating their passing places, so that at the time of starting the points of crossing shall always be known." Continuing, he explained that this could be "effected by making these places correspond with certain

¹⁴ Cited in Hill, *Roads, Rails and Waterways*, 61, from reprinting in "Corps of Engineers," *Niles' Weekly Register* (October 22, 1825): 121–122.

¹⁵ Though largely an inventory of existing and proposed canals, this report opened with a call for the "early and efficient aid of the federal government." Albert Gallatin, *Report of the Secretary of the Treasury on the Subject of Public Roads and Canals* (Washington: R.C. Weightman, 1808), reprinted (New York: Augustus M. Kelley, 1968), 8, italics original.

¹⁶ *Ibid.*, 7.

¹⁷ An Engineer, "Description of the First Division of the Long Island Railroad, with Remarks," *American Railroad Journal and Mechanics' Magazine* 7 (September 15, 1838): 176–188; (October 1, 1838): 208–217; and (October 15, 1838): 247–251.

divisions of time, hours or half-hours, and by determining an uniform rate of speed for all the engines at all times; or, if it should be necessary to have two descriptions of engines on the road, and two degrees of speed, that there should be two sets of passing places to correspond." Describing at length the graphic method by which he used these principles to determine the location of turnouts, he noted that his solution left some margin of error, as the road "would probably never be occupied by so many trains."¹⁸ Beyond the establishment of departure times, the road would need no management. On the earliest railroads, even departure times were not managed. An early railroad had almost no operating organization because supplying vehicles and conveying them along the line was not the railroad's business—the road operated like a turnpike or canal. The engineer established the system, and free agents used it. There was no such thing as traffic management.

Otto Mayr has discussed the connections between Adam Smith's economics and the notion of feedback in self-governing systems.¹⁹ Mayr cites David Hume's mid-eighteenth century argument that markets should be allowed to naturally equilibrate the balance of trade as the first unambiguous expression of economic self-regulation.²⁰ For Hume, as for Smith and other, later advocates of laissez-faire economics against mercantilism, government interference in the economy was morally wrong for its disequilibrating action. Mayr sees the notion of feedback as fully developed by the time of Smith's 1776 *Inquiry into the Nature and Causes of the Wealth of Nations*. The relevance here is that the role of the engineer of the early nineteenth century was seen as a matter of setting systems in motion that should then go of themselves. When self-governance failed—dramatically in the case of head-on railroad accidents—the engineer was forced to intervene and to regulate. Steam engines did not complicate underlying objectives, but they confounded the laissez-faire approach to circulation and in so doing shifted the engineer's role from economist to manager.

In this transition, the means used to manage steam engines form an important conceptual and practical link. James Watt's refinements to his 1765 steam engine included two notable subsystems: the gauge and the governor. The first of these, the gauge, enabled calculation of the actual behavior of

¹⁸ Ibid., 208–209. The diagrams were unfortunately not reproduced. H.G. Funkhouser cites French examples of similar graphic timetables of just after 1840, "Historical Development of the Graphical Representation of Statistical Data," *Osiris* 3 (1937): 269–404, citation, 308.

¹⁹ "Adam Smith and the Concept of the Feedback System" and *Authority, Liberty, and Automatic Machinery in Early Modern Europe*. See also Beniger, *The Control Revolution*.

²⁰ "Adam Smith and the Concept of the Feedback System," 3.

an engine relative to standards derived from theory. Given theoretical output calculated from physical laws and measures of actual behavior read from the pressure gauge, efficiency could be calculated. The use of this word to describe not simply the efficacy of an action, but its relation to a theoretical ideal, introduced a new way of thinking about the work of machines and men alike. Watt himself participated in the definition of 'horse-power' as a basis of comparison between the work of animals and that of steam-engines.²¹ The second subsystem of note here, the governor, in principle made the steam engine self-regulating. Set spinning by steam pressure, a governor worked through the action of centrifugal force on a pair of weights. These then opened a relief valve in proportion to the pressure of the engine.²² Though this innovation took a great deal of unpredictable behavior out of a steam engine, such machines still could not be left entirely on their own. Limits to knowledge in metallurgy, design flaws, and variations in the quality of coal made the behavior of the individual steam engine uncertain, necessitating continued recourse to human monitoring. Through measuring the behavior of engines, and critically through the ability to check observed output against theoretical power, a science of system regulation developed. The use of indicator diagrams, gauges, forms, and tables for calculating the efficiency of an engine based on comparing theoretical and realized curves were essential elements of the engineer's art.²³ Notably, the Stevens Institute's student engineering magazine of later in the century took *Indicator* for its title, marking the role of the engineer.²⁴

The key point in the forgoing is that the steam engine and the systems it powered required routine intervention to be kept going. Gauges and indicators delivered flows of operating data that could be used to diagnose and correct problems and to incrementally guide the engine to its proper, efficient behavior. In controlling and directing the pressures and forces of a steam engine, the engineer took on a governing role. Railroads and factories multiplied possibilities for and mandated the practices of such measurement and correction. Later in the century, limits to gauging and standardizing work

²¹ Of several experiments on the power of a horse over an eight-hour day, those of Bolton and Watt with brewery horses fixed the number at 33,000 pounds raised one foot per minute.

²² There were earlier forms of mechanical feedback systems, but the steam regulator is disproportionately important because of the significance of the systems to which it was attached. Mayr, Mindell, and Beniger all note earlier devices.

²³ There are numerous nineteenth century treatments of this topic, in both general works on steam engines and specialized explications of indicators and gauges. Examples of the latter include Frank Hemenway's *Indicator Practice and Steam-Engine Economy* (New York: John Wiley & Sons, 1885). Most later indicators took a 3-1/4 x 7-1/8 card that available through many printers, an example of an early standard form.

²⁴ The *Stevens Indicator* was founded in 1887.

would prove a basic obstacle to the application of management systems in non-repetitive activities, but the split between building and operating implicit with the coming of steam was little articulated before the Civil War.²⁵

Railroading Journals and an Emergent Community of Practice

The profession 'engineer,' such as it existed in the United States in the early 1800s, included West Point-trained military officers and field-learned practitioners, many of the latter having worked up the ranks from axman, to rodman, and then to surveyor on early canal and railroad projects. Daniel Calhoun has estimated that in 1816 there were perhaps 27 practicing engineers or "quasi-engineers" other than military officers in the United States and that with construction of the Erie and other New York canals that number had doubled by 1825.²⁶ Accounting for West Point graduates who left military service, the graduates of several less important academic programs, and apprentices educated on early canal and railroad projects, Calhoun puts the number of men plying engineering as a trade in the mere hundreds into the 1840s. Halting efforts to form a national professional society in the late 1830s and limited success in holding together local societies in the 1840s and 1850s marked interest in a defined status for civil engineers, but in their failures reflected the small and dispersed nature of the profession.²⁷ There were nonetheless anchors for this emerging profession. Journals—most notably the *American Railroad Journal*—and the boards and private companies that employed most engineers provided affiliations and markets for the services of a developing community. This section introduces the development of such extra-firm and inter-project supports, focusing on the instrumental role of professional allegiances in getting work done.

By the end of the nineteenth century, a plethora of journals published by engineering societies and a vast outpouring of commercial trade and industry magazines provided forums for the exchange of ideas and information in areas from domestic plumbing to safety engineering. But in the first decades of the 1800s, short-lived mechanics magazines justly referred to as ephemerals were the

²⁵ In an indirect way many engineers observed the split when they remarked on their continued employment by railroads even after construction was complete. An example can be found in a memoir of W. Milnor Roberts's career that provides the basis for one of the cases at the end of this chapter.

²⁶ Calhoun, *The American Civil Engineer*, 32.

²⁷ *Ibid.*, 182–199. See also M. Roe Smith, "Becoming Engineers in Early Industrial America," MIT Program in Science, Technology, and Society Working Paper no. 13, 1990.

extent of an American technical press. From 1826 the Franklin Institute of Philadelphia published its *Journal* and engineering topics were treated in other scientific and general periodicals, but there was no distinct, reliable forum for discussions of applied engineering.²⁸ Nor was there a distinct body of engineers for one to serve—most practicing engineers had West Point and the Army Corps as conduits for the intelligence and identity that a magazine or an association might provide.

Somehow from the diverse parties interested in railroads, the *American Railroad Journal* found an audience. The profession of civil engineering coalesced partly around this journal, finding in its columns digests of technical and financial information, advertisements for construction materials, and a means to circulate notices of contracts. Founded in 1832, and quickly absorbing the *Mechanics Magazine* and the *Mining Journal and American Rail-road Gazette* this magazine had the field to itself until the *American Railway Times* appeared in the late 1840s. Then at least seven other publications entered the market during the boom of the 1850s (figure 1.3, on following page). Not all survived, and the Civil War brought a lull in the establishment of journals, but new publications appeared in the late 1860s and early 1870s along with renewed railroad construction.

The general nature of these magazines as well as the particulars of their content provide a first example of how trade journals participated in and marked the development of an industry and profession. This trajectory can be mapped by following the *American Railroad Journal*. Started as a broadsheet advocating railroad construction in 1832, it survives today as part of *Railway Age*, a magazine primarily addressed to operational issues.²⁹ Since its founding it has absorbed at least ten once-independent journals and seen an equal number go out of business as railroading matured. Though the industry's maturation was drawn out over some decades, the *Journal's* shift from serving communities of constructors to informing the business of operating occurred in the 1850s, marking the end the industry's most fluid days.

²⁸ On the Franklin Institute see Bruce Sinclair, *Philadelphia's Philosopher Mechanics: A History of the Franklin Institute* (Baltimore: Johns Hopkins University Press, 1974).

²⁹ The early decades of *American Railroad Journal* are discussed in detail in Alfred Chandler, *Henry Varnum Poor: Business Editor, Analyst, and Reformer* (Cambridge: Harvard University Press, 1956). See also Mott, *A History of American Magazines*, Volume 2, 297–300.

Figure 1.3--Railroading Journals, 1830-1930. Note the shifts in the industry evident from journal titles, with publications started after 1870 likely to address subspecialties of operating engineering, reflecting changed activities and splintering divisions of labor. Note also patterns in formation, consolidation, and folding of journals against the industry cycles illustrated in figure 1.2. This and similar figures in subsequent chapters are based on inevitably incomplete efforts to track family trees, and so should be seen as suggestive of patterns rather than as exhaustive characterizations of literatures. Grey diamonds mark significant name changes, with new names indicated where space permits.

Though the *Journal* was unabashedly a promoter of railroads, in its first issue founding editor D.K. Minor admitted that railroads were still an experiment and, making oblique reference to the uselessness of canals when ice-clogged, that “further investigation may lead to the construction of new Canals, of the value of which, for part of the year, we are fully aware.”³⁰ Marking his hope that he would find paying subscribers, Minor stated that the first issue was a specimen that did not fully represent what the *Journal* would be when “under way with a *high pressure* locomotive of two or three *thousand* subscribers.”³¹ The first paid advertisement appeared on the last page of the second issue, advising readers of the availability of wrought iron spikes suitable for railroad use from a Troy, New York agent.³² Like many early U.S. periodicals, the *Journal* was partly a digest of materials culled from other publications. Minor duplicated a good portion of another publication he owned in the *Journal*. He also found a low cost means of filling pages with information of interest to his readers by publishing consulting engineers’ reports to railway commissions.³³

Reflecting the gyrations of a developing industry, Minor’s success at finding an audience varied over the course of his editorship. In its first numbers, *Journal*’s masthead carried only the basic title. In its second volume, it gained the subtitle, *and Advocate of Internal Improvements*, suggesting a broader coverage though railroading remained the focus. In the early issues of this second volume, Minor pledged to increase his coverage to include sections from the *London Mechanics’ Magazine* if he could get 500 more subscribers.³⁴ Late in the 1830s, with the collapse of railroad construction and following a fire that destroyed his presses, Minor reduced the physical format of the *Journal* and all

³⁰ D.K. Minor, “To the Public,” *American Railroad Journal* 1 (January 2, 1832): 1.

³¹ Editorial, 2. Italics original.

³² 22. Later advertisers included makers of rope and sellers of atlases and commercial statistics. The first paid notice of contract lettings appears in 1 (April 7, 1832): 239, in a notice regarding part of the Lexington and Ohio Rail-road. The second contract notice, for work on the Ithaca division of the Ithaca and Owego Railroad, indicated that “Maps and Profiles of this part of the road [the 20-odd miles to be let] may be seen at the office of the Engineer in Chief” and that it would be divided “into sections of suitable length.” 1, (May 12, 1832): 319.

³³ A representative example is Ephraim Beach, “Report of Ephraim Beach, Esq., Civil Engineer, to the Commissioners of the Susquehanna and Delaware Canal and Railroad Company,” *American Railroad Journal* 1 (March 17, 1832): 178–179. Notably, Minor also reprinted a substantial part of Charles Babbage’s *The Economy of Manufactures* in serial form in the first volume.

³⁴ See both the last issue of 1832 and the first of 1833 (1, December 8, 1832, and 2, January 5, 1833). Minor pledged this transformation upon reaching 1,500 subscribers. Minor claimed near 1,000 subscribers in the early issues of Volume 2. He briefly published a separate *American Mechanics’ Magazine*, folding this into the *Journal* in July 1838.

but eliminated illustrations.³⁵ In 1845, still under Minor's editorship, the paper enlarged again and became the *American Railroad Journal and General Advertiser for Railroads, Canals, Steamboats, Machinery, and Mines*. Paid notices in the *Journal* from the late 1840s offered track, rolling stock, steam locomotives, the services of engineers, and tables of railroad departure times.

In Chandler's assessment, the *Journal* survived during Minor's editorship only because engineers seized on it as a means of exchanging technical information. "The supplying of technical information came less from Minor's initiative," asserts Chandler, "than from the imperative need for such data in the railroad world."³⁶ Chandler quotes an early letter to the *Journal* that emphasized this role and expressly differentiated railroads from other works projects in their uncertainty:

"Something of this kind has for a long time appeared necessary as a means by which the variety of information connected with this subject may be collected and disseminated. Rail-roads, unlike other means of internal communication, have various modes of construction. Canals and turnpikes differ very little under any circumstances. But you will scarcely find two of all the numerous projects of Rail-roads now in progress in this country, whose construction is after the same plan. Even on the same work a variety of modes is sometimes used, as, for instance, on the Baltimore and Ohio Rail-road, where four different methods of *construction*, or more definitely of laying rails have been pursued. If engineers or other persons feeling sufficient interest in the matter, were to make communications from time to time, imparting such information in relation to the work on which they may be engaged, as would lead to a knowledge of the manner of construction noting defects, suggesting improvements, and in a word giving any statements which would be collected, and through your useful paper disseminated, that would lead to results in the Rail-road department of Engineering highly important and advantageous to the public."³⁷

In the early 1830s, a railroad was an ill-defined technology and there was consequently a market for up-to-date news of technical developments. The Reverend Dionysius Lardner's *The Steam Engine Familiarly Explained and Illustrated*, an English book that appeared in American editions in the 1830s, similarly marked demand for information on railroad construction. In his later and American issues Lardner added a chapter on "Plain Rules for Railway Speculators." Immediately following coverage of the efficiency of engines and the meaning of horse-power in a chapter on the "General Economy of Steam Power," the "Plain Rules" embraced the relative economics of canals and

³⁵ About this time Minor switched to a smaller format and issued a series of pleas for past-due subscribers to cover their balances.

³⁶ Chandler, *Henry Varnum Poor*, 36.

³⁷ *American Railroad Journal* 1 (January 28, 1832): 68, also cited in Chandler, *Henry Varnum Poor*, 35, 37.

railroads and basic railroad engineering of curves, inclined planes, and tunnels.³⁸ Through the first decades of the *Journal*, technical problems and the need for standardization were regular concerns of articles and letters.

Henry Varnum Poor succeeded Minor as editor in 1849, and changed the *Journal*'s tag line to *Steam Navigation, Commerce, Mining, and Manufacturers*. Within that year he added assistant editors for mining and metallurgy, manufactures and the mechanic arts, and civil engineering, but this broadened coverage of engineering disciplines did not last. Under Minor, the *Journal* had provided tabulations of goods moved by canals and railroads and of railroad finances. Under Poor, coverage of the financial and commercial aspects of railroading increased further. With the 1850s, the *American Railroad Journal* subtly shifted from serving the promoter and builder to addressing the owner and operator, marking a changing market for railroading intelligence. By the 1850s, the sort of basic technical information wanted by the engineer of the early 1830s could be found codified in manuals and handbooks.³⁹ While the term 'management' can be found in articles published under Minor's editorship, under Poor, this became a major focus. The locus of railroading problems had shifted and technical articles in the *Journal* attended more to bridge building, comparisons of rail sections, locomotives, and rolling stock.⁴⁰

In the 1850s, the *Journal* also increased coverage of legal actions in relation to railroads, with an occasional column on railway law in 1852 that became a separately indexed "Journal of Railroad Law" late that year. Poor published in full New York State's "General Railroad Law" in an 1854 issue, disparaging the State's tendency to sanction particular routes as "...the instinct of self-interest is a much better judge of the *expediency* of any project than the *opinion* of a body of legislators..."⁴¹ Poor's articles generally called for better internal accounting and external accountability to securities holders, for example praising Prussian systems for tracking locomotives that associated work with

³⁸ (2nd. American ed., Philadelphia: E.L. Carey & A. Hart, 1836), 277–307 and 307–318, respectively. The two chapters noted were newly added beginning with the 1835 fifth London edition. Lardner stated that he added these in response to developing interest in railroad projects.

³⁹ U.S. engineering handbooks or "pocket companions" appear in the 1840s and 1850s and proliferate later in the century.

⁴⁰ Chandler, *Henry Varnum Poor*, 42.

⁴¹ "General Railroad Law of New York," 27 (October 14, 1854): 641–647, quote, 641.

individuals.⁴² Coverage of business issues in the *Journal* focused on three areas—tighter controls of capital outlays, greater transparency in accounting practices, and better management.

Describing the dynamic through which the railroad boom of the 1830s had ended, the *Journal* commented that “scores of... persons [had] boldly launched out upon the sea of business, with a charter of a railroad as their chart, with the credit of a capitalist for their means, and, it is hard to say with what, for a compass,” and that,

“the first dividends in railroads were usually declared upon the amount actually *paid up* when the first train ran over the road. The net income upon *this* cost, determined the rate of dividend. But the construction account being never closed, and the roads often being not more than half completed when put into operation, the progress of the work of construction added to this debt every year. When this debt increased beyond the means of the company to manage, it was provided by the issue of new stock. This increase of stock of course diminished the rate of dividends, and stockholders, only when they received a less per cent than formerly, began to inquire into the management of their property.”⁴³

The dispatch of “great financial doctors” to ailing roads had not been enough in many cases.

Over its first two decades, the *Journal* helped clear a variety of markets—for technical information, financing, equipment, and services. Under Poor, it shifted to clearing a different kind of market. In this sense, it is an early example of a U.S. publication that tracked the shifting concerns of an emerging community of practitioners and which helped shape styles of thought. During the early days, the *Journal* itself had been buoyed on the rush of speculative and sometimes ill-advised investment that accompanies periods of system building. By the late 1850s, it was an operator’s reference serving an established industry. The *Journal*’s ups and downs and shifts in content are a microcosm of the dynamics that mark later swarms of publications around new industries.

The Emergence of Civil Engineering

The American Society of Civil Engineers formed first in 1852 but was not established as a national society until about 1867.⁴⁴ In its initial incarnation it was effectively a regional society for New York, and in this regard it was like the Boston Society of Civil Engineers, formed in 1848, and a

⁴² “Extravagance in Building and Managing English Railways, and its Remedy,” 31 (September 25, 1858): 609–610.

⁴³ “Massachusetts Railroads,” *American Railroad Journal* 23 (April 27, 1850): 264.

⁴⁴ Layton describes the ASCE as having been “moribund” until 1867 while Merritt indicates the Society was not “stable” until 1870. Calhoun implies that despite the name, the earlier ASCE and later ASCE were simply two different organizations. Layton, *The Revolt of the Engineers*, 29–30; Merritt *Engineering in American Society*, 3; Calhoun, *The American Civil Engineer*. See also Smith, “Becoming Engineers.”

short-lived New York engineering society formed in 1849. Only the Boston society continued through the 1850s, survival Edwin Merritt ascribes to the older, more established, and less mobile membership of that society. The two New York societies, by contrast, scattered and it was "the extreme mobility of the profession rather than lack of funds, membership, or interest" that doomed them.⁴⁵ The slow course of the professionalization in civil engineering embodies a further dynamic. Unlike later splinterings of engineering professions, the distinction of *civil* from *military* engineering did not reflect a technical division of labor. M. Roe Smith notes that the emergence of engineering, broadly, marked the increasing use of calculation and accountability in place of cut-and-try methods—and the associated delineation of an area of expertise, whether occupied by individuals in uniform or not.⁴⁶ So, the definition of civil engineering reflected a need for an alternative forum and source of sanction rather than a distinct body of knowledge. From 1824 until it was struck down in 1838, the General Survey Act had allowed discretion in the employment of military engineers in surveying and planning improvements. The repeal of the Act cut the private sector off from a direct supply of Army engineers. When engineers left the Corps to pursue private sector opportunities, they were then cut off from a basis of professional legitimacy. The formation of engineering societies thus had an instrumental role in simply getting work done.

Chandler notes that the British engineering societies and French *grands écoles* provided institutional channels for information in European railroad construction.⁴⁷ Similarly, though on a limited scale, the Engineer Corps was a conduit for technical information in early U.S. engineering. Engineering skill was not available in the early nineteenth century except through field-exposure or military training and service.⁴⁸ In authorizing the use of Army engineers on private projects, Congress recognized that "the greatest difficulty which Americans encountered in the execution of their public works, was not to procure the necessary capital, but to find men capable of directing operations."⁴⁹

⁴⁵ *Engineering in American Society*, 100–101.

⁴⁶ "Becoming Engineers," 23.

⁴⁷ *Henry Varnum Poor*, 39–40, 52.

⁴⁸ Hill, *Roads, Rails and Waterways*, vii.

⁴⁹ Michael Chevalier, *Society, Manners, and Politics in the United States*, trans. by T.G. Bradford (Boston: Weeks, Jordan, 1839), 272, quoted in Hill, *Roads, Rails, and Waterways*, 4.

Formal programs of education for engineering also expanded in the third quarter of the century, with the Rensselaer Polytechnic Institute transformed into an engineering school in 1850.⁵⁰ Other existing schools added engineering curricula in this period, including Union College, Harvard and Yale Universities. The Morrill Act of 1862 led to the post-war creation of agricultural and technical schools including the Massachusetts Institute of Technology.⁵¹ As a technical degree became a prerequisite for engineering employment, school ties became social currency. If an engineer had had military training, this was often marked by continued use of his rank at retirement from the service in later professional life—and sometimes engineers without Army experience acquired “major” or “general” as a marker of reputation. By late in the century, this marker was no longer needed as lists of professional affiliations and academic degrees came to serve the equivalent function. By-lines in turn-of-the-century engineering publications often unfurl long lists of memberships, and engineering biographies prominently featured technical accomplishments.

To summarize, improving communications, a developing body of technical knowledge, and the conscious efforts of engineers to define themselves professionally helped individual engineers anchor themselves in a social setting even as their work took them from place to place. Professional associations provided forums for the exchange of technical and commercial information. They also served a legitimizing and sanctioning function in relation to transactions in a service business. In light of this perspective, the regional nature of the earliest American engineering societies and the term *civil* in American Society of Civil Engineers make sense. Though military engineers built fortifications and those not in the military did not, there were not many further distinctions in the work. The difference was that military officers knew where their next job was coming from and had places in the social and official hierarchies of the Army that served as professional identities. The definition of civil from military engineering in the mid-nineteenth century marked less a change in the nature of the work done or a quest for autonomy than a developing need for institutional supports and social networks distinct from both the military and older ties.⁵²

⁵⁰ Merritt, *Engineering in American Society*, 3.

⁵¹ *Ibid.*, 29.

⁵² Smith, “Becoming Engineers,” 24.

A Prototypical Case: Sectional Logics and Railroading

Early in *Strategy and Structure*, Chandler marked off the origins of modern business organizations in the United States by distinguishing the operation of railroads from their construction, stating directly that “the *operation* of a railroad or canal called for more administration than its *construction*.”⁵³ For Chandler, running trunk-line railroads had “demanded wholly new methods of management” in the 1850s and, by way of contrast, he briefly described the modest administrative problems involved in building work:

“During construction, the line of the canal or road was divided into a number of ‘divisions,’ each in charge of an ‘assistant engineer’ who was responsible for surveying the route and then inspecting the progress of construction. At headquarters, a chief engineer supervised the work of his assistants in the field. The task of this organization, however, was more technical than administrative: it was only to lay out the line and then to see that the contractors carried out plans. A board, public or private, provided the funds and made the final major decisions as to the termini and general location. Until the 1850’s, the contracting firms which actually built the transportation works remained small. Since such a contractor rarely built more than a few sections of a road, he could easily supervise the job by himself.”⁵⁴

The engineering organization overseeing this work on behalf of the railroad’s directors was similarly easy to manage as, “the general superintendent had little difficulty in keeping close contact with the division engineers and all the employees carrying out the road’s business.”⁵⁵

Chandler contrasted the modest, local, and informal means that were sufficient to directing construction to the far-flung, formal methods developed to operate railroads once they were built. In his account, railway traffic was the original object of management rationalization and preventing train wrecks had mandated the creation of hierarchical business organizations, a development later extended to managing throughputs in mass production industries. Developing this reasoning in *The Visible Hand*, Chandler cited the case of the Western Railroad, which ran between Worcester, Massachusetts and Albany, New York, as exhibiting “the first modern, carefully defined, internal organization structure used by an American business enterprise.”⁵⁶ The Western created this structure in 1842 after a fatal wreck caused public outcry and an investigation into the road’s operations by the

⁵³ *Strategy and Structure*, 21, italics original.

⁵⁴ Ibid.

⁵⁵ Ibid.

⁵⁶ *The Visible Hand*, 97.

Massachusetts legislature. The structure devised by the Western consisted of central coordination of a divisional organization.

Once in operation, the uncertainties the Western needed to control were the actual positions of its trains, which could be thrown off intended schedules and passing points by weather, mechanical failure, or other problems. A divisional organization, aided by telegraphic communication, provided a means of monitoring and correcting the system's behavior in response to observed data. Marking the progress of formal communication systems, one railroad engineer commented in 1902, "...how worthless and futile a link in the chain of information needed is a verbal word of mouth report, which answered many, if not most, purposes in the earlier years of small mileage."⁵⁷ Writing in the *Transactions of the American Society of Civil Engineers* in 1910, Emile Low, a member of that Society, made a similar observation but with reference to the administration of early railroad construction rather than operation:

"In the early days of railroad building in the United States, the work, with rarely an exception, was divided into one-mile sections. Separate monthly reports of work performed were made for each section during the progress of the work and a final report at the completion of the same. These reports showed the value of the work done at the contract prices and this formed a record of quantities and values, which was generally known as the *estimate* and which has become a standard term for work performed, the same as the words, bill or statement for goods bought.

"In addition to the information mentioned, the estimate also contained a statement called the *force account*, which was a monthly summary of all the various classes of labor employed by the contractor on the one-mile section which the estimate covered.

"The rate of wages paid by the contractor being known, the total cost could be ascertained. The force account did not always contain every item of expense incurred by the contractor, but in a way served as a comparison, when compared with the value of work performed as returned by the engineer.

"These early rude records were the forerunners of the more elaborate methods and systems described [today]."⁵⁸

What were the relationships between "worthless and futile links" in operation and "early rude records" in construction? Charles O'Connell has contested the originality Chandler ascribes to the railroads and instead sees management systems as having reached the railroads by way of the Corps

⁵⁷ George Sampson, "Railroad Organization." *Journal of the Association of Engineering Societies* 28 (January 1902): 2.

⁵⁸ Emile Low, review of Halpert P. Gillette and Richard T. Dana, *Cost-Keeping and Management Engineering*, in *Engineering News* supplement (February 17, 1910): 17. Italics in original.

of Engineers.⁵⁹ Showing that the Baltimore and Ohio Railroad adopted management methods from officers of the Corps of Engineers who aided its construction, O'Connell remarks "a management system overtly tied to Army methods served the B&O well until 1847, when operational problems became more pressing than technical ones."⁶⁰ Tracing similar influence in the case of the Western, O'Connell argues "the key to the military's contribution to the Western was the ability of former officers to translate the techniques used to administer engineering projects into operational procedures for managing the complex daily business of a railroad."⁶¹ Both O'Connell and Chandler are correct—on the one hand, modern business organizations are translations of older forms but, on the other, the railroads radically transformed nature of these organizations in operation. This will be drawn out over the balance of this section.

Until late in the 1800s the coordination of construction work was little discussed. There is no reference to management in any engineering text or handbook of the period. The reports of engineering consultants from the early nineteenth century are remarkably modern, providing detailed analyses of alternative routes, projections of costs and revenues, and keen awareness of the interrelatedness of economic, social, and political aspects of the projected improvements, but such reports mention only physical obstacles, not organizational issues.⁶² Similarly, engineers' day books and accounts from before the Civil War include records of events, labor employed, and moneys spent, but pay little attention to organization beyond the initial letting of contracts and assignment of assistant engineers to follow the work. If labor issues appear, they do so in remarks on difficulties in getting and keeping good workers rather than on organizing. The organization of construction simply was not remarkable. Relying on unskilled day laborers, foremanship, and established craft relations, there was not much to be said about governing construction because this relied on known practices and working relationships. The organization of construction could be sufficiently described in contracts and technical drawings. In this sense, as Chandler says, the organization was "more technical than administrative." Early construction contracting shares with present practice a basic

⁵⁹ Charles F. O'Connell, "The Corps of Engineers and the Rise of Modern Management, 1827–1856," in M.R. Smith, ed., *Military Enterprise and Technological Change* (Cambridge: MIT Press, 1985): 87–116.

⁶⁰ Ibid., 106.

⁶¹ Ibid., 111.

⁶² There are many examples. For example, see *Report of the Commissioners of the State of Massachusetts, on the Routes of Canals from Boston Harbor to Connecticut and Hudson Rivers* (Boston: True and Greene, 1826).

logic of disaggregating, coordinating, and integrating work made up of sections—what would now be referred to as subassemblies or components. The intersections of administrative and technical logics are best shown through illustration.

In using graphic representation as an explanatory device, I echo historical practice and introduce a theme that runs through this and following chapters. Literal mappings of engineering projects and organizations in the nineteenth century provide connections to earlier practices in projecting engineering works and military campaigns.⁶³ The images in this chapter also provide links forward to later, more abstract representations used to manage project-based organizations, establishing a lineage in the communicative genres used in this form of enterprise.⁶⁴ Because technical drawings appear technical, their historical importance as management tools has been under appreciated. In engineering, they have served as both means of getting work done and as embodiments of expertise around and through which communities have coalesced.

Disassembly and Integration

In their simplicity, early practices in administering railroad construction are useful in several respects. First, railroad accounting and the organization of construction forces provide connections to earlier military organizing. Second, as physical artifacts, railroads provide a visible expression of sectional logics that still govern engineering projects. And third, railroad operation occasioned the development of ideas of operating management as distinct from other forms of governing work. Together, these show how the railroad harnessed the continuous operation of the steam engine to the standing organization of military forces. The interrelatedness of these issues can be discussed with reference to an illustration (figure 1.4).

⁶³ Antoine Picon, ed., *L'art de l'ingénieur - constructeur, entrepreneur, inventeur* (Éditions du Centre Pompidou, Paris 1997); Antoine Picon, *L'invention d'ingénieur moderne: l'Ecole des ponts et chaussées, 1747–1851*. Paris: Presses de l'Ecole nationale des ponts et chaussées. Edward Tufte's astounding *The Visual Display of Quantitative Information*, *Envisioning Information*, and *Visual Explanations* (Cheshire, Connecticut: Graphics Press, 1983, 1990, and 1997, respectively) richly illustrate precedents and associate technical illustration with the development of expertise. See also H.G. Funkhouser, "Historical Development of the Graphical Representation of Statistical Data."

⁶⁴ Orlikowski and Yates, "Genre Repertoire." See comment in footnote 23 of the introduction.

Figure 1.4—Dividing work and organizing labor along the line of a railroad.

Dividing labor in construction undertakings, whether through simple sectioning of equivalent lengths of track or more elaborate divisions based on qualitative aspects of work, was a matter of specifying overall goals and then the interactions of components needed to meet those goals. This exercise immediately shows the connections between military organization and railroad construction and further helps draw out the nature of the communications involved.

In the above figure, I have imitated a plan for an army encampment (figure 1.5) from the 1821 edition of the *General Regulations for the Army*, a book O'Connell calls the "first comprehensive management manual published in the United States."⁶⁵ Chandler cites an organization chart developed in the 1850s by Daniel McCallum for the Erie Railroad as the first ever printed by a U.S. company.⁶⁶ McCallum used the chart to establish lines of communication along which detailed reports would flow from operating divisions to a central organization that coordinated movements of trains, information, and capital among divisions. Chandler does not reproduce this chart, but he describes it as like a modern chart except for its upside-down orientation. In this regard, it must resemble a plan for an army encampment.

⁶⁵ U.S. War Department, *General Regulations for the Army; or Military Institutes* (Philadelphia: M. Carey and Sons, 1821); O'Connell, "The Corps of Engineers and the Rise of Modern Management," 93.

⁶⁶ Henry Varnum Poor, 147–148; *Strategy and Structure*, 22.

section on "Interior Economy of Regiments and Companies." The article called for "a spirit of good will, and even of brotherhood," as essential to "the harmony and discipline of the corps."⁶⁷

In figure 1.4, the line represents a stretch of railroad, but it could equally be a length of canal or the demarcation of a line of battle. As shown, it appears discrete, but in the selection of its termini, the setting of its gauge, and the assignment of forces it is integrated into larger systems and made to mesh with other components. The work it represents is divided into divisions and sections, whether according to length or the nature of the task, such as a bridge treated as a section in itself. So, defining a railroad required several nested levels of description. First, the overall system and its desired behavior were described. In early railroading, this came about through formation of a board, promotion of the projected line, and the preparation of initial surveys and reports by a consulting engineer. Second, a particular route by which these conditions could economically be met was decided and, along it, divisions of work were set. And third, a chief engineer and his assistants coordinated the work of contractors and saw that the component sections met up to create the desired system. In the case of a railroad, the simplicity of these interactions made them easy to see. Sections of rail conforming to a common standard were to meet at marked locations and by agreed-to dates. Within sections, organization and execution could be left to work gangs under the direction of foremen and individual contractors, with results checked against specifications by the engineer.

The role of the engineer, then, was one of balancing and coordination. In this sense, "sectioning" related to both the equalizing of cut and fill along and across the line of work during surveying and then the disaggregating of the work. These were technical tasks—involving quantities of dirt and rock, lengths of trestle, the plotting of curves and integrating of areas—but they were simultaneously descriptions of work and bases for organization. The measures of railroad construction were the cubic yard of material and the mile of track, either of which an engineer or contractor could use to estimate costs in labor, time, and dollars according to prevailing exchange rates. The drawn engineering section was thus the predecessor for later more abstract representations of work and means of graphic production control.⁶⁸ The ostensibly technical aspects of design drawings and engineering reports tend to obscure their role in organizing work.

⁶⁷ Article 16, 30.

⁶⁸ Intermediate forms between the literal engineering section and the Gantt chart are discussed in chapter 2.

Projective and Retrospective Controls in Early Engineering Practice

Engineering drawings need to be recognized as one of several types of communication used to direct work and establish accountability for completed projects. Project-based contracting and accounting systems, like military engineering drawings, have antecedents in government practices, and such illustrations were themselves typically component parts of contracts. To establish the roles of these documents and to further introduce the position of the engineers who used them, this section sets out some early history of administrative practices in U.S. government contracting, setting the stage for discussions of similar methods in later chapters, as the logics of project-based enterprise diverge from those of operating organization.⁶⁹

The Constitution of the United States requires that “no money shall be drawn from the treasury but in consequence of appropriations made by law.” As it remains today, the nature and extent of Congressional control of Executive expenditures has long been an area of contest.⁷⁰ Early debate on this subject concerned both projective appropriations and retrospective audits; that is, the setting of budgets in advance of work and the later verification of how money was spent. Funds for maintaining a standing military and the relative discretion to be allowed to government officers in spending were particular flash points in the early United States. Gallatin argued for “limiting discretionary powers” in the spending of public moneys, “whether by heads of Department or any other agents,” through “providing against the application of money drawn from the Treasury under an appropriation to any other object or to any greater amount than that for which they have been drawn.”⁷¹ In response to Thomas Jefferson’s advocacy of strict budgetary control along lines argued by Gallatin, Alexander Hamilton once asked whether the army’s horses should starve if an appropriation specified oats and only hay were available.⁷² The subsequent history of Congressional effort to either restrict or discipline the Executive’s spending is far from a uniform progress.

⁶⁹ These practices have still earlier precedents. An example of earlier French contracting practice can be found in R.S. Kirby, “Bidding Practice Two Centuries Ago,” *Engineering News-Record* 123 (Nov. 23, 1939): 72–73.

⁷⁰ See especially Lucius Wilmerding, Jr., *The Spending Power: A History of the Efforts of Congress to Control Expenditures* (New Haven: Yale University Press, 1943).

⁷¹ Albert Gallatin, *Writings*, I, 68, cited in *ibid.*, 50.

⁷² Wilmerding, *The Spending Power*, 51, citing Alexander Hamilton, *Works*, ed. by Henry Cabot Lodge (New York: G.P. Putnam’s Sons, 1885), VII, 256 ff.

In the early 1800s, Army engineers played a catalytic role as surveyors and administrators of both privately capitalized and state-financed works.⁷³ These engineers, typically graduates of West Point, were authorized to act as surveyors of civil works on a case-by-case basis after the War of 1812 and, as noted above, the General Survey Act allowed Executive discretion in employment of military engineers in surveying and planning improvements between 1824 and 1838. Administration of work under this Act was assigned to a Board of Engineers for Internal Improvements. In its limited role in allocating engineers this board adjudicated among projects. For each project, the board required data collection through initial reconnoitering and surveying, detailed location of prospective alignments, and preparation of plans and cost estimates. For a given work, multiple routes were to be evaluated such that in the selection the best could be chosen based not only on construction costs, but also on economic value to population centers and aid to the national defense. This logic was applied both to individual projects and across a general program.⁷⁴

Though I cite only the Federal case, similar battles over the control of expenditures took place at the state level and, as was true of many other aspects of Federal law, strictures on appropriations were often hybrids or standardizations of state practices.⁷⁵ During the early booms in canal and railroad construction, almost all projects involved direct or indirect government subsidy and hence were subject to public inquiry. An engineer's work embraced finding the economical means of carrying out work and then seeing that budgets were honored. Accounts served both to track work and to represent it in the event of scrutiny. Such accountability traveled through the military hierarchy, ultimately residing with the Chief of Engineers.

As noted above, in examining precedents for railroad administration in the practices of the Corps of Engineers, O'Connell observes the close kinship between the Army's hierarchical division of administrative responsibilities and that of railroads.⁷⁶ O'Connell focuses on the Department of War during John Calhoun's tenure as Secretary (1817–1825), a period during which Congress scrutinized

⁷³ The role of Army engineers is discussed in Hill, *Roads, Rails, and Waterways*. See also Todd Shallat, "Building Waterways, 1802–1861: Science and the United States Army in Early Public Works." *Technology and Culture* 31 (January 1990): 18–50 and *Structures in the Stream: Water, Science, and the Rise of the U.S. Army Corps of Engineers* (Austin: University of Texas Press, 1994).

⁷⁴ Hill, *Roads, Rails, and Waterways*, 48–56, 67. Hill reproduces a listing from a May, 1824 report of uncertain authorship which ranked 27 canals according to their value to, first, defense and, second, commerce, 52–53.

⁷⁵ Wilmerding, *The Spending Power*.

⁷⁶ O'Connell, "The Corps of Engineers and the Rise of Modern Management."

budgets and effectiveness in the wake of the War of 1812. Calhoun instituted formal structures and systems of accountability that had both instrumental and representational purposes, at once giving Calhoun means of control and coordination and a defense against Congressional inquiries. Extended in Brigadier General Winfield Scott's *General Regulations for the Army* in 1821, Calhoun's reforms "provided the department with the means to exercise a high degree of centralized control over the Army's functionally specialized, decentralized operations."⁷⁷ Detailed and regular reports allowed the Department to track expenditures and individuals alike.

Army reporting requirements included prescribed forms. Colonel Alexander Macomb, Chief Engineer in the early 1820s, advised one leader of a civilian "survey brigade" that his reports were deficient in failing to use these required forms, "altho' they are made out with as much distinctness probably as is customary with accounts relating to ordinary transactions of a private nature."⁷⁸ Though the 1821 *Regulations* did not provide forms for engineers' accounts, it did provide forms for construction accounting by the Quartermaster's Department (figure 1.6) and later editions provide similar forms specific to engineers' accounts.

Form No. 13. Abstract of Articles issued on special requisitions at in the Quarter ending on the by										
CLASSES		Building materials	A	B	C	D	E	F	G	H
Date	To whom issued	Pine boards, No. of								
		Pine boards, feet of								
		Oak boards, feet of								
		Timber, feet of								
		Axes, telling								
		Axes, broad								
		Axes, pick								
		Barrows, wheel								
		Barrows, hand								
		Barrows, crew								
		Chairs								
		Sec								
		Sec								
Total										

Note.—This abstract is to be supported by vouchers corresponding with form No. 24.

Figure 1.6—Form for special requisition accounting in the Quartermaster Department, 1821. From U.S. War Department, *General Regulations for the Army; or Military Institutes* (Philadelphia: M. Carey and Sons, 1821), article 69, form No. 13 of 36 following paragraph 118 and page 200.

⁷⁷ Ibid., 94.

⁷⁸ Alexander Macomb to Caspar Wever, December 16, 1825, quoted in *ibid.*, 96.

Portions of the 1821 *General Regulations* pertinent to the Engineer Department make clear that Macomb would have had cause to enforce these requirements as part of doing his job:

"All accounts relating to disbursements on account of the engineer department, before they be passed to the auditor for adjustment, must undergo a minute examination, as to prices, and the object and character of the disbursements, by the chief engineer, who, to be prepared for such examination, must keep himself always informed of the current value, at the several points at which disbursements are made, of the materials, labour, and workmanship that may be required at each of those points respectively: and the chief engineer shall endorse his approval on such accounts as meet his appropriation, and note his objections on the others, which will be retained for farther explanation."⁷⁹

Strict rule enforcement had a double role in military settings. It provided accountability and at the same time helped reinforce chains of command such that they would hold up under the stresses of war. Like interchangeable parts in armament, strict standards were worth developing in the military for political reasons irrespective of whether or not they made economic sense.⁸⁰ The Army's enforcement of procedures further reflected its need to manage widely spread and varied activities. In essence, military administrators in the early United States faced issues of size, complexity, and accountability that would later be found in railroad operation and other private businesses. Given the Army's role in administering a variety of civilian projects and the movement of personnel in and out of Army service, it is unsurprising that these methods were applied when private enterprises faced similar problems. O'Connell documents the application of Army procedures to civilian projects.

With Federal involvement in internal improvements after the General Survey Act of 1824, Army engineers followed War Department regulations in their work for private organizations. Engineer regulations provided the means of administering both the construction and the operation of the Baltimore and Ohio Railroad in the 1820s, down to the direct adoption of Army report forms.⁸¹ The Baltimore and Ohio continued to use these methods even after the employment of government

⁷⁹ U.S. War Department, *General Regulations for the Army; or Military Institutes*, article 67, paragraph 16, 167–168.

⁸⁰ The role of military exigency in driving coherence and consistency in both organizational and technological systems is a theme across many of the episodes in this study. See essays besides O'Connell's in Smith, ed., *Military Enterprise and Technological Change*. Also of note is work on accounting history by Keith W. Hoskin and Richard H. Macve who, like O'Connell, consider the Corps of Engineers crucial to the development of modern management. Unlike O'Connell, who in common with Chandler is interested in formal organizations and means of coordination, Hoskin and Macve stress the role of West Point and the Corps of Engineers in defining normative bases for accountability. "Reappraising the Genesis of Managerialism: A Re-examination of the Role of Accounting at the Springfield Armory, 1815–1845." *Accounting, Auditing & Accountability Journal* 7 (1994): 4–29; and "The Genesis of Accountability: The West Point Connection," *Accounting, Organizations, and Society* 13 (1988): 37–73.

⁸¹ O'Connell, "The Corps of Engineers and the Rise of Modern Management," 100.

officers ceased with the repeal of the Survey Act, and this road's methods were noted and disseminated through the railroading press and further exchanged through direct contacts among railroad superintendents and engineers. O'Connell cites documentary evidence that former Army Engineer George Whistler significantly influenced the Western Railroad's 1842 reorganization, agreeing with Chandler on the importance of the Western's innovations but establishing salience for precedents in military administration. Chandler is nonetheless correct to emphasize the distinction between building and operating. Lines of communication and accountability up and down an organization clearly derive from military organization. In construction or war, the engineer or the commanding officer handled intersectional coordination once, through specifications and contracts or through marching orders. Section gangs or divisions were expected to then cohere and accomplish assigned tasks without constant communication.

To summarize, formal management tools at the disposal of an engineer in the mid-1800s consisted of forms, drawings, ledger books, and narrative accounts. These were used both to define work to be done and then to follow up the execution of that work. Despite the sophistication of these documents and records, the work of coordinating engineering work was relatively modest. An ambitious canal or railroad project could be divided into sections and let as multiple contracts. An individual section might involve unusual conditions, but the coordination among contracts involved few points of contact: mating the end of one section of track with the next was a small matter. Coordination of day-to-day work could be left to individual contractors and their working knowledge of men and methods. Inspection, either by the chief engineer or his assistants, served to verify compliance with specifications. The contract itself specified *what* to accomplish rather than *how* to go about it. With problems of scheduling traffic movements *between divisions*, railroads needed to centrally coordinate movements based on as constant a flow of information as possible. Daniel McCallum instituted hourly, daily, and monthly operating reports after he became superintendent of the Erie Railroad in 1854.⁸² The crucial distinction between building and operation is not the divisional organization, but the rate and nature of movements along the line as these required

⁸² Chandler, *Henry Varum Poor*, 148–149.

particular forms of communication up and down the hierarchy. These differences will acquire greater distinction in subsequent chapters.

Accounts

The two accounts that follow both come from the end of the period covered in this chapter. Both are based on examples of a popular late-nineteenth century literary form, the engineering memoir. The first of these is a reminiscence of a career, the second of a single project. These accounts and the sources from which they are drawn are notable for two qualities. First, they show that awareness of a developing split between building and operation came only retrospectively, as engineers looked back on careers from the vantage of the much more industrialized United States of the 1870s and 1880s. Second, in their use of the memoir form, these accounts register the passage of an era of relatively informal, personal relationships. Smith notes that engineers of the nineteenth century viewed their work in “a highly personalized fashion because they came out of a world where people organized—and expected to organize—their lives primarily around ties of friendship, kinship, and other equally ‘local’ constraints rather than in relation to functionally defined careers thought to have the same contours everywhere.”⁸³ Later chapters will observe the increasing formality of working relationships but also the persistent importance of informal ties to networks of people at times when new industries are small, developing, and, in a sense, “local.”

W. Milnor Roberts

Engineers of the late nineteenth century were aware of changes that had transformed their work. When the American Society of Civil Engineers’ journal published a memoir by one of its members in 1878, it called for others of a then-passing generation to similarly preserve their experiences, for “but a few years can elapse ere all the engineering pioneers of our country will have departed.”⁸⁴ In books, journals, and meetings, engineers of the later nineteenth century accounted for their careers in terms of both material accomplishments and the progress of the profession. In common, these self-conscious reconstructions employed narrative to describe and dramatize accomplishments. It was

⁸³ “Becoming Engineers,” 24.

⁸⁴ Introduction to W. Milnor Roberts, “Reminiscences and Experiences of Early Engineering Operations on Railroads,” *Transactions of the American Society of Civil Engineers* 7 (1878): 215.

notably only in these later accounts that engineers discussed the increasing organizational complexity they had encountered during the boom years before the civil war. These accounts illustrate how managerial issues and social ideals twined in the work of nineteenth-century engineers.

The ASCE's 1878 request that older engineers share their experiences preceded the publication of a talk by W. Milnor Roberts. Addressing a meeting of his fellows, Roberts recounted a career that spanned both the transition from canals to railroads and that from informal working relations to bureaucratic structures. His accomplishments ranged from the reconnoitering of the transcontinental route of the Northern Pacific Railway to chairing a study of Philadelphia's water supply.

Near the outset of his career Roberts had been sent to Mauch Chunk, Pennsylvania to assist with the engineering of the Lehigh Canal. While there, he had observed the construction of one of the earliest railroads in America, a short gravity-powered line built to haul both coal and passengers. Shortly thereafter, in 1831, he joined the nearby state-financed Allegheny Portage Railroad as an assistant and supervised the construction of several of that road's inclined planes. As suggested by its name, the Allegheny was a short line connecting two waterways. These were separated by a mountain ridge. American engineers of the time, following English precedent, considered locomotives impractical on any but the most level tracks and so inclined planes were the Portage Railroad's equivalents to a canal's locks.⁸⁵ Along level sections carriages were drawn by horse, but where rises were required the animals were released and stationary steam engines hauled the cars by ropes. The business operation of this road was also closely akin to that of a canal or toll highway: "any persons who chose could put cars on the track, and haul them, with their own horses, from either end to the foot of the first plane, and on the levels between the planes; the State merely transporting the cars up and down the inclines..."⁸⁶

When the Allegheny opened in 1834, Roberts stayed on and had "the general charge and management of the running of the road ...as well as the general superintendence of the working of the

⁸⁵ Inclined planes were also used in porting canal boats between sections of canal. A description of such is in a communication from Robert Fulton to Albert Gallatin, reproduced as an appendix to Gallatin's *Report on the Subject of Roads and Canals*, 108–123, particularly 119. Of note, the second advertiser in the *American Rail-Road Journal* was a rope company, which noted that it could supply "full length [splice-free] Ropes for the inclined planes on Rail-roads at shortest notice," 1 (March 3, 1832): 160.

⁸⁶ Roberts, "Reminiscences and Experiences of Early Engineering Operations on Railroads," 204.

ten inclined planes.”⁸⁷ The volume of traffic made this a complicated business. As waiting times for first-come, first-served transit of the planes grew, this “demanded almost constant attendance on the line, as questions daily arose, in the use of the road by various independent parties, which I was daily called upon to settle.” Recalling this business from the perspective of the late 1870s, Roberts could mark such a state of affairs as having since been overcome through both technical and managerial innovations. In the 1830s, he noted, “the ‘telegraph’ was not yet born; and railroad experience was still a thing in embryo. The gigantic railroading of the present day had not then an existence even in dreams. Neither the ‘General Manager’ nor the ‘Receiver’ had yet been invented.”⁸⁸ For Roberts, “engineering operations” embraced both building and operating the railroad. By the time Roberts gave his talk, wearing both of these hats was no longer common in railroading and this was a fact worthy of remark.

Clemens Herschel and the Holyoke Dam

In the membership role of the American Society of Civil Engineers (ASCE) for 1886, Clemens Herschel was listed as a hydraulic engineer with the Holyoke Water Company, Holyoke, Massachusetts, along with an indication that he had been a member of the ASCE since 1869.⁸⁹ The August issue of the ASCE’s *Transactions* for 1886 reproduced Herschel’s account of work repairing the principle dam of the Holyoke Water Company across the Connecticut River. Introducing the subject, he put forward his doubts about its interest: it “was one of that class of engineering works which cannot readily be repeated” and, further, the work had left “little or no trace upon the surface of its very existence.”⁹⁰ The dam at Holyoke had originally been built in 1849 under the direction of a West Point dropout. Made entirely of timbers with rock fill between them and a boiler-plate surface over its crest, it had been repaired several times. By the early 1880s, it was in poor enough condition that it was no longer holding back enough water to serve the canals and falls of the owning company.

⁸⁷ Ibid.

⁸⁸ Ibid., 205.

⁸⁹ American Society of Civil Engineers, “Constitution, By-Laws and List of Members” 15 (September 1886): 35.

Herschel was later president of the Boston Society of Civil Engineers. Note his 1891 address, “On the Advancement of the Profession of Civil Engineering,” *Journal of the Association of Engineering Societies* 10 (March 1891): 132–145.

⁹⁰ This account is based entirely on Clemens Herschel, “On the Work Done for the Preservation of the Dam at Holyoke, Mass., in 1885, and on Some Studies for a New Stone Dam for the Same Place,” *Transactions of the American Society of Civil Engineers* 15 (August 1886): 543–580.

Herschel reported that 4,500 bags of gravel were dropped into a hole in the dam in order to block one leak with no effect.

Eventually, in late 1884, and against Herschel's recommendation for an entirely new stone dam, plans were made for a systematic refurbishing of the entire existing dam. Herschel described the plan as for a "subcutaneous injection of gravel."⁹¹ The bulk of Herschel's description of the work undertaken in late 1884 and through much of 1885 is taken up with the details of the methods by which the dam face was cleared of obstructions, crib enclosure were set against it, and the work of repairs carried on (figure 1.7). These descriptions disclose aspects of the personal, direct involvement of the engineer as contractor. When one of the divers employed in clearing the dam face was killed after being swept over the dam, Herschel learned that the accident had occurred due to the diver's "being not yet over his drunk" of the previous evening.⁹² This nonetheless required the discharge of the entire work gang, as the deceased's friends "went about with a hang-dog air" and stopped work for a day and a half. Herschel credited successful completion of the work to French Canadians, who were owed a "general meed of praise" on account of doing "most of the carpenter and other intelligent work required."⁹³

Figure 1.7—Workers posed along the crest of the dam, with cribs at left. Source: Clemens Herschel, "On the Work Done for the Preservation of the Dam at Holyoke, Mass."

⁹¹ Ibid., 557.

⁹² Ibid., 563.

⁹³ Ibid., 575.

Figure 1.9—Detail of preceding illustration.

Conclusion

From the beginnings of engineering in the United States, big construction jobs—canals, railways, dams—were part of the conscious, coordinated making of technological systems. During the mid-nineteenth century an increasingly integrated infrastructure, developments in power supply and communications, and a trend toward continuous and standardized production together made social, productive, and market relationships conceptually and practically governable as systems. Against these developments, engineering and construction remained in many respects relatively constant. Engineers and their expertise gained currency and power, but the manner in which engineers organized their own work admitted few changes. Internal communication in engineering work continued to rely on extra-firm social structures as well as formal routines, and through much of the nineteenth century, informal exchanges sufficed for working out many of the points of interaction between components of technical systems. Physical and social couplings in engineering work were loose, and the creation of professional associations provided networks for the transmission of ideas and the working out of divisions of labor.

In 1896, sociologist Edward A. Ross, a professor at Stanford University, published the article on "Uncertainty as a Factor in Production" that provides the epigraph to this chapter. In this piece, Ross contrasted the hazards presented by investments in mining or agriculture to those in manufacturing. In Ross's assessment, mining was a speculation about where minerals might lie and agriculture was a

gamble on the weather. Sheltered from the elements and plain to see, manufacturing was by contrast a fairly certain prospect. Averring that uncertainty about "derangements" to production could lead to "industrial anaemia" in risky business but also perceiving a logic to this pattern, Ross linked capital intensity to inflexibility:

"Flexibility is, therefore, an advantage, and is a greater advantage in a variable industry than in a stable one. As flexibility depends chiefly on the extent and form of auxiliary capital employed, the distinction just made resolves itself into a contrast between businesses with fixed capital and those without."⁹⁵

The sources of variability Ross noted included market fluctuations and technological change, the latter of which Ross referred to in terms of "the menace of a possible substitute." Consequently, "a business facing a squally future must not spread much sail."⁹⁶ Ross's comments reflect an awareness of distinctions between kinds of work that was nascent with the progress of factory and railroad systems in the United States. These made regularity in production a possibility such that speaking of its derangement could make sense. Railroads attached the regularity of the steam engine to an older kind of organization, and in so doing shifted the behavior and ultimate purpose of that organization without altering its outward form.

⁹⁵ Ross, "Uncertainty as a Factor in Production," 113.

⁹⁶ Ibid., 114.

Chapter 2

Economies of Space and Time:

Engineering Work and the Politics of Systematic Management, 1880–1920

“The work of [modern management in] the past has been mostly in the mechanical branch of engineering or commercial manufacturing. The work of the future will be in the *field* and under conditions that are seemingly against the efficiency engineer...where the man does not perform the same work twice; where the operations are conducted at widely scattered places; where the workmen are incompetent and the plant is inadequate, the designing department poor or nil, and possibly the bank account has been exhausted.”¹

Now the story gets interesting. In the last years of the nineteenth century, Frederick Winslow Taylor and other advocates of systematic management refined methods for gauging and regulating repetitive work processes. In doing so, Taylor and his coterie promoted language and tools through and against which managers of construction work had to explain how they did their jobs. In the light cast by popular faith in efficiency and system during the progressive era and in the face of growing complexity and shifting divisions of labor in their own work, managers of construction firms and engineering departments used project-based budgets, schedules, and drawings to both order and explain work. While some builders cited irregularity as grounds for entirely rejecting the applicability of system, the general dynamic over time was more one of a working out of limits and differences. The time, place, and product of engineering and construction work could be projected, but the most efficient means of meeting specifications could not be entirely known in advance. Organizing building work was a matter of sections and schedules rather than rates and efficiencies. With these developments, distinctions between building and operating born of the steam engine but little remarked in earlier decades grew more evident and argued.

¹Daniel J. Hauer, *Modern Management Applied to Construction*, (New York: McGraw-Hill, 1918), 2–3. Italics original.

This chapter focuses on descriptions of the management of construction engineering in the last decades of the nineteenth century and the first of the twentieth. During this period, work for Federal agencies and municipalities put engineers and contractors on public stages. At the same time, industrial plant development for growing manufacturing and processing companies set engineering in contrast to the routines of operating departments. On some projects both of these sources of potential scrutiny figured, as the immediate client and government regulators could investigate contract construction carried out for private operators of public works. In any case, the need to favorably represent engineering work in response to actual or anticipated inquiries influenced the tools used in its management. In common, public agencies and private companies turned to project or appropriation-based accounts as means of ordering construction and, by 1910, project-based systems were being promulgated by so many people and in so many contexts that the instances picked out here must be recognized as snippets from a weave of intersecting conversations. The voices I single out were those of practicing engineers and contractors trying to make irregular work knowable and measurable but also interested in simply getting it done.

This chapter has several aims. First, it discusses splinterings of the engineering profession and the technical press, seeing these as the creation of distinct marketplaces for specialized knowledge and labor—in Fleck’s terms, as coalescings of semi-autonomous thought collectives. Second, it shows that the gap between building and operating introduced in the preceding chapter had grown wider and more explicitly discussed. And third, in considering why people adopted formal project-based systems, it shows that these were used to cope with speed, complexity, and uncertainty and at the same time to both explain and insulate work. As part of this last point, it considers particularly the use of abstract timelines as means of structuring interactions, linking Gantt charts to earlier diagrams. Following the pattern established in the previous chapter, this chapter begins with an overview of pertinent historical context. With this background, it then considers formal tools and social contexts that shaped the management of engineering projects. Two case studies show the inseparability of these multiple issues in practice. Chapters 2, 3, and 4 together discuss a cluster of related conversations and communities during a general wave of system building. Within these conversations there were further subconversations and communities, and so demarcations within and between these chapters should be seen as inexact.

The Politics of System Building and the Splintering of Engineering

It might at first appear possible to draw lines between several construction engineering booms of around the turn of the twentieth century—among them power system development, street railway construction, and road building; however, these were all part of a single, general renewal of enthusiasm for internal improvements, by the 1890s more commonly referred to as ‘municipal engineering’ and its counterpart ‘rural engineering’ or, increasingly, ‘public works.’² This wave of system building also reached into private plant construction, as investment in new and modernized manufacturing and processing facilities accompanied the growing scale of industrial operations and the rise of integrated industrial corporations. Part and parcel of this era of system building, in the late 1800s the profession of engineering formally branched into several technical specializations, marked by the formation of separate societies by civil, chemical, electrical, and mining engineers. The objects being engineered, though, were integrations of the specialized skills held by members of these organizations. Building an electric street railway, for example, at once involved electrical, civil, and mechanical engineering. And despite splintering professional allegiances, the content of engineering journals and the biographies of individual engineers show that the business of engineering remained a common conversation.³

Both public and private construction work in this period were shaped by the politics of the progressive era. In the 1880s and 1890s, enthusiasm for public works accompanied interest in scientific, engineered solutions to urban and rural problems. The efficiency movement generally and municipal engineering in particular aimed to bring rationality and light into dark corners.⁴ Agitation for better public services came from many reaches of society, from muckraking journalists to muddy bicyclists. Observing the general increase in government contract lettings, a civil engineer noted in 1901 that, “the great works are multiplying so fast that we lose track of them and a hundred million dollars is becoming an ordinary sum,” and further that, “the public is becoming more and more

² The term ‘internal improvements’ can still be found, for example, in issues of *Good Roads* from the 1880s, but its use diminished in the 1890s.

³ Explicated further below.

⁴ See particularly Samuel Haber, *Efficiency and Uplift: Scientific Management in the Progressive Era, 1890–1920* (Chicago: University of Chicago Press, 1973 [1964]).

inclined to undertake these vast enterprises.”⁵ Given the tangible social and business problems that engineers’ work was meant to address and the interrelations between water, sewer, gas, electrical, and transit developments, these were conceived systematically—that is, engineers recognized the inseparability of the social and technical implications of their work and the multiple constituencies whose interests they needed to balance, extending the essence of physiocratic philosophy that had marked early engineering thought in the United States.

Figure 2.1 charts the cumulative value of investment in three regulated industries around the turn of the century. Investment in the industries shown—street and electrical railways, electric light and power, and telephony—all marked purchases of electrical and civil engineering services, and the largest engineering-contracting firms in this period were in general building and electrical engineering work.

Figure 2.1—Take-off periods in several electrical engineering-intensive industries. Data from U.S. Bureau of the Census, *Historical Statistics of the United States: Colonial Times to 1970*, CD-ROM edition, series V-276, V-278, and V280. Note that because this data is collected from public records of regulated industries, it neglects private installations. Including these would tend to shift the curves up and to the left, since many of the earliest power stations and telephones were installed to serve individual factories.

Relative to railroads, the complexity and interconnectedness of turn-of-the-century systems meant that these later works were more tightly coupled to each other and that the divisions of labor in their making were more involved. George Goethals, Chief Engineer of the Panama Canal was said to have

⁵ G.S. Bixby, comments to J. Albert Himes, “The Position of the Constructing Engineer, and His Duties in Relation to Inspection and the Enforcement of Contracts.” *Transactions of the American Society of Civil Engineers* 30 (1905): 140.

commented that "the people think the Panama Canal is a great engineering feat, but it isn't a particularly great work of that kind, but rather a job of handling a great amount of material; and as an engineering proposition the Panama Canal does not compare with the work done on the New York subways."⁶ Nonetheless, the coordination requirements faced on subway and other municipal work projects were complications of the section-to-section problems of coordination and integration in uncertain physical and technical environments also faced on earlier and, at least in retrospect, simpler systems. There were more interfaces between more subsystems, but in their construction these were still one-time connections rather than the regular flows coordinated in operating systems. This basic contrast threw the irregularities of building into ever-greater relief as scientific management broke planning apart from doing and cost accounting distinguished plant costs from production costs.

Systematic Management and the Refinement of Regulatory Science

Merritt Roe Smith has neatly summarized the basic thrusts of systematic management, stating that, "two premises underlie modern management: the primary goal is to control the entire job situation; the primary means of achieving control is through standardization."⁷ JoAnne Yates focuses on the role of communication technology in effecting management systems, showing that "flows of documents were the primary mechanisms of managerial control," across as well as up and down hierarchical organizations.⁸ Through fine-grained regulation of work, standardization of parts and processes, and installation of information-gathering routines, systematizers drove decision making off of shop floors. In doing so, they elaborated means for operating factories as if they were machines, defining the engineer as the operator through detailed cost accounting and communication routines. Time study and accounting were to the regulation of production processes as gauges and indicators were to the governance of steam engines. Scientific management set standards for theoretical output

⁶ Quoted from oral remarks in J.W. Rollins, "The Relation Between Engineers and Contractors," *Proceedings of the Engineers Society of Western Pennsylvania* 32 (1916): 122. See also John Ernest Munby, "New York and Panama: A Contrast in Engineering Achievement," *Engineering Magazine* 33 (April 1907): 1-20. The Panama Canal's engineering and construction engendered enormous volumes of comment, much of which treated management practices. Some citations are noted below; see also the run of the *Canal Record*, which began in 1907 (later retitled *Panama Canal Record*).

⁷ Merritt Roe Smith, introduction to *Military Enterprise and Technological Change*, 17. See also Litterer, "The Emergence of Systematic Management as Shown by the Literature of Management from 1870-1900"; Yates, *Control Through Communication*.

⁸ *Control Through Communication*, 20.

against which operating results could be measured, extending the reach of the term 'efficiency'; cost accounting provided data on the basis of which managers could identify and correct production problems, providing a gauge for the factory.

The Principles of Scientific Management, published in 1911, collected ideas that Taylor and others had published in engineering journals beginning in the 1890s.⁹ Taylor's early work included studies of cutting tools in machine shops, experiments in which he had painstakingly varied speeds and materials to identify optimal combinations, much as steam engineers collected and analyzed indicator diagrams to diagnose the optimal operation of their machines.¹⁰ Taylor's work led to formulations for high-speed steel and tabulations of standardized cutting speeds, and Carl Barth later introduced a slide rule that allowed a machinist to calculate cutting speeds without recourse to tables. In his subsequent work, Taylor applied this approach to the work of men. The basis of Taylor's system was to identify the fastest means of doing a repetitive task through systematic study of human movements, tools, and materials and then to incent the individual worker to apply this method through piecework pay schemes. In the 1911 book, Taylor prefaced the exposition of these ideas with reference to President Roosevelt's calls for "national efficiency" and Taylor's own hope that ideas he had developed for machine shops would be "applied with equal force to all social activities."¹¹ While

⁹ In a report issued in 1912, the Sub-committee on Management of the American Society of Mechanical Engineers noted the debts of scientific management to Adam Smith and Charles Babbage and listed the relevant papers on industrial management that had been published in the *Transactions of the American Society of Mechanical Engineers*:

No.		
207	The Engineer As An Economist.....	Henry R. Towne 1886
256	A Problem in Profit Sharing	Wm. Kent 1887
341	Gain Sharing	Henry R. Towne 1889
449	The Premium Plan of Paying for Labor	F.A. Halsey..... 1891
596	The Relation of the Drawing Office to the Shop in Manufacturing	A.W. Robinson..... 1894
647	A Piece-Rate System.....	Fred. W. Taylor 1895
928	A Bonus System for Rewarding Labor	H.L. Gantt..... 1903
965	Gift Propositions for Paying Workmen.....	Frank Richards 1903
1001	The Machine-Shop Problem	Charles Day..... 1903
1002	A Graphical Daily Balance in Manufacture	H.L. Gantt..... 1903
1003	Shop Management	Fred. W. Taylor 1903
1010	Slide Rules for the Machine Shop as Part of the Taylor System of Management	Carl G. Barth 1904
1011	Modifying Systems of Management	H.L. Gantt..... 1904
1012	Is Anything the Matter with Piece Work?.....	Frank Richards 1904
1115	A History of the Introduction of a System of Shop Management	James M. Dodge 1906
1221	Training Workmen in Habits of Industry and Cooperation.....	H.L. Gantt..... 1908

¹⁰ A considerable bibliography of studies of Taylor and Taylorism exists. A recent biography is Robert Kanigel, *One Best Way: Frederick Winslow Taylor and the Enigma of Efficiency* (New York: Viking, 1997).

¹¹ Frederick Winslow Taylor, *The Principles of Scientific Management* (New York: W.W. Norton Company, 1967 [1911]), 5, 8.

Taylor focused his attention on the shop floor, the systematic management movement broadly sought to act on all levels of hierarchies and on all areas of activity. And while Taylor was not alone or first in advocating systematic management, it was with the popularization of his writings that no engineer could ignore the phenomenon. Under systematic management, management data collection shifted from gross measurements of the inputs and outputs of a production process to fine-grained attention to the hours, minutes, and movements spent in carrying out tasks. Time-motion using photography and wire models allowed dissection of the minutest actions.¹² Disaggregating the unit of work fundamentally changed communication. Armed with “bogeys” or “yardsticks” for how long a task should take and how it should be done, managers could expect foremen to direct work according to scientific principles and could calculate efficiencies. Problems—often called slippages or leaks reflecting the analogy between mechanical and human systems—could be diagnosed from flows of operating data. An order that once passed through a shop based on a description of the product was now described in terms of tasks and transfers. In sum, Taylor’s methods encouraged engineers to think about production and profits as outputs of an engineering equation that included both men and machines and in which human frictions could be greased through wage incentives and governed by engineers armed with flows of data.

Edwin Layton, David Noble, and others have pointed out that this involved a ceding of authority by both workers and managers and the insertion of the engineer as an intermediary.¹³ The chief of Sperry Gyroscope’s drafting department, writing in *The Sperryscope*, noted in 1918 that the industrial world increasingly recognized drafting departments “as the heart of the organization, from which emanates complete data, necessary for the practical and efficient production of its apparatus.”¹⁴ Under scientific management, planning department men dictated where once an owner’s judgment ruled. Layton further comments that in theory the engineer was himself subordinate to objective laws that his science revealed, but that in practice “the engineer was the lawgiver.”¹⁵ The word ‘interpreter’ fits better—as in the case of engine operation the engineer helped the machinery of production speak. As

¹² These and related developments of Taylor’s principles were carried out by contemporaries, among them, Frank Gilbreth, Carl Barth, and H.L. Gantt.

¹³ Layton, *The Revolt of the Engineers*, 139. This is a general theme in Noble’s *America by Design*. See also Daniel Bell’s 1963 introduction to Thorstein Veblen’s 1921 *The Engineers and the Price System*.

¹⁴ E.M. Rosenberg, “The Drafting Department and Its Functions,” *The Sperryscope* (1918): 15.

¹⁵ *The Revolt of the Engineers*, 140.

put forth by Taylor, the chief organizational change at the shop level was from “military type” foremanship in which orders passed down a chain of command “from the manager through superintendents, foremen of shops, assistant foremen and gang bosses to the men”¹⁶ to a “functional type” in which “all possible brain work should be removed from the shop and centered in the planning or laying-out department, leaving for the foremen and gang bosses work strictly executive in nature.”¹⁷ As matters of routing, the formal communication methods in the Taylorized factory were like those for railroad coordination—exercises in traffic management enabled by flows of data from the stations (rather than sections or divisions) in the production process.

A Gauge and Meter for the Factory: Cost Accounting

Halpert Gillette, the editor of several magazines serving the contract construction industry and a chief exponent of system in construction, coauthored a 1909 book titled *Cost Keeping and Management Engineering*, which he and his coauthor, Richard Dana, dedicated to Frederick Taylor.¹⁸ In this book, Gillette and Dana noted the distinction between the engineer-cost keeper and the mere keeper of accounts:

“Bookkeeping has been evolved by merchants, and is essentially a system for showing debits and credits. Cost keeping has been evolved by managing engineers, and is essentially a system for showing the efficiency of workmen and of machines.”¹⁹

From beginnings in the late nineteenth century, by 1920 some 69 uniform accounting systems had been promulgated by various industry associations and cost accounting had emerged as an occupation distinct from bookkeeping.²⁰ The contemporary development of cost accounting and industrial engineering—the latter being the more generic terms for scientific management—were complementary; one provided the gauge, the other tuned the engine.

The earliest cost-keeping systems described and recommended in the pages of the *Engineering Magazine* were “job-ticket” systems. In these, a paper ticket followed work around the shop floor, with each person working on a piece recording the hours they spent on the ticket. Used in place of

¹⁶ F.W. Taylor, *Shop Management* (New York: Harper & Brothers Publishers, 1911 [1903]), 92–93.

¹⁷ *Ibid.*, 98–99.

¹⁸ With Richard Dana (Chicago: Myron Clark, 1909).

¹⁹ *Ibid.*, vi.

²⁰ See Hugh J. Jackson, “A Half-Century of Accounting Progress,” *N.A.C.A. Bulletin* 34 (September 1952): 7.

rule-of-thumb costs based on weight or raw materials, tracking by job ticket linked the immediate costs of materials and labor directly to the output, but analysis of total costs was complicated by uncertainty over how to consider fixed costs. In a series of *Engineering Magazine* articles in 1898 and 1899 under the common title "Finding and Keeping Shop Costs," Henry Roland presented accounting systems in use at a variety of establishments.²¹ In the concluding article to this series, Roland focused on the importance of accounting for fixed assets. He noted, "as it is an innate fallacy of the human mind to ignore obligations grown old, it is not uncommon to find systems of factory accounting which fail to recognize some of the first-made elements of factory expense," chiefly buildings but extending to "all of the expense account so far going directly to provide a suitable theatre for the exertions of the workmen..."²²

Alexander Hamilton Church published a more extensive series of articles two years after Roland's articles appeared.²³ Later reprinted in book form and widely circulated, Church's exposition emphasized that in bringing any good to market both direct and indirect expenses should be fully accounted. He particularly sought to correctly attach overhead costs to each unit of output. Church's title, "The Proper Distribution of Establishment Charges," reflected this emphasis. Using "prime cost" to refer to direct expenditures on material and labor in producing a good as against the more inclusive "shop cost," Church noted "that prime cost is in extreme cases not even the larger half of shop cost, and in mass production may even cease to have any tangible value whatever,"²⁴ but that in no case should it be overlooked. Reviewing a variety of then-practiced methods for assigning overhead to output—using percentages, hourly rates, and machine rates—Church felt that each was imperfect in that some averaging was necessary. His solution lay in a more detailed breakdown of the costs of both owning and operating productive capacity. Church devoted the fifth of his six articles in the series to "Factory and Mass Production and the New Machine Rate" which explained a method of detailed accounting for the cost of owning and housing each machine in relation to the value of the work to

²¹ Henry Roland, "An Effective Method of Finding and Keeping Shop-Costs." *Engineering Magazine* 15 (1898): 77–86, 241–248, 395–400, 610–620, 749–758, 1000–1016; 16 (1899): 37–48, 207–214.

²² *Ibid.*, 16 (1899): 207, 209.

²³ Hamilton A. Church, "The Proper Distribution of Establishment Charges." *Engineering Magazine* 21 (1901): 508–517, 725–734, 904–912; 22 (1902): 31–40, 231–240, 367–376.

²⁴ *Ibid.*, 21 (1901): 514.

which it was applied. This locating of engineering costs as overhead or burden had implications. If money was tight, such expenses were the first to go.

While the ideas and methods of systematic management and cost accounting were known and discussed in engineering circles in the 1890s, Taylor's 1911 *The Principles of Scientific Management* marks a highpoint of general public enthusiasm for efficiency and system. Publication of this book came on the heels of Attorney Louis D. Brandeis's successful prosecution of the Eastern Rate Case. In this case, several railways had applied to the Interstate Commerce Commission to increase freight charges, arguing that these did not cover costs. Brandeis applied Taylor's principles in an effort to demonstrate that it was the railroads' failure to apply sound business practices that lay at the heart of their financial difficulties. He coined the term "scientific management" and put forth the figure of a million dollars a day as the amount the roads could be saving, both of which seized press attention and, though the Commission put aside scientific management in its ruling, Brandeis won the case.²⁵ After the Eastern Rate Case and the headlines it garnered, political realities both within organizations and on larger stages meant that systematic management could not simply be waved off as irrelevant regardless of what business was being discussed. The popularity of scientific management was such that managers had to respond in some fashion to the "glittering generalities and catching epigrams... so successfully used" by its proponents.²⁶

The Emergent Architecture of Engineering

In the 1880s, a publication such as the *Engineering Magazine* could reasonably aspire to provide a digest of the entirety of American engineering practice and to carry news from across the Atlantic as well. Multi-volume technical and scientific encyclopedias could embrace articles on the strengths of things as disparate as bridge trusses, boilerplate, and acid solutions. Articles on steam, mechanical, and electrical engineering could appear cheek-by-jowl and find at least partly common readerships. By the 1920s, these were related but distinct discourses. As subdisciplines formed, claimed areas of

²⁵ The Commission noted that, "the system is everywhere in an experimental stage," and that based on conflicting testimony as to its applicability, "we can hardly find that these methods could be introduced into railroad operations to any considerable extent, much less... the definite amount of saving..." Cited in "The Railways and Scientific Management," *Engineering-Contracting* 35, (April 5, 1911): 379.

²⁶ E.C. Peck, "Systematic versus Scientific Management," *Journal of the Society of Naval Engineers* 23 (November 1911): 1177-1185, quotes, 1177-1178. This article was reprinted from *Iron Age*.

expertise, and established independent forums and journals, the purview of civil engineering shrank. The American Institute of Mining Engineers (AIME) formed in 1876, the American Society of Mechanical Engineers (ASME) in 1880, and the American Institute of Electrical Engineers (AIEE) in 1884. These were splinterings rather than *sui generis* associations. Merritt points out that Alexander Holley, the first president of the AIME, and Robert Thurston, first president of the ASME, both held degrees in civil engineering and had been active in the ASCE.²⁷ The ASCE had itself only come together in 1867. As late as the turn of the century, the ASCE still considered itself the root from which other engineering disciplines branched and resisted efforts to form an engineering association of equals with the three just noted societies, but it ultimately acquiesced. The continued cross-association among engineering societies was most evident the formation of the United Engineering Societies (UES) in 1904, which brought together the ASCE, AIME, AIEE, and ASME. The UES served as both a social and technical club. Endowed by Andrew Carnegie, the UES building in New York, completed in 1906, provided a common headquarters building and, in 1915, the societies combined their libraries into the Engineering Societies Library (ESL). The ESL took over publication of the *Engineering Index*, which had been started in 1896 and continued by ASME, and provided a literature service to members. Even as engineering disciplines branched and established separate journals the UES marked their continued interrelations and served as part of the connective tissue within and between these collectives.

Engineering's branchings were thus practical divisions of labor in response to the growing complexity of technological artifacts and the breadth of knowledge applied in their creation as much as they were abstract quests for professional autonomy. Social relations were recognized as vital to the professions. One author noted that "no other profession has been so quick to overcome personal and selfish motives" and to exchange information through societies and institutes. He hopefully saw this salutary circulation as being extended to otherwise competitive enterprises such as railroading, seeing this as a means of advancing social efficiency rather than enabling anticompetitive behavior.²⁸

²⁷ *Engineering in American Society*, 5.

²⁸ William D. Ennis, "The Industrial Management of Engineering Works." *Engineering Magazine* 22 (1901): 246.

Scientific American observed in 1870 that, “no one who watches the growth and progress of journalism can fail to mark the tendency of the age toward the establishment and support of publications devoted to specialties.”²⁹ The splitting of engineering as a profession and identity in the later 1800s was marked and enabled by the emergence of distinct literatures. Where the *American Railroad Journal* was at times the only journal devoted to the development of railroading in the years of that industry’s ferment, in the later nineteenth century publications swarmed and dispersed along with emerging professions and industries in a search for markets, as entrepreneurs and established publishers placed bets on the outcomes of eras of technical definition.³⁰ Individually and collectively, journals serving the electrical and construction industries followed trajectories similar to that of the *Journal* (figures 2.2 and 2.3). From beginnings in the broadsheets of promoters, publications in road building, sanitary engineering, steam engineering, and other fields developed into forums for system builders and marketplaces for constructors and capital equipment. Though some publications oriented to promoters and builders persisted, most ultimately failed, shifted focus, or were folded into other publications as swarms passed. In contrast to the period of definition for railroading, these industries developed and standardized quickly.

There were connections among these magazines that, if diagrammed, would turn the above images into a much more complex weave and which also reveal their incompleteness. A magazine serving power generators, *The Central Station*, included a “Monthly Review of the Technical Press” in its first volumes. This listed *Cassier’s Magazine*, *Municipal Journal*, *Electrical Review*, *American Electrician*, *Engineering News*, *Western Electrician*, *Scientific American*, *Power*, *Electrical World and Engineer*, *Electrical Review*, *The Coal Trade Journal*, *Electricity*, *The Journal of Electricity*, *Power and Gas*, and *The Engineering Magazine* as the journals it followed.³¹ Advertisements inside the back cover of Frank Gilbreth’s 1908 *Field System*, a manual of field construction discussed below, included a similar constellation of serials and books—*Engineering-Contracting*, *Technical*

²⁹ 22 (January 15, 1870), cited in Mott, *A History of American Magazines*, vol. 3, 104.

³⁰ Burlingame’s *Endless Frontiers* captures the entrepreneurial and opportunistic nature of technical publications. Mott’s coverage of technical literatures for this period is in *A History of American Magazines* vol. 3, 104–136, and vol. 4, 182–186 and 319–336.

³¹ *The Central Station* began publication in 1901; this was a running feature.

Figure 2.2—Electrical and power engineering journals, 1870-1960. Note that coverage of the electrical industry in this diagram is biased toward power generation and transmission as opposed to signal communication, though individual journals often covered both areas. More communications-oriented publications are treated in chapter 5. Notes and caveats accompanying figure 1.3 apply here as well.

Figure 2.3—Journals serving the construction engineering industry, 1870 - 1960. Notes and caveats accompanying figure 1.3 apply here as well.

Literature (a digest), *Engineering News*, Gillette and Dana's *Handbook of Cost Data*, *Rock Products*, Homer Reid's *Concrete and Reinforced Concrete Construction*, *The Railway Age*, *The Electrical Review*, *The Railway and Engineering Review*, *Concrete Engineer and Contractor's Handbook*, *Concrete*, several books from *Concrete Age*, *Practical Cement Testing*, *Municipal Engineering Magazine*, and other publications. Some of these were offered by the publisher of the *Field System*, but the list marked plausible cross-pollinations between readerships. *Good Roads*, which began in the 1880s, agitated on behalf of bicyclists, rural farmers, carriage builders, and others kept from commerce and fresh air by mud, and its early advertising revenue came from makers of bicycles and road building and maintenance equipment alike. All these things and the communities building them were connected.

Because of the sheer volume of material being published by the late nineteenth century, it is not possible to follow the literature as closely as in the case of *American Railroad Journal* in the 1830s and 1840s. Citations in the pages that follow mark particular effusions of interest in management topics in the engineering and contracting business. The effusions, in turn, reflected booms in commercial activity that also sustained the swarming of magazines. In announcing the appendage of "*and American Contract Journal*" to its name in 1882, *Engineering News* editorialized on the tug-of-war between commercial and more academic aspects of engineering:

"It will not *pay* for any one journal to undertake to publish all the engineering and contracting intelligence of this continent and, at the same time, undertake to give its readers lengthy papers on engineering, which now more than occupy the columns of several good-sized journals. So it is that we prefer to deal with the curious, news-seeking, 'sordid' side of our constituency, and if we can assist them in securing profitable situations or 'fat' contracts, we are very willing to let [other publications] delight their readers in the mysteries of calculus and other recreations of the intellectually inclined. We propose to give the *news* as fully as we can, and at the same time contribute to the intellectual 'hankerings' of our patrons."³²

The editor continued to advise his readers that they would "look upon the subscription price of this journal as a very satisfactory investment." It would be so thanks to "the plethoric condition of the National Treasury," which would "make glad the hearts of untold numbers of contractors, however much the individual taxpayer may deplore the necessity for 'improving' all the mountain streams of

³² "Our New Name," *Engineering News and American Contract Record* (May 20, 1882): 160.

the continent, or erecting first-class post offices in numerous Pedunks, which our benevolent law-makers are so diligently log-rolling about at the National Capital..." Preceding this advice to subscribers came a shorter note to prospective advertisers: "We call the attention of city engineers, railway engineers, and all other parties having control of contract lettings to the superior advantages of advertising their proposals in this journal..." as, "...it goes direct to the leading contractors of the country, men who are ready for any work, from building a culvert to a transcontinental railway."³³ In short, the swarms and splits of engineering professions and literature marked the increasing complexity of the division of labor in engineering, and the timing of these swarms is linked to when and where problems of organization came to the fore.

Systems and Their Limits in Contracting Organizations

The administration of municipal infrastructure was, like any public spending, highly scrutinized. To distance themselves from intrigues in the letting of public works contracts, engineers portrayed their role and their profession as closely aligned with the public interest, asserting that their knowledge and professional independence freed them from the influence of "the money interests." Claiming, "it will always pay to place work of a public character in the hands of an engineer," one writer in *The Engineering Magazine* averred in 1895 that with systematic planning by engineers, "the ultimate saving in time, money, law-suits, and comfort would be immense."³⁴ In public forums engineers positioned themselves as dispassionate administrators of public works projects and as expert regulators of public systems. Arguing in favor of "better provision for a system of internal improvements," by Congress, the president of a group formed in the 1880s that called itself the Civil Engineers' Committee on National Public Works alerted engineers that, "to promote a change to a rational policy from the present wasteful and unfruitful system, if indeed it may be called a system, is the duty of a profession which can most clearly understand its deficiencies."³⁵ Another author writing closer to the turn of the century indicated that to see to this duty, an engineer should keep a daily log of progress, "noting every occurrence which may have bearing on the settlement of the contract."

³³ Ibid.

³⁴ Francis Collingwood, "The Ideal City-Engineering Bureau," *Engineering Magazine* 9 (1895): 445.

³⁵ L.E. Cooley, also member of the Western Society of Civil Engineers, "A Rational Policy of Public Works," *Journal of the Association of Engineering Societies* 5 (January, 1886): 69-82, quote, 69.

This was especially useful in the event legal proceeding entailed: "Such a journal, when supplemented by photographs, is not easily controverted, and will often clear away disputes which might otherwise be taken into court."³⁶

If a contractor's methods and records saw light, it was unlikely to be favorable. Writing in the first decade of the 1900s, one engineer-contractor noted that even once construction accounts had been closed and engineered systems were in operation, books remained subject to scrutiny when utility and transit companies justified rates on the basis of both capital and operating expenses. "With the advent of Government regulation of public service corporations," this engineer observed, "it becomes very necessary to be able to make, not approximate, but accurate estimates of the value of tangible property, and what it would cost to reproduce the same, as of various dates."³⁷ He noted that the lack of standard accounting systems had made data irrelevant in court cases, to the disadvantage of the utilities. Hence, the application of systematic management had a defensive aspect in construction settings. Battles over management systems and piece rates and management intervention in work processes were hardly unique to construction, but the terms of these debates differed on construction sites, turning on system's relevance and its limits.³⁸

The best-known application of systematic management to construction was promulgated by Frank Gilbreth, a general contractor in the first years of the 1900s and later an associate of Taylor.³⁹

Gilbreth developed elaborate methods for rationalizing building construction and his 1908 *Field*

³⁶ J. Albert Himes, "The Position of the Constructing Engineer, and His Duties in Relation to Inspection and the Enforcement of Contracts." *Transactions of the American Society of Civil Engineers* 30 (1905): 104-143, quote, 117.

³⁷ W. Boardman Reed, in discussion of Myron S. Falk, "A System of Cost Keeping," *Transactions of the American Society of Civil Engineers* 64 (1909): 401-409, discussion 410-440, quote 432. Falk's article and discussion of it are treated further below.

³⁸ Among studies of shop floor resistance to management systems, see notably, Hugh Aitken, *Scientific Management in Action: Taylorism at Watertown Arsenal, 1908-1915* (Princeton: Princeton University Press, 1985 [1960]).

³⁹ Though Gilbreth is noted and his career is sketched in many management histories (for example, Wren, *The Evolution of Management Thought*, 141-150) there is no recent biography. In the first years of the 1900s Gilbreth maintained New York and Boston offices for his contracting business. As then and since common of contractors, he published promotional accounts of major projects. On completion of a building for MIT when the Institute was located in Boston he printed a pamphlet, "Process of Construction of the Augustus Lowell Laboratory of Electrical Engineering for the Massachusetts Institute of Technology," including photographs and testimonials from the satisfied client. The first inside page indicated that his company would "solicit contracts for which the time for construction is limited" and for "mills, power stations, office buildings, and concrete masonry." 1902.

System provided detailed instructions for the efficient handling of men and materials.⁴⁰ The underlying logic for this system, as for scientific management in general, was in disaggregating work processes such that time could be wrung out of every step by dividing labor, reducing motion, improving routing, and increasing use of labor saving devices. In bricklaying, for example, the innovations Gilbreth advocated included use of scaffolding, separation of brick-getting from brick-laying, and exact specification of steps in trowling mortar and tamping brick.⁴¹ In order to establish, abet, and monitor these perfected processes, Gilbreth recommended estimating, record keeping and filing systems, competitions between work gangs, prizes for worker suggestions, the use of photographs and ticket systems to track progress, exact methods for the care and tracking of tools and machines, and systems of individual accountability.

Though Gilbreth's system was known even before its publication, when the *Engineering Magazine* surveyed general contractors on their use of cost keeping in 1908 it received few responses. "Diligent inquiries," the editors wrote, "have failed to elicit from more than 10 per cent of those approached anything that can be called a system or method. If the other 90 per cent are using modern methods, they are hiding their light under a bushel."⁴² These comments appeared in the introduction to a three-part series on cost-keeping methods in contracting. The first article in the series quoted several responses to the survey, including such as, "our methods of keeping up costs and estimates are so crude and antiquated they would be of no service to you," and, "the only system we have of cost keeping on contract work consists in having our foremen on the different jobs send in postal cards every evening stating the number of men employed, bags of cement and yards of sand used, and the amount of work finished each day."⁴³

Though the *Engineering Magazine* found few systems in use in 1908, five years later an engineer writing in the *Journal of the Association of Engineering Societies* commented that "the day of the contractor whose only written record is a pocket time book and the stubs of a check book has passed,"

⁴⁰ Frank B. Gilbreth, *Field System* (New York: Myron C. Clark Publishing Co., 1908). The introductory essay by John Slack noted that Gilbreth decided to publish what was originally a company handbook after a black-market trade in privately printed copies had developed.

⁴¹ Ibid.

⁴² Introducing A.W. Buel, "Cost Keeping on General Contract Work," 28 (1908): 971.

⁴³ A.W. Buel, "Cost Keeping on General Contract Work," 973.

and, "somewhat intricate methods and elaborate organization have taken his place."⁴⁴ Beginning about before 1910 and continuing through the teens, a plethora of accounting systems were proposed and debated in professional engineering and trade journals. Enough such expositions appeared that a certain genre emerged. Almost every such article began with a note that on some project "a new system of cost keeping was originated and introduced on this work by the writer and gave such satisfactory results as to warrant, in his opinion, a brief description here."⁴⁵

This outpouring of writing partly reflected the general infection with scientific management, but articles in engineering magazines—as opposed to those in the general press—dwelt particularly on how systems had to be altered to fit the special circumstances presented by project-type work. These articles collectively provide the earliest clear expression of a theory of engineering management. Several common themes can be found in explanations of the adaptations needed to fit management systems to construction, all revolving around implications of the differences in the predictability and regularity of construction relative to operation. The implications raised in response to observed differences included questions of the possibility of system in construction, shifts in practices in contracting and the division of technical labor, methods of cost keeping and graphic record keeping, and the unit of work in construction. Before considering these issues, it helps to first get a sense of how these blended and how both advocates and opponents of systematic management noted limits to ordering construction.⁴⁶

Recounting his own experience, A.W. Buel, author of the 1908 *Engineering Magazine* series just cited, noted that costs were not easy to track in construction and that the cost of maintaining a system could easily bankrupt a contractor. Buel recounted the story of an elaborate system of accounts used by one company, in which the forms and blanks set up had been too complicated for the company's personnel to use and consequently had remained blank. In the meantime, paying the accountants hired to run the system bankrupted the business. Buel used this story to advocate simplicity and approximation in keeping costs in construction. Assigned to monitor costs on a railroad job, Buel had

⁴⁴ Leonard C. Wason, "The Problems of the Contractor." *Journal of the Association of Engineering Societies* 51 (1913): 242.

⁴⁵ This instance is from Charles R. Gow, "Methods and Costs of Construction of the Slow Sand Purification Works for the New Springfield, Mass., Water Supply," *Journal of the Association of Engineering Societies* 45 (1910): 189–263, quote, 191.

⁴⁶ In addition to the immediately following examples, see the cases that appear at the end of this chapter.

had success despite relying on "the only available assistance for this work," namely "about half the time of an ordinary boy with a common-school education,"⁴⁷ rather than a trained time-study man. In this and most other successful systems he cited, the accounts were gross in their tracking and only on very big projects did he recommend detailed accounts and the use of machine tabulation.⁴⁸ Buel opined,

"What systematic cost keeping in detail has done for manufacturing industries it can do for general contractors, and often in greater measure. It is generally admitted that the business of a general contractor is one of the most difficult industrial enterprises to manage successfully. As a general rule the organization is not entirely permanent, but changes to some extent with each new contract. The location of the work is first in one place and then in another, and whatever of the permanency the organization possesses must be accompanied by the characteristics of mobility which introduce complications. Not only do most of the conditions of the work vary for each contract, but the kind and class of work may be entirely different."⁴⁹

Buel was typical of many engineering managers of the time in that he did not reject the applicability of system in construction, but saw characteristics that limited or altered how system could be applied. The limits most often articulated derived from limits to observation, differentiation, and measurement.⁵⁰ In an article from 1918, an engineer wrote that "the constant change in its requirements for labor and materials due to its own growth is the point where most construction work differs inherently from manufacturing, and it is the insufficient recognition of this that has caused the failure of many pretty schemes laid out by efficiency engineers successful in other fields."⁵¹ One contractor wrote in 1910 of the relative advantages of the factory setting:

⁴⁷ A.W. Buel, "Cost Keeping on General Contract Work," 974.

⁴⁸ The systems and the forms used are illustrated in A.W. Buel, "Cost Keeping on General Contract Work, II. The Working Systems of Several Successful Contractors," *The Engineering Magazine* 29 (1909): 243–254.

⁴⁹ A.W. Buel, "Cost Keeping on General Contract Work," 972.

⁵⁰ Examples include John P. Cowing, "Cost Keeping in Construction and Contract Work," *The Engineering Magazine* 29 (1909): 921–928; "Cost Keeping System of the Fort Orange Construction Co., on the New York State Barge Canal," *Engineering-Contracting* 34 (December 21, 1910): 560–562; H.H. Rousseau, "Method of Securing and Recording Costs in the Panama Canal Work," *Engineering-Contracting* 34 (December 21, 1910): 563–566; Richard L. Russell, "Contractors' Cost Keeping and Organization," *Engineering-Contracting* 34 (July 6, 1910): 19–23; Daniel B. Luten, "Comments on Contracting for Concrete Bridges with Description of a Form of Cost Recording," *Engineering-Contracting* 33, (March 2, 1910): 194–196; W.N. Connor, "Cost Accounting for Contract Work," *Engineering and Contracting* (October 25, 1922): 395–397; E.W. Robinson, "An Office System for Construction Work Covering Records of Plans, Progress and Cost and Bookkeeping Methods," *Engineering and Contracting* 40 (December 17, 1913): 683–686.

⁵¹ Francis Donaldson, "Contract Organization Vitally Important for War Work," *Engineering News-Record* (September 19, 1918): 535.

“The subject of properly recording costs is a very difficult and complicated one when applied to construction work, and is not only complicated, but in some cases is exasperating and almost impossible of application. The subject of cost recording has been covered very fully by a number of writers, with regard to its application to manufacturing plants, where we have an industry within the limits of four walls of a building, and where the men are always in sight and subject to close observation and a close check upon their output. Labor working under these conditions is largely independent of the weather, is generally of a higher grade, and the facilities for a close check of the actual time employed are greatly increased.”⁵²

Continuing, this writer noted that in construction several factors frustrated the application of system: the need to hire and fire labor regularly; the high rate of employment of “foreigners to whom it is impossible even to explain what is desired;” and, the fact that “the output is measured more from the gang unit than from the individual unit.”⁵³ Cost accounting was tripped up by a fluid division of labor, in that the individual worker, “as a result not of being hired except in especial cases for any particular line of work, is shoved around from one class of work to another, so that at the best all that can be expected is an approximate estimate of the distribution of his time and the work accomplished; and he may also at any time be placed on work where there is absolutely no unit measurement of output.” As a consequence of these several factors, “if an attempt is made to reduce the subject to too fine a point, and too much stress is laid upon it the attention of the superintendent, foreman, sub-foreman, and timekeeper is soon distracted, and the result is an increased cost.” In short, construction work required a “broad-minded policy, far different from the red-tape system which is possible in manufacturing.”⁵⁴

Daniel Hauer, from whom the epigraph to this chapter is taken, sharply contested any limits to the potential of *Modern Management Applied to Construction* in a so-titled 1918 book, asserting that the planning function was the kernel of systematic management and that in construction this was a matter of drawing, scheduling, and routing work.⁵⁵ Hauer stated that in popular opinion, “it has been thought that these principles, so successfully applied in the manufacturing field, are not applicable to engineering and architectural construction.” He continued, “this idea, however, has been proven

⁵² DeWitt V. Moore, “Methods of Cost Analysis as Applied to Construction Work,” *Engineering-Contracting* 33 (February 23, 1910): 181.

⁵³ Ibid.

⁵⁴ Ibid., 182.

⁵⁵ Hauer, Daniel J. *Modern Management Applied to Construction*. (New York: McGraw-Hill, 1918), 14–25. See also “Modern Management Methods Applied to Construction, Mean Higher Efficiency,” *Contract Record* 33 (1919): 585–589.

erroneous by the successful work of those pioneers in the contracting field.”⁵⁶ But his further description indirectly acknowledged the difficulty in monitoring construction once underway:

“Under modern management the contractor and the general manager, with a corps of assistants, plan the work, manage the schedules (both time and material), route the work, making drawings and instructions for all details, and devise reports. When this is done they no longer direct the work, for, in doing these things, they have already issued the directions. They become part of the organization to carry out these directions, and it is as necessary for them to obey their own instructions and follow their plans as it is for the humblest apprentice on the job to do so.”⁵⁷

Around the height of the scientific management craze in 1911 and 1912, the *Journal of the Society of Naval Engineers*, which otherwise occupied itself with technical matters and news of members, published three articles on management. The first of these was written by a lieutenant and amounted to a regurgitation of the basics of Taylorism.⁵⁸ The second was a more balanced appraisal reprinted from *Iron Age*. The author noted that it was “hardly possible at the present time to pick up a trade journal or magazine without seeing something about ‘scientific management,’” and continued that, “it seems to be a craze for everyone who has ever done anything along this line to rush to the front with it, seemingly for fear that unless he gets it before the public, the two or three most prominent exponents of ‘scientific management’ will absorb all the future credit for what seems to be a new era in industrial management,” but did not reject the value of systematic management.⁵⁹ The third article was a scathing attack on “The Fetishism of Scientific Management,” in which Admiral John R. Edwards noted that “with the exception of a very few of the most influential and important engineering magazines, the attitude of the technical press is generally agnostic if not hostile to the system.”⁶⁰ In Edwards’s opinion, “the question of scientific management of particular industries has been somewhat intimately associated with the more important problem of national efficiency.” Consequently, “railway officials, industrial managers and technical experts have been forced to meet the attacks and arguments of the efficiency promoters.”⁶¹

⁵⁶ Ibid., vii.

⁵⁷ Ibid., 16.

⁵⁸ G.J. Meyers, “The Science of Management,” *Journal of the Society of Naval Engineers* 23 (1911): 994–1015.

⁵⁹ E.C. Peck, “Systematic versus Scientific Management,” *Journal of the Society of Naval Engineers* 23 (1911): 1177–1185, quotes, 1177–1178, reprinted from *Iron Age*.

⁶⁰ *Journal of the Society of Naval Engineers* 24 (1912): 355–416, quote, 390.

⁶¹ Ibid., 356–357. Edwards further found that scientific management, with its commitment to system, did not allow for variability. Referring to the experimental aspect of ship construction and repair, Edwards noted that “every navy yard is, and

Having introduced some of the terms of arguments over the relevance and extensibility of systematic management, I now turn to consider more closely how the management of engineering projects was described and prescribed.

Sectioning and Coordinating

Coordination of engineering work in the late 1800s and early 1900s retained the basic logic of sectioning, coordinating, and assembling that typified railroad construction a half century earlier. Despite this constancy, institutional relationships in engineering administration shifted in response to technical changes. The relationship between engineering and contracting shifted with increasingly complex administrative requirements and the more varied technical expertise involved in a given contract. Where two sections of track could be let to two contractors, there was little coordination needed. More complex interfaces between sections of work—as between a power station and a dam—tested the ability of the engineer to act as go-between. In response, both contractors and their clients made increasing use of general contracts, under which a single contractor assumed responsibility for the entire project but sublet some or all of the work to other companies.⁶² Under such an arrangement, the contractor assumed the integrating role that has been that of the engineer.

In building construction, the general contractor was typically in the masonry or concrete business and sublet work on subsystems such as wiring and plumbing. The president of one engineering-contracting company commented that, “in the old days when work was done mainly by hand labor the engineer was ‘boss’ in many ways, and the successful contractor was the one who could drive his men to the limit, but who had no technical knowledge.”⁶³ By contrast, the contracting organization of the early twentieth century involved special expertise. Though he did not use this language, this contractor’s examples dwelt on the unpredictability of interfaces and interferences within new

should be, an experimental military plant for the development of engineering and ordnance appliances.” He especially criticize a report prepared for the Navy by Henry Gantt, Harrington Emerson, and Charles Day, stating that the trio of efficiency men had been flummoxed by “...big *repair* shops as distinguished from manufacturing shops,” in which “the magnitude of the job was appalling in the variety of work that these shops were called on to do,” 402–408.

⁶² Subcontracting was not a new practice, but the use of general contracts by purchasers of engineering appears to have increased in this period, at least if contemporary articles are to be believed.

⁶³ J.W. Rollins, “The Relation Between Engineers and Contractors,” *Proceedings of the Engineers’ Society of Western Pennsylvania* 32 (1916): 122.

systems and between these and existing systems. Increasing complexity in turn motivated ever more complicated delineations of which party to a contract assumed risks for which aspects of the work.

The relative merits of separate and general contracts were hotly debated. A discussion of the question, "in contract work, either public or private, is it preferable to make separate contracts for the different branches of trades involved or to combine all under one contract?" in 1902 revealed considerable variation in opinion and practice.⁶⁴ The main speaker, George Gifford, observed that "there have been formed large contracting firms and corporations who are prepared to undertake work of almost any magnitude, and involving many different trades," but he nonetheless knew of no contractors who did not prefer to take contracts by specialty.⁶⁵ Referring to what would later be called joint-venture contracting, he noted that even in a "community-of-interest contract someone has to be the principal" and provide the primary contact with the owner and settle the accounts.⁶⁶ The main issue was that a general contract transferred risks associated with fitting a system together from the owner's representative, the engineer, to the contractor.

Agreeing that the general contract did not pay, a later speaker felt that "the work of generalization devolves upon the engineer of construction,"⁶⁷ But another participant in the discussion noted that there was a special class of work in which the lines between machinery and its housing were complicated and that in such situation the direct interaction between the owner and the machinery manufacturer and the importance of *in situ* tests of machinery were necessary and justified general contracts.⁶⁸ Still another discussant observed that a general contract relieved the owner of a good deal of work and uncertainty, and that "the fact that the general contractor accepts the responsibility of making a complete structure or plant, and thus relieves the owners of expense in making the work of the various sub-contractors come together, is what makes his position so strong."⁶⁹ This person noted further, that "there are few so far-seeing or perfect that they can prepare specifications which will draw the lines of definition between the various crafts so that they will come together as a harmonious

⁶⁴ George E. Gifford et al., "Separate versus General Contracts," *Transactions of the American Society of Civil Engineers* 49 (1902): 1-13.

⁶⁵ Ibid., 1-2.

⁶⁶ Ibid., 2.

⁶⁷ Charles G. Darrach, comments to George E. Gifford, "Separate versus General Contracts," 8.

⁶⁸ S. Bent Russell, comments to George E. Gifford, "Separate versus General Contracts," 9.

⁶⁹ M. Ward Easby, comments to George E. Gifford, "Separate versus General Contracts," 10.

whole.”⁷⁰ There was no general solution to the trade-offs presented by these problems. Where uncertainty and complexity made ends easier to specify than means, general contracts were more likely to be employed. Across efforts to describe and cope with the increasing complexity of both technical and professional relations in construction engineering, individuals focused on means of sectioning work. Often the demarcations between sections fell according to both the distinct skills and knowledge needed and along fault lines between degrees of uncertainty.

Dividing Time, Labor, and Risk

There were (and are) two basic forms of contract in engineering and construction. Fixed-price or lump-sum contracts involved a fee set in advance through either negotiation or competitive bidding. Percentage or cost-plus contracts based compensation on the actual cost of the work plus some agreed percentage to cover the contractor’s administrative costs and reasonable profit. Both forms presented advantages and hazards. While a fixed-cost contract guaranteed the purchaser a price, it did not guarantee what the purchaser would get for the money except in so far as this could be fully specified and monitored. A cost-plus contract relieved the contractor of risks, which could seem a more fair arrangement where physical or technical uncertainties or information asymmetries prevented the contractor from knowing what tasks lay ahead, but it also exposed the owner to the contractor’s temptation to pad the job. As with general versus specific contracts, the relative advantages of these forms were hotly debated in the first decades of the twentieth century, and these hazards were acknowledged.⁷¹

A writer associated with the Thompson-Starrett Company, at the time one of the largest contract construction firms in the United States, discussed the risk inherent in contracting in a 1922 article in the *National Association of Cost Accountants Bulletin*. Whereas in most lines of manufacture, the

⁷⁰ Ibid.

⁷¹ See Frank B. Gilbreth, “Different Plans of Letting Contracts,” *Engineering News* 56 (October 18, 1906): 411–412; G.G. Ommanney, “Supervising the Execution of Large Percentage Contracts to Protect the Clients’ Interests,” *Engineering News* 71 (April 30, 1914): 948–949, discussed further in a letter from Frederick O. Lewis, “Safeguarding the Client,” *Engineering News* 71 (May 14, 1914): 1089–1090. A similar discussion of the need to drive out ambiguity is Major Cassius E. Gillette, “The Responsibility of the Engineering Profession for the Conduct of Public Contracts,” *Engineering News* 57 (May 30, 1907): 587–589. See also John Miller, “Aligning Infrastructure Development Strategy to Meet Current Public Needs” (Ph.D. dissertation, Massachusetts Institute of Technology, 1995), which offers an historical survey of U.S. government contracting practice in construction.

selling price was determined in bringing the produced good to market (or at least could be adjusted based on experience), "in the construction business, the selling price is usually established before the actual cost of the work can be determined."⁷² Hence, a contractor made a calculated risk in bidding for and accepting a job. Construction was a gamble, and known to be such.

Some proposed solutions to these hazards advocated mixed forms. A technical component of a larger system might be specified only in terms of its performance and bid as a lump sum while the method for placing concrete was specified in exacting detail and priced per yard. For example, in letting contracts for the foundations of the New East River Bridge (later called the Williamsburg Bridge), the commissioners adverted that bidders must be in full conformity with the contract requirements and provided blanks in forms to indicate total bids.⁷³ The full contract to be negotiated with the winning bidder required that he "employ only competent, skillful men to do the work," and gave the engineer the right to request dismissal of any worker found "incompetent, unfaithful, disorderly, or in any manner detrimental to the work."⁷⁴ The full contract and specifications provided for agreements on unit costs for work required beyond that projected by the engineer, details of the caissons within which the work would take place, and detailed descriptions of the masonry construction. This project followed traditional practice in that the work was let in sections—foundations, piers, anchorages, towers and end spans, cables and suspenders, approaches, and suspended structure, and so forth were each separately contracted.

The records of a job for Michigan power company provide a roughly contemporary example of a different approach.⁷⁵ The construction of a power station was let as a general contract with wide ranging variation in the specificity of the requirements for the component work. On simple aspects of work, such as dredging or excavation, methods were simply left at the contractor's discretion. Structural elements and masonry were, by contrast, minutely described. One of the most important

⁷² Affelder, William M. "Principles and Practice of Construction Cost Keeping." *National Association of Cost Accountants Bulletin* 3 (Aug. 15, 1922): 3.

⁷³ Documents relating to this work are collected in "New East River Bridge—Contracts, Plans, and Specifications, 1896 to 1901," Linda Hall Library.

⁷⁴ Ibid., 10, of "Form of Advertisement, Proposal, Contract and Specification for Constructing the New York Tower Foundations of the New East River Bridge," October 1896.

⁷⁵ General assertions here are based on inspection of nineteenth and early twentieth century contracts in the collections of the Linda Hall Library. The particular document referenced is a contract by The Engineer of the American Lake Superior Power Company, Sault St. Marie, Michigan (July 1, 1898).

parts, a set of large pumps, were left to the contractor's discretion, the specification indicating that, "the particular type of pumps, the plan of installing and the method of operating the same may be elected by the Contractor, provided that the plant's efficiency meets the requirements, that it is installed in the location designated by the Engineer and that the operation method guarantees unbroken continuity."⁷⁶ While the term 'black box' was not employed, in these practices the basic logic of later efforts to extend exact specification and procedure as far as possible and then to wrap remaining uncertainties in general descriptions of performance can be seen operating.

Projects, Costs, and the Unit of Work in Engineering

As shown in the preceding chapter, the use of 'project' for the organization of work and accounts predated the nineteenth century, but it came into more general use around the turn of the twentieth century. During World War I, the Navy adopted a system of project accounts to enforce financial controls on emergency work. In a bulletin advising personnel of this new system, these were described as requiring "an allotment of funds for each project or job of work undertaken." The bulletin noted that the system would not be entirely foreign to readers as "this is simply an extension of the system of making appropriations," a means by which individual yards could track spending so as to stay within appropriated funds.⁷⁷ Project-based accounting systems were widely adopted in the decades around the turn of the century, and many of the articles so far cited in this chapter provided sample form and accounting blanks for tracking project work. With the formation of the National Association of Cost Accountants (NACA) in 1919, its associated journal regularly touched on the problems of tracking costs in jobbing or project-oriented settings. These problems revolved around measurement and the costs of measurement.

The relation of these problems to other aspects of the organization of engineering can be introduced through recounting the 1915 remarks of Ernest McCullough to a paper by Sanford E. Thompson and William O. Lichtner. McCullough was an engineer and contractor, a periodic contributor to Halpert Gillette's *Engineering-Contracting* and other trade publications, and, in 1915, First Vice-President of the Western Society of Engineers. Thompson was notably a sometimes

⁷⁶ Ibid., quote, 5, of "Sixth Set of Specifications," covering a pumping plant and associated work.

⁷⁷ U.S. Navy, Bureau of Yards and Docks, "Allotment System, Obligation Accounts," *Public Works of the Navy*, Bulletin No. 29 (January 1918): 5-6, quotes, 5.

associate of Frederick Taylor. McCullough's remarks followed Thompson and Lichtner's presentation of a paper to the Western Society of Engineers on "Construction Management."⁷⁸ In this paper, the authors explained the practices of their firm in building formwork for concrete structures. Applying system to construction required "the services of a new man," they offered, a "production engineer" charged with "the treatment of the construction organization and methods in full detail."⁷⁹ The system to be applied by this new man involved minutely detailed tracking of every aspect of work, down to filing a separate "operation ticket" to cover cutting a piece of lumber into three pieces, with the dimensions of both the original and cut pieces of wood clearly spelled out. Thompson and Lichtner argued that the high administrative costs so incurred were more than compensated by savings in the time and materials of construction.

In the published discussion of Thompson and Sanford's article, McCullough strongly objected to the limited relevance of their system. Under scientific management, he averred,

"The productivity of the men employed by contractors has been increased by taking from men on the job the necessity of thinking beyond their task. The brains of the company are located in the head office, the convolutions of the brain being represented by masses of red tape, the gray matter being represented in white, yellow, green, red and other color sheets and cards. The job superintendent is an operator at a switchboard receiving and transmitting calls. Such highly developed systems are good, as we all know, for large organizations where the initial expense can be borne and a large overhead expense carried, which can be reduced to a small per cent of the cost because of the large volume of business. But we need something better adapted to the sporadic contract undertaken by the individual, or the very small company, lacking capital and working in sections of the country where each job means a new organization. There must be considerable waste on such work, but as many contractors make some money, might it be possible to enable them to earn more and be more humane to their men by the introduction of common sense methods adapted to the understanding and financial ability of the average contractor?"⁸⁰

⁷⁸ Sanford E. Thompson and William O. Lichtner. "Construction Management." *Journal of the Western Society of Engineers* 20 (1915): 115–130, discussion following. See also, by the same authors, "Scientific Methods in Construction," *Proceedings of the Engineers' Club of Western Pennsylvania* (June 1916): 433–454, discussion 454–465. Thompson did time-study work at Bethlehem Steel and for Taylor and coauthored with Taylor *Concrete: Plain and Reinforced* (New York: John Wiley & Sons, 1905). For details on the Taylor-Thompson relationship see Charles D. Wrege, Ronald G. Greenwood, and Regina Greenwood, "A New Method of Discovering Primary Management History: Two Examples Where Little Things Mean a Lot," *Journal of Management History* 3 (1997): 59–92, of which 60–71 relate to Thompson.

⁷⁹ Sanford E. Thompson and William O. Lichtner. "Construction Management," 115.

⁸⁰ Ernest McCullough. comments to Thompson, Sanford E. and William O. Lichtner. "Construction Management." *Journal of the Western Society of Engineers* 20 (1915): 131–135.

For McCullough, system in construction should be more about planning and less about paperwork. "Because a job does not bristle with hooks on which to hang blanks and is not plastered with special forms does not mean it is not systematically run."⁸¹ Speaking from his personal experience on job sites, McCullough reviewed some of the factors that complicated the application of system to contract work. In his remarks, he was carefully sanguine about the desirability of efficiency in contracting; but he made clear that irregularity of contracting made typical systems inefficient.

Foremost in checking the value of system was the nature of the labor market. "The labor question is ever with us," McCullough remarked, "local labor is seldom efficient and imported labor belongs to the 'drifting class.'"⁸² He described a large job that should have kept 400 men in constant employment, especially as he had had "good camps and fine cooks and the climate was all that could be desired." When the work was done, though, his cumulative payroll record contained 1700 different names. Only eleven men had stayed on the job from start to finish. Complicating the difficulty of finding and keeping good workers for McCullough was that hand-to-mouth contracting operations could not afford to pay workers or to keep expensive equipment between jobs. He concluded his remarks, "I believe in efficiency, and when system means efficiency I am for good system. When system means the pre-organization of a large staff at considerable initial expense, then I believe the efficiency experts have to revise their message to engineers—perhaps add a postscript."⁸³

McCullough's remarks clearly state the nature of the debate between efficiency engineering and efficiency in engineering. No engineer disputed the goals of business success and social benefit through efficient operations. Where they differed was in the means to those ends and in disagreeing they often talked past each other—addressing different kinds of work by different kinds of firms. Thompson and Lichtner's description of their system was based on the serial and relatively routine task of cutting wood for formwork to build a generic, rectangular, concrete office building in an urban setting. Their firm specialized in this kind of construction, and the system they established for this work could be dusted off and applied to the next job, even if the column spacing and floor-to-floor distance were a bit different.

⁸¹ Ibid., 134.

⁸² Ibid., 133.

⁸³ Ibid., 135.

McCullough, however, described irregular work in isolated circumstances. In addition to several treatises on structural design his books included *Engineering Work in Towns and Small Cities*, which reflected his attention to social context as it shaped engineering practice. McCullough was also active in discussions of methods in contracting, writing a series of articles in *Engineering-Contracting* in 1909.⁸⁴ In this series he lamented, “unfortunately, in these days of vertical files and card indexes and business men’s magazines and industrial literature generally, a great many amateur form-makers have been working.”⁸⁵ McCullough used mimeographed or hektographed forms that he worked up himself and then applied on a trial basis. He addressed his system to the small operator and referred large contractors to Gilbreth’s *Field System*. Notably, McCullough felt that the only reason systems were needed at all in construction was because of the poor quality of workers—he yearned for the days when a gang needed no foreman because “each man knew his place and the work proceeded finely.”⁸⁶

Cost accounting methods had to accommodate this:

“On some work employing a certain class of men, and especially in large cities, the men shift frequently. In a city like Chicago in certain sections the common laborers seldom stay more than two or three days. They may work on the job several times a month but only for very short periods. The law requires that a man be paid in full when discharged and these fellows generally managed to be discharged, for if they left voluntarily they would have to wait until pay day for their money.”⁸⁷

While hiring this class of men would ideally be avoided, because some of them made good work when on the job, McCullough advised a time-keeping system that fit the pattern. He kept on hand two or three times as many numbered work badges as there were men employed at any given time. Using a slate book ruled with acid ink, he then marked men and the available numbers in pencil and when payday came he gave out small bills so men would not have to make change at saloons.⁸⁸

Under such conditions, there was little sense to tracking the output of individual workers beyond getting to know who were the better men. As a consequence, contractors sought to isolate and standardize measures of work such that costs could be rendered comparable but did so using gross

⁸⁴ Ernest McCullough, “Accounting and Cost Methods for Contractors,” *Engineering-Contracting* 32 (1909): 195–197, 219–220, 238–239, 258–259. These are collected in Halpert Gillette and Richard Dana, *Cost Keeping and Management Engineering*, (Chicago: Myron Clark, 1909), 312–339.

⁸⁵ “Accounting and Cost Methods for Contractors,” 195.

⁸⁶ *Ibid.*, 258.

⁸⁷ *Ibid.*, 238.

⁸⁸ *Ibid.*, 239.

measures. Using control boards and cost forms field engineers did their best to approximate the fine metering possible in routinized settings, but the mere possibility of tracking costs was a matter of some debate.⁸⁹ Cost intelligence was a basic currency in exchanges among civil engineers from earliest days of the profession. Writing in the 1870s, one engineer noted that “every engineer of experience has his collection of memoranda concerning work on which he has been engaged, but when called upon to estimate on another class of construction, data are very difficult to obtain... the only data which can be relied upon are founded on observation of the time actually taken to perform certain operations.”⁹⁰

Cost Keeping Systems in Contracting

Halpert Gillette and Richard Dana’s 1909 *Cost Keeping and Management Engineering* is the best single source of information of cost keeping systems in use by construction contractors in the early twentieth century. Illustrating a number of systems in use by particular firms, this book allows consideration of both the range of variation and distillation of common features. Among the forms the authors illustrated was a system using punch cards (figure 2.4)—with this system praised because the punch’s mark survived weather better than others and, since “the determination of volume on construction work is liable to be very difficult,” the imprecise markings possible using a punch sufficed.⁹¹ “Field work is constantly presenting obstacles and difficulties which have to be met and fought,” Gillette and Dana offered, “calling for emergency judgment on the part of the men in charge and on the part of all the men on the work to a greater or lesser extent; and here alone is one of the chief reasons why a contractor comes to depend almost exclusively upon the personality of his superintendent or foreman, to the exclusion of systematic analysis.”⁹²

⁸⁹ See S. Whinery et al. “Unit Costs of Work in Progress” (informal discussion), *Transactions of the American Society of Civil Engineers* 49 (1902): 62–73. One of the discussants, Charles S. Churchill, stated that “in as much as engineering is the power of producing the greatest and most permanent results for the least ultimate cost, even the intimation that actual and detailed costs cannot be determined and kept is a stroke against the foundation of the profession,” 65.

⁹⁰ J. James R. Croes, *Memoir of the Construction of a Masonry Dam for a Storage Reservoir* (New York: Evening Post Steam Presses, 1875), 31. Also appears as “Memoir of the Construction of a Masonry Dam,” *Transactions of the A.S.C.E.* 3 (1874): 337–367.

⁹¹ Gillette and Dana, *Cost Keeping and Management Engineering*, 343.

⁹² *Ibid.*, 356.

Total Feet of Holes Drilled										3	4	5	6	7	8	9	10	11	12		
1	2	3	4	5	6	7	8	9	10	Tens	4										
0	1	2	3	4	5	6	7	8	9	Units	2										
Depth of Hole (Feet)										2	3										
1	1	1	1	1	1	1	1	1	1	Spacing of Holes in Feet	5										
2	2	2	2	2	2	2	2	2	2	Kind of Bit	Condition of Drill										
3	3	3	3	3	3	3	3	3	3												
4	4	4	4	4	4	4	4	4	4	No of Drill	W.Cut E	1	2	3	4	5	6	7	8	9	10
5	5	5	5	5	5	5	5	5	5												
6	6	6	6	6	6	6	6	6	6												
7	7	7	7	7	7	7	7	7	7												
8	8	8	8	8	8	8	8	8	8												
9	9	9	9	9	9	9	9	9	9												
0	0	0	0	0	0	0	0	0	0												
No of Hole																					
CONSTRUCTION SERVICE CO.										Punch Double when starting & quitting work, inc. lunch time.											
NEW YORK										Punch Single for time of starting & finishing hole.											
DRILL RECORD																					
Original 2-08 25-5A																					
DATE	7	0	8	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34		
JAN	FEB	MAR	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32		
APR	MAY	JUNE	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32		
JULY	AUG	SEPT	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32		
OCT	NOV	DEC	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40		
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60		
61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80		
81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Figure 2.4—Punch-card time record for drilling operations. I reproduce only the bottom half of the form. The top half provided a backward version of the same layout such that by folding the page in half the foreman punching the form created a duplicate record. Source: Gillette and Dana, *Cost Keeping and Management Engineering*, 85.

Gillette and Dana argued forcefully for the extension of Taylor's principles in construction but repeatedly observed the limits to such extension. Scheduling and routing were part of the "law of coordination," and though, "there will be a considerable variation to be accounted for by ignorance on the part of planning department on the one hand, and by the interference of the elements on the other," a chart on tracing cloth that would "admit of many alterations and additions" was invaluable.⁹³ Aspiring to the perfect measure of entirely atomized tasks, they saw fit to note that the human engine, converting three pounds of solid food per day, had the theoretical output of 10,000,000 foot-pounds at a realized efficiency of 15 percent and that the foot-pound was the ideal measure.⁹⁴ At the same time, they admitted that shifting tasks and gang work limited measurement.⁹⁵ At best, the time and dollar cost of completing "sections" of like work could be compared.

In a separate article on "Cost Analysis Engineering" in the *Cyclopaedia of Civil Engineering* these authors noted some further aspects of the unit of measure in construction.⁹⁶ "There are, and always will be, certain kinds of work that must be performed by a group of men working together, or,

⁹³ Ibid., 6. Gillette and Dana set out ten laws of scientific management: subdivision of duties; educational supervision; coordination; standard performance based on motion timing; divorce of planning from performance; regular unit cost reports; reward increasing with increased performance; prompt reward; competition; and, managerial dignity.

⁹⁴ Ibid., 50–51, 322.

⁹⁵ Ibid., 50–63.

⁹⁶ Frederick E. Turneaure, ed. *Cyclopaedia of Civil Engineering* (8 vols. Chicago: American Technical Society, 1913), Gillette and Dana's article is in vol. 3, 313–380. It is largely a summary of material covered in their earlier book.

as we shall call it, a *gang* of men. When this is the case, the first step to be taken is to devise a method of readily and accurately measuring the work performed *each day*—not each week or each month—by the gang.”⁹⁷ With this measure in hand, bonuses could be allotted on a gang basis, while the foreman could be incented to not indulge “a good fellow” and to discharge the lazy or inefficient. Wherever possible, though, gangs should be broken up. At the same time, and contrary to their drive for atomization, Gillette and Dana noted the salutary effect of a group of men getting to know each other’s working methods. They had had experience on a building project in which the upper floors had been built much more quickly than those lower down, and “the greater part of the extraordinary increase in efficiency was attributed to the fact that the men were so educated that a man at the top of the building knew how the men at the mixer and in other parts were doing their work,” an early description of the learning effect.⁹⁸

Given these factors, the application of the notion of efficiency in construction was limited to a less-precise unit of time than could be used in the factory. Figure 2.5 shows an “efficiency chart” modeled on cards used in factory settings to plot the output of a production process against a standard or theoretic efficiency, but here used to represent excavation work in January of 1908 on which two steam shovels were in use. The three lines, from top to bottom, represented yards of material removed, labor expenses, and labor cost per yard. As evident, production was highly variable from day to day on account of weather and problems with the shovels. Other systems published about this time included one from the Aberthaw Construction Company, a Boston-area builder of industrial buildings, which used daily cost sheets for each major area of work and graphed the collected data. Figures might serve, but “a line traveling upward or downward and above or below a red line which is recorded as the desired cost line, the foremen grasp the meaning of very easily.”⁹⁹ This firm achieved some efficiencies by distinguishing a planning and routing department from an operating department, but was not overly persuaded of the application of system in construction. Forms similar to figure 2.5 were used to track work on the Panama Canal. The Canal’s report for 1909 included a section on cost keeping, which noted,

⁹⁷ Gillette and Dana, *Cost Keeping and Management Engineering*, 315–316.

⁹⁸ *Ibid.*, 363.

⁹⁹ Leonard C. Wason, “The Problems of the Contractor.” *Journal of the Association of Engineering Societies* 51 (1913): 272.

similar work.”¹⁰⁰

Figure 2.5—"Efficiency Chart" used to track performance on a steam-aided excavation job. Source: Gillette and Dana, *Cost Keeping and Management Engineering*, 99.

The several foregoing examples have emphasized the measurement of quantity work—in the context of a large project, a big excavation taking months and involving manual labor was little different than the routines of pig iron loaders used by Taylor in *The Principles of Scientific Management* to demonstrate the potential of his system to purely manual undertakings. In quantity work, measurement might be subject to the sorts of uncertainties emphasized by McCullough, but these were ultimately small versions of the kind of work Goethals contrasted to the complexity of

¹⁰⁰ 169 of original report, cited by Emile Low in discussion of Myron S. Falk, "A System of Cost Keeping."

subway systems. So, these preceding examples show the persistence of measurement issues that obtained equally on early railroads.

Where there was need to integrate disparate aspects of a project both physically and in accounts, systems were more complicated. The system of project offices and cost keeping adopted in the Bureau of Reclamation offers a useful example of efforts to maintain accounts and accountability under field conditions while breaking down component work in detail. It also connects systems used in construction to those used in laboratory administration and discussed in the next chapter. In the early 1900s, reclamation and agriculture were allied activities, and personnel including civil engineer Elwood Mead moved between Agricultural Experiment Stations and the Bureau of Reclamation.

The Reclamation Service was established within the Geological Service of the Interior Department by a law of June 17, 1902. Authorized to sell public lands to pay for dam projects following two decades of wrangling over the relationships between public projects and private interests in irrigation, the work of the Service began with "general instructions being given to all engineers in the field to push the work as rapidly and economically as possible."¹⁰¹ The circumstances of the Service's creation and the individuals who served in it both connect it to the progressive ideals attached to engineering works in this period.¹⁰²

The Bureau's cost keeping methods were one of several systems discussed at a meeting of the ASCE in 1909, a discussion transcribed and illustrated in both the Society's *Transactions* and in the Gillette and Dana volume already discussed.¹⁰³ Matters discussed more generally at this meeting included the hazards of cost collection given irregular, out-of-doors work and means of coping with resulting variation through averaging.¹⁰⁴ Richard Dana, Gillette's coauthor, was among the

¹⁰¹ The quote is from Department of the Interior, United States Geological Survey, "Twenty-Fifth Annual Report" (Washington: Government Printing Office, 1904), 284; a brief background to the Service's establishment is Department of the Interior, United States Geological Survey, "Twenty-Third Annual Report" (Washington: Government Printing Office, 1902), 11–15.

¹⁰² Studies of the Bureau and its personnel include Donald C. Jackson, "Engineering in the Progressive Era: A New Look at Frederick Haynes Newell and the U.S. Reclamation Service," *Technology and Culture* 34 (1993): 539–574.

¹⁰³ Myron S. Falk, "A System of Cost Keeping," *Transactions of the American Society of Civil Engineers* 64 (1909): 401–409, discussion, 410–440. Also appears in part in "Some Cost Keeping Systems," *Engineering-Contracting* 32 (1909): 234–237 and 252–259. A substantial part of the discussion was also reprinted in Gillette and Dana, *Cost Keeping and Management Engineering*, 288–312.

¹⁰⁴ Discussion of Myron S. Falk, "A System of Cost Keeping," 416–422.

discussants and praised the Bureau's use of man-days as establishing a standard of comparison.¹⁰⁵ Details of some of the forms used by the Bureau came to the discussion by way of a letter signed by Frederick Newell but prepared by a V.C. Croissant.¹⁰⁶ Supplemented by other sources, these form one of the earliest detailed descriptions of project management in more or less modern form.

The law establishing the Reclamation Service had mandated that the major portion of moneys from the sale of public lands be spent on reclamation work within the state containing those lands and, further, that charges for irrigation should be accounted for "with a view of returning to the reclamation fund the estimated cost of construction of the project."¹⁰⁷ In order to comply with this law, an accounting system that attached expenses and revenues to project and state was required. Because rivers and state borders often coincide, this meant creating two cost accounts reflecting the jurisdictional division at mid-stream.

Desiring a system applicable across the diversity of its operations, the accountant and field inspector of the Bureau of Reclamation built their control system around a choke point called the "project office."¹⁰⁸ In establishing administrative control, the Bureau assigned a "project engineer, the officer in charge in the field of one complete project," who oversaw a small field bureaucracy of agents and clerks.¹⁰⁹ Using Bureau-supplied blanks, the project office monitored and accounted for all materials used through a storehouse and requisition system. Within the project, accounting was by "feature," operationally defined as any work sufficiently distinct as to require separate supervision by at least one foreman. Daily reports required for each feature were to include notes on the weather, labor conditions, and other factors affecting the work. At month's end, the project office rolled up costs by feature and project (figure 2.6). The daily and monthly reports by engineers and foremen to the project office formed the basis of the project engineer's card file documenting "such costs as

¹⁰⁵ Ibid., 422.

¹⁰⁶ Ibid., 423-430; though these details appeared under Newell's name, Newell indicated that they had been prepared by V.C. Croissant.

¹⁰⁷ Cited in N.E. Webster, Jr., "Bookkeeping in the Reclamation Service," in U.S. Department of the Interior, United States Geological Survey, "Proceedings of the Second Conference of Engineers of the Reclamation Service" (Washington: Government Printing Office, 1905): 148-153, quote, 149.

¹⁰⁸ *Manual of Field Accounting* (1906?). I have not found a copy of the manual. The system is summarized "Cost-Keeping in the U.S. Reclamation Service," *Engineering News* 57 (1907): 445-447 and "The Cost-Keeping System of the United States Reclamation Service," *Engineering Record* 60 (1909): 47-49 as well as in the sources noted just above.

¹⁰⁹ "The Cost-Keeping System of the United States Reclamation Service," 47. Guidelines allowed for variation in the size the office staff according to the nature of the work.

chief engineer is to a very great extent the one who stands between the public and those who are doing the field and office work.”¹¹² Given this exposure, the ability of the chief engineer to represent the work of the Service to Congress and the public depended on the reach of the accounting and reporting system as it extended down through district and project engineers to chiefs of working parties and then down to subparties.

Between the Engineering Section and the Gantt Chart

In the second chapter of *Organizing for Work* in 1919, Henry Gantt indicated that he would present a “system of progress charts which bear the same relationship to the statistical reports that are so common that a moving picture film bears to a photograph.”¹¹³ Complaining that typical business accounts were retrospective rather than projective—and that this had been their chief failing during the then just-ended war—Gantt presented this new chart in a chapter titled “Democracy in Production (Progress Charts)” (figure 2.7)¹¹⁴ He had already published a simpler version of the chart in *Industrial Management* in 1918, having developed both in 1917 while consulting to General William Crozier, Chief of Army Ordnance, on methods of speeding up supplies headed for the European war.¹¹⁵ Gantt distinguished this chart by noting that under conditions of war, time and capacity had become governing factors with money no object.¹¹⁶ Writing after the armistice, he noted that similar charts had been used to track “schedules and progress in building ships, shipyards, and flying boats” and that they had come into use “in connection with the manufacture of many kinds of machinery.”¹¹⁷

¹¹² A.L. Fellows, “Reports and Accounts,” in U.S. Department of the Interior, United States Geological Survey, “Proceedings of the Second Conference of Engineers of the Reclamation Service” (Washington: Government Printing Office, 1905): 49–56, quote, 50.

¹¹³ Henry L. Gantt, *Organizing for Work* (New York: Harcourt, Brace and Howe, Inc, 1919), 17. Thanks to his charting technique, Gantt holds an almost mythical position in relation to the modern practice of project management. There is (at least as of this writing) a web site that targets information technology project managers called “gantthead.com.” There is no recent study of Gantt, though he is routinely discussed in histories of management. An older, laudatory biography is Leon Pratt Alford, *Henry Laurence Gantt, Leader in Industry* (New York: Harper & Brothers, 1934).

¹¹⁴ Gantt, *Organizing for Work*, 74–83.

¹¹⁵ JoAnne Yates reproduces this chart in *Control through Communication*, 90.

¹¹⁶ *Organizing for Work*, 77.

¹¹⁷ *Ibid.*, 82. For applications in other areas see L.P. Alford, “Putting Our Merchant Ships on Schedule,” cheek by jowl with Walter N. Polakov, “Mastering Power Production,” *Industrial Management* 56 (1918): 227–230 and 217–226. Adoption of Gantt-type progress charts in construction was widespread. Representative examples are Richard P. Wallis, “A Graphical Method of Determining the Approximate Date of Completion of a Building Operation,” *Engineering and Contracting* (December 27, 1922): 586; H.N. Snow, “Cutting Costs with the ‘Progress Chart,’” *Engineering and Contracting* (July 26, 1922): 86–87. A valuable compendium of graphic methods in use at this time is C.E. Knoeppel, “Graphic Production Control,” *Industrial Management* 56 (1918): 177–180, 284–288, and 383–390. Knoeppel published a

Gantt had himself been using and promoting chart keeping as a part of tracking machine output and human labor since the first years of the century, but these had generally been depictions of accomplished rather than future work.¹¹⁸

FIG. 6.—PROGRESS CHART (top) and FIG. 7.—ORDER CHART (bottom)

At the left of the upper chart is a list of articles to be procured. The amounts for which orders have been placed are shown in the column headed "Amount ordered." The dates between which deliveries are to be made are shown by angles. The amount to be delivered each month is shown by a figure at the left side of the space assigned to that month. The figure at the right of each time space shows the total amount to be delivered up to that date.

If the amount due in any month is all received, a light line is drawn clear across the space representing that month. If only half the amount due is received, this line goes only half way across. In general, the length of the light line or the number of lines indicates the amount delivered during that month.

The heavy line shows cumulatively the amount delivered up to the date of the last entry. It will be noted that, if this line is drawn to the scale of the periods through which it passes, the distance from the end of the line to the current date will represent the amount of time deliveries are behind or ahead of the schedule. It is thus seen that the short cumulative lines are the ones which require attention, as they represent items that are farthest behind schedule. Z represents no deliveries.

The top line on the lower chart is a summary of the individual orders and is represented on the upper chart by line A.

Figure 2.7—A combined progress and order chart. Source: Gantt, *Organizing for Production*, figures 6 and 7, facing 82.

book on the subject in 1920, *Graphic Production Control* (New York: The Engineering Magazine Company, 1920). Knoeppel and Gantt likely knew each other as members of the Taylor Society and as having both testified on behalf of newspaper publishers in connection with hearings before the Federal Trade Commission in 1918. See L.P. Alford, "Evolutionary Business Principles," *Industrial Management* 56 (July, 1918): 8–9. Knoeppel's 1920 book is especially useful to the historian because of its detailed descriptions of how to use various techniques and its extensive illustration. On the use of graphs around the turn of the twentieth century see also JoAnne Yates, "Graphs as a Managerial Tool: A Case Study of Du Pont's Use of Graphs in the Early Twentieth Century," *Journal of Business Communication* 22 (Winter 1985): 5–33. Also of note is Howard Gray Funkhouser, "Historical Development of the Graphical Representation of Statistical Data," *Osiris* 3 (November 1937): 281, 337–342.

¹¹⁸ Note Gantt's paper listed in footnote 9.

Gantt's earlier systems of "man records" had formed the basis for monitoring task-and-bonus compensation systems providing an easy way to see which workers were rising to and surpassing standards set by efficiency engineers.¹¹⁹ In this use and their basic form, these charts were elaborations of graphic records of machine performance kept by some railroads late in the 1800s (figure 2.8). Similarly, Gantt's progress diagrams were abstractions from methods used to plot the progress of municipal engineering contracts, which in turn were based on engineering sections.¹²⁰ Tracking earlier variants is useful not just for setting the Gantt chart in a longer lineage, but for illustrating the role of the graphic schedule in representing and controlling irregular activities.

Figure 2.8—Graphic records used in the maintenance department of the Chicago Great Western Railway in the 1890s. The record for an engine showed time in the shop, with the type of repairs denoted by the height of the bar, cost of repairs by the area of a box, and running mileage by the height of a second box. The system for coaches tracked time in and out of service, with time out of service coded by cause. Source: Tracy Lyon, "Graphic Methods as Applied to Railway Records," *Railway Master Mechanic* 21 (March 1898): 32. This article, based on a paper read to the Northwest Railway Club, also ran in *Railway and Engineering Review* the same month.

Like construction work, machine failure was an irregular occurrence and so recognizing patterns in and tracking costs of maintenance work on a particular locomotive was aided through graphic summary. These maintenance charts and Gantt's diagrams from before World War I were similarly retrospective looks at operating data rather than projective looks at work yet to be done. The melding

¹¹⁹ Several types illustrate H.L. Gantt, *Industrial Leadership* (New Haven: Yale University Press, 1916).

¹²⁰ I do not have evidence of a direct link between these and Gantt's work but hybrid engineering section-progress diagrams were sufficiently common and published to suggest that Gantt's major innovation was in applying an existing type of chart to other activities.

of this type of diagram with the forward prediction came by way of engineering sections. The use of engineering drawings as a projective control was common in the early twentieth century, with particular use of sections, plans, or elevation drawings as a basis for predicting future costs and monitoring accomplished work. In an article on "Uniform Methods of Record and Cost Keeping on Railroad Construction," in 1910 a member of the American Society of Civil Engineers explained the use of forms for cross section and transit records and the use of a planimeter to work up estimates. In tracking progress, each month's work was to be marked in color on a large profile of the work.¹²¹ A similar example from 1913 is shown in figure 2.9.

Fig. 1. Speciman Progress Elevation and Profile of a Bridge.

Figure 2.9—A progress profile for a bridge. Source: E.W. Robinson, "An Office System for Construction Work Covering Records of Plans, Progress and Cost and Bookkeeping Methods," *Engineering and Contracting* 40 (December 17, 1913): 683.

These examples measured progress against literal representations of the work underway, but there were also more abstract, intermediate forms between the engineering section and the Gantt chart in use. The creation of the Los Angeles aqueduct under William Mulholland followed an organizational logic similar to that described for railroads in the preceding chapter, with the work divided into

¹²¹ *Engineering-Contracting* 33 (1910): 176. A later example of the use of such a chart is in John C. Manning, USN, "Construction of Repair and Fitting Out Pier, Navy Yard, Puget Sound, Washington," *Public Works of the Navy*, Bulletin no. 36 (October, 1927): 1-58.

fourteen divisions, of which eleven covered segments of the aqueduct itself and one each covered railroads, cement plants, and power plants and electrical distribution. Demarcations among geographic segments were based on political boundaries and significant features of the canal.¹²² Reports of the canal used “progress profiles” to represent total and incremental progress in the course of the work, coded to denote when the work had been completed and complemented by pie charts that showed the proportion of work done.¹²³ These representations appeared in large foldouts from the annual reports submitted to the City of Los Angeles, and so should be understood as serving a political as well as direct function.

In 1911 and 1912, DeWitt Moore, a member of the American Society of Engineering Contractors, published a series of articles on “Contracting Practice,” in which he laid out estimating and tracking systems with particular reference to roadwork.¹²⁴ Acknowledging the leadership of Gillette and Gilbreth in studying efficiency in the field, he emphasized the difficulty of keeping records where both men and materials were “shifting and difficult to locate.”¹²⁵ He divided the articles into three groups, covering estimating, actual work, and later analysis of data collected such that experience could then be applied to the next job, observing, “one of the most important considerations in the making of any estimate and conducting of construction with the idea of future analysis in prospect is to divide the job into sections...”¹²⁶ In preparing a bid and then tracking the work, Moore advised the preparation of a combined tabulation, plan, and profile of the work, each divided into sections for use in tracking progress and costs. The breaks between sections were to be based on any qualitative change in the work—say, diameter of sewer pipe or depth of cut (figure 2.10).¹²⁷

¹²² City of Los Angeles, “Third Annual Report of the Bureau of the Los Angeles Aqueduct,” November 30, 1908, particularly map inside front cover, discussion of organization and divisions, 9, 61–76, and section following 60.

¹²³ Because of the fragility and size of the originals I do not reproduce these diagrams.

¹²⁴ Moore noted that the forms he supplied could be adapted to other lines of work, including, “in fact, every kind of work coming to any contractor.” The series ran from 1911 into 1912. See *Municipal Engineering* 40 (1911): 393–395 and 475–480; 41 (1912): 1–9, 93–101, 173–179, 253–256, 337–341, and 421–426; and, 42 (1912): 23–33, 104–106, and 149–152. Moore presented some aspects of his system in an earlier article, “Cost Keeping on Municipal Contract Work,” *Municipal Engineering* 36 (1909): 1–5.

¹²⁵ DeWitt Moore, “Contracting Practice,” 393.

¹²⁶ *Ibid.*, 479.

¹²⁷ *Ibid.*, 7–8.

Figure 2.10—Moore's method of outlining work. This illustration appeared in "Contracting Practice," *Municipal Engineering*, in both 40 (1911): 6-7 and 42 (1912): 24-25.

Moore's articles provided a discussion of estimating various aspects of overhead, blanks for keeping time and materials, bookkeeping practice, and so forth, with all documents tied to the illustrated outline of work and to the type of work. Hence the work outline shown in figure 2.10 served as a master from which other controls branched. Individual documents contributed to keeping costs in the course of work such that progress could be kept against both budgets and the work itself, with supplemental use of dated photographs. Moore recommended further keeping a detailed progress diagram for each section within the overall outline of work (figure 2.11). The value of these interrelated records were several,

These detail charts not only serve the purpose indicated of supplying the data for the computing of quantities, but they also serve as a permanent record of the work accomplished during any period; and this information is a great many times of the utmost importance in financial settlement of the contract, especially where the same goes into litigation... Under this system we have a thorough field record of the job; viz: By the time sheet we have a record of the forces employed; by the detail progress chart we have pay-roll dates, and by the indication of the colored pencil a complete record of the work accomplished and the progress of the various kinds of work; and by the photographs we have a pictorial record substantiating the first two records."¹²⁸

Figures 2.11—Moore's detailed progress tracking by section, showing the simultaneous tracking of work in plan and section and by type of work. Source: Moore, "Contracting Practice," 27.

From the records tabulated by section and by work at each payroll period, Moore recommended preparation of bar chart representations of quantities and costs relative to estimates based on percentages.¹²⁹ Once a job was complete, the records were to be assembled and put into a form enabling the comparison of actual costs between jobs.¹³⁰

The Stone & Webster Engineering Corporation was using charts more directly similar to Gantt's 1917 chart at least as early as 1912 (figure 2.12). While it would be hard to overstate the importance of Gantt-type charts to the history of project-based organizing, Gantt's work should be seen in the context of other efforts to graphically account for and project progress in engineering work. These efforts in common sought to represent and plan for the interactions within technical systems and also

¹²⁸ Ibid., 26–27.

¹²⁹ Ibid., 29–32, referencing earlier versions of this type of diagram recommended by Gillette and Dana in *Cost Keeping and Management Engineering*, 165–186. See also Moore, "Cost Keeping on Municipal Contract Work."

¹³⁰ Ibid., 149–152.

to aggregate data in a manner such that irregular work would yield information more readily available in routinized settings.

Figure 2.12—"Construction Progress Chart" in use at Stone & Webster by 1912. The use of this form is explained at the upper left. Source: R.M. Henderson, "Organization and Methods of a Large Engineering Construction Company, with Particular Reference to the Stone and Webster Engineering Corporation," [pamphlet, no publisher indicated, circa 1913] 20.

Cases

The two cases presented here both reflect the efforts of construction engineering organizations to represent their work in response to external pressures. Relative to the illustrations used so far in this chapter, both represent more complex work in more complicated settings. The first tells the story of E.I. du Pont de Nemours's engineering department's adoption of a project-based appropriation system in the context of a diversifying and integrating corporation. The second looks at the efforts of Stone & Webster, a large independent engineering consulting and contracting firm, to cope with time pressure.

William G. Ramsey was the Chief Engineer for E.I. DuPont de Nemours & Company in the late nineteenth and early twentieth century, over which period he witnessed the transformation of the firm from a family business producing one largely commodified good—black powder—into an innovation-driven diversified producer of patented chemicals.¹³¹ In 1902, a trio of relatively young, MIT-educated DuPonts bought control of the firm from an older group. The younger DuPonts—Alfred, Coleman, and Pierre—then set about consolidating and reorganizing the assets of the company. In doing so, they applied Pierre and Coleman's experience at the DuPont-owned Lorain Steel Company and the abilities of J. Amory Haskell and Hamilton M. Barksdale. Haskell and Barksdale had run DuPont's Repauno dynamite operation. The systems these men established were based on division by product group, with centrally administered purchasing, manufacturing, and marketing departments housed in a single building in Wilmington, Delaware. The larger story of E.I. DuPont de Nemours's development in this period has been told, but within it there is a small story of the development of a project-based accounting system used to cope with the demands and scrutiny placed on construction work in an integrated, operation oriented firm.¹³²

The Engineering Department that Ramsey led was treated on organization charts as an operating department alongside the High Explosives, Black Powder, and Smokeless Powder Departments. Its work, though, was more akin to that of the purchasing department—it was a service department that existed to provide the manufacturing departments inputs to their processes. Though this role was repeatedly emphasized in company communications, engineering was initially identified as an operating rather than staff function.¹³³ The exact date of the adoption of project-type controls in DuPont's engineering department is not clear, but by 1911 there was a formal system of project approvals according to predicted cost and monthly reports for tracking the incremental and

¹³¹ General information on DuPont here comes from Chandler, *Strategy and Structure*, 52–113; David Hounshell and John Kenly Smith, Jr. *Science and Corporate Strategy: DuPont R&D, 1902–1980* (New York: Cambridge University Press, 1988); JoAnne Yates, *Control through Communication: The Rise of System in American Management* (Baltimore: Johns Hopkins University Press, 1989), 201–270; and Alfred D. Chandler and Stephen Salsbury, *Pierre S. DuPont and the Making of the Modern Corporation* (New York: Harper and Row, 1971).

¹³² Ibid.

¹³³ Chandler indicates that the engineering department was formally recognized as a staff function about 1919. *Strategy and Structure*, 73.

cumulative percentage of work completed on approved projects. These reports included written descriptions of work accomplished, and accounted for any deviation from the original completion date.¹³⁴ The system used the term "project" to cover the entirety of the administrative and construction work required to make any addition to DuPont's fixed assets, and was distinguished from the term "appropriation" since the latter referred to allotments of funds that could embrace only part of a project or span multiple projects.

In a typical notice informing the treasurer that preparatory work for new and altered buildings at the Experimental Station was under way, Ramsey wrote,

"OPENING CONSTRUCTION PROJECT -

Work order card has been approved and we have opened account as below, to which all charges for the study and preparation of plans and estimates for the following project should be made. This account, however, is to be used only until such a time as construction appropriation, with account numbers, has been authorized to cover work and in no case shall material be charged to this project."¹³⁵

The close tracking of materials reflected accounting requirements that were designed to allow allocation of expenses against the operating plant being created for purposes of depreciation. Further details of the system appear in a paper Ramsay wrote titled, "Construction Appropriations," that detailed how DuPont had budgeted for capital expenditures using a system he indicated had been under development since 1903.¹³⁶ This paper set out a system of formal requests and justifications intended to ensure there were "no expenditures to the earning equipment if the same amount of money could be applied to some better purpose in another branch of the Company's business."¹³⁷ According to Ramsay, institution of this system had been needed because of the growth of the company and the increasing remove of the Executive Committee from the operating needs of its divisions. From 1903 the Accounting Department had tracked all permanent investment as

¹³⁴ See records of work at the Experimental Station, Accession 1784, Box 19, E.I. DuPont de Nemours & Company, Central Research and Development Department Files, The Hagley Center for the History of Business, Technology, and Society, Wilmington, Delaware. Hereafter Hagley 1784.

¹³⁵ March 21, 1911. Hagley 1784.

¹³⁶ Accession 500-II-2, Records of E.I. DuPont de Nemours & Company, The Hagley Center. Hereafter Hagley 500-II-2. This paper is also reproduced in H. Thomas Johnson, ed., *System and Profits: Early Management Accounting at DuPont and General Motors* (New York: Arno Press, 1980). In this period the High Explosive Operating Department (HEOD) held regular meetings of its superintendents at which members of the staff circulated memoranda on technical and administrative matters for discussion. Ramsey's paper was for a HEOD meeting held in New York in April 1910.

¹³⁷ Ibid., 2.

construction and strict rules were in force for delineating operations from construction because the former could not be capitalized and depreciated against revenues.

The system also served a crucial planning function. Where the Company's treasurer could reasonably anticipate operating expenditures from experience, construction appropriations were unpredictable. In order to smooth these out, an annual forecast was made, with projects classified according to their value to the Company in terms of both increased profits and reduced risks. On these bases projects could then be ranked and then approved according to the number that could be afforded within a planned budget. Once approved, and from the initial receipt of a work order card until the requested work was turned over to the requesting operating department, the Engineering Department tracked the task under its project number. At closing, the work was reassigned from Construction to Permanent Investment by the Accounting Department. Monitoring the work in progress was assigned to a resident engineer or superintendent who was to check costs and compliance with specifications on an at least weekly basis. In the printed remarks to the paper, Hamilton Barksdale underscored the relation between accurate capital accounting and the determination of both sales prices and profitability.

"Organization for Dispatch": Russell Robb and Stone & Webster

The role of time pressure in confounding the operation of scientific management was widely noted in discussions of construction organization, long anticipating the mid-twentieth century notion of "concurrency." In the 1912 attack on scientific management by Admiral Edwards, cited above, he observed the value of time, as "in construction work we frequently adopt methods which might be considered extravagant if we overlooked the advantages which come from the completion of the work by a certain date"¹³⁸ During World War I, Federal practice shifted to use of cost-plus-bonus contracts, a shift necessitated because during war "military works must be well under way before the plans can be complete."¹³⁹ The pressure of time arising from competitive and cost considerations, and the influence of these pressures on organizational form, appear with striking currency in the writing of Russell Robb, an engineer-administrator with Stone & Webster.

¹³⁸ John R. Edwards, "The Fetishism of Scientific Management," 363-364.

¹³⁹ Francis Donaldson, "Contract Organization Vitrally Important for War Work," *Engineering News-Record* 81, (September 19, 1918): 535.

After graduating from MIT in electrical engineering in 1888, Charles A. Stone and Henry S. Webster formed a partnership that they initially called the Massachusetts Electrical Engineering Company. Starting in the business of testing and instrument manufacture, Stone and Webster expanded into electrical machinery installation and then into consulting engineering. Benefiting from Webster's family ties to Kidder, Peabody and Company, during the recession of 1893 Stone & Webster was asked to evaluate bankrupt power and electrical companies on behalf of creditors.¹⁴⁰ By then renamed Stone & Webster and aided by Kidder, Peabody financing, the firm took over ailing power concerns, re-organized both their plants and their operations, and assumed their management. The firm itself did not own utilities, but instead served as a "centralized management association" that arranged financing, carried out improvements, and operated separately owned companies. On behalf of the interlocking boards of directors of these companies and a management made up substantially of MIT and Harvard graduates who had "hosts of friends," "...Stone and Webster [endeavored] to expand, thru investigation by their expert department of the merits of different public utility plants which it is thought may be purchased upon advantageous terms."¹⁴¹ Once such a purchase was identified, Stone & Webster's Securities Department marketed shares. By 1916 the Stone & Webster Management Association operated companies with an aggregate capitalization near \$100 million and \$27 million in gross earnings. Arthur D. Little noted jealously in 1911 that Stone and Webster was one of several firms that had "by an orderly but inexorable evolution, passed from the status of engineers to that of engineers and bankers."¹⁴²

Though engineering consulting and design had been part of Stone & Webster from its inception, until 1903 the execution of construction work was subcontracted to other companies. In 1903, the

¹⁴⁰ General data on Stone & Webster comes from several sources. A company-sponsored history is David Neal Keller, *Stone & Webster, 1889-1989: A Century of Integrity and Service* (New York: Stone & Webster Incorporated, 1989). The company is treated briefly in Thomas P. Hughes, *Networks of Power* (Baltimore: Johns Hopkins University Press, 1983), 386-395. See in addition to these sources and several cited immediately below, W.H. Blood, "The Organization of the Stone-Webster Corporation," MIT Archives, AC114-1-12; Judd Tumbidge, "The Financial Policy of Stone and Webster," unpublished thesis, Graduate School of Business Administration, Harvard University, 1920, copy in Stone & Webster, Inc., Records 1892-1956, Baker Library, T-7-27; R.M. Henderson, "Organization and Methods of a Large Engineering Construction Company, with Particular Reference to the Stone and Webster Engineering Corporation." [pamphlet, no publisher indicated, 1913?]; and "Methods of Large Engineering and Construction Company," *Electrical World* 62 (July 12, 1913): 68-69. There is no scholarly history of the firm.

¹⁴¹ W.H. Blood, W.H. "The Organization of the Stone-Webster Corporation," 3

¹⁴² "Industrial Research in America, Presidential Address," *The Journal of Industrial and Engineering Chemistry* 5 (1913): 797.

company capitalized the Columbia Improvement Company "to systematize this work" and enable the firm to bid on the execution of the work it designed.¹⁴³ In 1906 Columbia was folded into Stone & Webster, becoming the engineering division of the firm.

Russell Robb, an 1888 MIT graduate, was a vice president with Stone & Webster in its engineering division. In the spring of 1909, he delivered three lectures at Harvard Business School, later collected in *Lectures on Organization*.¹⁴⁴ In the first of these, "Organization as Affected by Purpose and Conditions," Robb described the pressures arising from the cost of capital and the fact that today's construction was tomorrow's production capacity. Every day cut from a construction schedule was a day that could be added to productive use, and where time pressures were great, "organization for such an undertaking will not be the same as for deliberate construction systematized in all details for lowest construction-cost."¹⁴⁵ He referred specifically to Stone & Webster's experience building additions to power stations for the Boston Elevated Railway, capacity which had been needed to meet anticipated Christmas-season loads:

"The organization of a street railway could not economically provide for emergency construction of such magnitude, and even the engineering company that did the work found it necessary to make important modifications in its organization in order to secure dispatch, even at the risk of losing the greatest economy in details. It was necessary to place as much responsibility down along the line as possible, so that time would not be lost in referring questions for confirmation. It was necessary that the work be segregated, so that in functional departments there would be no question of 'right of way.' The specialization was in the direction of 'Boston Elevated work,' not in the direction of 'electrical engineering,' or 'purchasing,' or 'drafting.' A special smaller organization was set off for this particular piece of work."¹⁴⁶

Robb went on to describe an organization in which the construction manager had complete authority over "an organization for dispatch" that cut the time to put the stations into service in half relative to work done in the regular functional divisions of the firm. System and order were admirable goals and necessary in an era in which competition, time pressures, and shrinking margins allowed little room for trial-and-error or rule-of-thumb approaches to business, but there were conditions under which this logic did not make sense. Robb emphasized the importance of not becoming

¹⁴³ Tumbridge, "The Financial Policy of Stone and Webster," 4.

¹⁴⁴ Boston (?): privately printed, 1910. These lectures and Robb are discussed in Edmund R. Gray and Hyler I. Bracey.

"Russell Robb: Management Pioneer," *SAM Advanced Management Journal* 35 (April 1970): 71-76.

¹⁴⁵ *Ibid.*, 7. This lecture was given February 24, 1909.

¹⁴⁶ *Ibid.*, 8.

enamored with any one approach or becoming “twisted with specialization” and over-application of functional divisions.¹⁴⁷ Concluding, he also noted the importance of informal organizational factors and normative controls (though not in those terms):

“Organizations are not difficult to sketch out on paper. They always have there a definite and workable look, as if nothing could escape a far-reaching arm that would pull all into the hopper somewhere; but in the working organization, unless it be the most simple, there is a constant call for the unscheduled cooperation, for the action that can be secured only through a genuine, lively, and loyal interest in the success of the whole undertaking. And it is interesting here to note that this sort of thing is often expressed by a simile that is the outcome of the activities of intercollegiate life, for we urge this spirit by urging ‘team play.’”¹⁴⁸

He concluded, “We begin to realize that there is an art of organizing that requires knowledge of aims, processes, men, and conditions, as well as the principles of organization.”

Robb’s second lecture, “The Limits of Organization,” noted “the returns from increasing organization do not continue proportional to the effort, and limits are reached, beyond which one may well proceed with care.”¹⁴⁹ Citing particularly the bicycle industry, in which the development of the best and most efficient organization had proved needless relative to having on staff “a good student in human nature, an expert on the stability of fads and fancies.” The industry had collapsed after a few boom years in the 1890s, leaving owners of “substantial and elaborate plants” built with “the investigations of specialists and the calculations of engineers” out of pocket. “One of the most important factors in the business was the time it was to last, and some apparently gave it little thought.”¹⁵⁰ In Robb’s assessment,

“The problem of organization bears a close resemblance to engineering problems. It requires analysis, it involves balancing and setting values, it is a constant estimation of the relation of the parts to the whole, the function of these parts in the purpose of the whole, and we gain in setting about the problem with these ideas of proportion and relative value in our minds.”

Robb held particular disdain for functional divisions that resulted in functionaries only too pleased to perfect their own operations without regard to the profit of the whole and noted the especial tendency toward functional organization in government. Referring to the increasing use of

¹⁴⁷ Ibid., 15.

¹⁴⁸ Ibid., 22.

¹⁴⁹ Ibid., 24. This second lecture was given February 26, 1909.

¹⁵⁰ Ibid., 29.

functional organization by telephone companies, he related this to the standardization of technologies and techniques and organization. "If the business were nearer the time of its formation, when franchises in different places had to be secured, when the securing of subscribers, the nature of the service, and the extension of the plant into new sections, all became parts of larger questions and were intimately interwoven, it is quite likely that grasp of the institution as a whole would seem, as it apparently did seem, of first importance, and would dictate a type of organization that provided for at least one in authority in each section."¹⁵¹ Once the system had stabilized, internal communications and central hierarchies could prevail. Referring to Stone & Webster's own organization, Robb argued, "as in the administrative system of our own bodies, he, the mind of the organization [the executive], must leave to the lower ganglia, to lower nerve centers, the minor coordinations."¹⁵²

Other material describing Stone & Webster's engineering department reinforces that issues associated with the post-World War II spread of project management were acknowledged much earlier. J.H. Hood, a member of the firm, lectured to Erwin Schell's courses on business management at MIT, suggesting that the sort of special project organization Robb described was less unusual than Robb implied and that "its flexibility is such... that modifications in any or all departments can readily be made to meet the requirements of any special cases which may arise."¹⁵³ He also indicated that Stone & Webster practiced concurrent engineering long before the term was in use. "By means of our centralized organization our construction department is enabled to start work before the engineering details are all worked out, and making it unnecessary for complete specifications to be furnished right at the start."¹⁵⁴ Such procedures also allowed engineering staff to be closely informed of field conditions through the "benefit of the opinions of the construction men" as engineering and construction proceeded iteratively.¹⁵⁵

In an internally published record of the construction of an electric power station, Stone & Webster saw fit to reproduce a photograph of a chalkboard used to track work in progress and to

¹⁵¹ Ibid., 58. This quote comes from the third of Robb's lectures, "The Organization of Administration," given March 3, 1909.

¹⁵² Ibid., 68.

¹⁵³ J.H. Hood, "The Construction Department of Stone & Webster," MIT Archives, AC114-2-2.

¹⁵⁴ W.H. Blood, "The Organization of the Stone-Webster Corporation," 7.

¹⁵⁵ "Methods of Large Engineering and Construction Company," 69.

record the average unit cost of work accomplished (figure 2.13).¹⁵⁶ Despite its seeming crudeness, this could be proudly shown as evidence of cutting-edge construction management at the lower ganglia of an organization in the late 1910s.

CONCRETE SCHEDULE OCT.				UNIT COSTS			
DATE	WORK	YDS.	TOTAL	DESCRIPTION	UNIT COST LAST WEEK	WEEK ENDING 10-13-20 QUANTITY UNIT COST	TO DATE QUANTITY UNIT COST
16	1" Wall, a to d, to Gr. 37			SUB. EXC.	8.43		22031 CY 1.81
17	Sunday			TUNNEL EXC.	2.74	798 CY 2.08	12256 CY 2.09
18	Slab Gr. 31, 1 to 11.		255	SHEET PILING	1.34	5302 CY 1.09	47351 CY 1.57
19	F 7 Pedestal	37		REIN. CONCRET	4.27	15265 CY 2.04	60923 CY 3.27
	F 14	37		R. CONC. (TUNNEL)			2196 CY 2.94
	F 14a	37					
	F 20a	10					
	F 24	56					
	F 24a	36					
	F 38	38					
	F 20a	10	241				
20							
21	Tunnel Mat. coff + 5		65				

CONCRETE SCHEDULE OCT. (CONT)			
DATE	WORK	YDS.	TOTAL
22	23" Wall, a to d, to Gr. 30.		60
23	Slab Gr. 31, 11 to 15		170
24	Sunday		
25	1" Wall, a to d, to Gr. 37		
26	Condenser fl. Gr. 1 to 8		

Figure 2.13—"Blackboard used at Foremen's Meetings, Illustration of Construction Methods." Source: Plate Va of *Steam Power Stations: Work Done and Personnel Available* (Boston: Stone and Webster, 1920), Baker Library, Harvard University.

Conclusion

In engineering-contracting in industrial and municipal settings in the decades around the turn of the century, the mediating role served by accounts and graphic representations in project-based organizations operated both within projects and between the irregular output of project workers and external pressures. These go-between objects helped explain what was happening in project-oriented departments, providing loose couplings between incongruent labor processes and making clunky one-time costs into smooth machine rates and building depreciation schedules. Basic differences in the possibilities of efficiency and communication and reliance on different bases of accountability thus

¹⁵⁶ As did other engineering firms, including Gilbreth's as noted above, Stone & Webster used pictorial accounts of completed works in a variety of promotional literature. Having studied over a hundred such books, this is the only instance I have found of an image such as this chalk board.

shaped firms. Divisional organizations and functional separations within firms followed fault lines among labor processes as much as they did products and geographies. Whether a firm chose to make or buy engineering services, arrangements between this function and other parts of the organization often resembled arms-length contracts because that was how builders and operators could find common terms.

In addition to these formal expressions of the incompatibilities between building and operating, engineer-contractors of the turn of the century theorized the differences between their work and that of factory operatives. At the heart of these theories were discussions of the speed, complexity, and uncertainty of building. The need to manage engineering work grew as projects required the integration of specialized knowledge and know-how that had not existed just years earlier. Not only were the points of contact and connection among different aspects of the work more involved, but also they were less likely to coincide with standing practice in terms of who would do what work. Accounting arrangements mediated between the worlds of projects and production. Within projects, engineering drawings marked demarcations between sections of the work. Between projects, timelines and accounts helped make this work knowable. And while the underlying problems of construction management stayed constant, coordinating and integrating grew more involved and mediation of working relationships through documents increased. Engineers' efforts to identify and control flows, pressures, and feed-rates in the operation of engines had been the seeds of a revolution in operating management. With efforts to extend these methods to the management of the work of engineers themselves, they drove a search for justificatory and deflecting explanations.

Chapter 3

From Subjects to Projects:

Laboratory Administration and Its Discontents, 1900–1930

“The project as a means of formulating and defining a scientific inquiry has rapidly gained ground and has come into quite general use. It is an evidence of clearer and more deliberate planning, and of more systematic, ordered effort. As such it is a distinct sign of advance.”¹

The growing importance of science-based change to corporate strategies in the early 1900s drove efforts to coordinate laboratory work with on-going business operations. Institutional arrangements in response to this problem varied—ranging from creation of internal research departments to hiring contract research firms to setting up cooperative programs with universities.² In common across these solutions, project-based accounting and organizing systems provided means by which the messy, disruptive, and uncertain work of scientists and engineers could be presented to executives, shareholders, and the public as controlled and incremental. John Kenly Smith comments that “the popular image of industrial research at mid-century was that of

¹ Editorial in U.S. Department of Agriculture, *Experiment Station Record* 43 (1920): 301.

² Overviews of the emergence of industrial research include John Kenly Smith, Jr. “The Scientific Tradition in American Industrial Research,” *Technology and Culture* 31 (1990): 121–131; David Hounshell, “The Evolution of Industrial Research in the United States,” in Richard Rosenbloom and William Spencer, eds., *Engines of Innovation: U.S. Industrial Research at the End of an Era* (Boston: Harvard Business School Press, 1996), 13–85; and David C. Mowery, “The Emergence and Growth of Industrial Research in American Manufacturing.” (Ph.D. Dissertation, Stanford University, 1981). Other valuable general accounts of the history of industrial research include Kendall Birr, “Industrial Laboratories,” in Nathan Reingold, ed., *The Sciences in American Context: New Perspectives* (Washington, D.C., 1976); Howard R. Bartlett, “The Development of Industrial Research in the United States,” in National Research Council, *Research: A National Resource* (Washington D.C.: U.S. Government Printing Office, 1941), 19–77. David Noble’s *America by Design* casts an ideological light on this same ground. Company- or industry-specific studies generally set out broader contexts. See, notably, Leonard Reich, *The Making of American Industrial Research: Science and Business at GE and Bell, 1876–1926* (Cambridge: Cambridge University Press, 1985), W. Bernard Carlson, *Innovation as a Social Process: Elihu Thomson and the Rise of General Electric, 1870–1900* (Cambridge: Cambridge University Press, 1991) and David Hounshell and John Kenly Smith, Jr. *Science and Corporate Strategy*.

scientists inventing new technologies in a systematic and predictable fashion.”³ This image was manufactured early in the twentieth century not just for external consumption but also to coordinate communications within organizations. The classic stage-based description of the research and innovation process as a passage from laboratory to development and then production marked efforts to coordinate irregular movements of information across functionally and hierarchically segmented organizations. The production-focused design of the classic American corporation drove frictions between the organizational logics of building and operating work. In other words, the need for stage-based representations of research and development existed only by virtue of larger organizational contexts.

Before 1900 most laboratory work within industrial organizations served a control function that could be attached to operating plants physically, in cost accounts, and in organization charts. Early industrial and consulting laboratories were in the assaying business, checking that inputs and outputs were what they were supposed to be. The early 1900s saw the relocation of the laboratory function from control to exploration, a movement marked by the creation of distinct research departments and growth in contract research. With the increasing size and complexity of the laboratory function came problems of communication and coordination within departments and projects. Discussions that emerged in response to these problems revolved around several core issues: the need to appropriately value and budget for investments in experimental work, the relationship of research to the firm, and the day-to-day management of creative work by individuals and groups. Project-based organizing systems provided means of demarcation that served across these issues. The shift in scientific work from serving a control function to being part of projective corporate strategies was marked by a change in language: as the role of the laboratory changed, the objects of its work shifted from ‘subjects’ to ‘projects.’⁴ This was not a simple, smooth progress, though, as economic ups and downs led to cyclical fluctuations in attitudes toward and spending on research.

³ John Kenly Smith, “The Scientific Tradition in American Industrial Research,” 122.

⁴ This was a broad, general, long-term, and incomplete shift in language. I observed the tendency first in reading through laboratory notebooks from DuPont, where it was partly the product of the adoption of formal project-based accounting systems in research work, a topic treated in one of the cases at the end of this chapter.

This and the next chapter overlap. This chapter focuses on conversations that emerged in relation to laboratory or research work while the next chapter concentrates on product development, reflecting the historical fact of the division of labor between these functions and distinct conversations around *scientific* laboratories as opposed to *engineering* departments. In the early twentieth century, the terms 'research' and 'laboratory' were associated most strongly with chemical work while other kinds of bench investigation might or might not be construed as research. Only later in the century did engineering settings start to be called laboratories. In other words, the boundaries of these two chapters are based on the approximate demarcations I have seen in my evidence.

The present chapter has several aims. First, it shows how frictions between the uncertain work of industrial laboratories and the routine operations of production departments drove adoption of project-based accounting system in the former. Second, in considering how these methods were adapted to laboratory administration, it shows that research administrators theorized explicitly 'relational' forms to capture the need for their workers to stay abreast of external developments. And third, it extends the theme of connection and insulation that carries across this study, marking an increasing need for this Janus-faced management as disparate labor processes were increasingly part of the same organization and overall production process. Following the pattern of preceding chapters, this chapter first briefly reviews the general history of the research in U.S. industry and its simultaneously developing social contexts. It then turns to focus on efforts to administer projects in industrial laboratories. In closing, two cases enrich the overview provided in the body of the chapter.

The Emerging Economics of Research and Development

The history of industrial research in the United States is generally dated to around the turn of the twentieth century. As this story has most often been retold, in the two or three decades before World War I inventive work passed from the era of the inventor-genius conjuring new marvels in isolation to that of the coordinated pursuit of knowledge within (or with the funding of) large

corporations.⁵ Writing from the vantage of the early 1930s, Laurence Hawkins, Executive Engineer with General Electric, explained:

“Corporations have organized research. They have made it self-perpetuating, continuous, orderly and systematic. Instead of waiting for the casual genius to appear and startle them with a new engine or a new explosive, they rely on research to proceed step by step from something that is good to something that is better.”⁶

Similarly, surveying the development of the field in a report issued by the National Research Council in late 1940, Howard Bartlett could state:

“Although the ‘practical men’ and the ‘curious amateurs’ continue to make their contributions to the technical progress of the country’s industries, the importance of their work, compared with that done by trained scientists and engineers cooperating in organized laboratories, has, for the last 50 years, been steadily diminishing.”⁷

The early institutional progress of industrial research can be marked in many ways. The number, size, and budgets of formal research programs in corporate settings all took off in the first years of the twentieth century. Many well-known companies—General Electric, E.I. DuPont de Nemours, Eastman Kodak, and American Telephone and Telegraph among them—created their first central laboratories in the first years of the century.⁸ Firms also increased their external purchases of research through cooperative and contract research by independent laboratories, academic institutions, and industry associations. Arthur D. Little incorporated his eponymous firm in 1909, mapping the projective work of the consulting engineer from civil and electrical to

⁵ This common characterization is correct but incomplete. Research in industrial settings gained prominence in this period but lone inventors and small shops continued to generate important developments. See Mowery, “The Emergence and Growth of Industrial Research in American Manufacturing,” 193–211. Further, inventive activity was not limited to settings sanctioned by the term ‘laboratory.’ A number of studies have addressed the longer history and persistence of shop-floor innovation. See Brooke Hindle, *Emulation and Invention* (New York: New York University Press, 1981) and Paul Israel, *From Machine Shop to Industrial Laboratory: Telegraphy and the Changing Context of American Invention, 1830–1920* (Baltimore: Johns Hopkins University Press, 1992). For my purposes, the important aspect of the rise of industrial research (and development in the next chapter) is that it marked an effort to formally integrate and manage creativity within operating organizations and thus more required insulative representation than did less-formal settings.

⁶ L.A. Hawkins, “Organization and Operating Principles,” in Malcolm Ross, ed., *Profitable Practice in Industrial Research: Tested Principles of Research, Laboratory Organization, Administration, and Operation* (New York: Harper & Borthers, 1932), 63–76, quote, 64.

⁷ Howard R. Bartlett, “The Development of Industrial Research in the United States,” 40.

⁸ All of these firms had laboratories of one sort or another from their inceptions, but the centralization and accompanying segregation of laboratory work from operating departments dated to this period.

chemical engineering.⁹ Employment of newly graduated scientists reflected the shifting setting of laboratory work. New Ph.D.s were increasingly likely to find jobs with industrial laboratories rather than in academic settings, and the demand for graduates fueled growth in the size and variety of scientific departments in universities.

A general sense of when and where research administration became a problem can be conveyed through reviewing historical data on laboratory formation. The National Research Council (NRC) sponsored surveys of industrial research every two to four years beginning in 1920 and David Mowery has used this data to identify sectoral patterns in laboratory formation and employment over the first half of the twentieth century.¹⁰ Summarized, these data show accelerating rates of laboratory formation in the decades up to and including the 1920s, followed by leveling or modest decline in the 1930s and 1940s.¹¹ Though fewer new laboratories were being created after 1930, total numbers and the number of personnel employed in them continued to grow. Under the classification scheme used by the NRC, the chemical industry stands out as the most prolific creator of laboratories and also as the most significant employer of scientific personnel. The importance of chemical research in this period is further emphasized if figures for related industries are added to the tallies for the chemical industry, since these industries employed substantial numbers of chemists (figure 3.1)

⁹ Little had been in business in various forms since 1886. 1909 is an approximate marker for the growth of his firm and its shift from serving primarily as a contract testing laboratory to carrying out more general investigative consulting work. Though A.D. Little is sometimes called the oldest management consulting firm by virtue of its 1886 founding, engineering contracting firms (Stone & Webster among them) were doing work that closely approximates present-day business consulting before Little took up this business in earnest. A company-sanctioned history of A.D. Little is E.J. Kahn Jr., *The Problem Solvers: A History of Arthur D. Little, Inc.* (Boston: Little, Brown and Company, 1986).

¹⁰ Mowery, "The Emergence and Growth of Industrial Research in American Manufacturing." The NRC data Mowery uses is also collected in George Perazich and Philip M. Field, *Industrial Research and Changing Technology* (Philadelphia: Works Project Administration, 1940). This data and the early growth of industrial research are also presented in C.E.K. Mees and John A. Leermakers, *The Organization of Industrial Scientific Research* (2nd ed., New York: McGraw-Hill Book Company, Inc., 1950), 10–12.

¹¹ Mowery notes that the number of laboratories reported in this data is limited to those still extant in 1940 or 1946, hence accurate figures would be higher.

U.S. Employment of Selected Technical Professions, 1900 - 1940

Figure 3.1—Technical employment in chemistry and chemistry-related industries. Note that the definition of "laboratory" introduces a bias to these figures, in that research in engineering took place in engineering departments, not engineering laboratories, hence the original data collection inscribed a definition of science from engineering. Source: derived from data reproduced in Mowery, "The Emergence and Growth of Industrial Research in American Manufacturing," tables 2.4–2.8 and 2.21. See footnote 10.

Year-to-year estimates of laboratory formation provide a further sense of when and why swarms of activity around the management of research and development work occurred (figure 3.2). Research spending ebbed and flowed with sector-specific booms, wartime contracts, and general economic conditions. In particular, several crises drove firms and managers to look for means by which to account for and order this work. Before World War I, competitive pressures and antitrust legislation were the major motivations for expanding scientific work beyond a control function. The war provided major impetus to the development of research programs, particularly in chemistry. Cut off from German sources of chemical compounds, the United States sought alternate sources and turned to the domestic chemical industry. The war itself was also a demonstration of the national importance of chemical and mechanical innovations, as these shaped the course of the conflict. Post-war research spending was checked by a short but sharp depression following the armistice, but then boomed with the expansion of the 1920s. These bursts of activity are reflected in rates of laboratory formation.

THE "BIRTH RATE" OF INDUSTRIAL RESEARCH

FIGURE 46.—The "Birth Rate" of Industrial Research

Figure 3.2—Annual laboratory foundations 1890–1940. Source: Franklin Cooper, "Location and Extent of Industrial Research Activity in the United States," in National Research Council, *Research—A National Resource*, volume II, "Industrial Research" (Washington D.C.: U.S. General Printing Office, 1941), 176.

Attention to the problem of organizing industrial research closely tracked these cycles, but sometimes with a significant lag. Each expansion was followed by a retrenchment that does not appear in statistics for laboratory formation. During downturns, few laboratories were entirely discontinued, but budgets in existing laboratories gyrated as companies shifted attention from seizing opportunities to controlling costs. Describing the whip-saw effect of the depression of 1921 on development work, one author noted that after a long boom and the "rush and excitement" of the war,

"Management facing bankruptcy did the thing that is usually does in all depression periods. Overhead departments were slashed right and left. Engineering departments which had reached the scope of 50 or 60 men were cut down to one or two. Cost departments were entirely eliminated. A great many companies threw over their entire development program and proceeded to go directly into their shells."¹²

During downswings, one response from research directors (who suddenly had more time on their hands) was to increase their output of articles promoting the value of their departments and

¹² N.M. Perris, "Burden Trends in Modern Management," *American Management Association Production Series* no. 85 (1930): 3.

the rationality and far-sightedness of their work, and the onset of the depression of the 1930s somewhat counter-intuitively led to increased research expenditures in some firms. Faced with a crisis in demand for existing products, companies turned to research as a means to developing new markets. In an article titled "Research in Hard Times," the director of the NRC's Division of Engineering and Industrial Research and a coauthor noted that "there has been a change in the object of research during the past four years. In 1928, the major emphasis was on the lowering of production costs. In 1931 it was on the development of new products and increasing the quality of existing products."¹³ But this was not a uniform response. A vice-president of a manufacturing organization noted in that same year that "in times of stress, overhead reduction becomes the keynote of successful business administration."¹⁴ In general, the appetite for speculative, potentially disruptive research expenses was cyclical. Writing in 1931, one author noted "in times such as exist during the present business depression, research projects are generally approved only when the object is likely to produce tangible results which can be commercialized so as to given the greatest dollar return for each research laboratory dollar spent."¹⁵

As for the construction and engineering enterprises discussed in the preceding chapter, pressures to explain and justify research spending came both from within companies and with the general embrace of efficiency. Like contract engineering, laboratory management was seen through the lens of systematic management. In a 1931 book titled *Science in Action*, two consultants argued that,

"Until about fifteen years ago research-laboratory management was commonly regarded as an empirical matter, mastery of which could be attained only in actual practice. Gradually, however, the organon of scientific management, with its division of work, systematic planning, and use of recorded experience, has been examined in the laboratories of science, and its methods are now permanent features of every research laboratory of importance."¹⁶

¹³ Quoted in Mowery, "The Emergence and Growth of Industrial Research in American Manufacturing," 117.

¹⁴ O.D. Reich, "Effect of Design on Overhead." *American Management Association Production Series* no. 93 (1931), 3.

¹⁵ Walter E. Lee, comments to Richard F. Wilder, "Coordination of Research, Sales, and Production," *Transactions of the American Society of Mechanical Engineers* 54 (1932): 35.

¹⁶ Edward R. Weidlin and William A. Hamor. *Science in Action: A Sketch of the Value of Scientific Research in American Industries* (New York: McGraw-Hill Book Company, Inc., 1931), 269–270.

Pressures for efficiency extended to the social position that science was expected to occupy. In the same sense that nineteenth century civil engineers were to facilitate flows of natural wealth, physical scientists in the early twentieth century were to release stored potentials. Chemistry, in particular, was expected to break the nation's mineral potential free of the rocks that concealed it. Discussing the need for research in the chemical and metal industries, an article in August 1914, noted "we may also imagine a time, not far distant, when the people as a whole may caution owners of mines and mills not to waste by crude manufacturing methods substances which are at the same time useful and rare."¹⁷

Logics and Logistics

Strategic, organizational, and technical logics motivated the creation of formal research and development programs. Though many of the companies that established central laboratories had origins in the entrepreneurial exploitation of technological innovations, by 1900 companies such as General Electric and E.I. DuPont de Nemours had grown into large operating organizations focused on volume production. In the late nineteenth century, such businesses began to look for means by which to consolidate competitive positions as markets matured. Enforcement of the 1890 Sherman Antitrust Act after 1900 limited trust-based market coordination and blocked firm expansion within any single market.¹⁸ Checking expansion within existing product lines and markets—the basic form of corporate capability embodied in plant construction—forced a search for alternative forms of growth, shifting the nature of capability building. Innovation-based diversification and cost reduction provided means by which companies could expand into new markets and maintain positions in existing markets, with patent protection against the strictures that operated in commodified markets.¹⁹ Once these goals had been identified, and as with the role of the Chandlerian visible hand in general, bringing research within the firm provided a means of coordinating and capturing the value of innovation to both cost reduction and growth—

¹⁷ Warren F. Bleeker, "Research Work in the Laboratory and Mill," *Metallurgical and Chemical Engineering* 12 (1914): 515.

¹⁸ While Chandler credits the rise of the large corporations in the last decades of the nineteenth century to the technology-enabled creation of mass markets, Neil Fligstein gives more weight to legal contexts. See *The Transformation of Corporate Control* (Cambridge: Harvard University Press, 1990).

¹⁹ John Kenly-Smith particularly emphasizes this point, "The Scientific Tradition in American Industrial Research."

ideally through coordination of information in as flow-like a manner as possible. Mowery notes that in early industrial laboratories managerial coordination of the research function served because of the "imperfections of the market mechanism as a device for the provision of research and development expertise."²⁰ Arthur Little, in the article in which he praised Stone & Webster for bringing banking and engineering together, expressed his hopes for an influx of capital into chemical work:

"Our own profession has not yet evolved the chemist and banker, but such an evolution, or at least the close alliance of chemistry and banking is a fundamental prerequisite if the results of industrial research are to find their full fruition in America. Let me add that no field within the purview of the banker is more ripe for tillage or capable of yielding a richer harvest."²¹

Portrayed broadly, both these problems and their solution appear tidy: continuously innovate to stay ahead of commodifying businesses. Seen from a great distance and over a long period of time, this is what successful firms did. While the objectives of research work as part of the long-term strategy of the diversifying firm could be stated in a paragraph or two in the minutes of a directors' meeting or the pages of an annual report, effecting such a strategy was more involved.

Organizational solutions to the management of research and development and particularly to the interfaces between invention, innovation, and production that were required because these happened in different departments evolved slowly, through trial and error, and in response to crises. Integration of these functions carried temporal and spatial aspects—executives had to figure out where to locate research work physically and organizationally and also how to manage output that disrupted on-going operations. But this strategy was rarely articulated clearly and the means of organizing to effect it were muddier still. Firms lurched, haltingly, toward innovation-based strategies and even more awkwardly (and never completely) toward coherent organizational solutions.

There was a push as well as a pull in this regard. In the systematically managed business, strict functional organization and task definition in production had driven innovation off of the shop floor. Firms needed to house innovation in new ways partly because they had eradicated it

²⁰ Mowery, "The Emergence and Growth of Industrial Research in American Manufacturing," 4.

²¹ "Industrial Research in America, Presidential Address," *Journal of Industrial and Engineering Chemistry* 5 (1913): 800.

from its older shelters. Change and adaptation that could once happen in the context of the everyday needed to be formalized and isolated because they no longer fit operating logics dictated by management principles. This was not original with scientific management, but was common to line-and-staff conceptions of organization. The director of Eastman Kodak's laboratories, C.E.K. Mees, stated tersely, "staff functions are concerned with planning, line functions with operation."²² In a small, craft-organized shop, what we now call customer requirements and market intelligence were not filtered through marketing branches and administrative hierarchies. But in the integrated, systematically managed firm, science and engineering were adjunct activities to planning departments rather than part of day-to-day work. This position did not stop efforts to systematically manage scientific work, and as in contract engineering, there followed a long working out of limits.

The large systems being engineered by the contractor-engineers who figured in the previous chapters were tightly integrated, but the connections between their building and their operation were relatively loose. By contrast, research in the chemical and electrical industries had intimate and uncertain effects on the operating sides of businesses. To L.A. Hawkins, cited earlier, "self-perpetuating, continuous, orderly and systematic" were qualities he contrasted favorably to a preceding era he referred to as that of the "picturesque, temperamental, romantic, heroic inventor."²³ But Hawkins's words should be recognized as deliberate representations, spoken during a deepening depression. Leonard Reich has asserted, "because rapid change could be disruptive, corporations supporting industrial research laboratories made certain that innovation proceeded at a measured, controlled pace."²⁴ Steven Usselman has found a pattern of restraint of innovation in the behavior of railroads in the latter half of the nineteenth century and Reich finds

²² C.E.K. Mees, *Organization of Industrial Scientific Research*. (New York: McGraw-Hill Book Company, 1920), 58.

²³ L.A. Hawkins, "Organization and Operating Principles," 64.

²⁴ Leonard Reich, "Radio Electronics and the Development of Industrial Research in the Bell System," (Ph.D. Dissertation, Johns Hopkins University, 1977), 179. See also Reich, *The Making of American Industrial Research*, 218-238.

a similar pattern of managerial regulation of laboratory products aimed at protecting the profitability of existing lines of business.²⁵

Hawkins's comments had a third quality that reflected the timing for their appearance. In describing the new world of research as orderly and systematic, he also represented research work in a favorable light within the corporation. With deepening recession in the early 1930s, corporations were curtailing capital outlays of all sorts. The imprecise value of current research made it vulnerable even in more modest periods of belt-tightening and Hawkins's words echoed a larger outpouring of writings that at once tried to make research appear as regular as an assembly line and to hold out the promise of a science-led economic recovery. The authors of a book that appeared not long after the recession of the early 1920s saw fit to emphasize, "development is an investment of the long-pull type and must be prosecuted irrespective of the condition of the current business cycle."²⁶

Social Settings and the Emergence of a Conversation

Academic societies in the physical sciences predated the turn of the century and, more importantly, academic conversations in the sciences predated those focused on practical application. In this regard, scientists and engineers followed distinct trajectories but arrived at a common quandary. In the aggregate, engineering professionalized (became more academic in its outlook) while science industrialized (becoming less academic in its outlook), but seen up close professional, academic, and business cultures mixed uneasily in both. Early reluctance to hire scientists by industry reflected a perception that academics would be incapable of adjusting to the time discipline of a business setting. Reflecting splits in the ranks of scientists, new divisions of societies and new journals provided forums for the practically inclined as distinct from the solely scholarly. The American Chemical Society's *Journal of Industrial and Engineering Chemistry*, started in 1909, provided such a forum. The NRC, created in 1916 to mobilize U.S. industry for war, also served as an anchor for discussions of the administration of scientific work. The

²⁵ Steven Usselman, "Running the Machine: The Management of Technological Innovation on American Railroads, 1860-1910," unpublished Ph.D. dissertation, University of Delaware, 1985. Usselman emphasizes managers' interest in near-term profits and protecting the value of existing assets.

²⁶ John M. Weiss and Charles R. Downs, *The Technical Organization: Its Development and Administration* (New York: McGraw-Hill, 1924), 1.

Directors of Industrial Research (DIR), a loose club of the most prominent scientist-administrators in the United States, originated in the early 1920s as a partial outgrowth of the NRC's wartime activities. These nascent social and professional networks helped convey accounting and management techniques among laboratories.

Chemical and electrical research were the objects for the most significant early efforts at organizing research work (figure 3.3). Research work in these fields grew rapidly in the late nineteenth century with innovations in power generation, lighting, motors, and chemical process control.²⁷

Figure 3.3—Relative employment of chemists and engineers in laboratory settings in 1921 and 1946, by industry. The size of the individual circles reflects the relative numbers of laboratory personnel employed in a given industry in that year, but these weights are not comparable between years. For example, the chemical industry employed the most laboratory workers of any industry in 1921, and of these about 63 percent were chemists and 24 percent were engineers. The general trend marked by the differences between the two years is the relative increase in engineering disciplines in laboratories, a trend that I suspect marked as much the reclassification of engineering work as research as any underlying shift in the work itself. This helps clarify the distinctions between the conversations emphasized in this chapter and those that figure in the next. Source: derived from data in Mowery, "The Emergence and Growth of Industrial Research in American Manufacturing," table 2.21.

Of the two dozen or so articles on research organization that appeared in commercial or society publications (as opposed to government serials) in the United States between 1910 and 1920, most were written by chemists or appeared in chemical industry journals.²⁸ The most

²⁷ Sanford Jacoby links the rapid growth and bureaucratization of these firms to the relatively short time in which they went from small batch production to volume output. See *Employing Bureaucracy: Managers, Workers, and the Transformation of Work in American Industry, 1900–1945* (New York: Columbia University Press, 1985).

²⁸ The bibliography to C.E. Kenneth Mees's *The Organization of Industrial Scientific Research* (New York: McGraw-Hill, 1920) provides a separate listing for articles on research organization. It should be noted that as a

prolific early authors on this topic were C.E. Kenneth Mees, Director of Eastman Kodak's laboratory, and Willis R. Whitney, head of General Electric's research organization.²⁹ Both were chemists and published management articles largely in chemical industry journals, though Whitney also wrote for his company's organ, the *General Electric Review*. In 1920, Mees collected his articles of the teens in *The Organization of Industrial Scientific Research*,³⁰ the first book-length treatment of research management published in the United States. Other notable authors of papers on research organization in this period included Arthur D. Little, Frank B. Jewett, and R. F. Bacon, of A.D. Little & Co., American Telephone and Telegraph, and the Mellon Institute, respectively. The second book on research management to appear in the United States was 1924's *The Technical Organization: Its Development and Administration*, by John M. Weiss and Charles R. Downs, consulting chemists with a New York office.³¹

The appearance of these publications reflected increases in both the supply of and demand for administrative guidance by research managers. On one hand, an increasing number of scientists found themselves acting as managers; on the other, articles and books on the topic were increasingly likely to find an interested readership. The individuals noted in the preceding paragraph provide a useful kernel from which to map significant contributions to the research management literature. Mees, Whitney, Bacon, and Little were all chemists by training while Jewett had taken his Ph.D. in physics. Whitney, Little, and Jewett had all studied at MIT, and, as managers, hired substantial portions of their staffs from MIT. All were members of a coterie of research administrators that developed informally at first, but which was brought together in committees of the NRC and later formed around the DIR. When they wrote about research management, they cited each other's articles as well as direct correspondence.

chemist, Mees was more likely to know the literature in that field and so to list articles from chemistry-related journals. Nonetheless, despite considerable effort, I have found very few articles on research organization in this period beyond those noted by Mees.

²⁹ There is no biography of Mees, though he figures in histories of his employer. See Reese V. Jenkins, *Images and Enterprise: Technology and the American Photographic Industry, 1839-1925* (Baltimore: Johns Hopkins University Press, 1975) and Douglas Collins, *The Story of Kodak* (New York: Abrams, 1990). Whitney's life and career are treated in George Wise, *Willis R. Whitney, General Electric, and the Origins of US Industrial Research* (New York: Columbia University Press, 1985).

³⁰ (New York: McGraw Hill, 1920).

³¹ Excerpts from this book were published in *Chemical and Metallurgical Engineering* under the title "What Machinery is Necessary for the Management of Industrial Research?" 30 (1924): 475-478, 513-516, and 549-554.

In early 1923, Robert Yerkes, then of the Research Information Service of the NRC, invited a dozen directors of research programs to dinner at the Engineers' Club in New York. The invitees were a who's-who of research administrators in private industry—including Jewett of Western Electric, Charles Reese of DuPont, Mees, and Charles Kettering of General Motors. The meeting had been sparked by the desire to continue exchanges of ideas that had been facilitated by the NRC during the war, and had its immediate seed in a conversation between Reese of DuPont, and E.P. Hyde, Director of the Nela Park Laboratory of the National Lamp Works.³² Yerkes's invitation indicated that the group was to provide a "research by-products exchange service" that would eliminate the waste of ideas that were "incidental to [the originating laboratory's] main interest and quest."³³ From its establishment, it was the practice of the DIR to maintain the informality and openness of its meetings by not soliciting formal presentations or recording minutes beyond administrative details. Consequently, little can be known about the particulars of the DIR's discussions. However, the group's records do mark the regular meeting of a fraternity of scientists and engineers in positions of administrative responsibility and, further, the administrative details that were recorded make clear that management practices were among the "by-products" that they exchanged.

The minutes of the April 25, 1925 meeting note that H.B. Batchelor, of Union Carbide and Carbon, "gave an unusually interesting talk on 'The Human Side of Research,'" and that "the discussion which followed was very spirited."³⁴ The program for the October 16, 1931 meeting included a roundtable discussion of "Organization and Direction of Research Laboratories," led by C.E.K. Mees and held at Eastman Kodak's Rochester laboratories.³⁵ The minutes for that meeting indicate that finance and budgeting systems were discussed at length. Minutes for other meetings include notes of topics including methods of selection of research projects, financing, and similar management concerns. In a 1934 résumé of the group's activities, the secretary noted,

³² Alfred D. Flinn, "Directors of Industrial Research History," June 1934, 1. Accession 1851, Box 1, Records of the Directors of Industrial Research, Secretary's Files 1923-1934, The Hagley Center. Hereafter Hagley 1851.

³³ Robert M. Yerkes to F.B. Jewett, et al., January 22, 1923, transcribed in Alfred D. Flinn, Secretary, "Directors of Industrial Research History," June 1934, Hagley 1851.

³⁴ W.M. Corse, Secretary, "Minutes of the Meeting of the Directors of Industrial Research, held in New York City, April 21, 1925." Hagley 1851.

³⁵ "Rochester Meeting-Final Notice," September 24, 1931, Hagley 1851.

"organization and personnel in the laboratories of the group and problems related thereto, received attention in the early meetings and at various times."³⁶

While the DIR's records lack detail, the members of this club published articles on research administration in technical and professional journals that likely echoed off-the-record conversations. Further, as members of a larger fraternity that included academic and government administrators of research work (who, by nature of their employment, were not eligible to join the strictly industrial DIR), they interacted with educators and managers in a variety of settings. The NRC's Division of Engineering and Industrial Research sponsored a collection of essays by notable research administrators, *Profitable Practice in Industrial Research*, in 1932. Collecting essays by Stine, Mees, Jewett, and others, the book aimed to distill past experience as a guide to fighting "the industrial battles of the future."³⁷ Its articles included Charles Kettering on strict appropriation-based controls in use at General Motors³⁸ and C.E. Skinner on the need to "pitch" research work to operating divisions.³⁹ *Profitable Practice* was in some sense a last hurrah in the face of the worsening depression. The DIR continued to meet, but managing large and rapidly growing research programs was less of a problem during the 1930s than it had been. Marking the apogee of interest in research administration in the pre-World War II period, a magazine called *Research Laboratory Record* appeared in 1931 and was gone in 1933, having in its brief life featured articles by Vannevar Bush and other prominent research administrators.

Laboratory administration did not generate a distinct periodical literature during its formative years in the teens and twenties. Early conversations around organizing research appeared on the margins of other discussions. That the Directors of Industrial Research and books such as *Profitable Practice* existed reflected the ostracization of management issues from academic conversations in chemistry and electrical engineering as well as the formation of a small community of research administrators. Academic haughtiness in relation to business matters is discussed further below, but even those taking a more sanguine view of commercial activities felt that management was to be field-learned. This attitude can be observed in a 1931 exchange of

³⁶ Alfred D. Flinn, Secretary, "Directors of Industrial Research History," 5.

³⁷ Holland, Maurice. Introduction to *Profitable Practice in Industrial Research*, x.

³⁸ "Trouble as an Approach to Research," 40-62, see especially 50.

³⁹ "Getting Laboratory Results into Factory Production," 87-103.

letters between Karl Compton, MIT's President, and Maurice Holland. In this exchange Compton rejected Holland's suggested creation of a graduate school course in laboratory operation and management on the grounds that the best men for such work would show themselves in the laboratory and that it was in any case a small field.⁴⁰ Frank Jewett, in his contribution to *Profitable Practice*, "The Philosophy and Practical Application of Industrial Research," noted that the term 'industry,' "is more usually applied to something vaguely conceived of as an aggregate of human strife only slightly inferior to that of war, of sordid greed and routine commonplace."⁴¹ He hoped to rescue the term by revealing the "romance" of research and by carefully discounting of the role of research as a driver of "so-called" technological unemployment and forced obsolescence.⁴² Describing General Motor's research organization in the same volume, C.F. Kettering noted that the firm had a strict system of control of project expenditures, but when it came to the research work itself, Kettering explained somewhat nonchalantly, the "plan of procedure is perfectly simple—merely a man or a group of men in a definite place with a problem worthy of solution."⁴³ A technical director would check in periodically to ensure that the work made "economic horse sense" rather than drifting off into "science for science's sake."⁴⁴ Since assignments and work often defied organization charts, these were of limited use. Clearly, by the early 1930s project-based controls were sufficiently widespread in research organizations to be commonplace but were used to bracket or delimit projects as much as to direct them. Considering the particular tools and ideas used can further draw out these dynamics.

⁴⁰ Maurice Holland to Karl Compton, October 27, 1931 and Karl Compton to Maurice Holland, October 30, 1931. MIT Archives, AC-4-155-9.

⁴¹ "The Philosophy and Practical Application of Industrial Research," in *Profitable Practice in Industrial Research*, 1-39, quote, 3.

⁴² Ibid., 15.

⁴³ C.F. Kettering, "Trouble as an Approach to Research," in *Profitable Practice in Industrial Research*, 40-62, quote, 52. On Kettering, see Stuart Leslie, *Boss Kettering* (New York: Columbia University Press, 1983). I discuss Kettering's involvement in the aircraft industry in the next chapter.

⁴⁴ Ibid., 52-53.

Direction and Representation in the Administration of Research Projects

Controlling and pacing laboratory output involved designing both the operations of laboratories and their relations with firms, industries, and professional fields. "Managing the flow of technology" was as much about making research look like a flow as actually managing it as one.⁴⁵ For the author of "A Plan for Organized Research and Analytical Chemistry in Successful Chemical Manufacturing," in the *Journal of Industrial and Engineering Chemistry* in 1912, regularity was the chief objective of research administration.⁴⁶ Formal and informal management methods in laboratory work thus operated at multiple levels. As companies adopted and adapted tools to control research, managers applied these to both the work under their direction and the environment in which this work took place. Budgets and timelines quantified accomplished and projected work. Regular conferences and meetings encouraged communication among staff members. Libraries and house journals provided for the control and dissemination of information. Project-based organization and representation of laboratory work facilitated, directed, and insulated the irregularities of research work against the pressures of operating organizations. Citing the need for flexibility and external stimulus, managers invoked *esprit de corps* and unfurled timelines to control and protect their departments.

Locating the Laboratory

The development of industrial laboratories created problems in locating, organizing and accounting for this work. There were relationships between research and operation to be configured, internal relationships to be understood, and external connections to academic and professional discourses to be maintained. In such laboratories as existed in industrial contexts in the United States before 1900, none of this had mattered. A small laboratory, on or adjacent to the factory floor, sampled and assayed the flows of goods in and out of the factory. The personnel in the typical testing laboratory were more technicians than scientists. Where an investigation went

⁴⁵ The phrase is from Thomas Allen's much later *Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information within the R&D Organization* (Cambridge: MIT Press, 1977). Allen's information processing approach to understanding research and development activities fits within the electronics engineering paradigm of the 1950s and after, discussed in chapter 5. Here the point is simply that the representation of technology as a flow is an arbitrary act.

⁴⁶ *The Journal of Industrial and Engineering Chemistry* (December, 1912): 905-908.

beyond routine monitoring, it was typically at the request of an operating department that needed help with a problem of some sort and the solution resulted in an incremental improvement to an existing process rather than any radical, exogenously inspired transformation.

With the creation of central laboratories, the place of scientific work was remapped alongside staff functions such as accounting departments. The role of scientists and engineers became more speculative and accounting definitions less clear. The increasingly ambiguous relation of scientific work to existing departments and on-going work made charting and tracking flows of money and communication a more difficult enterprise. As operating departments resisted carrying the cost of uncertain work that might not even pertain to their business, these changes made locating research and development work relative to a firm more difficult. The placement of this work—both in terms of where, physically, laboratories should be built and how research should be located on organization charts—involved decisions about how and with what other parts of a firm scientists and engineers would communicate. There were three aspects to be considered: the location of laboratory research within the corporation; the organization of labor within the laboratory; and, the relations of the laboratory with the outside world. Research and development were pushed around organization charts, devolved to operating divisions, recentralized, divided, and reassembled. One author noted “the efficiency of a laboratory seems to be influenced in no small degree by its position in the general plan of organization of the company” but offered no uniform solution.⁴⁷

Further consideration of C.E.K. Mees’s *The Organization of Industrial Scientific Research* provides a step toward understanding these dynamics. Published in 1920 by McGraw-Hill, then emerging as the leading house for technical and management journals and books, Mees’s volume knit together essays he had published over the course of the teens and, as noted above, is the first text on the management of innovation published in the United States.⁴⁸ Using an oft-quoted line

⁴⁷ Charles W. Hill, “Efficiency in Industrial Research,” *Metallurgical and Chemical Engineering* 18 (1918): 182.

⁴⁸ Mees had earlier presented much of the material in this book at conferences and in journal articles. See C.E.K. Mees, “The Future of Scientific Research,” *The Journal of Industrial and Engineering Chemistry* 6 (1914): 618–619; “The Organization of Industrial Scientific Research,” *Science* 43 (1916): 763–773; “The Production of Scientific Knowledge,” *The Journal of Industrial and Engineering Chemistry* 9 (1917): 1137–1141; “Planning a Research Laboratory for an Industry,” *The Journal of Industrial and Engineering Chemistry* 10 (1918): 476–480; “Industrial Research Laboratory Organization,” *Mechanical Engineering* (1919): 667–668, and discussion, 669–671, 718. Because the content is substantially the same and the book-length version is easier to obtain, I cite the book in references below.

ascribed to Arthur Little as his epigraph—"there is danger in an organization chart—danger that it might be mistaken for an organization"—Mees prefaced his study noting, "at the present time it seems to be clear that the future of any industry depends on its being able to command a sufficient supply of knowledge directed toward the improvement of the product and the development of the industry, and that any shortcoming in this respect may involve eventual failure."⁴⁹ He classified laboratories into several types:

- "1. Works laboratories exerting analytical control over materials, processes and product.
2. Industrial laboratories working on improvements in product and in processes, tending to lessen the cost of production and to introduce new products on the market.
3. Laboratories working on pure theory and on the fundamental sciences associated with the industry."⁵⁰

Applying a line-and-staff model, Mees located research alongside accounting, engineering, and efficiency departments and charted its relations with these departments and with the operating branches of a business, noting that as a staff function a laboratory could be attached to the line at any point, according to where its work was needed. Mees broke the work of a firm's scientific division into routine process control, development of new processes for existing lines, and more general research. According to a firm's size and its manufacturing organization, these functions might be hard to clearly isolate from one another, but Mees argued that the distinct qualities of the work and the "mental equipment for the proper discharge of their respective functions" called for as much division as possible.⁵¹ Routine control could be left within plants, development work could occur centrally or in relation to the plant or division it related to, and general research should be centralized. Mees argued that in any case "the position of the research laboratory in an industrial organization is perhaps best determined by the criterion that the research department should be responsible to the officer of the company who is in charge of the development of new products."⁵²

Hence, at a firm scale Mees could work within conventions for hierarchical organization charts, though he noted the potential need for multiple points of attachment. Turning to the

⁴⁹ Mees, *The Organization of Industrial Scientific Research*, 8.

⁵⁰ Ibid.

⁵¹ Ibid., 62 ff, quote 65.

⁵² Ibid., 62.

internal organization of these departments, he abandoned simple vertical diagrams. Emphasizing the need to avoid over-organization, Mees represented the department's workings in terms of nested circles of influence, flows of information, and fields of knowledge (figures 3.4 and 3.5).⁵³ Where in a production department internal organization could be represented by further branches down a tree, in research and development the organizational logic differed.

FIG. 1.

FIG. 2.

Figures 3.4 and 3.5—C.E.K. Mees's representations of information flows from (left) and to (right) scientific departments. Source: C.E.K. Mees, *The Organization of Scientific Industrial Research* (New York: McGraw-Hill, 1920), 76.

Citing the organization of his own laboratories at Eastman Kodak, Mees described the use of a conference system, with weekly conferences organized topically and attended by those workers involved in the particular area.⁵⁴ In essence this system acknowledged that both accomplishments and their value were uncertain from week to week. Mees explained that “the conferences really direct the work of the laboratory” by allowing work to be “thrashed out” in a group. By charting the position of various conferences in relation to the departments within Kodak's laboratory, Mees could represent studies as existing in networks of relationships (figure 3.6).

⁵³ Ibid., 89.

⁵⁴ Ibid., 122 ff.

FIG. 7.

Figure 3.6—Mees's graphic representation of the conference system of laboratory coordination. Circles top and bottom represent laboratory departments, rectangles are weekly conferences, and lines are problems. The bullets on lines were used to code the status of the work; their placements along the lines reflect graphic convenience rather than convey further information. Source: C.E.K. Mees, *The Organization of Scientific Industrial Research* (New York: McGraw-Hill, 1920), 126.

Mees's exposition usefully introduces the internal and external problems to which project-based organizing was applied. These problems can be shown to have been widely recognized and discussed in the circles then forming around laboratory administration. In a 1909 address, Willis Whitney argued that "the organization of industrial research involves arranging a body of involute parts as an operating whole of highest efficiency,"⁵⁵ but privately he stated that "I dread organization and system so much that I want to warn others from expending much time and effort upon it."⁵⁶ His solution was to employ a system of regular group meetings, liaison with other departments, and "suggestive" direction of research men. He later adopted an informal system of project directors, relying on senior staff to track work going on in ostensible independence.⁵⁷ Whitney placed himself at a bottleneck between the laboratory and the rest of the company, requiring that other departments at GE's Schenectady Works communicate to research staff

⁵⁵ In "Organization of Industrial Research," *Journal of the American Chemical Society* (1910): 71.

⁵⁶ Whitney to F.W. Lovejoy, 24 October 1912, cited in Reich, *The Making of American Industrial Research*, 100.

⁵⁷ Reich, *The Making of American Industrial Research*, 101

through him.⁵⁸ Accounts were kept by project, and had to be supported either by the requesting department or carried by the laboratory itself. Self-financed efforts were speculative: the laboratory recouped costs for such work only when it could sell results within the company.⁵⁹ After 1910, Whitney developed appraisals of the profitability of laboratory products in order to justify costs to outsiders. Whitney spoke of the internal organization of the laboratory in terms of a division of mental and physical labor:

“This [organization] permits, in our case, of the combined use, to maximum efficiency, of the delicate hands of young women, the strength and skill of trained mechanics, the mind of the useful dreamer, the precision and knowledge of the skilful chemist, and the data of the accurate electrical engineer.”⁶⁰

As in organizing an engineering corps almost a century earlier, *esprit de corps* was the term most often used to capture the more nebulous aspects of internal management. Both Whitney and Mees used this term regularly.⁶¹ Others suggested fostering *esprit de corps* through trust and openness.⁶² Mees stressed the development of “a corporate spirit and a corporate object” and that “men who are only average when dealt with singly may become extremely able by the mental contact which follows association with other men working on similar problems.”⁶³ For Mees, the potential value of men of different inclinations meant that it would be “impossible to consider any rigid system of organization.”⁶⁴ In a 1916 report to a Senate Subcommittee on Research in Industrial Laboratories, Mees and several other research administrators emphasized the importance of an effective division of labor within laboratories knit together by *esprit de corps* and “that a fraternal spirit will play an important rôle in the productiveness of any research department.”⁶⁵ Like the need to keep military organizations together as they moved against the

⁵⁸ Ibid., 102.

⁵⁹ Ibid., 108.

⁶⁰ Whitney, Willis R. “Organization of Industrial Research,” 73.

⁶¹ Reich, *The Making of American Industrial Research*, 109.

⁶² Weiss and Downs, “What Machinery is Necessary for the Management of Industrial Research” and *The Technical Organization*.

⁶³ Mees, *The Organization of Industrial Scientific Research*, 92, 91, respectively.

⁶⁴ Ibid., 98.

⁶⁵ R.F. Bacon, C.E.K. Mees, M.C. Whitaker, W.R. Whitney, and W.H. Walker, “Research in Industrial Laboratories,” *Science* 45 (1917): 34–39, quotes, 34, 35.

uncertain conditions along a line of battle, teams of scientists needed to have reason to trust and rely on each other as they moved against the outline of a research problem.

The more formal expression of this form of coordination came in representations such as Mees's and in arguments for horizontal organizations and the use of conferences. Regarding the organization of his company's technical activities, a vice president overseeing engineering and development departments explained, "We are trying to get as far away as possible from that type of organization in which the information required by one minor employee of one department, from a minor employee in another, must go up through his own department organization and then down through the other organization, and then up again and down again to the originator of the inquiry."⁶⁶

Coordination of the research function with other parts of businesses generally relied on committees made up of both general and research executives, with further conferences organized by function and project as well as routine meetings of an oversight committee within the research department. After World War I, the General Electric Company's laboratory adopted a system of committees that allowed its personnel to keep abreast of company needs, displacing the earlier intermediate control function served by the Research Laboratory Advisory Council.⁶⁷ Westinghouse used a coordinating committee drawn from the lines of its other divisions to govern research. In a 1929 discussion of Westinghouse's system printed under the title "Co-ordination of Research and Development Departments with Other Specialized Departments in Manufacturing," J.M. Hipple explained that a group drawn from development, plant layout, cost analysis, and tool departments evaluated development initiatives.⁶⁸ "This group," Hipple explained, "although directed from a single point, is physically decentralized, each major manufacturing department having suitable representation from each branch of this staff group."⁶⁹ Of this system, one discussant noted that "even committees, which have frequently been discredited as 'debating

⁶⁶ C.S. Redding. "Research and Development Departments: Their Functions, Activities, and Relation to Other Departments." *American Management Association Production Executives' Series* 78 (1929): 3-10, with discussion following, quote, 7.

⁶⁷ Reich, *The Making of American Industrial Research*, 92.

⁶⁸ J.M. Hipple. "Co-ordination of Research and Development Departments with Other Specialized Departments in Manufacturing." *American Management Association Production Executives' Series* 78 (1929): 17-31.

⁶⁹ *Ibid.*, 24.

societies' and which are not always the best means of bringing about action, may prove to be usefully bringing about a better understanding and cooperation among the departments."⁷⁰ Hipple observed that despite elaborateness of his firm's group system, its success depended on "the character of the personnel and the spirit and enthusiasm they bring to their work."⁷¹ While the use of conferences or groups to manage this sort of activity seems unsurprising to a present-day reader, the existence of such things was anomalous below the level of the board of directors, since below that level communication and labors were supposed to be routine. Another discussant responded to Hipple's comments:

"The idea of management by group is rather new to me. If this thing has been made a success (and it must have been a success) then there are two things in that organization:

"1. They have a master mind that originates the force that percolates through the whole organization and makes it work;

"2. They have a wonderful bunch of cooperators."⁷²

In response, R.E. Hellmund, also of Westinghouse, further elaborated the need for group work and addressed the logic for horizontal integration based on learning. In a very simple organization with purely independent divisions, "there would of course be no reason why any of these independent units would have any advantage over a small company handling the product of one of the units," nothing having been "gained by the mere fact that the profits of the various independent units go to the same stockholders."⁷³ Hellmund continued to set out the advantages that did obtain where "the various units can learn and benefit from one another," especially in creative work. He noted the organizational obstacles to this action:

"The question then arises as to whether the possibility of the various units learning from one another can be left to chance or to voluntary action on their part, or whether any additional set-ups are necessary for bringing about desirable contact among the various units. The answer to such a question depends largely on the products under

⁷⁰ R.E. Hellmund commenting on J.M. Hipple, "Co-ordination of Research and Development Departments with Other Specialized Departments in Manufacturing," 28.

⁷¹ Hipple. "Co-ordination of Research and Development Departments with Other Specialized Departments in Manufacturing," 25.

⁷² Mr. Rhodes commenting on J.M. Hipple, "Co-ordination of Research and Development Departments with Other Specialized Departments in Manufacturing," 25.

⁷³ R.E. Hellmund commenting on J.M. Hipple, "Co-ordination of Research and Development Departments with Other Specialized Departments in Manufacturing," 25.

similar considerations.”⁷⁴

basic product line organization (figure 3.7).

FIG. 2. RELATIONSHIPS BETWEEN LINE AND STAFF EXECUTIVES IN THE WESTINGHOUSE ELECTRIC & MANUFACTURING COMPANY.

Figure 3.7—Staff function represented as intersecting with Westinghouse's product line organization. Source: R.E. Hellmund commenting on J.M. Hippie. "Co-ordination of Research and Development Departments with Other Specialized Departments in Manufacturing." *American Management Association Production Executives' Series* 78 (1929), 27.

The need for such intersections was driven by both the commonalities and the complexities of various lines of products as used by customers. Hellmund observed that, “The central station customer, for instance, utilizes a great many of the various products combined in such a way as to operate his system efficiently; similar conditions apply in the larger industries as well as in electric railway and marine work.”⁷⁵ The multiple allegiances created by using such a system meant that “the staff members will naturally have a somewhat difficult position” and that “a good many other refinements have been found necessary, and most of them have proved useful in establishing bridges and tie-ins between the various activities.”⁷⁶ Consequently, Hellmund

⁷⁴ Ibid., 26.

⁷⁵ Ibid., 27.

⁷⁶ Ibid., 26, 28.

emphasized the ultimate authority must rest with either horizontal or vertical lines and that the lesser weave should rely on “co-operative tie-in.”

The need to continuously adapt and innovate through flexible connections was routinely emphasized by research managers. Referring to their own experience, consulting chemists Weiss and Downs noted that in the dynamic organization of an chemical research operation “...it was not possible to operate for any time with a rigid, inflexible arrangement, but that it was necessary continually to shift the line-up in order to take care of changing conditions of work.”⁷⁷ Weiss and Downs reproduced an organization chart which substituted small brass frames for drawn boxes such that it could be updated as personnel and projects changed, “as flexibility was... the all important essential.”⁷⁸ Even this device (figure 3.8) did not fully accommodate change. Periodically the entire chart had to be replaced to accommodate new groups or divisions.

Figure 3.8—Organization chart used to keep track of a chemistry department, with open brass frames used to accommodate frequent personnel and project changes. Source: Weiss and Downs, *The Technical Organization: Its Development and Administration*, 47.

These authors also emphasized the need for external connections and professional association outside the firm, not simply in order to keep up with developments but also to heighten the spirit or individuals. Whitney, at GE, encouraged publication and activity in professional societies, partly as a strategy for attracting and keeping scientists with academic interests, and partly as a

⁷⁷ Weiss and Downs, “What Machinery is Necessary for the Management of Industrial Research,” 513.

⁷⁸ Weiss and Downs, *The Technical Organization: Its Development and Administration*, 46.

means of keeping the laboratory and its staff connected to larger discourses.⁷⁹ Bell Laboratories arrived at similar openness, but more slowly. Structured initially around the needs of the Bell System and with an enforced culture of secrecy, the Research Branch was relatively isolated. The Branch was large enough, though, to support a working community. In Reich's words, "the Research Branch gave its professional staff a scientific environment in which to function—a community of substance that could effectively extend or withhold its approval."⁸⁰ Over the course of the teens and the twenties, the firm gradually relaxed its control over research.⁸¹ DuPont similarly sought to enable research staff to stay involved in professional activities.

Such external links had instrumental value to research directors as well. In organizing research and development, managers relied on information and sanction from external networks to aid in the identification of prospective employees. Laboratory administrators used faculty contacts to solicit information about promising students who might be interested in non-academic careers. In research work within industrial concerns, employment patterns were more stable than in contracting organizations, but they were nonetheless more exposed to the market than other departments. In the early establishment of research and development organizations, academic affiliations played a vital role. In lists of laboratory staff, academic backgrounds were prominently noted.

With this general overview, and particularly having introduced Mees's writing of the 1910s, several aspects of the controls used and advocated in the research organizations can be set out.

Projects and Control

In 1920, E.I. DuPont de Nemours's Experimental Station adopted a "project system" of accounting for research work.⁸² Describing the organization of the Bell Laboratories, jointly operated by American Telephone and Telegraph and Western Electric, a later history noted that "the basis of the Laboratories' accounting arrangement is the 'case,' similar to that originally

⁷⁹ Reich, *The Making of American Industrial Research*, 110–111.

⁸⁰ *Ibid.*, 189.

⁸¹ *Ibid.*, 195.

⁸² DuPont's early research organization is discussed further in one of the cases at the end of this chapter.

employed for development work, prior to the organization of the Laboratories" in 1925.⁸³ Project accounts had earlier been the organizing principle in Western Electric's engineering department and in its research and development work a system of projects and programs was in place in 1923, before when this work had been "a rather hit or miss affair."⁸⁴ Under the 1923 system, research program appropriations were allocated to various lines of apparatus, and these appropriations were built up from projects, each of which involved a "development report signed by the sales and engineering representative, this constituting an agreement as to the work to be undertaken, the cost of that work, and ... the specifications on which the resulting apparatus is to be accepted or rejected."⁸⁵ In a 1921 article in *Industrial Management*, a manager with the U.S. Forest Products Laboratory (a branch of the U.S. Forest Service) described a project-based control system his organization had adopted based on study of "several of the coordination plans used in commercial plants."⁸⁶ Approved projects received cost-charging numbers and standardized forms documenting the nature of the work were filled out. These included plots of progress curves, tabulations of costs as they were incurred, and summary reports, all of which were filed by project in a "revolving visible panel" (figure 3.9).

Though the cases just mentioned would seem to imply that the project or case method diffused through research departments in the 1920s, such orderings can be found significantly earlier—earlier even than Mees's articles. In 1903, when Willis Whitney, the MIT-educated chemist who had charge of General Electric's laboratory, undertook too many extraneous and open-ended studies, the laboratory's directors, Charles Steinmetz and E.W. Rice, created a "Research Laboratory Advisory Council" and required that Whitney keep financial records and make estimates of the value of research on a case-by-case basis.⁸⁷ In his 1913 Presidential Address to the American Society of Chemical Engineers, Arthur D. Little praised the efficiency of U.S. Department of Agriculture-funded experiment stations, noting, "the efficiency of their

⁸³ Memorandum, January 16, 1953, Location 176 02 03 03, AT&T Corporate Development and Research History, Compilation of Materials on Bell Laboratories, 1919–1952, AT&T Corporate Reports, AT&T Archives, Warren, New Jersey. Hereafter AT&T Archives.

⁸⁴ C.D. Dugan, discussion of Roscoe Seybold, "Controlling the Cost of Research, Design and Development," *American Management Association Production Series* no. 86 (1930): 3–11, quote, 9.

⁸⁵ Roscoe Seybold, "Controlling the Cost of Research, Design and Development," 7.

⁸⁶ "Research Laboratory Adopts Modern Management," *Industrial Management* 61 (1921): 98.

⁸⁷ Reich, *The Making of American Industrial Research*, 72.

work is stimulated by the requirement... that appropriation shall be confined to definite projects.”⁸⁸

Fig. 4. Revolving Visible Panel for Records

Figure 3.9—Revolving panel for displaying project records. Though difficult to make out, the flap is raised to show the plotting of a progress curve for a particular project. Source: “Research Laboratory Adopts Modern Management,” *Industrial Management* 61 (1921): 100.

Go-Betweens

From the earliest establishment of formal research programs, management in such departments depended on go-between managers who could at once direct projects within the laboratory and explain this work to directors. This was a subtle balancing act. Motivating laboratory personnel who cared about science as much as (if not more than) personal income and

⁸⁸ “Industrial Research in America,” (Oct., 1913): 797. This requirement was imposed by the terms of the Adams Fund, created by a 1906 Act that expanded support to agricultural experiment stations originally funded by the Hatch Act of 1887. Accounting in these stations is discussed further in one of the case studies at the end of this chapter.

firm success to turn out work that served a firm's objectives meant careful coaching. Motivating patrons to continue funding work in which progress not always measurable or knowable required skilled boosterism. Leonard Reich notes that Thomas Edison was a shrewd manipulator of the press, which served both to excite interest in his inventions and to keep his investors salivating.⁸⁹ As research moved within the corporation, these functions continued, though under different institutional circumstances.

William Morton Wheeler, an academic, wrote an article in 1920 marked by significant hostility to the formal administration of research. In this piece he invoked a simple typology of organizations as organic, mechanical, and hybrid. Respectively, these terms corresponded to organizations that had evolved through natural divisions of labor, those that had been willfully created for some purpose, and those that had been in the whole willfully organized but which contained subelements that had been allowed to self-organize.⁹⁰ Wheeler opined that prior to the industrial era, research had organized organically, "through a natural division of labor and inclination of investigators and by means of such cooperative *liaison* agencies as learned societies and publications."⁹¹ Where Wheeler could yearn for the halcyon days of "a natural division of labor" and "cooperative *liaison*," in settings where financial accountability held sway *liaison* continued but in a more formal guise.

Willis Whitney created the position "Executive Engineer" (that occupied by L.A. Hawkins, quoted above) in 1908 to provide coordination between General Electric's research laboratory, its engineering laboratories, and its production operations and to relieve himself of administrative duties.⁹² The position was effectively that of a general contractor. In a 1926 description of the Bakelite Corporation's research organization, two members of that firm similarly identified the go-between nature of the chemist-manager:

"Formerly the researcher and the 'business man' were different—so much so, that they did not cooperate well. The chief chemist spoke a different language, a language of symbols and technicalities which made non-researchers disinterested and bored. Recently there have appeared interpreters, who happened to be both chemists and

⁸⁹ *The Making of American Industrial Research*, 44.

⁹⁰ William Morton Wheeler, "The Organization of Research," *Science* 53 (1920): 53–67, quote, 55.

⁹¹ *Ibid.*

⁹² Reich, *The Making of American Industrial Research*, 100.

'business men,' and who by reason of dual understanding, have been able to do much in effecting cooperation."⁹³

This article further detailed the liaison role not only of the director of the department, but also of the "Development and Engineering Service," which existed to serve an interpretive function in relation to prospective users who might not understand the company's products. A significant reason for Bell Laboratories' adoption of a case-based accounting system derived from its position as a jointly owned subsidiary—as with the Bureau of Reclamation's need to please multiple patrons, Bell Laboratories' case-based lists of authorizations and billings effected and represented the allocation of costs to its two parents.⁹⁴

Given the need to balance interests, R.F. Bacon of the Mellon Institute emphasized the need for a "peculiar normality" in research directors, required because "the direction of a research laboratory is very much like running a 'zoo'—there are all kinds of animals with all kinds of tastes and habits."⁹⁵ Yet Bacon also found that "it is particularly adverse to progress to regard able investigators as abnormal men; for successful research demands neither any peculiar conformity nor any deformity of mind, but it requires, rather, peculiar normality and unusual industry and patience."⁹⁶ While variety in individual temperaments should be accommodated, a common observation was that the need for "laboratory spirit and teamwork" meant "men who do not mix well with the others, who start dissension, who 'blow' or 'bluff' or who are confirmed 'knockers' should not be retained on the staff."⁹⁷

Accounting and Projecting

The basic problems of applying cost accounting in research and development had kinships to those encountered in construction work. Measurement of work was difficult and it was even harder to correctly identify and link present expenditures to either individual performance or

⁹³ A.V.H. Mory and Leon V. Quigley, "How the Bakelite Corporation Effectively Manages Organized Research," *Manufacturing Industries* 11 (1926): 13–16.

⁹⁴ J.E. Moraves, General Auditor, Bell Laboratories to C.A. Heiss, Comptroller, American Telephone and Telegraph, February 7, 1925 and H.Charlesworth, Vice President, Bell Telephone Laboratories to F.B. Jewett; Vice President, American Telephone and Telegraph, August 23, 1929. AT&T Archives, Location 176 02 03 03.

⁹⁵ Cited in "Society of Chemical Industry, Meeting of the New York Section" *Metallurgical and Chemical Engineering* 13 (1915): 922.

⁹⁶ R.F. Bacon et al., "Research in Industrial Laboratories." *Science* 55 (January 12, 1917): 34–39, quote, 35.

⁹⁷ Charles W. Hill, "Efficiency in Industrial Research," *Metallurgical and Chemical Engineering* 18 (1918): 182–184, quote, 183.

future benefits. Looking for ways to better measure its work at the height of the scientific management craze in 1911, the Engineering Department of American Telephone and Telegraph noted in its annual report that,

“Because of the fact that development cases differ so radically one from another, no satisfactory plan has been evolved for establishing standard units of performance and cost. Standard units for manual labor may be determined without difficulty, but it is not so easy to establish standards for mental labor and mental labor is a very large factor in the development processes in which the Engineering Department is engaged. It is not the intention, however, to let the matter rest with this conclusion; it is the plan to have a competent experienced engineer devote his entire attention to this during 1912 in order that efficiency plans which have been formulated may be investigated and applied, if they are found to be feasible.”⁹⁸

Based on subsequent reports, no such plans were found feasible. Given these limits, methods of measuring work and tracking costs were adjusted to fit. The gathering and keeping of prime, direct, and indirect costs in research differed little in principle from these tasks in other businesses, but the logic of cost accounting required associating costs with on-going operations. Managers of this work did not want to be beholden to functional departments and their budgets, but the alternative carried its own hazards:

“Too often the accounting of a research and development laboratory is merely a summary of total expenditures largely kept for tax purposes, and the developments appear in reports only as an expense and is prominently evident as something that may be conveniently cut off when the first call for economy in operations is made.

“To represent properly what is being done, the work of a development laboratory must be subjected to a cost system that will represent with reasonable accuracy the cost of various problems or undertakings and then, in some other way, the value of past work and present or future value of current work be set up against this in an intelligent fashion.”⁹⁹

When Charles A. Stine of DuPont explained the research worker and his purpose in relation to the manufacturing organization, he stressed that it was against manufacturing that research needed to be accounted for, in both explanations and dollars.¹⁰⁰ Indeed, for Stine, research was part of the function of a manufacturing plant.¹⁰¹ A C.P.A. teaching at a California college in 1934 could simply summarize the distinct qualities of “Accounting for Experimental and Developmental

⁹⁸ AT&T Archives, Location 250 07 01 01. 3.

⁹⁹ Weiss and Downs, “What Machinery is Necessary for the Management of Industrial Research,” 549.

¹⁰⁰ C.A. Stine “Fundamental and Applied Chemical Research,” *Profitable Practice in Industrial Research*, 109.

¹⁰¹ *Ibid.*, 112.

Costs": uncertainty and risk.¹⁰² This author set out five systems, which, "if the situation is analyzed it will be seen that there are only five possible general ways of handling these costs, everything has been tried."¹⁰³ His list of possibilities included capitalizing the work and charging it against subsequent production, charging it off directly as a current expense, carrying it as administrative overhead, treating it as a manufacturing expense, or mixing the foregoing approaches according to the nature and success of the project. As with other types of projects, the chief quandary was in knowing in advance how to account for expenditures of which the benefits could not be entirely foreseen. By contrast to plant construction, only the source of the risk differed—in that scientific work might come up against the limits of knowledge while plant construction might come up against the limits of knowledge. Most companies adopted either job-based or annual systems, and sometimes used a combination of an appropriation-based system and a yearly budget, with individual development efforts becoming subject to appropriation as they passed into engineering and semi-works development.¹⁰⁴

Tracking work in the laboratory served both to link costs to particular lines of investigation and to document the work for patent purposes. Among the first formalized procedures within the industrial laboratory was the establishment of systematic record keeping that established precedent for further investigation and potential legal defense. These systems had academic forebears in laboratory notebooks: Whitney, for example, required keeping of notebooks, weekly reporting, and regular photographing of individual apparatus and the laboratory as a whole. Documents were read and witnessed to further set their dates.¹⁰⁵ That is, while *financial* record keeping and accountability were increasingly important in industrial laboratories, record keeping and accountability were not new to scientific work.

The cost accounting system in use at A.D. Little was developed by William W. Caswell, the company treasurer, who presented the basics of the system to a meeting of the American Chemical Society in 1919. This paper was published in the *Journal of Industrial and Engineering*

¹⁰² Norman B. Clark, "Accounting for Experimental and Developmental Costs." *N.A.C.A. Bulletin* 15 (1934): 701–717, quote, 701.

¹⁰³ *Ibid.*, 702.

¹⁰⁴ This hybrid system was recommended by Weiss and Downs, "What Machinery is Necessary for the Management of Industrial Research," 551.

¹⁰⁵ Whitney, "Organization of Industrial Research," 75.

Chemistry the following January. Caswell was vague on details beyond emphasizing the need to recognize and allocate prime, direct and indirect costs and indicating that “each man turns in a time slip every day showing the number of hours he spent on a case and from this slip the cost figures are made up.”¹⁰⁶ Caswell noted that, where possible, cumulated time on tasks was checked against data for similar cases in the past and such comparisons were used in reviewing individual output and determining salaries and bonuses.

C.E.K. Mees’s *The Organization of Industrial Scientific Research* provides details of Caswell’s system, serving as the basis of Mees’s description of correct accounting practice.¹⁰⁷ Mees reproduced job tracking and daily labor reporting cards (figures 3.10 and 3.11) and described the bookkeeping procedure by which “problems” could then be tracked.¹⁰⁸

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Problem No.		ASSIGNMENT CARD																													
Problem																															
Ref. Referred by Rec'd																															
Assigned to Dept. Individual No.																															
Promised																															
Remarks																															
K P 9122																															

FIG. 8.

DAILY REPORT						
DAY _____ MO _____						
PROBLEM	1	2				
TIME						
NAME						
NO.						
(Kindly fill out this card each day before leaving)						

FIG. 9.

Figures 3.10 and 3.11—Assignment card used for problem-based accounting (left) and individual labor time card (right) as illustrated by Mees based on Caswell’s system. Source: C.E.K. Mees, *The Organization of Industrial Scientific Research* (New York: McGraw-Hill, 1920), 128.

Surveying practice toward the end of the 1930s, the staff of the National Association of Cost Accountants acknowledged the incoherent state of accounting for research and development. Because so many distinct kinds of projects were lumped under R&D, no single approach sufficed. A survey of 106 companies showed that 67 budgeted for research separately from other expenditures, 41 used project budgets in planning work, and two-thirds of the total sample

¹⁰⁶ (1920): 81.

¹⁰⁷ In a footnote, Mees comments, “I owe the arrangement of this account system to Mr. Caswell, Treasurer of Arthur D. Little, Incorporated, of Cambridge, who has worked out a very complete accounting system for his own firm and very kindly placed all his material as my disposal,” 129.

¹⁰⁸ Ibid., 127–129.

tracked costs on a project basis.¹⁰⁹ This survey also considered where authority over research expenditures resided within organizations, and noted frequent use of combined “construction and experimental” committees, marking the position of these activities as alternative means of investing in future capabilities.

“Under What Project Did Darwin Work?”¹¹⁰

The people whose work they disciplined did not uniformly welcome the extension of project-based controls. The sarcastic remark that provides the title to this section comes from a speech by Eugene Davenport printed in *Science* in 1917. In this article, Davenport—vice-president and chair of the American Association for the Advancement of Science’s agriculture section—objected to the use of “modern efficiency standards” that had been “developed from the manufacture of shoes, clothes-pins, overalls, etc., and which are expressed in motions per hour” in the laboratory. While tangential to this study’s focus on techniques and their uses, the writings of those who objected to management systems in research work help show just how prevalent project-based systems had become and help articulate the limits to system in research laboratories.

The same accounting system that Little celebrated and helped to disseminate was deplored by others. Davenport noted that a great deal of public money had been thrown at agricultural research stations. Spending having increased more quickly than the supply of able personnel, Davenport worried about the costs of hastiness. He reserved special spite, though, for “the cult of administration.” Administrative requirements attached to appropriations meant that “many if not most investigators in agriculture are now required to begin a piece of research work by drafting a formal project in which the materials and methods are definitely described, the cost specified, and the expected results foretold.” He compared this procedure to the design of an automatic machine and confessed “extreme difficulty” in discussing the subject “with such moderation of language and statement as are appropriate to the dignity of the occasion.”¹¹¹ Davenport’s diatribe against the procedural requirements imposed by public funding concluded with a lengthy sentence:

¹⁰⁹ Rand Marple, “Present-Day Practice in Accounting for Research and Development Costs,” *N.A.C.A. Bulletin* 40 (1939): 890–891.

¹¹⁰ Eugene Davenport, “The Outlook for Agricultural Science,” *Science* 45 (February 16, 1917): 158.

¹¹¹ *Ibid.*, 154–155.

"Efficiency is more insidious, for it works under the guise of service and proves by figures that scientists, teachers, and others in the public service must be standardized in order to be made efficient, and before this car of Juggernaut, training, loyalty, counsel, experience, even deliberative acts of boards of trustees of successful and high-minded citizens serving without salary do not count as against a small group of self-selected and politically appointed individuals shut up in an office miles away with neither special training, knowledge of the situation nor other qualification to enter our laboratories but the blind authority of law working in the dark and largely through individuals who would never, except by the accidental working of the law, be connected in any way with our work."¹¹²

While such rants are individually amusing, collectively they represent a defense of a kind of work justified on underlying qualities of that work. Wheeler defended scientific discovery as driven by "individual interest, initiative, invention, and energy, all of which must be resident in the worker."¹¹³ Suggesting that the current interest in organization had been "abnormally stimulated" by the experience of World War I and the "instincts of self-assertion and domination, which are so evidently associated with the accumulation of hormones in the older males of all mammals," Wheeler set himself squarely against organization charts, schedules, time clocks, and "that noble superorganization of superorganizers, the National Research Council."¹¹⁴

Wheeler also focused on the capacity of organizations to adapt to their environment. "Most organisms," he commented, "retain a lot of relatively unorganized, or more or less generalized structures and functions as reserves for prospective adjustments to the changing environment." These structures could be found in our mental as well as physical make-up, as "we all carry with us in our subconscious a great reservoir of very primitive instincts and tendencies..." For Wheeler, "this whole relatively undifferentiated and imperfectly organized equipment must be of the greatest value as a source of future adaptations."¹¹⁵ Wheeler recommended keeping "a certain number of our activities in a primitive, unorganized condition... free from the organizing mania of man, as national and city parks or reservations to which we can escape during the holidays from the administrators, organizers, and efficiency experts and everything that they stand for and

¹¹² Ibid., 157.

¹¹³ Ibid., 158.

¹¹⁴ Wheeler, "The Organization of Research," 53.

¹¹⁵ Ibid., 66-67.

return to a Nature that really understands the business of organization.”¹¹⁶ Among these activities should be scientific research.

Wheeler was responding immediately to efforts of the NRC to secure some form of permanent funding and an institutional home for research rather than face demobilization following the war. On one hand, Wheeler’s ranting would have found little acceptance among the ‘superorganizers’ he attacked. In Charles Kettering’s words, “anybody who has had dealings with the tribe of scientists knows that there are some—not, fortunately, so many as some folks might think—who love science for science’s sake.”¹¹⁷ On the other, and as his comments about the loose management of research teams within General Motors suggest, Kettering would likely have accepted that research should be allowed to “self-organize” to some degree. Wheeler’s position as an academic gave him a cozy roost from which to caw. For the individual research director facing internal and external pressure to rationalize every aspect of the balance sheet, the question “is it possible... to buy research as an investment, not as a wildcat speculation?” needed to be continuously reanswered in the affirmative.¹¹⁸ This meant that research needed to be represented in the manner of a building or dam or canal—that is, projected and so made palpable and bankable. C.E.K. Mees noted that where laboratory work was directly related to production it was easy to see and value, and hence he perceived “much stress being generally laid upon the immediate returns which can be obtained from works laboratories and upon the advantage of scientific control of their operations” as opposed to more speculative investigations.¹¹⁹

Cases

The two cases that follow further show the diffusion and function of project-based organizing in research work in the early twentieth century. The first provides further documentation of the project-based controls in the Department of Agriculture Experiment Stations already noted in the body of the chapter. The second of the two cases continues the consideration of project

¹¹⁶ Ibid., 66.

¹¹⁷ C.F. Kettering, “Research, Horse-Sense, and Profits,” *Factory and Industrial Management* 75 (1928): 735–739, quote, 737.

¹¹⁸ Z.C. Dickinson, “Research—Gold Brick or Gold Bond?” *Factory and Industrial Management* 79 (1930): 1075–1077, quote, 1075.

¹¹⁹ *The Organization of Industrial Scientific Research*, 9.

administration at DuPont introduced in the preceding chapter. Both illuminate connections between practices in construction engineering and laboratory administration.

U.S.D.A. Experiment Stations

The experiment station movement began in Germany in the 1850s and extended to the United States in the 1870s.¹²⁰ In both the German instances and their adaptation in the United States, early experiment stations were cooperative associations between academic institutions and farmers. These were local arrangements, involving the systematic study of variation in cropping or husbandry practices aimed at aiding the productivity of farms. Government support of stations in the United States came first at the state level, involving general annual appropriations, usually to agricultural colleges then being established in the wake of the Morrill Act of 1862. When Federal support to aid existing and help establish new stations was first contemplated, a report noted that "the most immediately pressing need seems to be that of a clearing-house and an exchange for the stations," given their remoteness from one another and the potential benefits of co-ordination.¹²¹ The role of federal aid would be expressly mediating: "negotiating between the stations and the agricultural public on the one side and between the stations and the world of science on the other."¹²² Publications—farmers' bulletins and research digests—would serve these respective roles, bringing in and broadcasting information. The direction of experimental work within the stations was expected to develop informally, as the practical wants of farmers and the potential of theoretical work informed the problems chosen by the stations.

Federal support of experiment stations began with the Hatch Act of 1887, which allowed each state an initial grant and the promise of annual operating support for the establishment of a station in connection with its land grant college. This led to the rapid development of new stations and

¹²⁰ Secretary of Agriculture (J.M. Rusk), "Introduction," and A.C. True, "A Brief Account of the Experiment Station Movement in the United States," in U.S. Department of Agriculture, Office of Experiment Stations, Bulletin No. 1, "Organization of the Agricultural Experiment Stations in the United States" (Washington: Government Printing Office, 1889), 5–10 and 73–78, respectively. For the general history of the stations see A.C. True, *A History of Agricultural Experimentation and Research in the United States, 1607–1925* (Washington: Government Printing Office, 1937).

¹²¹ Cited in U.S. Department of Agriculture, Office of Experiment Stations, Bulletin No. 1, "Organization of the Agricultural Experiment Stations in the United States" (Washington: Government Printing Office, 1889), 13.

¹²² Ibid.

the reorganization of some of those existing. The text of the act required "that in order to secure, as far as practicable, uniformity of methods and results in the work of said stations, it shall be the duty of the United States Commissioner of Agriculture to furnish forms, as far as practicable, for the tabulation of results of investigation or experiments..."¹²³ The act further mandated regular annual reports and that "reports of progress shall be published at said stations at least once in three months." Subsequent bulletins issued by the overseeing office summarized the general and long-term lines of investigation at the various stations, reported the meetings of the Association of American Agricultural Colleges and Experimental Stations, and provided directories aimed to facilitate exchange. Early bulletins also noted the inconsistency of early reporting and accounting practices despite the law's mandates, and attributed this variation to inexperience and the fact that the Hatch Act had led to a greater demand for capable researchers than could be supplied existed in the United States.¹²⁴

The Adams Act of March 16, 1906, provided additional funding but also set further conditions for the experiment stations.¹²⁵ This act required detailed accounting of how funds had been disbursed using forms prescribed the Secretary of Agriculture. It further restricted the funds authorized above those under the Hatch Act to "the necessary expenses of conducting original researches or experiments bearing directly on the agricultural industry of the United States."¹²⁶ The Act did not directly set out means by which to comply with this clause, and the subject was taken up in a previously dormant "Committee on Experiment Station Organization and Policy" within the Association of American Agricultural Colleges and Experiment Stations.¹²⁷ Finding

¹²³ 49th Congress, 2nd session, Chapter 314, Statutes of the United States, vol. 24, 440 ff.; reproduced in U.S. Department of Agriculture, "Organization of the Agricultural Experiment Stations in the United States" (Washington: Government Printing Office, 1889), quote, 66.

¹²⁴ See "Introduction," U.S. Department of Agriculture, Office of Experiment Stations, Bulletin No. 2, "Digest of the Annual Reports of the Agricultural Experiment Stations in the United States" (Washington: Government Printing Office, 1889), 15-19.

¹²⁵ On the Adams Act see Charles E. Rosenberg, "The Adams Act: Politics and the Cause of Scientific Research," *Agricultural History* 38 (1964): 3-12.

¹²⁶ Reproduced in U.S. Department of Agriculture, Office of Experiment Stations, Circular No. 86, "Federal Legislation, Regulations, and Rulings Affecting Agricultural Colleges and Experiment Stations," October 22, 1906.

¹²⁷ See U.S. Department of Agriculture, Office of Experiment Stations, Circular No. 71, "Report of Committee on Experiment Station and Policy," January 9, 1907.

that the greatest difficulties in ensuring originality lay in failures to define the purpose and plan of investigations, and a consequent tendency to broad, open-ended researches.

Charles Rosenberg appraises the passage of the Adams Act and the terms it set as marking power relationships among the various constituencies involved—the agricultural colleges, local political interests, and scientists.¹²⁸ Rosenberg describes the history of the Office of Experiment Stations in the decade preceding the Adams Act as a “record of a consistent and stubborn and at times almost unbelievably petty war of attrition against the shoddy and opportunistic elements in experiment station science.”¹²⁹ While Rosenberg does not study the measures subsequently adopted to enforce the Act, his evidence helps explain the measured tone of subsequent commentary on the use of project accounts within stations.

The Department of Agriculture’s editorial comment in the issues of *Experiment Station Record* that followed adoption of the Adams Act noted the novelty that keeping project-based records would present to many researchers. Describing some of the work planned under the Adams Act, it stated, “the working out of these projects in considerable detail has itself been a somewhat new experience for a considerable proportion of station men, whose work has not always been characterized by a systematic and well-digested plan.”¹³⁰ The writer hoped for the extension of the Adams Act requirements to station work in general, partly through the development of administrative system within the stations. A further comment in an issue of later that year added, “at one time a station council headed by a chairman was deemed sufficient to settle and manage the station business, or a college president through whose office the funds could be allotted and certain general business and correspondence conducted,”¹³¹ but that this would no longer do because “the very diversity of station work, with funds for research, for more general use in agricultural experimentation, and often from the State for more popular features such as local or cooperative trials or demonstrations, imposes unusual duties on the administrative

¹²⁸ Rosenberg, “The Adams Act.”

¹²⁹ *Ibid.*, 4.

¹³⁰ U.S. Department of Agriculture, *Experiment Station Record* 18 (May, 1907): 806. Earlier issues of this publication had regularly commented on the need for definite aims and clear organization in station work, but this advice was not detailed and it was further muddled by the multiple constituencies the stations needed to serve.

¹³¹ U.S. Department of Agriculture, *Experiment Station Record* 19 (November, 1907): 201.

officer.”¹³² The writer felt that better coordination through system and regularity would help develop *esprit de corps* within stations. “Experience has shown that a certain amount of regulation of the work as to amount and quantity is quite essential. The amount undertaken is not always fully realized until it is outlined on paper, and this is one of the arguments for the submission of a programme of work or a list of projects.”¹³³ Discussing the multiple obligations faced by the research director, this person’s role in balancing a station’s “campaign and policy” with an eye to “the interests of different classes of constituents and the need for various grades of work must be considered, but in this the broader and more permanent needs of agriculture should be given full consideration.”¹³⁴

Reporting in 1920, the editor of the *Experiment Station Record* looked back on the adoption of project accounting. Continuing from the paragraph that serves as the epigraph to this chapter, he opined:

“Objection to the project system in experiment station work, quite marked at one time, have very largely died out, for it has proved to be a reasonable basis of operation in research as in engineering or in industry, and to have marked advantages. It is found not to impose undue restraint on the freedom of investigation, but on the other hand to give convenience and stability to it. It has proved to be a convenience to workers as well as administrative officers, and to be an essential in organized effort. Nothing has done more to give character and direction to the various types of station work, or to promote adequate preliminary study and planning.”¹³⁵

E.I. Du Pont de Nemours (2)

As with early scientific work at General Electric and American Telephone & Telegraph, before 1902, chemistry work within E.I. DuPont de Nemours served a production control function within operating departments.¹³⁶ The transformation of DuPont from a powder producer into a diversified chemical business in the early 1900s was based significantly on redefining the main work of the laboratory from control to development. This was not an instantaneous change, and

¹³² Ibid., 202.

¹³³ Ibid., 203.

¹³⁴ Ibid.

¹³⁵ *Experiment Station Record* 43 (1920): 301.

¹³⁶ Hounshell and Smith, *Science and Corporate Strategy*, significantly informs my treatment here. See also sources cited in the case on DuPont in Chapter 1.

reconceptualization of the company as development-driven occurred over a longer period. Further, this change did not come easily or immediately, nor was it ever complete. DuPont's laboratory remained a "service" or "auxiliary" function even as it became central to corporate strategy, and power struggles over the control and location of laboratory work continued for decades. DuPont's history has been ably told from several angles so my purpose here is only to briefly recount the progress of project-based accounting in the laboratories, noting particularly the forces that drove this development. I focus on management within the Experimental Station, established in 1904 just downstream of the firm's original powder mills near Wilmington, Delaware.

In the debates preceding the establishment of the Experimental Station, there were questions of how it should relate to the Eastern Laboratory at the Company's Repauno Chemical Works, which had only taken up research in 1902. Discussing the value of a general laboratory tasked primarily with developing new processes and products (in contrast to the control function of the works laboratory), the DuPont Executive Committee noted, "that it was not desirable to interfere with the freedom of action on the part of any employee in the matter of developing his inventions or ideas, provided there was sufficient likelihood that these could be turned to advantage by the Company."¹³⁷ The committee was split, however, on whether efficiency could be better achieved with a works laboratories or a central laboratory and elected to continue the Repauno laboratory. Control of the work of the Experimental Station through its first years emanated directly from the company's Executive Committee—authorizations for research were made incrementally over time for investigations the members of the committee felt promising.¹³⁸ Investigations were accounted for such that total appropriations could be tracked and judgment could be passed on the value of further spending, but into the 1910s these strictures were semi-formal. In 1907, a separate board was established to oversee the Station and so relieve the Executive Committee, but this arrangement remained a loose matter of incremental appropriations based on the promise of the work in the judgment of the Station's board.

¹³⁷ Executive Committee minutes July 11, 1904. Hagley 1784-19.

¹³⁸ Hounshell and Smith, *Science and Corporate Strategy*, 41-50.

The system in place in 1907 for "development and experimental work," involved creating named accounts for each experiment and charging these to Administrative expense monthly. Once an experiment was deemed successful, its total cost was capitalized and the Administrative account credited.¹³⁹ A typical résumé of work underway at the Station in 1908 lists the subjects under study and notes dates but not dollars.¹⁴⁰ Prior to World War I, work at the Experimental Station was either the initiative of or subject to approval by operating departments. A summary of the Station's work in 1911, for example, reviews work by division, with the divisions corresponding to operating departments. This report, like others of the period, consistently applies the term "subject" to experimental undertakings.¹⁴¹ While subtle, the term "subject" reflected the often externally generated and refinement-oriented nature of the experimental work.

In 1911, both the Experimental Station and the Eastern Laboratory were brought under the control of a new Chemical Department.¹⁴² During and immediately after World War I, this central department grew significantly and there followed a period of experiment with the organization of experiment. In 1917, the department organized along lines corresponding to divisions of the company's operating branches—solvents, high explosives, powders, organic chemicals, and acids¹⁴³ At this date, the role of the Chemical Department was defined as evaluating proposed and existing processes but not originating proposals.¹⁴⁴

With the post-war recession of 1919 to 1921, the operating departments were put under pressure to reduce expenses. In 1919, the Chemical Department reorganized and added separate assistant directors for research and "operative chemical engineering."¹⁴⁵ The 1917 organization had mimicked the form of the firm as a whole, marking the imprint of the Department's customers upon its internal organization. Hounshell and Smith suggest that the 1919 reorganization coupled with this reorganization to force the ultimate 1921 breakup of the

¹³⁹ L.R. Bradshaw to P.S. DuPont and A.J. Moxham, June 13, 1907. Hagley 1784-18-1.

¹⁴⁰ Hagley 1784-19.

¹⁴¹ "Summary Report of Work Done at the Experimental Station During the Year 1911." Hagley 1784-20.

¹⁴² I neglect several rounds of reorganization in this period that are detailed in Hounshell and Smith, *Science and Corporate Strategy*.

¹⁴³ Charles L. Reese, Chemical Director, to W.W. Bacon et al., February 1, 1917, Hagley 1784-18-19.

¹⁴⁴ Ibid.

¹⁴⁵ Hounshell and Smith, *Science and Corporate Strategy*, 102–103. These pages reproduce organization charts for the 1917 and 1919 organizations.

Chemical Department and devolution of the research function to the operating departments. There was, though, an intermediate step of significance here. In late 1919, as pressure for accountability grew, the Chemical Department and the Engineering, Development, and Manufacturing departments agreed to a plan to "govern the relations between these Departments in the performance of experimental and technical supervising functions."¹⁴⁶

The resulting "experimental project plan" took effect on January 1st, 1920, with the stated goal being to "provide definite means for placing responsibility for undertaking experimental work and for controlling expenditures within predetermined limits."¹⁴⁷ This plan would correct the deficiencies of the preceding arrangement, under which there had been no way to know how to credit the value of each department's financial contributions to the Station's work in relation to any gain realized.¹⁴⁸ Some at DuPont judged the project plan an immediate success that had brought about "more thorough advance consideration and more logical planning of work" though others worried about the control that the Station had ceded to other department. "Especially with the system of projects now in force," wrote the director of one of the Chemical Department's laboratories, "we fear a tendency on the part of the various member of the Operating Departments to become judges, without adequate information, of the desirability of proposed researches."¹⁴⁹ The pressure under which the Department operated is evident in a note written to the Station's Director in May of 1920:

"The writer has found that some so-called research chemists come to the laboratory with a very poor conception of the word "work." They may have been trained under some teacher of chemistry to whom the typewriter is more important than the test-tube in gaining the respect of his professional confreres... This, of course, involves the whole question of the research efficiency of our laboratories and it scarcely seems necessary to discuss this much discussed question at this time."¹⁵⁰

¹⁴⁶ "Memorandum: Experimental and Technical Supervising Functions Affecting the Production Department," October 16, 1919, Hagley II, 2, 291 cited in Hounshell and Smith, *Science and Corporate Strategy*, 102.

¹⁴⁷ W.M. Whitten to Charles L. Reese, September 28, 1920. Hagley 1784-16. See Hounshell and Smith, *Science and Corporate Strategy*, 102-104.

¹⁴⁸ Various reports, Hagley 1784.

¹⁴⁹ R. Calvert, Director, Delta Laboratory, to Dr. H. Bradshaw, Director, Experimental Station, May 3, 1920, Hagley 1784-18-19.

¹⁵⁰ C.M. Stine, Assistant Director for Research, to Dr. H. Bradshaw, Director, Experimental Station, May 3, 1920, Hagley 1784-18-19.

By the late 1920s, the economic pressures that weighed on research in 1919 and 1920 had relaxed. After the 1921 decentralization of research Charles Stine directed the surviving elements of the Chemical Department through the early 1920s, doing work substantially in cooperation with General Motors.¹⁵¹ In 1927 DuPont embarked on the program of research that ultimately led to the commercialization of Nylon by appropriating a lump sum for general research. Stine commented, "we are including in the central Chemical Department's budget for 1927 an item of \$20,000 to cover what may be called, for want of a better name, pure science or fundamental research work."¹⁵² Stine justified this expenditure on several grounds: public relations, staff morale, contact with universities and institutes, and practical applications. By March of 1927 discussions led Stine to propose a rather higher \$200,000 for that year with anticipated increases to "somewhere between \$300,000 and \$500,000" in later years.¹⁵³ For present purposes, the course of the control of this program is worth further describing because it marks patterns in the use of project controls within a single department within a single company—a micro version of the cycles that structure this study. That is, just as different industries go through development periods involving working out of technical and social relationships, similar dynamics obtain within companies at smaller scales and over more compact time frames as internal relationships develop—in this case over the course of the development of Nylon and in the context of the depression of the 1930s.¹⁵⁴

Control of research expenditures under the new program was at first minimal, but increasing control tracked the onset of depression in the early 1930s. According to an internal history written in 1940, "under the original fundamental research plan, no projects for fundamental research work were written" Instead, only an open-ended expense account was set up, and this could be very general.¹⁵⁵ In 1930, a system of more detailed accounts was instituted. In October of that year, Arthur Tanberg, the director of the Station, wrote a paper for internal distribution entitled

¹⁵¹ See Hounshell and Smith, *Science and Corporate Strategy*, 125–146.

¹⁵² Charles Stine to Executive Committee, December 18, 1926. Hagley 1784-18-1.

¹⁵³ Charles Stine to Executive Committee, March 31, 1927. Hagley 1784-18-1.

¹⁵⁴ I do not fully treat the Nylon story. See Hounshell and Smith, *Science and Corporate Strategy*, 183–190, 221–274.

¹⁵⁵ Wise, L.G. and N.G. Fisher, "History, Activities, and Accomplishment of Fundamental Research in the Chemical Department of the DuPont Company, 1926–1939 Inclusive." August 14, 1940. Hagley 1784-21. 14.

"The Conduct of Research." The intent of this paper, he explained, was to help men "direct their research in the best possible manner, not only from the standpoint of insuring a successful outcome of the research, but also of getting the work done with a minimum expenditure of time and money."¹⁵⁶ Efficient prosecution of research in an industrial setting, Tanberg offered, required continuous awareness of changing market conditions, including materials costs, competitors' products, new patents. Acknowledging, "the mental side of research is the most important side," Tanberg suggested that this aspect involved "intangibles such as environment; stimulation through association with the other members of a congenial, well-balanced staff; and finally considerable freedom of action."¹⁵⁷ He concluded that "research can not or should not be standardized," but also that "when the Company spends money on research it is making an investment" that must eventually yield some form of return.¹⁵⁸

Internal pressures to find economies in light of the deteriorating external economic situation reached the Station in form of searches for tighter administrative controls,¹⁵⁹ and an internal conference of July 30, 1931 marked the pressures for greater accountability and more explicit evaluation of fundamental research.¹⁶⁰ In August 1932, a system of "informal projects" was adopted for the fundamental research program.¹⁶¹ These did not circulate outside the Station but did require an estimate of likely expenditures and were subject to evaluation within the Experimental Station, even if this evaluation came in the form of normative pressures.¹⁶² Regular requests for information about what sort of work was going on circulated between the Experimental Station and the Executive Committee and regular group meetings within the Station provided forums for discussing work in progress.¹⁶³ Research at the Station in the late 1920s was organized into groups by general area of investigation, with a leader for each group. The initial informality of this leadership function gave way in the early 1930s to a more explicit system of

¹⁵⁶ Hagley 1784-19.

¹⁵⁷ Ibid.

¹⁵⁸ Ibid.

¹⁵⁹ Ernest B. Bengert to A. Tanberg, August 29, 1930. Hagley 1784-19.

¹⁶⁰ E.O. Kraemer, "Fundamental Research in an Industrial Laboratory," July 30, 1931. Handwritten note on page indicates that Drs. Bengert, Coolidge, Cameron, Carothers, Chilton, Kenney, and Kraemer attended. Hagley 1784-21-9.

¹⁶¹ Wise and Fisher, "History, Activities, and Accomplishment of Fundamental Research in the Chemical Department," 15.

¹⁶² Ibid., and W.E. Lawson to Dr. Carothers, March 7, 1933. Hagley 1784-21-7.

¹⁶³ W.H. Carothers et al. to C.M. Stine et al., May 21, 1928. Hagley 1784-21-6.

accountability. In 1932, Tanberg only informally solicited progress reviews.¹⁶⁴ By 1934, formal progress reports were required and, after 1936, the term “fundamental research” began to disappear from reports and conversations. A 1937 report notably reinstituted the term “subjects” as a marker for fundamental research, suggesting the need to set this work aside from project controls that had become the norm.¹⁶⁵

Outside of the fundamental research program, project-based accounting and internal approvals had been a constant in research at the Experiment Station across the 1920s and 1930s. Tanberg wrote in the later 1930s that

“The project system has been in operation for many years and has proved very satisfactory. A project is drawn up for a definite expenditure and usually for a definite number of months. It includes a description of the proposed work and the reasons why it should be undertaken.” Approval for an individual project would rest either with the originating department or with the Steering Committee of the Station, except for small internal studies which could be approved by an individual and very large projects which might require higher approvals. The Steering Committee, composed of several Directors and Research Supervisors, met weekly to consider new projects and, separately, to hear progress reports from Group Leaders.”¹⁶⁶

The notable qualities in the preceding are two. First, project-based systems were introduced and reintroduced in DuPont’s Experimental Station in time with external pressures, which followed from the company’s appetite for uncertain undertakings. This, in turn, tracked general economic conditions as well as the ability of individuals to represent the potential of ill-defined, exploratory work. Second, the application of project-based controls followed from the need to account for work in terms that would be acceptable to the demands of operating departments. Such departments and individuals within them were oriented to bottom-line profitability in present operations, hence how, when, and why they should pay for investment in uncertain futures were significant matters. Project-based accountability in Du Pont allowed for allocations

¹⁶⁴ Wallace Carothers’s report noted that his work, including that of his assistants, had cost DuPont over \$300,000 since his joining the firm early in 1928. Wallace H. Carothers, “Fundamental Research in Organic Chemistry at the Experimental Station, A Review” Aug. 5 1932 and A. Tanberg to E.K. Bolton, August 24, 1932. Hagley 1784-21-7.

¹⁶⁵ Chemical Director to Executive Committee, January 14, 1937. Hagley 1784-16-3. Hounshell and Smith document the use of “bootleg” research on a department-by-department basis, with researchers granted discretion within limits to undertake less specific studies. *Science and Corporate Strategy*, 304–305.

¹⁶⁶ A. Tanberg to J.A. Burckel, September 20, 1938. Hagley 1784-19.

of costs and benefits between functional jurisdictions in a manner akin to the Bureau of Reclamation's use of projects to divide spoils among territorial jurisdictions.

Conclusion

Management systems used in laboratory administration in the formative years of the industrial research laboratory were partly adopted by and partly forced on scientists and research administrators. In some cases, tools were carried within firms directly from practices in engineering and accounting for capital investment. Like construction, experiment and innovation could be understood as building future capacity. In other cases, project-based systems came by way of consultants or through government contract requirements. While these methods were often adopted from those used in other areas, the governance of research work presented new complications. The time and place of interactions between research departments and operating divisions were at once more involved and less predictable than in the case of construction.

As with construction management, the organization of research and development work could not practically extend beyond scheduling and coordinating work practices that were governed by the individuals and groups doing the work. Like construction, research and development involved work in uncertain environments and enlisted social structures that extended beyond the boundaries of the firm to serve as repositories of knowledge, as bases for normative control, and as markets for labor. But unlike construction, the desired performance of research work could not be written into a specification except in the most general terms. And also unlike construction, the results of research could change both how and what the rest of the organization did. Collectively, the evidence presented in this chapter shows that by the 1930s scientists and research administrators were familiar with and acculturated to the use of project-based controls, however much they might resent the intrusion.

Chapter 4

Developing Product Development: Continuous Output versus Irregular Improvement, 1920–1940

Times innumerable, reputable engineering staffs have been damned, because other organizations, endeavoring to use their drawings for manufacturing purposes, ran into all kinds of difficulties and troubles.”¹

In the interwar period, companies in industries that competed in established consumer markets on the basis of appearance or performance developed methods for managing regular product change. In businesses producing in volume, incremental improvements and refashionings could be made part of an annual routine and woven into marketing campaigns. When General Motors introduced annual model changes to the automobile market in the mid 1920s, it won customers from a market saturated with Henry Ford’s look-alike Model Ts, and in response Ford ultimately had to entirely shut down to retool.² G.M.’s punctuated variant on mass production was nonetheless a planned process. Selling a stabilizing product into a maturing market, G.M. could plot a “self-perpetuating, continuous, orderly and systematic” course of progress.³ In the words of Charles Kettering, General Motors’s Director of Research, “the function of research is to keep ourselves moderately dissatisfied, and to keep the customer no more than moderately dissatisfied,” since moderate dissatisfaction would encourage regular vehicle replacement without driving the customer to a competitor’s product.⁴ Kettering described the function of research as “scientific change-making”⁵ and researchers as “change artists.”⁶ For companies producing smaller volumes, facing less predictable markets, and looking

¹ John F. Hardecker, “Aircraft Drafting,” *Aviation* 28 (1930): 1162.

² David Hounshell, “Cul-de-sac: The Limits of Fordism and the Coming of ‘Flexible Mass Production,’” chapter seven of *From the American System to Mass Production, 1800–1932* (Baltimore: The Johns Hopkins Press, 1984), 263–301.

³ L.A. Hawkins, as quoted in chapter 3.

⁴ “Research, Horse-Sense, and Profits,” 737. A useful biography is Stuart Leslie, *Boss Kettering* (New York: Columbia University Press, 1983).

⁵ Charles F. Kettering, “The Functions of Research,” *Industrial and Engineering Chemistry* 19 (1927): 1215.

⁶ *Ibid.*, 1216.

ahead to ill-defined technical futures, the path between the efficiencies of volume production and the hazards of unsold inventory was less clear.

Companies in the aircraft industry in the 1920s and 1930s faced such ambiguity. The nature of aircraft and the market for them refused to stabilize, despite the best efforts of government and industry bodies and the hopes of manufacturers.⁷ The Society of Automotive Engineers's (SAE) committee on the standardization of aircraft waved its hands in 1926 and gave up trying to carry out its task for anything but small parts such as eyebolts and cables.⁸ There was too much variance in the construction of aircraft. As a consequence of the materials, methods, and technologies brought together, organizing aircraft production blended aspects of job shops, assembly lines, construction sites, and research laboratories. In the face of complexity and uncertainty and stuck at production volumes too big for informal organization but too small for mass production, managers of aircraft companies adopted project-based organizing methods to cope with internal constraints and external pressures. In doing so, they adapted these methods to a particular kind of project: ferrying short-lived, batch-produced goods through brief production runs.

While this chapter focuses on aircraft production, it sets this industry in the context of a developing field of 'product development.' Born of the competitive pressures of fashion and war and applied across a range of batch-oriented industries, the management of product development was closely related to and often overlapping with laboratory administration. But as noted in the previous chapter, research and development were considered distinct steps and departments, with development occupying a connecting and insulating position between research and production. In *The Technical Organization: Its Development and Administration*, Weiss and Downs saw development departments as serving a diplomatic function that isolated research work from operational concerns—"research

⁷ Historical studies of technological flux in aircraft design include Walter Vincenti's studies of aeronautical engineering, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History* (Baltimore: Johns Hopkins University Press, 1990) and "The Retractable Airplane Landing Gear and the Northrop 'Anomaly': Variation-Selection and the Shaping of Technology," *Technology and Culture* 35 (1994): 1-33; and, Eric Schatzberg, "Ideology and Technical Choice: The Decline of the Wooden Airplane in the United States, 1920-1945," *Technology and Culture* 35 (1994) 34-69. A general history is John B. Rae, *Climb to Greatness: The American Aircraft Industry, 1920-1960* (Cambridge: MIT Press, 1968).

⁸ See "Aeronautic Standards Cancelled," *Journal of the Society of Civil Engineers* 19 (October 1926): 340. I discuss the SAE's relationship to the aircraft business further in one of the cases at the close of this chapter.

and production do not mix” they dictated, and “development must be the connecting link.”⁹ This chapter focuses on the distinct literature that formed in relation to this peculiar function.

This chapter has several aims. First, it shows how managers in the aircraft industry adopted and extended means of project-based organizing to cope with uncertainty in small-numbers manufacturing. Second, it shows how the production, management, and social architecture of aircraft embodied sectional logics akin to earlier engineered systems. And third, it establishes the role of project-based management in development departments in representing engineering work and batch production against volume throughput. Keeping to the established pattern, this chapter begins with a review of the contexts in which product development developed, here focusing on the extension of operating logics discussed in earlier chapters to mass production. It then addresses arrangements and methods used to govern product development in relation to production. Finally, two cases show the blending of issues treated thematically in the body of the chapter.

Booms and Busts and Mass Production

Henry Ford helped make mass production both *cause célèbre* and a *bête noir*. Which was a matter of perspective. In 1925, the annual supplement to the American edition of the *Encyclopaedia Britannica* included an entry titled simply “Mass Production” under Ford’s name. Though the term was already in use and the piece was ghost written by a Ford spokesman, the *Britannica* article popularized the term and associated it with Ford.¹⁰ Like Brandeis’s courtroom brandishing of scientific management in the preceding decade, this article set rationally managed routines as an ideal against which all productive processes should be measured. But, as David Hounshell has pointed out, mass production proved a cul-de-sac for the Ford Motor Company when General Motors started talking about “change artists.”¹¹

The salient issue here is not what happened to mass production in the automobile industry, but that the image of mass production became a bogeyman for people trying to organize other kinds of work. Before the term mass production was in popular use, volume production of the Model-T had

⁹ 5.

¹⁰ William J. Cameron was the ghost writer. See David Hounshell’s introduction to *From the American System to Mass Production*, 1–13. The *New York Times* featured the article before it was published in the *Encyclopaedia Britannica*.

¹¹ Hounshell, “Cul-de-sac: The Limits of Fordism and the Coming of Flexible Mass Production,” chapter 7 of *From the American System to Mass Production*, 263–301; Kettering, “The Functions of Research.”

been portrayed in populist terms—assembly lines were seen as democratizing consumption through high-volume, low-margin production of what would otherwise be luxury goods. In light of the evident potential of mass production systems, stage-based models of product evolution and their organizational manifestation in the research-development-production triptych implied that industries and products underwent a teleological process of evolution toward “mature” volume production. Already misfits relative to Taylorism, by contrast to the automobile business project-oriented industries appeared stunted in their development. During the 1920s and 1930s, the construction industry and the aircraft business alike were widely seen as not just backward, but morally wrong for their failure to achieve the efficient, democratic ideal of mass production. During World War I, *Aviation and Aeronautical Engineering* noted the hopes of men in Washington that “...though the line of demarcation between production and quantity production has not yet been reached [in aircraft], it not only soon will be, but will also be passed.”¹² Two decades later, on the eve of U.S. involvement in the Second World War, an article in the *National Association of Cost Accountants Bulletin* commented, “the aviation industry is a lustily growing infant that is several kinds of a problem child to its parents or administrators.”¹³ This latter article acknowledged that problems arose because “advances in the art” were occurring with “bewildering rapidity,” but did not note that infancy had been a permanent state of affairs.

Such observations were a constant in the interwar years. In a series of articles in *Aviation* in 1928, Edwin R. Douglas, a consulting engineer and former member of the SAE’s Standardization Committee, pontificated on “Modern Management and the Industry.”¹⁴ Opening with a declaration that at long last the aircraft industry was “passing from childhood to adolescence” and that the day of organizations run by “flying men rather than production men” would soon be past, Douglas proceeded to lay out a textbook treatise on factory management with no further comment on the aircraft industry’s particulars. As did many other industrial engineers from manufacturing industries, Douglas turned his eyes to the aircraft industry and saw a field aching for the application of his

¹² “Washington Views on Production,” *Aviation and Aeronautical Engineering* 4 (1918): 776–777, quote, 776.

¹³ R.M. Woodham in Frank Klein, R.M. Woodham, and Ernest O. Lothrop, “Accounting Problems on Government Contracts,” *N.A.C.A. Bulletin* 21, no. 21 (July 1, 1940): 1361–1382, quote, 1362.

¹⁴ This series started with 25 (1928): 402, 434–438. Later topics included labor tickets, purchasing forms, stock ledgers, and sundry aspects of by-then-generic office systems.

expertise.¹⁵ Asking "Where Is the Executive?" another engineer wrote in 1932 that "the aviation industry seems to be an outstanding example of a young industry in which, while there is a great deal of enthusiasm, there has been a sad failure to get down to business principles, for after all, practically all business must be run on the same fundamental principles in order to make money."¹⁶ To this author, the trouble was that in the typical aircraft company, "engineers seem to dominate the business."¹⁷ With such commentaries as constant background noise, during the 1920s and 1930s the aircraft industry developed batch production methods that hybridized project and volume production, using a modular, sectional logic of assemblies and subassemblies. As with engineering contracting and laboratory administration, the dynamic that played out in aircraft production was one of working out limits and logics. The use of Gantt-type progress charts, the application of theories of learning and of product cycles, and the use of a staccato variant on factory production in which irregular batch runs were conceived as projects all helped organize and represent the aircraft industry.

The wanderings of aircraft manufacturing in the no-man's land between craft and mass production tracked crests and depressions in output (figure 4.1). After a brief flurry of sped-up production and hand wringing about insufficient capacity and a lack of standardization during World War I, the industry returned to its inchoate pre-war state.¹⁸ As it had been before the war, it became again a domain of hobbyists, enthusiasts, and promoters—much like railroading in the 1830s. At a banquet of the SAE during the summer of 1918, aircraft standardization was a prime topic and the disarray of the industry was widely deplored. Hope was held out, though. Finishing his speech closing the Orville Wright Banquet, Charles Kettering summed the attitude of the assembled engineers, "so let's just build good stuff and get it over there in tremendous quantities."¹⁹ Expectations were that the war would get the infant industry on its feet.

¹⁵ The Society of Automotive Engineers turned attention to the aircraft industry particularly during World War I and its *Journal* regularly commented on the backwardness of aircraft production. See the second case in this chapter.

¹⁶ James B. Taylor, "Where is the Executive?" *Aviation* 31 (1932): 295–296, quote, 295.

¹⁷ *Ibid.*

¹⁸ See, for example, Howard E. Coffin, "Aircraft Industry Needs Standardization," *Aviation and Aeronautical Engineering* 2 (1917): 309. Coffin described the industry as chaotic and noted that a parts manufacturer was making several thousand variants on a bolt in order to meet different specifications. Despite hue and cry over the lack of sufficient aircraft to even train military aviators, members of the SAE conceived of the proper course as a program of standardization and tooling for volume production.

¹⁹ "The S.A.E. Aeronautical Convention," *Aviation and Aeronautical Engineering* 4 (1918): 749, and several articles following in the same issue, quote, 771.

Figure 4.1—Aircraft production, 1910 to 1961, in units per annum. I truncate the diagram at 40,000 units to show detail of early ups and downs. Peak production (entirely of military aircraft) in both 1943 and 1944 exceeded 80,000 units. Source: U.S. Bureau of the Census, *Historical Statistics of the United States*, CD-ROM edition, Series Q565–567.

Focusing on aircraft and their production overlooks the broader development of the aviation industry. The 1920s and 1930s were a period of system building in aviation infrastructure as well as a search for markets for air transportation. Development of landing fields and navigation aids during these decades followed the pattern of railroads, with local boosters pushing for air fields that they hoped would put their towns on the map, hucksters promoting schemes, and government bodies subsidizing development.²⁰ In this period, nobody was quite sure who would buy or use airplanes or for what.²¹ Enthusiasts noted the potential of aircraft to forestry and agriculture, mapping, passenger service, exploration, airway policing, coastal patrols and other upstanding activities while worrying that actual uses for stunt flying, joy riding, and bootlegging would compromise public perceptions of the machines. The Guggenheim Foundation paid for several of the first academic facilities for aircraft engineering and at the same time subsidized *Slipstream*, a boosterish publication, as part of a campaign to make the public more “air-minded” through “confidence derived from familiarity and understanding.”²²

²⁰ In an article called “Vigilance Committee Warns Investors,” *Aviation* described the efforts of the National Vigilance Committee of the Associated Advertising Clubs of the World to warn the public away from get-rich-quick aeronautical promotions and of the ability of wildcatters to imperil the public confidence in a yet-undeveloped field. 12 (1922): 265.

²¹ As a representative example of many articles on the search for paying lines of work, see Walter E. Burton, “Attracting the Passenger,” *Aviation* 25 (1928): 31, 49.

²² Edited for a time by Harry F. Guggenheim. “Former Slipstream Editor Heads Air Course Campaign,” *The Slipstream*, 9 (1928): 9.

Like canals, railroads, and other systems before and since, government agencies supported and shaped the nascent air transportation industry. From 1915, the National Advisory Committee for Aeronautics (NACA) facilitated aircraft development through both funds and the dissemination of technical information. The Air Mail Act of 1925 required that the Post Office let contracts for mail routes to commercial operators, replacing government-operated mail planes that had flown since 1918. Mail contracts subsidized the establishment of passenger airlines by providing steady income in the face of uncertain ticket sales. The Air Commerce Act of 1926 provided funds for navigation aids and emergency fields and established the agency that later became the Civil Aeronautics Board.

The extraordinary peak in military aircraft production during World War II obscures otherwise significant fluctuations in commercial aircraft production during the preceding twenty years, in the late 1920s and then the latter half of the 1930s. In the early 1920s there was virtually no market for new aircraft. Surplus military machines satisfied much of the market and served as mail carriers and leftover engines could be had cheap until late in the decade. Government subsidy through NACA and military contracts sustained research, but actual production rarely reached beyond prototypes and short series. Toward the end of the 1920s, with a booming economy and sales of aircraft for sporting use and to newly formed airlines, aircraft production appeared on the eve of maturing into volume output. An article in the SAE's *Journal* stated in April 1930 that "the investment banker has poured some \$760,000,000 into aviation recently."²³ Depression checked the hoped-for maturation. Following a lull, in the mid 1930s, the Douglas DC-3 combined features that fit the needs of the aircraft industry and looked and felt safe to passengers. Imitated by other makers, all-metal, monocoque construction became a dominant design and because of operating efficiency permitted lower fares that in turn led to a more sustained take-off period for airlines. Despite growing demand for commercial aircraft in the late 1930s, production remained well short of full mass production. Only with World War II would the number of planes being built justify volume production techniques, and even these had to be modified to accommodate unpredictable changes midstream.

²³ W.B. Stout, "What the Public Wants in Airplanes," *Journal of the Society of Automotive Engineers* 26 (April 1930): 443-445, discussion 445-449, quote 443.

War and Fashion: Flexibility and Cyclicity

Harry Tipper, an engineer, consultant, and regular columnist in *Automotive Industries*, noted in 1921 that “some of the industrial engineers... are beginning to talk of the necessity of decentralizing in the large industrial organizations...” on the grounds that the overhead of systems and standards had become too costly.²⁴ By returning power to foremen and sub-foremen, these engineers expected “to render the system more flexible, to improve the executive capacity of the foreman and to reduce the overhead by simplifying the special departmental requirements.”²⁵ In other articles, Tipper more explicitly set standardization for routinized production against the ability to change. Discussing the over-extension of standardization in personnel selection, Tipper argued against “the general tendency of all organization work” because “the principal possibility of development lies not in... fundamental similarities but in the endless individual variation which develops an infinite variety in the quality of action and thought,” and because “all methods of examination of human beings which are standardized are inefficient to that degree.”²⁶ “As a matter of fact, the idea of standardization in human relationships is simply another way of attempting to do by system what we have not sufficient knowledge to do by understanding, and the result is likely to be more confusion and more difficulty, because these organizations of various kinds will be limited by the systems which they have adopted.”²⁷ “Almost all of them have been formed by people who are not only interested in the subject, but who are also interested in certain systems of development—of which each system, of course, contains the only elements of thorough value in dealing with the situation.”²⁸

The distinct incentives of builders and of operators and the separation of these two functions into separate people and departments according to line-and-staff or Taylorist principles had made innovation a conflict. Describing the tug-of-war between engineering and operating departments in steel making, an editor with *Blast Furnace and Steel Plant* typified the two kinds of men involved:

²⁴ Harry Tipper, “The Trend toward Decentralization in Organization,” *Automotive Industries*, 44 (1921): 670–671, quote, 670.

²⁵ Ibid.

²⁶ Harry Tipper, “Standardization without Understanding is Harmful,” *Automotive Industries*, 44 (1921): 720–721, quote, 720.

²⁷ Ibid.

²⁸ Ibid., 721.

"The operating and producing departments want progress, but want that progress without disturbance of a present condition of static comfort, order, and method; for change, even in the smallest routine matters, means change in existing relationships between present operatives; means change in functional activities; means change in mental processes."

...

"On the other hand, the engineering department thrives on change. Its business is drawing, and scheming and planning; ever investigating, making comparisons, weighing results of experimentation, adding, deducting, calculating, pitting the slide-rule against the rules of practical experience, tearing down on paper and rebuilding again, ever seeking..."²⁹

The wrenching difficulty of reworking efficient but inflexible production systems faced by Ford's in the later 1920s was marked more generally by awareness of the commercial value of style-based product differentiation. "There has been an increasing education in style and good taste throughout the country, and competition has learned how profitable to respond to the desire for products in better taste."³⁰ This sense of accelerating competition in consumer markets made an odd pair of war and fashion—both drove the need to continuously improve (or at least restyle) products. As a consequence, the coordination of engineering development and production grew more complicated as technical progress seemed to accelerate and because apparatus needed to "be frequently redesigned with distinctive design features to change appearance more than the performance, and attract the attention of the market."³¹

Explaining the role of development departments toward the end of the period covered in this chapter, a manager noted,

"It is characteristic of human nature to strive for improvement, for more perfect performance, for competitive advantage. The consumer expects improved quality and lowered prices each year; the competitor expects to increase his share of the business. Hence, over any substantial period of time, no business enterprise can be static without retrogression. It must be the responsibility of some unit in the enterprise to meet change with change, to beat the gun on changes, to anticipate the demands of the consumer and the performance of the competitor. This unit is *development*, basically a non-repetitive job."³²

²⁹ F.J. Crolius, "The Relation of the Engineering Department to the Operating Department," *Proceedings of the Engineers' Society of Western Pennsylvania* 40 (1924): 45–55, quote, 45–46.

³⁰ Ben Nash, comments to Richard F. Wilder, "Coordination of Research, Sales, and Production," *Transactions of the American Society of Mechanical Engineers* MAN-54-4b (1932): 36.

³¹ Roscoe Seybold, "Controlling the Cost of Research, Design and Development," 9.

³² C.C. Heritage, "Budgeting Research and Development," *The Paper Industry and Paper World* (March 1940): 1255.

Emphasis on human nature in this last citation and Tipper's concern for differentiation among individuals reflected shifts in management theory since the heyday of scientific management. Reacting against Fordism and seeking a reconciliation of the individual and mass production, writers of the 1920s and 1930s began to articulate the 'human relations' paradigm.³³ In Mauro Guillén's timeline, the earliest canonical expression of this view came with Elton Mayo's *Human Problems of an Industrial Civilization* of 1933, which applied perspectives akin to those of turn-of-the-century German sociologists to American mass production, as seen from the far side of the boom of the 1920s.³⁴ But, as Guillén acknowledges, the work of Mayo and others extended concern for recognizing the "human element" or "human factor" that appeared in opposition to scientific management from the 1910s. Tipper's comments were part of this concern, marked also in the writings of Mary Parker Follett.³⁵ These writings were, though, part of a literature on resistance, accommodation, and reconciliation in relation to large scale, bureaucratic processes and volume production. Like the larger effusion of work on human relations during the 1950s, the focus of such works was in tempering these processes and the human experience of them. By contrast, efforts to understand project-based organizing derived from basic limits to the possibility of regular output.

Like other building activities, product development was an irregular activity carried on in a world that valued regularity. Both micro- and macroeconomic agendas in the interwar period—before as well as during the depression—focused on stabilization. The American Management Association's annual convention in 1926 included a number of papers and a symposium on the "regularization of industry." Regularization of production in irregular markets meant production for stock rather than to order as a means of buffering.³⁶ As with earlier variants of such theories, these sought system stability through mechanisms that acted as automatically as possible. In the period covered here, statistical quality control and production engineering extended the application of mathematical techniques in tweaking factory production and reducing variance. The bigger story was of the application of

³³ Guillén, *Models of Management*, 58–80, is a succinct overview of the academic mainstream of this development in the United States.

³⁴ Elton Mayo, *The Human Problems of an Industrial Civilization* (New York: Macmillan, 1933).

³⁵ Mary Parker Follett, *The New State: Group Organization, the Solution of Popular Government* (New York: Longmans, Green, 1918), *Creative Experience* (New York: Longmans, Green, 1924).

³⁶ Willis Wissler, et al. "Planning and Maintaining a Regular Flow of Work and Employment." *American Management Association Production Executives' Series* no. 37 (1926): 28–39.

regulatory science to macroeconomic phenomenon, most notably expressed in New Deal economic policy. Like the regulation of steam engines, the economics of the New Deal was a science of correction, in which government intervention would serve to offset irregularities.

The politics of stabilization put construction work and innovation in a strange light. In a 1931 article, L.E. Jermy, the editor of *Machine Design* acknowledged, "the engineer is definitely on the defensive" given widespread public scrutiny of the engineering profession and its outlook with the onset of the depression and blame of Hoover's administration.³⁷ This position reflected perceptions not of how the engineer worked but of the products of engineering. Jermy went on to stress the social function of the engineer and the need to actively consider external relationships with the goal that new machines "are installed in the industrial and social world without undue shock."³⁸ "Technical unemployment," the displacement of human labor by machines, was seen as a cause of a crisis of overproduction created by increasing output while reducing the ability of workers to purchase that output. This logic led to theories of means by which the government could get money into the pockets of consumers. A chief mechanism was through public works projects.

Writing in early 1933 as the depression worsened, Leo Wolman, a Columbia University economist, commented in *Engineering News-Record* that "The virtues of public expenditures in construction have, in fact, been so extravagantly praised that there has become attached to public works a magical potency hitherto associated only with inflation."³⁹ Wolman noted that there were several theories of how this potency would work its magic, each associated with a different period of the depression. In the earliest, during late 1929 and 1930, people had believed and President Hoover had argued for continued private and public capital expenditure at pre-1929 levels that would check the downward momentum of "a brief corrective moment." By late 1930, the failure of this effort was palpable and this theory was replaced by another:

"...the even more elaborate hypothesis that depressions of extraordinary magnitude are likely to become cumulatively worse unless they are arrested by the action of some fortuitous circumstance, such as war, a crop failure, an epoch-making invention and the like. Failing the intervention of uncontrollable forces of this nature, it became imperative to devise a practicable and effective substitute for them. And of the available substitutes,

³⁷ Jermy, J.L. "Shall We Revise Our Conceptions of Engineering Functions?" *Machine Design* 3 (1931): 23.

³⁸ Ibid.

³⁹ Leo Wolman, "Financial Aspects of Budgeting Public-Works Construction," *Engineering News-Record* (1933): 659.

the release of large public funds for the purchase of materials and the payment of wages in the furtherance of projects of public improvements appeared the most natural and the most practicable of expedients.”⁴⁰

Though there were competing theories as to the mechanisms by which the economy could be best equilibrated, writing in *Mechanical Engineering* in the early years of World War II Paul Samuelson observed that “economists are increasingly of the opinion that an important casual element of the cycle is to be found in the behavior of real investment.”⁴¹ During the depression of the 1930s, capital spending became both the source of and solution to economic problems. Ironically, irregular projects came to be a mechanism by which the economy could be regulated, a theory expressed in depression-era work programs. While this discussion may seem to have wandered from the organization of aircraft engineering, it illustrates the continued importance of regular, volume production as *the* foil for explanations of other production logics. Criticism of the aircraft industry both before and after World War II focused on its deviance from the model set by the automobile industry.⁴² Common welfare was broadly associated with the smooth functioning of an engine-like economy and measures taken to cloak projects in auras of expertise and certitude after World War II can be seen as marking lessons learned from the *political* experiences of the aircraft business.⁴³

Journal Aeronautical Engineering and a Developing Technical Community

The inaugural issue of *Aviation and Aeronautical Engineering* in August 1916 announced its intention to serve as a gatherer of technical information “useful to the constructor, the engine maker, the aviator, and the sportsman.”⁴⁴ Immediately following was a brief note that “congressional appropriations for aeronautics have shown that at last the importance of this arm of the military and naval service is being taken seriously,” thanks partly to “the public, awakened as it is by the daily reports of air exploits, [being] in a mood to support any action which Washington takes in the

⁴⁰ Ibid., 660.

⁴¹ Samuelson, Paul A. “Building and Business,” a review of Clarence D. Long Jr., *Building Cycles and the Theory of Investment* (Princeton: Princeton University Press, 1940), *Mechanical Engineering* (1941): 286.

⁴² A commissioned report prepared by the Harvard Business School in 1947 can be read as marking the degree to which volume production was an *idée fixe* in academic perceptions of business administration. Tom Lilley et al., *Problems of Accelerating Aircraft Production During World War II* (Cambridge: Division of Research, Harvard Business School, 1947).

⁴³ I have no evidence to support the implication that post-war managers of weapons programs consciously learned from criticism of the aircraft industry—this observation is suggestive.

⁴⁴ 1 (August 1, 1916): 7.

direction of American supremacy in the air.”⁴⁵ Among its early pages was a running “Course in Aerodynamics and Aeroplane Design,” by two MIT Instructors.⁴⁶ Early issues carried advertisements for spruce logs, aluminum castings, flying schools, engines, and complete aircraft. Like other engineering disciplines and industries before it, the development of aeronautics was tracked in a journal literature and marked by professional association.

The Institute of the Aeronautical Sciences (IAS) was organized in 1932. There had been earlier efforts to establish a professional association in aeronautics, but for practical work committees within the ASME and the SAE served this function. Early academic work in the aeronautical science was served by journals in physics. When the IAS did form, it did so with the initial aid of the American Physical Society. The IAS publication, the *Journal of the Aeronautical Sciences*, initially carried advertisements, but dropped these after two years, seeking a more academic position. It did, though, continue to provide a “personnel opportunities” column that was “the means of arranging several very successful connections for members.” A typical example of a notice in this column read,

“Engineer wishes to make new connection. Four years of stress analysis, layout, and detail design. Has thorough knowledge of Army and new Department of Commerce Requirements. M.I.T. Graduate.”⁴⁷

Slipstream noted in 1928 that several firms of consulting engineers had set up to assist airline operators and aircraft manufacturers.⁴⁸ As with earlier eras of system building in other industries, a general sense of the trajectory of the aircraft building and operating and the formation of divisions of labor and thought collectives in relation to it can be provided by tracing the emergence, swarming, and consolidation of its journal literature (figure 4.2).

From early efforts to serve balloonists, the periodical literature in aviation gained some altitude with the Wright Brothers’ 1903 flight at Kitty Hawk, but through the 1910s most magazines remained oriented to hobbyist airplane builders and flyers. Anticipating a boom, entrepreneurial journals addressed to the engineer and operator appeared in greater numbers in the 1920s. Describing this

⁴⁵ “The Appropriations for Aeronautics,” 1 (1916): 7.

⁴⁶ A. Klemm and T.H. Huff, with the introductory “lecture” appearing in 1 (1916): 9–16.

⁴⁷ *Journal of the Aeronautical Sciences* 3 (March, 1936) 182.

⁴⁸ (June 1928): 42.

Figure 4.2--Aviation and aerospace periodicals, 1880--1980.

phenomenon, *Slipstream* correspondent "Wing Dope" described the "indefinite number of aeronautical magazines on exhibit" at a 1928 air show in Detroit as having included the "*Eyebolt Digest*," the "*Airport Seedplanter's Guide*," and the "*Wing-Coverer's Needle Guild Journal*."⁴⁹ Marking belief that the business was on more certain terms, Simmons-Boardman Publishing Company later that year bought several early promoter-oriented journals—*Slipstream*, *Aerial Age*, *Flying*, and *International Aeronautics*. On acquiring *Slipstream*, Simmons-Boardman described itself as "a new stabilizer" in an industry "approaching the commercially practicable stage."⁵⁰ Simmons-Boardman had made a business of taking over publications during such transitions, having similarly acquired *American Engineer and Railroad Journal* (the erstwhile *American Railway Journal* of Minor and Poor) and the *Marine Engineering and Shipping Age* at moments of industry consolidation.

Reflecting the continued overlap of constituencies for aircraft periodicals, in its monthly digest a typical issue of the *Aeronautical Engineering Review* from during World War II abstracted articles on aircraft production from *Flying and Popular Aviation*, *Aviation*, *Wings*, *Aero Digest*, *Western Flying*, *Automotive and Aviation Industries*, *Metals and Alloys*, *Commercial Aviation*, *Mechanical Engineering*, the *SAE Journal*, and *American Machinist*. But by this time, the periodical literature no longer needed to define the industry. In response to the war, there was a great effusion of handbook publications and training courses created to aid the enlistment of workers in support of the national defense.⁵¹ Writing of this, one 1943 book noted, "schools, institutes, and technical courses have been established for the preparation and training of aircraft welders, riveters, sheet metal workers, engine mechanics, and so forth. Also, numerous articles, books, pamphlets, and mechanic's handbooks have been prepared for this purpose."⁵² The author of these words proposed to fill a gap in this literature by considering the organization of production departments. In addition to their expositions of technical

⁴⁹ "Impressions Gained at the All-American Air Show," 9 (May 1928): 23.

⁵⁰ 9 (June 1928): 6. In 1928, Simmons-Boardman owned *Railway Age*, *Railway Mechanical Engineer*, *Railway Engineering and Maintenance*, *Railway Electrical Engineer*, *Railway Signaling*, *Boiler Maker*, and *Marine Engineering and Shipping Age*.

⁵¹ Examples include C.F. Marschner, *Aircraft Assembly* (New York: Pitman Publishing Corporation, 1942); Alex M. Robson, *Airplane Metal Work and Shop Practice* (4 vols., New York: D. Van Nostrand Company, Inc., 1940); and Stuart Leavell and Stanley Bungay, *Aircraft Production Standards* (New York: McGraw-Hill, 1943).

⁵² H.D. MacKinnon, *Aircraft Production: Planning and Control* (New York: Pitman Publishing Corporation, 1943), v.

subject matter, these handbooks usefully present organizational forms that had become dominant in aircraft production. The next section examines these and where they came from.

Sections into Subassemblies: Organizing Aircraft Production

What construction contractors and civil engineers called 'sections,' aircraft manufacturers and their project engineers called 'subassemblies.' The underlying logic of breaking work into component parts was the same under either terminology. The overall system was cut into manageable pieces that were then assembled. As in construction, this was the basic organizing principle in aircraft production, evident in budgets, Gantt charts, factory floor arrangements, organization charts, and the arrangement of the industry as a whole. Demarcations between subassemblies both followed divisions of labor and determined them.

In an official history of aircraft procurement during World War II written in the 1960s, I.B. Holley described the division of the prewar aircraft industry into engine makers and airframe suppliers, but asserted "most airplane manufacturers did not rely heavily upon subcontractors for components and subassemblies."⁵³ Describing investments in new plant and equipment during the 1930s by companies including Consolidated Aircraft, Boeing, and Curtis, Holley stated, "unfortunately for the cause of national defense, the appearance of facilities fully adequate for continuous, straight-line operations did not actually herald the day of mass production," and that instead firms "continued to fabricate airplanes in piecemeal fashion with handiwork the rule rather than the exception."⁵⁴ He lamented, "in one typical large-scale manufacturing establishment there were several groups of functional specialists: an aerodynamics group, a landing gear group, a fuselage group, a weight control group, and, finally, a general group handling details for all groups including such matters as specifications, preparation of handbooks, operating manuals, spares lists, bills of materials, production releases, and contract requirements. Clearly, engineers dominated the field."⁵⁵ Surveying the periodical literature up to 1939, Holley saw that "for every infrequent article on tooling and production engineering in the thirties, one can find literally hundreds of articles on experimental

⁵³ Irving Brinton Holley, Jr. *Buying Aircraft: Matériel Procurement for the Army Air Forces* (Washington, D.C.: Office of the Chief of Military History, Department of the Army, 1964), 7. Holley restated many conclusions from Tom Lilley, et al., *Problems of Accelerating Aircraft Production During World War II*.

⁵⁴ *Ibid.*, 29.

⁵⁵ *Ibid.*, 32.

engineering and design.” Despite his general tone, Holley did acknowledge a basic difference between automobiles and aircraft during the 1930s: the latter, he noted, were in the midst of “a violent technological revolution.”⁵⁶

Describing a forced shift from informal management to more elaborate systems during the early war years, a 1947 study by the Harvard Business School similarly implied that there had been no systematic management in the industry:

“In the process of substituting paperwork for face-to-face relationships no one could be expected to set up in a first attempt a system which included all the necessary communications. Much important information failed to reach the right persons. Thus, innumerable crises arose as one part of a company’s operations got out of line with the its other activities. Only after much struggling was real progress made in establishing systems of adequate controls that would give danger signals as operations began to get out of balance. Ultimately, some companies tended to believe that all difficulties could be solved by using the proper systems, with a resultant overemphasis on paperwork during the later stages of the expansion.”⁵⁷

This study failed to consider just what controls were in place before the war and gave short shrift to the reasons irregularity and flexibility persisted in the aircraft industry. Three decades earlier, as the United States mustered materiel for World War I, a wing commander with the Royal Naval Air Service presented a paper to the SAE in which he argued against standardization and quantity production, noting that “from what I have so far read and heard, I have gathered, perhaps wrongly—indeed, I sincerely hope so—that manufacturers here are far more anxious to reproduce standard types of aircraft, than to enter the field as designers and builders of original types of aircraft.”⁵⁸ He judged the “vogue-period” for a single-seat fighter aircraft at about six months, by the end of which time it would be militarily obsolete.

Commenting on an ASME paper on the design of aircraft manufacturing facilities in 1930, a member from Boeing described how in the preceding four years the basic structure of his company’s product had gone from welded tubular steel bodies and fabric-covered wood wings, to welded steel and bolted dural bodies with the same wings, then to a hybrid of the earlier body forms, and most

⁵⁶ Ibid., 28.

⁵⁷ Tom Lilley, et al., *Problems of Accelerating Aircraft Production During World War II*, 59.

⁵⁸ I.W. Seddon, “Design and Production of Aircraft in War Time,” *S.A.E. Journal* 12 (May, 1917): 204–210.

lately to all metal construction.⁵⁹ In consequence of these shifts, he noted, there had been “quite a change... in the shop organization.” In 1927, skilled electric welders and cabinetmakers were among Boeing’s most important employees but by 1930 these trades had been almost entirely displaced by sheet metal workers and riveters. In the same period, the plant had had to adjust to a ten-fold increase in finished aircraft weights and an over four-fold increase in wing spans. The communication technologies adopted by the aircraft business to cope with such shifts included a language of release dates, design freezes, and change orders as well as Gantt charts, assembly diagrams, conferences, and project squads.

The Logic of Projects in Aircraft Engineering

Writing in *Industrial Engineering* on the eve of the armistice in 1918, an anonymous industrial engineer contrasted the view of the military man with that of the manufacturer. Noting that in pre-war aircraft production one aircraft per month was considered large production and that most companies worked “on a small jobbing scale,” this author stated directly, “the airplane manufacturers were not versed in the art of mass production and their plants were not suited to it in size, personnel, equipment, nor organization.”⁶⁰ But, at the same time, as automobile makers were drawn to the field, they had failed to understand the nature of the market for aircraft. The military man might dislike change, but “he has to make changes, and make them promptly, in order to meet new conditions—conditions over which he has no control.”⁶¹ A little over two decades later, with another war underway, *Product Engineering* wrote on the distinctions between aircraft and automobiles. The magazine noted that “not many recognize the absolute necessity for flexible engineering designs and production methods” in aircraft.⁶² The pre-war build up of the air fleet had occasioned “a great deal of shouting about ‘freezing the design,’ the implication being that with the designs ‘frozen,’ aircraft production could be put on a basis similar to automobile manufacture.” Where the “steel dies,

⁵⁹ Gardner Carr, comments to G.W. Plaisted, “The Layout and Design of Modern Airplane Plants,” *Aeronautical Engineering* 3 (April-June 1931): 77–81, quote, 81. On manufacturing problems, see also several papers written for ASME’s Fourth National Aeronautic Meeting, Dayton, May 19–22, 1930, and printed in *Aeronautical Engineering*.

⁶⁰ An Industrial Engineer, “Effect of Changes on Airplane Output: Manufacturers Must Abandon the Idea of Standardized Production,” *Industrial Engineering* 56 (1918): 375–377, quote, 375. See also in the same volume, C.H. Hart, “Airplane Cost Finding,” 56 (1918): 208.

⁶¹ *Ibid.*, 375.

⁶² G.F. Nordenholt, “Aircraft are Different,” *Product Engineering* (May 1942): 368.

elaborate assembly lines, and all the other embellishments for mass production 'a la Detroit' would kill all further design improvements or torpedo the production schedule." In the intervening years, and in common with other engineering-intensive businesses, aircraft companies had adopted project-based methods to order limited-term production. As an engineering manager writing in *American Machinist* noted, a fixed organization would not work in any engineering department "on account of the necessity of frequently breaking into a smoothly operating department and turning it topsy-turvy...."⁶³

Describing "Airplane Production Problems," the president of the Curtiss-Robertson Airplane Manufacturing Company described the sequence of events in making an airplane:

"Production routine includes the sequence of production in an organized factory, starting with the original conception of the design; its impression upon the officials who are competent to authorize sales estimates; its release from the engineering department; the steps in securing the raw material and passing it through the stock room, the inspection department, and factory management; and the assembly and delivery of the finished airplane into the hands of the sales or distributing organization."⁶⁴

This author suggested, "a good first-production trial run is 25 machines," a number determined by the need to give "serious consideration to tooling the major and expensive items."⁶⁵ Continuing this line of reasoning, he assumed a 500 machine annual output and that minor items would make up the bulk of engineering changes. Anticipating criticism of his figures, he noted that there were three factories in the United States that had built more than 500 aircraft in 1929.

Such a description and such projections were hardly relevant. An engineer at Keystone Aircraft, a Pennsylvania manufacturer, noted, "it is far more sensible for us at this time to consider the practical difficulties we are encountering, and which are analogous to those in the bus, custom built car, and boat industries, than to talk feely in terms of 'line production,' which will not be reached on articles requiring the present amount of engineering technique for a very long time."⁶⁶ He described Keystone's attempt to set up a distribution network at the peak of the market in 1929, a miserable failure as aircraft built for stock were obsolete and unwanted almost by the time they reached local agents. He attributed this to a cycle in consumer psychology in which the latest engineering

⁶³ P.H. Bryant, "Some Comments on Engineering Department Organization." *American Machinist* 63 (1925): 233.

⁶⁴ William B. Robertson, "Airplane Production Problems," *S.A.E. Journal* 27 (1930): 234-236, quote, 234.

⁶⁵ *Ibid.*, 234.

⁶⁶ R.S. Damone, "Production Methods," *Aviation Engineering* 5 (November, 1931) 28-31, quote, 28.

improvement lost its ability to attract customers as soon as it was readily available, at which time orders would start to pile in for the next improved model. Significantly, this engineer likened Keystone's governance to construction contracting, in which field he had started his career.

Kits of Parts

In 1943, with large volume production suddenly the norm in aircraft production, the method used to track work in progress at North American Aviation required elaborate numbering based on assemblies and subassemblies. In order to cope with both volume production and an influx of new workers into the aircraft industry, elaborate visual representations of the product and its subassemblies were used to divide work and establish schedules. Scheduling work was then based on an established first-flight date, the closeness of which would dictate definition of what would constitute sufficient design. North American's engineering department typically released drawings for production work when the design was considered 80% complete, but this number could be lowered under duress. Upon receipt of a contract, the chief engineer called in "the chief project engineer, project engineer, planning engineer, electrical engineer, and the power plant engineer." These people then planned simultaneously the technical and manpower management.⁶⁷

"When sufficient information is available concerning the construction and equipment of the airplane, a drawing breakdown chart is made showing the major assemblies previously determined and establishing the major subassemblies in the proper relation to the completed airplane. This chart shows the structural parts of the airplane in an exploded view, and in addition system parts such as electrical, radio, and hydraulic. New estimates of the required drafting man-hours are made of each assembly shown on the drawing breakdown chart. These are the scheduling units by which the planner maintains a follow-up of the work; this is placed on a Gantt Chart, which shows the start and finish of each unit and the personnel required weekly. The time is applied on the Gantt Chart in connection with the basic curve, developed from the basic curve, developed from recorded past performances, showing what is considered the maximum efficient rate that man-hours can be applied to a contract."⁶⁸

Over the course of the contract, elaborate card-file systems were used to track progress both by engineering subassembly and aircraft. Any aircraft in production at the time a design change took place received special treatment, since affected parts would need to be pulled from the sequence and modified or replaced. Individual subassemblies were released for production when they reached the

⁶⁷ Paul Sheets, "Planned Engineering Records Aid Production Scheduling," *Product Engineering* (July, 1943): 400-405.

⁶⁸ Ibid.

80% engineered mark even if the aircraft as a whole had not reached that stage. Trumpeting North American's production achievements, an article in *Aviation* focused on the B-25 as a flexible aircraft built through flexible production methods.⁶⁹ Construction of the B-25 used a "component breakdown plan" in which subassemblies, after initial "tie-together," were moved in wheeled jigs along separate lines before coming together on a "master jig" and down a final assembly line. Though not from North American, the diagram in figures 4.3 and 4.4 illustrate the manner in which a production run could be conceived as a single object.

Fig. 14. Scheduling system.

Figures 4.3—The life of a contract as it passed from the Air Corps through scheduling and engineering to the shop floor. The assembly line is shown as involving twelve stations supplied by fabricating, subassembly, and surface departments. From H.D. MacKinnon, Jr., *Aircraft Production Planning and Control* (New York: Pitman Publishing Corporation, 1943), 55.

⁶⁹ Robert E. Dawe, "Producing the B-25 Bomber," *Aviation* 42 (1943): 106–111, 359–362. This article is typical of others. See J.M. Gwinn, "B-24s in Quantity Production," *Aviation* 41 (July 1942): 98–103, 323; and, Jay P. AuWerter, "Bombers in Quantity," *Aviation* 39 (November 1940): 34–37, 108.

AIRCRAFT MANUFACTURER

PLANNING RELEASE SCHEDULE

January 15, 1943

Page 1

Model AT W.O. 140-500

	500-A, 5 units					500-B, 10 units					500-C, 15 units					500-D, 30 units				
	Serial Nos. 863-867 incl.					Serial Nos. 868-877 incl.					Serial Nos. 878-892 incl.					Serial Nos. 893-922 incl.				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
1	160	175	185	200	205	193	208	218	233	238	210	225	235	250	255	217	232	242	257	262
2	166	181	191	206	211	199	214	224	239	244	217	232	242	257	262	223	239	249	264	269
3	187	201	212	227	231	206	221	231	246	251	231	236	246	261	266	228	243	253	268	273
4	190	205	215	230	235	210	225	235	250	255	235	240	250	265	270	232	247	257	272	277
5	197	208	218	233	238	211	226	236	251	256	236	243	253	268	273	235	250	260	275	280
6	198	211	221	236	241	216	231	241	256	261	231	246	256	271	276	238	253	263	278	283
7	199	214	224	239	244	219	234	244	259	264	234	249	259	274	279	241	256	266	281	286
8	204	217	227	242	247	224	239	249	264	269	237	252	262	277	282	244	259	269	284	289
9	205	220	230	245	250	228	243	253	268	273	241	256	266	281	286	248	263	273	288	293
10	208	223	233	248	253	231	247	257	272	277	244	259	269	284	289	251	266	276	291	296
11	211	226	236	251	256	236	251	261	276	281	247	262	272	287	292	254	269	279	294	299
12	215	230	240	255	260	240	255	265	280	285	250	265	275	290	295	257	272	282	297	302

A - Machine and Outside Production Parts--

B - Sheet Metal Detail--Elec. Wiring--Conduit--Plumbing

C - Subassemblies

D - Major Assemblies

E - Position

Figures 4.4—A schedule of production releases for component parts by batch number by part type by station in the assembly line. The numbers within the grid are days relative to the start of the program. From H.D. MacKinnon, Jr., *Aircraft Production Planning and Control* (New York: Pitman Publishing Corporation, 1943), 60.

Where in construction the rough-and-ready predictors of costs was in yards of material or square feet of finished space, in aircraft, the comparable figure was the weight of the aircraft less engines and propellers. Just as an engineering contractor could predict labor costs and time from a number such as gross building area, an aircraft engineer could back into man-hours from an estimate of pounds of aluminum, wiring, cables, and so forth. Based on this estimate and an approximately normal curve that described the allocation of hours over the course of a typical aircraft-engineering project, labor costs could then be plotted over time (figure 4.5).

Figure 4.5—A "project performance" diagram used at Lockheed Aircraft Corporation. H.F. McCann, "Engineering Planning," *Aero Digest* 37 (August 1940), 65.

Figure 4.5 merits further comment because it marks the use of the arbitrary divisions and markers to structure projects. Using rule-of-thumb bases for estimating overall time required, the steps in the process and the significant milestones along the way were set using simple fractions and round percentages. In using these markers, an engineer could describe a project in terms of a temporal dynamic willed onto the uncertain work involved, providing a familiar set of events in spite of the unfamiliar technical and social relationships the project might bring.

Project Engineering

The role noted in North American Aviation's description of its organization—the project engineer—was common to the aircraft industry by the mid 1920s. There was no standard term for this

position, with firms adopting titles such as "contract engineer," "squad leader," "development engineer," and "project supervisor." In common, the role of this person was somewhere between that of a foreman and a line manager, serving to shepherd work across functional lines and providing a point of contact for external relations. He was a sort of internal general contractor. The use of projects and project engineers was also common in other product development organizations as a means of integrating functions and aligning responsibilities and, in order to set aircraft engineering in broader discussions of the management of product engineering, a brief detour is merited.

The Coleman Lamp and Stove Company assigned "project engineers" who would see a product from design into production.⁷⁰ A similar method was used at Cutler-Hammer, a Milwaukee electrical apparatus manufacturer.⁷¹ Cutler-Hammer assigned projects to development engineers, who followed development from inception until the design was either rejected or entered into production. In another case, that of a boiler manufacturer's operations, a similar position was assigned to a "job leader," who was "the coordinating factor between all other squads and the distributing agent for the dissemination of all information pertinent to the drafting work of the design as a whole." Under this leader "contract engineers" acted as the "coordinating factors between customers and the corporation in the establishment of designs throughout the life of the job in the drafting department."⁷²

In balancing flows of work, a chief task of these people was to reassign work among squads and individuals among squads in an effort toward "straightening up the work curve." The tools used to carry this out echoed those in use in early cost accounting practice, such as tracking cards that stayed with the job rather than at a workstation and accounts and schedules maintained on the basis of the object being created rather than the time available from each employee or machine. As noted above, the project engineer was responsible for internal and external coordination. "Unless all parties involved in a combined contract of this kind are working at the same speed, each coping with their design problems in the proper sequence, there will be difficulties and delays."⁷³ Attempting to illustrate the integrative role of the engineering administrator, L.E. Jermy, the editor of *Machine*

⁷⁰ See H.W. Strong, discussion of O.D. Reich, "Effect of Design on Overhead." *American Management Association Production Series* no. 93 (1931): 11-12.

⁷¹ See "Control of New-Product Development." *Factory and Industrial Management* (March 1931): 437-438, 454.

⁷² Kunz, William J. "Production Management Applied to the Drafting Department." *Transactions of the American Society of Mechanical Engineers* MAN-54-1 (1932): 1-8, quote, 2.

⁷³ *Ibid.*, 8.

Design, contrasted an incorrect image location of the chief engineer's relationships on an organization chart (Figure 4.6) with a proper representation (Figure 4.7):⁷⁴

Figures 4.6—An incorrect depiction of the place of the chief engineer per J.L. Jermy "Shall We Revise Our Conceptions of Engineering Functions?" *Machine Design* 3 (May 1931): 25.

Figures 4.7—A correct depiction of the place of the chief engineer per J.L. Jermy "Shall We Revise Our Conceptions of Engineering Functions?" *Machine Design* 3 (May 1931): 23.

⁷⁴ Jermy, J.L. "Shall We Revise Our Conceptions of Engineering Functions?" *Machine Design* 3 (May 1931): 23–25.

Since the diagrammed exchanges could not be entirely predicted, effecting the correct location was a matter of interoffice memoranda, visits, reports, conferences, meetings, and committees.⁷⁵ The unpredictability of engineering work meant that the project engineer and these forums and documents served as clutches or buffers between the routines of the production line and the irregularities of development. A typical commentary on the need for this mediating function echoed comments on the management of scientists discussed in the previous chapter. "At a recent meeting between executives and engineers of a large plant," one engineer-manager observed, "the general manager remarked that engineers were a peculiar lot and the hardest to handle of all departments."⁷⁶ This author further noted the difference between engineering work and other labors. "Methods that are legitimate and productive of results will not work at all, except negatively, in a department for development... You can drive a machine operator to a certain action and his machine will do the rest, but you must not drive a man engaged in creative work at a speed in excess of his natural mental capacity and expect to get greater brain output...." He continued, "the higher grades of men... reach the peak of their ability when allowed to set their own pace."⁷⁷ "Managers who try to railroad work through their engineering departments have been chagrined at their failure to get a better product in a shorter time without a lowering of both quantity and quality. This is peculiar without a doubt, but its peculiarity disappears when the personal characteristics of the employee are given consideration and dealt with accordingly."⁷⁸ At best, a manager could expect only brief spurts of activities from a "brain worker," and these would be need to be compensated by extended periods of rest. While this author expressly limited his discussion to small engineering departments, similar comments can be found in writings across a spectrum of similar labors and organizations.

J.L. Alden of Western Electric described the organization of engineering design in the Hawthorne Works. In two articles based on a paper he presented to the Machine Shop Practice Division of ASME at its 1931 meeting, Alden set out some problems he had encountered at Western Electric. He noted that it was "easier for a design force to become stagnant and ingrown than for any group of

⁷⁵ Jermy, J.L. "Co-ordinating Engineering with other Company Activities," *Machine Design* 3 (June 1931): 27-29.

⁷⁶ Bryant, P.H. "Some Comments on Engineering Department Organization." *American Machinist* 63, no. 6 (August 6, 1925): 234.

⁷⁷ Ibid.

⁷⁸ Ibid.

technical men of equal ability. Broadening contacts are often absent, habits of thought become fixed, and an attitude of self-sufficiency is developed which is a bar to the progress not only of the organization but of the individual as well.”⁷⁹ Describing the movement of information in the course of project using the conventions of a production flow chart, he created a labored diagram (figure 4.8):

Figure 4.8—J.L. Alden, “Care in Selection of Personnel Marks Good Management,” *Machine Design* (December, 1931): 37–38.

Alden’s effort reflects pressure to extend the certainty and system of the shop floor to planning functions. Though from almost a decade earlier, a 1923 article in *American Machinist* is typical,

“Much has been said and done in the interest of industrial efficiency, but unfortunately these activities have for the most part been confined to actual production and the so-called ‘non-operating’ departments have received very little attention. Most seriously has the engineering branch of industry been neglected. The department, which plans and advises efficient and economical means of mechanical production, is often the least efficient in the use of its own time.”⁸⁰

The author of this paragraph explained his experience with a company in which “it was found that not all of the lost time was the result of dilatory habits and absences” but because of “the men not

⁷⁹ J.L. Alden, “Machine-Design Management,” *Transactions of the American Society of Mechanical Engineers* MSP-54-9 (1932): 105–118, quote, 106. A condensed version of this paper is J.L. Alden, “Care in Selection of Personnel Marks Good Management,” *Machine Design* (December, 1931): 37–38.

⁸⁰ Warren P. Willet, “Efficiency in the Engineering Department,” *American Machinist* 59 (1923): 706.

knowing what to do next.” Consequently, the chief engineer had increasingly spent his time keeping his staff occupied. The solution he recommended was a schedule board that would allow work orders to be placed in grid by designer by date required (figure 4.9). This would allow the chief to monitor workloads and move assignments *en masse* despite the individuality of work.

DATE	DESIGNER	DESIGNER	DESIGNER	DETAILER	DETAILER	TRACER	TRACER	CHECKER	DATE
1									1
2									2
3									3
4									4
5									5

SCHEDULE BOARD FOR AN ENGINEERING DEPARTMENT

Figure 4.9—Tracking system for work in an engineering department. Source: Warren P. Willet, “Efficiency in the Engineering Department,” *American Machinist* 59 (1923).

Returning to aircraft engineering, similar issues were described in locating the function of the project engineer. Because of frequent changes in design, engineering and production were located in close proximity. “Production orders for airplanes are in relatively small quantities, and are subject to numerous changes during fabrication, which requires the constant service of the engineering department throughout the life of the order.”⁸¹ Because of this, centralization of engineering where a company had multiple plants was not considered practical, in contrast to the automobile industry. The author of these words explained the use of “project engineers” to oversee design, noting that this was the most interesting aspect of the organization. Project engineers were to be experienced men who had specialized in the type of aircraft under design. Their knowledge was to embrace both manufacturing and the specifications of the army, navy, or Department of Commerce, serving as the Chief Engineer’s delegate in enforcing the relevant specification.

In a similar exposition, a 1929 article in *Aviation Engineering* provided two illustrations of the position of project engineers, calling them line-and-staff and functional (figures 4.10 and 4.11). This article described the role of the “project engineer” as the coordinator.⁸²

⁸¹ E. Molloy, “Engineering Organization in the Aircraft Factory,” paper presented to the Fourth National Aeronautic Meeting of the American Society of Mechanical Engineers, May 19 to 20, 1930. A.S.M.E. Miscellaneous Papers, Linda Hall Library, 2.

⁸² Sidney H. Goldman, “Engineering Organization,” *Aviation Engineering* 2 (June 1929): 15–16, 28.

FIG. 1. LINE & STAFF ORGANIZATION

Figures 4.10 (top) and 4.11 (bottom)—“Line and Staff” and “Functional” organizations in a project-oriented plant. From Goldman, “Engineering Organization,” *Aviation Engineering* (June, 1929)

The article explained,

“The Project Engineer is the co-ordinator of work. He is placed in both types of organization illustrated, but the similarity is in name and not in function. In the line and staff organization, the Project Engineer is assigned to a model, or a series of models of recurrent similarity. In addition to coordinating work on the plane, he may also do some of the actual work; direct the major trends of drafting, instigate minor design innovations, make his own stress analysis of minor parts, etc. In the functional organization, however, his efforts are highly unified and centralized. He coordinates, but his stress work is done by the structural division, his drafting contract is replaced by lead men, and he no longer handles an entire model, but rather, a unit; landing gears, wings, etc. He coordinates departmental engineering for his unit, and a job manager supervises co-ordination between Project Engineers.”⁸³

⁸³ Ibid., 16.

In this capacity, project engineers handled all correspondence, preparation of data for customer approval, change orders, approvals, and acted as liaisons among the engineering, tool, and manufacturing departments. This person also coordinated the work of the structural, research, and weight departments and draftsman were assigned to him for the duration of the project, or, if were specialized in the same type of airplane as the project engineer, "more or less permanently." Further, he worked with the acquiring agency to coordinate flight and service testing. While the author of this article considered both of the forms illustrated acceptable, he considered the functional organization to be "the truly scientific way," as it allowed complete division of labor under a leader "whose personality is the *esprit de corps* which create company pride, builds up good will, and makes the organization dynamically successful."⁸⁴

Turning to the method used to order engineering work at Lockheed on the eve of World War II, a 1942 article noted that in 1940, 70% of the engineering-hours scheduled in Lockheed's engineering department had been in commercial work.⁸⁵ A research manager and chiefs for research and projects worked under the overall department chief. The vast majority of the staff was under the project engineer, who kept track of his men in terms of staffs, projects, and, within projects, groups. In learning the ropes, engineering men were acquainted with a "Drafting Room Manual," a "Design Handbook," and, in the case of administrative personnel, a "General Management Book" covering drawing procedures, standard specifications, and company policies, respectively.

Once approved by the three chief engineers, the department's planning engineer developed a project schedule and time estimate. In making this estimate, the estimated empty weight of the aircraft (without power plants) was multiplied by an hours-per-pound factor. The resulting figure was then pro rated to different groups based on past experience and further divided by job title in order to generate a preliminary cost estimate and design schedule.⁸⁶ This result then passed to group supervisors who used standard forms to develop drawing counts that formed the basis of adjustments to the initial estimate and schedule. Scheduling for engineering was based on manufacturing sequence.

⁸⁴ Ibid., 16.

⁸⁵ Hall L. Hibbard, "Value Received from an Engineering Department," *Aviation* 39 (June, 1940): 44-45, 122, 124 and (July, 1940): 46-47, 104-106.

⁸⁶ Ibid., 47.

The staff engineers for each part or function served as technical advisors to the department as a whole and also for administering and maintaining organization charts for his staff.

"The project engineer is responsible for complete coordination of his project, including all activities outside the department... He is responsible for the meeting and completing of a design schedule and budgets... the making of decisions on all design problems affecting his project and the meeting of project weight schedules."⁸⁷

Beginning early in the war, Lockheed adopted an "Expediter System" that assigned men to "break production bottlenecks" using methods that ran "the gamut from direct action to applied psychology."⁸⁸ The "all-around men" selected for this function held regular social and athletic functions in order to promote teamwork. Lockheed further used a "specification staff" that relieved project groups and coordinated work between projects and other engineering departments by writing specifications for use by both engineering and production.⁸⁹ Various forms of specification also served as intermediaries with other departments. "Contract specifications" served to work out changes with customers and develop prices, with changes incorporated into "design directive and construction specifications," which in turn resulted in derivative brief and detailed "sales specifications," used to entice further orders. In this process, a specification staff engineer served "to translate the customer's requirements into the contract specification."⁹⁰ The expanded version was "stabilized" through the use of standard paragraphs. Describing the process and the reason it existed, a member of the engineering department explained,

"Since the first price is set by the specifications, changes to the specification, and thus the complete airplane, must necessarily include all effects on the contract and the specification as that change affects it... Upon approval by the chief engineer, the proposed changes are forwarded to the contract administration division for coordination with the customer and the contract.

"The basis for the preparation of all design directives is written instructions issued by the chief engineer. These instructions are supplemented by additional data of a general nature which have the approval of the chief engineer or chief research engineer, as indicated by written communication on file in the engineering specifications office.

"A draft of the proposed design directive is prepared and submitted for comment to the project engineer, the chief engineer and, in addition, the various sections pertaining to such items as power plant installation, electrical equipment, etc., are submitted to the

⁸⁷ Ibid., 106.

⁸⁸ Harvey C. Christen, "Lockheed Expediter System," *Aviation* 41 (July 1942): 122-124, 317-321.

⁸⁹ Peter A. Beck, "Airplane Specification Engineering," *Aviation* 40 (September 1942): 56-57, 182-184.

⁹⁰ Ibid., 182.

staff engineers and appropriate group engineers on the project. One or more additional drafts are then prepared incorporating all changes and additions requested by various parties concerned and are resubmitted for correction and approval. This function replaces the personal contact which was possible when the company was smaller."⁹¹

At the time, Lockheed had 1,260 people in its engineering department. On military aircraft, these steps were guided and aided by the requirements of Air Corps or Navy Department design manuals and model specifications.

In order to cope with similar problem Curtis-Wright established a "release section" within its engineering department and the position of "release engineer." Aided by a punch card recording and accounting systems, the use of lot releases rather than general production releases was aimed to reduce ordering of parts that might be rendered obsolete as a result of design changes.⁹² The function of the project engineer was also referred to as "engineering liaison" or "expedition." A "production liaison engineer" working on the Cyclone engine development described his role as selling the value of adherence to engineering specifications in the production department.⁹³ By anticipating the production group's needs and accordingly making changes early and when "tooling and other production facilities are likely to be liquid," he could return the favor.⁹⁴ In the case of Curtis-Wright, the Liaison Engineer was used in addition to Project Engineers, with liaising a term reserved for work in carrying refinements back and forth between engineering and production once the machine was in production. In his words, "by observation of the variations in production engines, the liaison engineers have been able to *find out what the engine wants* so the personality problem becomes non-existent. The story that the engine tells cannot be refuted."⁹⁵ In other words, by resting interpretive authority with an engineer in a go-between position, Curtis-Wright sought to defuse conflict between builders and operators.

Some sense of the overall breakdown of the staff in an aircraft-engineering department in the late 1930s is provided in a paper presented by T.P. Wright, the Vice President for Engineering with Curtiss-Wright and a member of the Aeronautical Section of the National Defense Advisory

⁹¹ Ibid.

⁹² L.N. Pizzuto, "Engineering Release for Mass Production," *Aviation* 41 (July 1942): 108-112.

⁹³ Donald U. Kudlich, "Engineering Liaison and Production Control," *S.A.E. Journal* 50 (May 1942): 169-176.

⁹⁴ Ibid., 170.

⁹⁵ Ibid., 176.

Committee.⁹⁶ Wright, who also authored some early articles on the learning curve in aircraft production, presented information on his company's organization in a paper before the Royal Aeronautic Society on "U.S. Methods of Aircraft Production."⁹⁷ He listed the personnel in an airplane-engineering department given an assumed project staff of 200 as:

Project Engineers	6	
Aerodynamic Section	6	
Weights Section	8	
Structures Section	16	
Designers	4	
Draftsmen:		
Layout and Leadmen	16	
Detailers	100	
Tracers	24	
	140	
Others including Blueprinters, Clerks, etc.	20	
Total		200 ⁹⁸

This engineering department roughly represented that required for a 3,000-person factory in which 2,250 were employed in direct labor. Wright also described the role of the project engineers:

"A word, perhaps, may be of interest concerning our so-called project engineers, who are engineering managers and, quite frequently, designers as well of a given project. It is their duty to co-ordinate the efforts of the draftsmen, weight engineers, structural analysts, designers, and aerodynamicists. It is also their duty to effect proper co-ordination with the factory organization in connection with specifying a design which can be fabricated by tools and methods with which the factory is familiar or are available for procurement and familiarization. This coordination at the outset cannot be too strongly emphasized and the success or failure of a job, particularly financially, is usually measured by the managerial and executive ability of the project engineer. Because of the rapid technological advances of the industry, augmented frequently by the inexperience of draftsmen in production method, the change order has become a serious problem with all aircraft engineering and factory organizations. Frequently, change orders issued after initial drawing releases have reached quite appalling numbers, and many conferences have taken place in an attempt to remedy this situation."⁹⁹

The problem, as Wright judged it, was a failure to properly keep research and development work and prototype development distinct from production, though he endorsed the practice of involving the

⁹⁶ T.P. Wright, "50,000 Planes a Year," *Aviation* 39 (July 1940): 34-37, 98-102.

⁹⁷ presented November 9, 1938 and published, *Aircraft Engineering* 10 (December 1938): 386-411. In addition to the engineering department practices discussed here, this article has a thoroughly illustrated description of the manufacturing process that is a considerable help to understanding the state of aircraft making in 1938.

⁹⁸ Ibid., 388, table 4.

⁹⁹ Ibid.

“production engineering sections” found in “most American aircraft companies” on experimental projects. He noted his own organization’s use of a Hollerith card accounting machine to keep track of bills of materials and parts lists and that automobile manufacturing techniques were becoming more relevant to aircraft, but that assembly line conveyers were not yet in use or warranted.

While the foregoing examples establish the prevalence of project-based organizing in aircraft production in the 1920s and 1930s, but two additional instances drive the point further. As these both come from training manuals sold for general classroom use, they reflect the standardization of the form. A 1939 manual for aircraft draftsmen-in-training listed the “group” and “project” systems as typical, with the group system used in smaller factories where individual projects were not large enough to justify assigning personnel entirely to single projects (figure 4.12). In the former, “the major structural and equipment units of the air plane such as Wing, Fuselage, Armament, etc., are each handled by a group of specialists working under the direct supervision of a Group Leader, and under the general supervision of Project Engineers for the various models or projects under design and construction.”¹⁰⁰ By contrast, in a “Project System” the “Project Engineer” directly supervised individuals. Similarly, in a text on aircraft production written during World War II, in handing-off a project from engineering to production, the “project engineer” passed the job to the “project planner,” with the first piece of information conveyed being the “interpretation sheet,” which detailed how the new aircraft differed from previous models. This sheet then aided the production department in “making position breakdowns and establishing priority dates” as part of a “manufacturing record.”¹⁰¹ In addition, each model was handled by a “project dispatcher,” who followed models (batches) through production, enforcing the schedule.¹⁰²

¹⁰⁰ James G. Thompson, *Aircraft Drafting Room Manual* (San Francisco: Aviation Press, 1939).

¹⁰¹ H.D. MacKinnon, *Aircraft Production: Planning & Control* (New York: Pitman Publishing Corporation, 1943), 23,

¹³⁵
¹⁰² *Ibid.*, 208.

the aircraft business), "frequently... schedules are dictated not only by the time required to carry on the development in an orderly manner, but by the exigencies of the commercial situation, such as competition, production demands, sales needs. It is hard for people outside of the development group to understand why schedules cannot be set and met, and it is equally hard for those within to set up and meet them."¹⁰³

War increased the importance of graphic communication in coordinating work, and perspectival drawings were enlisted in response to increasing employment of untrained workers and the complexity of the interactions of crafts involved. A series of articles in *Aviation* explained,

"...the spotlight of industry and the armed services has been focused on pictorial drawings and sketches. For the semi-skilled and unskilled workers, which industry and the armed services must now somehow use to achieve the victory, can easily read this type of engineering drawing, although they may not know how to read the conventional engineering drawing."¹⁰⁴

In a similar vein, a writer in 1943 described problems training "green hands" to produce work that would otherwise be assigned to skilled craftsman and that the solution involved "the breakdown of the long and involved processes of fabrication into small, simple jobs."¹⁰⁵ Such breakdown had allowed the employment more unskilled workers and women, but, despite "all the talk of sub-assemblies, assemblies, and mechanized conveyor lines, we are still only approaching mass production."¹⁰⁶

The need for elaborate representations created a labor problem of its own—an "aching void of skilled makers of pictorial (perspective) drawings and sketches."¹⁰⁷ These drawings were seen as better going between different groups in the production process; that is, the "literal" perspectival rendering was a better boundary object. During World War I and the interwar period, incommensurability in drawing techniques had been a significant, on-going problem. Writing of the engineering difficulties connected with a wave of consolidations in aircraft manufacturing at the end

¹⁰³ C.M. Ashley, "Philosophy of Design: The Foundation for Better Planning," *Product Engineering* (October 1940): 443–444, quote, 444.

¹⁰⁴ George F. Bush, "Theory and Technique of Perspective Projection," *Aviation* 42 (1941): 118–125, 349 and (1941): 150–153, quote, 118.

¹⁰⁵ C.W. Perelle, "Present-Day Manufacturing Problems of the Aircraft Industry," *Aero Digest* 42 (May 1943): 346.

¹⁰⁶ *Ibid.*, 340.

¹⁰⁷ *Ibid.*, 119.

of the 1920s, Eddie Molloy, Executive Engineer with Keystone Aircraft Corporation noted that engineering drawings were imperfect communication tools:

“Airplane manufacturers who have manufactured airplanes, or parts of airplanes, from drawings made by a competitor, know the difficulties encountered. In some cases large sums of money had to be spent on drawings before fabrication could be accomplished. This difficulty was partly due to the drafting-room system being different at the plant where the drawings were made. The manufacturer’s personnel being trained to a very different system could not adapt itself readily to the new system.”¹⁰⁸

Pictographic, exploded views of aircraft were used well before the war and wrote large the logic of subassemblies used to order aircraft projects just as the line of a railroad could be used to mark sectional logics in early civil engineering (figure 4.12).

FIG. 19.—Production breakdown illustrating how section numbers can be assigned to major parts of the airplane in order to obtain cost information. (Courtesy of Douglas Aircraft Company, Inc.)

Figure 4.13—See original caption as shown. Source: A.B. Berghell, *Production Engineering in the Aircraft Industry* (New York: McGraw-Hill Book Company, Inc., 1944), 93. While this instance is from during World War II, this kind of image can be found in prewar practice.

The logic of subassemblies shaped the organization of plants and people as well, with the technical organization of the objects being created echoing through other aspects of aircraft firms. Several examples of graphic production control tools and plant layouts show this more succinctly than words (figures 4.14 through 4.17).

¹⁰⁸ E. Molloy, “Engineering Organization in the Aircraft Factory,” 1.

FIG. 13.—Work flow chart on nine wing assembly positions.

Figure 4.14—Gantt-type chart used to represent the movement of a batch of wings through positions in an assembly routine. Source: Berghell, *Production Engineering in the Aircraft Industry* (New York: McGraw-Hill Book Company, Inc., 1944), 75.

Figure 4.15—"Control chart of Metal Aircraft Corp., showing pins (small circles) indicating several states of assembly...." Pins in the far left column represented sets of parts ready for assembly; these were then moved through stages in subassembly and removed as they were joined to a fuselage which was itself being tracked. Source: "Progressive Assembly of Airplanes Resembles Automotive Production," *Automotive Industries* 60 (May 25, 1929): 800-802, graphic, 802.

Figure 4.16—For comparison, an early, non-aircraft example. From Knoeppel's 1918 articles on "Graphic Production Control," 287 as discussed in chapter 2. Neither the illustration nor the accompanying text specified the object being assembled.

Figure 4.16—A “typical plant ‘C’ for 1100 airplanes annually,” *Aeronautical Engineering* 3 (April-June 1931): 79. Note the degree to which the routing of the work and abstract representations such as in figures 4.15, 4.12, and, below, 4.17 echoed one another.

Summarizing, the organizational logic of aircraft production in the interwar period followed from the uncertain nature of the objects being engineered. Production organized spatially according to a sectional logic and temporally by projects allowed the short-production runs typical of most aircraft

to be shepherded through ill-defined periods in engineering and production. The role of liaison in these settings was crucial—because of the lack of definition and the potential for change in the course of projects, project engineers played a political role in relation to technical problems, ferrying things across boundaries and adjudicating between different parts of organizations and aircraft.

Cases

The first of the two cases that follow is drawn from articles written by John Hardecker, a Cornell-educated civil engineer, member of the SAE Standards Committee, Aeronautic Division, and representative at annual Army-Navy aircraft standards conferences. While many of the ideas expressed by Hardecker have already been introduced, presenting his exposition of these ideas provides a snapshot of issues and methods in aircraft engineering in the 1920s. Like Ernest McCullough in municipal contracting or C.E.K. Mees in laboratory administration, Hardecker was a theorizing practitioner who addressed his fellow engineers rather than a theorist interested in more academic discussions. The second case revolves around the SAE and its relations with the aircraft industry. As introduced at the beginning of this chapter, the adoption of routinized change in automobile production in the 1920s and 1930s stood in contrast to the less-predictable changes faced by the aircraft industry.

John Hardecker and the Naval Aircraft Factory

Established in 1917, the Naval Aircraft Factory in Philadelphia served the U.S. Navy's air branch as its shipyards did its sailing operations.¹⁰⁹ Justified as an experimental plant and for providing the Navy a "yardstick" against which the procurement of aircraft from private industry could be measured, the plant designed and developed a number of land and seaplanes over its four-decade existence. In 1926, John Hardecker, an engineer and eventually chief draftsman with this plant, described the organization's administrative structure in a pair of articles in the *American*

¹⁰⁹ Early articles on the factory include "The Naval Aircraft Factory," *Aviation and Aeronautical Engineering* 6 (February 1, 1919): 28–30; and F.G. Coburn, "Problems of the Naval Aircraft Factory During the War," *Transactions of the Society of Automotive Engineers* 14, part 1 (1919): 304–332. The general history of the factory is covered in William F. Trimble, *Wings for the Navy: A History of the Naval Aircraft Factory, 1917–1956* (Annapolis: Naval Institute Press, 1990).

Machinist.¹¹⁰ "The most flexible type of technical organization yet devised that can be successfully carried out in actual practice is the one in which a single engineer is given the task of 'living' with a job from start to finish so that at all times he is the one man in the organization who is most familiar with that particular job."¹¹¹ At the Naval Aircraft Factory, that "one man," was called a "project engineer." Hardecker went on to note that this organization "lends itself readily to the manufacture of machinery, locomotives, automobiles, electrical equipment and, in fact, to any large plant making a number of mechanical or structural products."¹¹²

From this introduction, Hardecker continued to describe the cross-departmental navigation necessary if the project engineer were to guide his ward through development and into production. "With respect to each of his projects, he is the source of information for all departments and is particularly the liaison man between the customer, the manager, the engineering department, the testing department and the production department."¹¹³ Within the overall organization, the role Hardecker described occupied a modest place—below an assistant chief engineer—but the occupant of this position was required to interact directly with individuals throughout the organization and was furthermore considered the executive over design work on his project or projects. At each stage in the engineering work, there were special forms used to document decisions and track the movements of the work between functional areas.

The second of Hardecker's articles in *American Machinist* was introduced as a sequel to his description of the Naval Aircraft Factory, but was carefully general in its description of the management methods advocated.¹¹⁴ The work schedule, "report of delay" form, job card, and form for reporting changes that illustrated the article came from aircraft production, civil engineering, and machine design. Coupled with Hardecker's own move from civil engineering into aircraft work, the generic and transferable aspects of project-based production methods are evident in his exposition.

¹¹⁰ John F. Hardecker "The Functions of a Project Engineer in a Technical Organization." *American Machinist* 64 (April 22, 1926): 641–642; and "The Functions of the Design Division in a Technical Organization," *American Machinist* 65 (October 21, 1926): 663–666. Hardecker reprised and extended these arguments in a series of articles for *Machine Design* in 1929 and 1930. See "Organization and Supervision of Design Department," parts I to VI, *Machine Design* 1 (September 1929): 22–25; 1 (October 1929): 27–31, 34; 1 (November 1929): 26–30; 1 (December 1929): 33–37; 2 (January 1930): 36–40; 2 (February 1930): 39–43. Also, John F. Hardecker, "Aircraft Drafting," *Aviation* 28 (June 14, 1930): 1162–1165.

¹¹¹ "The Functions of a Project Engineer in a Technical Organization," 641.

¹¹² *ibid.*

¹¹³ *ibid.*

¹¹⁴ "The Functions of the Design Division in a Technical Organization."

Hardecker also wrote articles for *Machine Design* and *Aviation* and participated in the SAE's committee on aircraft standardization. One of his articles for *Aviation* recounted U.S. experience working with British engineering drawing during World War I. British practice was to draw sheet metal parts both flat and bent into final shape, but without allowing for bending in dimensioning the piece. Allowing for the extra material needed to turn corners was left to the shop, where it was a known part of the work. U.S. practice was to show only the bent part, leaving the flat template entirely to the shop. Hardecker stated that the enormous waste that followed when parts drawn to according to one convention were then produced by workers operating within another could be "attributed to the failure to understand fully the production practice behind the drawing scheme."¹¹⁵ "Foreign plans" redrafted to fit "home organizations" and willingness of planning offices to not be "adamant in insisting on compliance with the only system or systems it knows" had caused these problems.¹¹⁶ In other words, there had been no go-between liaison between design and production.

Hardecker emphasized the need to bring producers and designers together. Calling this a "copartnership in design," he noted that involving shop men in the engineering work both bred cooperation and avoided technical difficulties.¹¹⁷ Experimental machinery could require "special handling or operation peculiar to the design in hand, and not previously recorded."¹¹⁸ Hardecker's articles reproduced scheduling sheets for following tasks by personnel assigned and by project. On large projects, preparing these forms was the responsibility of a "schedule clerk" and served to keep the entire organization abreast of the work. Hardecker's "form for scheduling work according to design details" is essentially a Gantt-type chart that breaks down the design of the aircraft into component assemblies—such as wings and tail—and within these to further subassemblies—rudder, elevator, and so forth (figure 4.17).¹¹⁹ Drafting these assemblies was a team effort (Hardecker uses the term "squad"), and elaborate crosschecking and approval procedures were used to ensure compatibility of both "local and foreign" drawings—that is, those produced in-house and those from subcontractors.

¹¹⁵ "Aircraft Drafting," 1162.

¹¹⁶ *Ibid.*, 1163.

¹¹⁷ "Organization and Supervision of Design Department," part III (November 1929): 29.

¹¹⁸ *Ibid.*

¹¹⁹ "The Functions of the Design Division in a Technical Organization," 664.

production, as it is known in the automobile industry, for instance, does not exist in the aircraft industry today," he commented and, as a consequence, complete production drawings were uneconomical and, further, "may require so great an elapsed time to prepare under even the most favorable conditions, that the particular designs may well be obsolescent, if not obsolete, when the shops are fully equipped with blueprints and detail manufacturing orders to proceed."¹²³ Despite his espousal of the project organization's flexibility, he also felt in 1928 that the time had arrived such that "as reluctant as I am to express it, the airplane industry must now definitely pass from the control of the pilot and designer into the hands of the financier, the production man, and big business in general."¹²⁴ In this article, Hardecker addressed particularly the need for engines, noting that the industry had until recently enjoyed a supply of cheap World War I surplus engines. He felt that an investment on par with Ford's \$25,000,000 tooling for the Model A would, in the "honest belief of all those now engaged in the industry," pay. Hardecker noted that the Army and Navy had fully developed all-metal aircraft that, if produced in quantity, would be economical and that "this work, in many instances too costly for a new-born industry to assume, is the contribution of the government to the airplane of the future."¹²⁵ It would, though, be more than a decade before either the Naval Aircraft Factory or the airplane business in general would be producing more than irregular batches of aircraft.

The SAE, Fashion, and the Aircraft Industry

As touched on in the course of this chapter, kinships between the products of the automobile and aircraft industries and between the pressures of war and fashion linked these two businesses. There were, however, critical differences that help further draw out the opposition between the exploratory nature of aircraft design in the 1920s and 1930s and the exploitative aspects of automobile production in the same period.¹²⁶ The position of the Society of Automotive Engineers in relation to the aircraft industry is illuminating because it highlights frictions between the ideals and expectations of a production-oriented community and the labors of a less uncertain industry.

¹²³ "Aircraft Drafting," 1162.

¹²⁴ "Hand of 'Big Business' Needed in Aircraft Development," *Automotive Industries* 58 (May 12, 1928): 732-734, quote, 733.

¹²⁵ *Ibid.*, 734.

¹²⁶ I here use "explore" and "exploit" in the sense I more generally use "build" and "operate," per James March, "Exploration and Exploitation in Organizational Learning."

In some regards, early automobiles and aircraft *were* alike. The engineering of each borrowed from that of bicycles.¹²⁷ Both partly consisted of welded metal frames produced on jigs and were produced by bringing together component subassemblies—at the grossest scale marked by the chassis/body relationship in cars and the fuselage/wing relationship in aircraft. Both were self-propelled vehicles that presented problems of fuel choice and engine design. But as early as 1907—just four years after the Wright Brothers gained fame for their flight at Kitty Hawk—the automobile was already beginning to be considered a necessity.¹²⁸ By the 1920s, the automobile was a well-defined technology produced in large volume and supported by an established infrastructure while aircraft were well short of that stage. When GM evolved an annual marketing cycle built around incremental improvements and refashionings, it made cars a novelty again—a quality that as a stabilizing technology they had otherwise lost. Marketing and design served similar functions for other consumer goods as well, contributing to what Hounshell calls a “consciously orchestrated economy of change and consumption that stressed style and comfort.”¹²⁹ While attention to appearance and marketing could be found in aircraft manufacture as well, conscious orchestration was not possible in the same sense, partly as a consequence of the small size of the market and partly because the product did not have a stable technical or social definition.

The SAE, founded in 1905, considered itself a sound organization in an increasingly confident industry by 1911, the year aircraft are first mentioned in the *Transactions* of the Society. At a meeting of the its Business Council in January of that year, Rolla Carpenter, a professor in Cornell’s Sibley College of Engineering, commented that the SAE should turn its attention to aeroplane engineering:

“While this is outside of the Council work, it seems to me that the Society could very well start a branch along the lines of aeroplane construction. Of course this is a little different in its general features of engineering, but in a short time it will need an

¹²⁷ Hounshell, *From the American System to Mass Production*, treats production techniques developed during the bicycle industry boom of the 1890s as an important bridge between armory practice and mass production, 189–215. A general history of automobiles is James J. Flink, *The Automobile Age* (Cambridge: MIT Press, 1988). An ideologically biased but nonetheless interesting view is David Gartman, *Auto Opium: A Social History of American Automobile Design* (New York: Routledge, 1994).

¹²⁸ James Flink makes this assertion in *America Adopts the Automobile, 1895–1910* (Cambridge: MIT Press, 1970), 31–86.

¹²⁹ *From the American System to Mass Production*, 264. Properly treating the spread of marketing and consumer psychology in the 1920s is beyond my scope. See Pamela Walker Laird, *Advertising Progress: American Business and the Rise of Consumer Marketing* (Baltimore: Johns Hopkins University Press, 1998).

engineering branch; in fact, it needs it to-day. A section started at a very early time would result not only in benefit to the automobile art but also to the aeroplane art.”¹³⁰

This proposal bore no immediate fruit, however. Only in 1916 did the SAE form a division to focus on aircraft, and in its first year this division attended to engines only, starting as the Aeronautical Engine Division within the Standards Committee before dropping the term “engine” to become the Aeronautic Division in 1917.¹³¹ Having published no articles on aircraft up to and through 1914, then just one in 1915, and two in 1916, in 1917 the *Transactions* addressed aircraft or their power plants in seven of 54 papers. With the prospect of large military contracts, this existing technical community woke up to the aircraft business.

Charles F. Kettering, already quoted at several points in this chapter, was president of the SAE in 1918, coincidentally the same year he joined General Motors and the year the SAE moved into the Engineering Societies Building in New York.¹³² Educated in electrical engineering at Ohio State University, Kettering had cofounded Delco (Dayton Engineering Laboratories Company) in 1909 to manufacture an ignition based on his own patent. Staying on after selling Delco to United Motors, Kettering became a minor executive with GM with the merger. Delco was, though, just one of a number of Dayton-area ventures with which Kettering was involved in the teens. From joining the SAE in 1912, he quickly became a leading member of that organization and traveled in the main circles of engineering administrators of the early twentieth century. Alfred Sloan made Kettering the head the General Motors Research Corporation when the latter was created in 1920, initially locating the new division in Dayton as part of wooing Kettering.

Of Kettering’s pre-GM enterprises, the most relevant here is a partnership he joined in 1916 to build aircraft, the Dayton Wright Airplane Company, with the name of the firm reflecting Orville Wright’s involvement as a partner. Stuart Leslie describes Kettering’s attitude toward aircraft production as “foolish overconfidence.”¹³³ Having won a contract to build training aircraft based on the belief of Washington politicians that automobile manufacturing experience was more important to volume production than understanding aircraft, Dayton Wright fell far behind promised delivery

¹³⁰ In minutes of the meeting of January 11 and 12, 1911. *Transactions of the SAE* 6 (1911): 21.

¹³¹ See “Formation of Aeronautic Engine Division,” *Transactions of the SAE* 11, part 2 (1916): 52–53.

¹³² Kettering became a GM employee at the close of 1918 as a consequence of the consolidation of United Motors with General Motors. On Kettering’s career, see Leslie, *Boss Kettering*.

¹³³ *Boss Kettering*, 70. Leslie describes a particular utterance made by Kettering, but it stands more generally.

schedules and was ultimately investigated for corruption and inefficiency.¹³⁴ There was, though, no mention of these problems when Kettering gave an address on "The Future of the Airplane Business" to an SAE gathering during 1918, noting in response to a question that:

"At the beginning of the war the United States had about 100 airplanes, and I do not believe any were alike, because there had been no large orders. Ten or twelve was a large order and most of the fittings were made by hand. When we took this machine we analyzed it from a manufacturing standpoint, and we have gone ahead, not really making airplanes but parts to be assembled.... All out parts are interchangeable. Any plane will fit any chassis."¹³⁵

Aviation and Aeronautical Engineering took a colder look at the record of outfits such as Dayton Wright, asserting that production problems had been the products of migrant engineers in the employ of crafty financiers and "the desire of production experts to follow a Bible of automobile rules."¹³⁶ Reviewing what was widely termed the "aircraft situation," this journal noted in early 1918 that despite the war emergency, many airplane plants had no orders and that some expected to close down for lack of work. The magazine urged letting contracts for at least some units, complaining that "too much reliance has apparently been placed upon automobile production methods" which could require up to a year to engineer a new model and that "advantage has not been taken in the past of the skilled engineering and production forces of the aircraft manufacturers." Further, this article emphasized that construction should go ahead even as plans and specifications were being revised rather than entirely stopping work when changes occurred.¹³⁷

Following the war, the attention of the SAE to the aircraft industry waned. The Aeronautic Division was practically moribund in the early 1920s, but then revived toward the middle of the decade as production picked up and government funding for infrastructure increased. In mid-1926, the Aeronautic Division put forward a list of twenty areas it thought susceptible to standardization.¹³⁸

¹³⁴ Ibid., 72.

¹³⁵ C.F. Kettering, "The Future of the Airplane Business," *Transactions of the SAE* 13, part 2 (1918): 363-375, discussion, 375-379, quote 378.

¹³⁶ An Aeronautical Engineer, "The Airplane Problem," 4, no. 11 (July 1, 1918): 777-779, quote, 778.

¹³⁷ "Aircraft Situation from a Manufacturing Viewpoint," *Aviation and Aeronautical Engineering* 4, no. 6 (April 15, 1918): 383-384, quotes, 383. See also subsequent articles, "The Aircraft Situation," 4, no. 8 (May 15, 1918) and "The Aircraft Situation," 4, no. 11 (July 1, 1918): 772-775. This last article featured a round-up of the state of the industry and noted that several of the large manufacturing companies that had won early army contracts on the strength of their capacity had failed to get lines operating while, at the same time, small ante-bellum aircraft companies had managed to adjust to quantity manufacture. Further, note An Aeronautical Engineer, "The Airplane Problem," 4, no. 11 (July 1, 1918): 777-779.

¹³⁸ "Aeronautic Standardization Outlined," *The Journal of the Society of Automotive Engineers* 19 (July 1926): 13-15.

Just months later, though, development of the proposed standards was cancelled, partly because they might conflict with new Army-Navy standards, but more immediately because the “number of materials used in aircraft construction is so large that to cover them completely at this times would be out of proportion to the value of the specifications.”¹³⁹ At the same time, articles in the SAE’s *Journal* had started to attend to topics such as “Fashion and Art Appeal in the Automobile,” noting that tastes in automobiles could be inferred from the color preferences of women.¹⁴⁰ By contrast, in an article proposing to state “What the Public Wants in Airplanes,” highlighted that “the public is not competent to state what it wants in an airplane.”¹⁴¹

In 1929, Kettering was one of the directors of a new holding company, the Detroit Aircraft Corporation, self-described as the “General Motors of the Air,” and promising to become “the most self-contained unit in the industry.”¹⁴² Like quickly amassed holding companies before and since, Detroit Aircraft amounted to a gamble on a continued economic boom. Having projected that the small hill production figures had started to climb would lead to larger mountains rather than a wide valley (figure 4.1); the firm was bankrupt by 1931, pulling Lockheed—its most significant holding—into receivership.¹⁴³

While GM produced significant technical innovations during the years Kettering directed its research, it also undertook the program of change artistry that used incremental improvements and restyling by which consumers “could be stimulated to be dissatisfied.”¹⁴⁴ GM did not “invent” incremental innovation or the program of annual cycles of automobile models *per se*—Alfred Sloan acknowledged that the notion “evolved” rather than being invented.¹⁴⁵ GM discovered that in an industry like automobiles or women’s wear, fashion was an induced phenomenon that could be paced. From the perspective of a small producer, there was always the danger of missing a trend, but once a

¹³⁹ “Aeronautic Standards Cancelled,” 340.

¹⁴⁰ “Fashion and Art Appeal in the Automobile,” *SAE Journal* 23 (December 1928): 595–599, discussion 599–601.

¹⁴¹ W.B. Stout, “What the Public Wants in Airplanes,” *The Journal of the Society of Automotive Engineers* 26 (April 1930): 443–445, discussion, 445–449, quote, 443.

¹⁴² Both cited in Rae, *Climb to Greatness*, 46 and 46–47, respectively. The latter is from a statement by E.S. Evans, the president of Detroit Aircraft, originally printed in L.C. Dibble, “Detroit Aircraft Corporation,” *Automotive Industries* 40 (June 15, 1929): 921.

¹⁴³ *Ibid.*, 50.

¹⁴⁴ *New York Times* (November 5, 1927): 4:3, cited in Leslie, *Boss Kettering*, 181.

¹⁴⁵ See citation in Hounshell, *From the American System to Mass Production*, 263.

rhythm was in place the timing of seasons or model-year introductions had a fixedness.¹⁴⁶ GM, given its size, could dictate both fashion and timing. In contrast, there was no large, reliable market for aircraft and given a *technically* unstable product, no firm could dictate change. The cyclical efforts of the SAE to treat the aircraft engineering like automobile engineering reflected incompatibilities between the organizational logics of operating and building.

Conclusion

The competitive pressures of war and fashion together drove interest in managed innovation during the 1920s and 1930s. Though there were significant overlaps in the early technologies and communities involved in aircraft and automobile production, the paths of the two industries diverged in the interwar period. The aircraft industry produced an uncertain product for a small and ill-defined market while the automobile industry operated in a near-commodity marketplace. In response to the problems of small-number manufacturing in an uncertain industry, aircraft companies used project-based organization to provide a means of conveying odd orders through the disparate processes brought together in an aircraft. The logic of assemblies and subassemblies expressed in technical and administrative artifacts made the management of aircraft projects a matter of coordination and integration. These were more intricately integrated and tightly scheduled production processes than those of earlier project-oriented engineering activities, but the basic idea was the same. In using these methods, engineers both ordered their work and explained how it was not like mass production. In describing the need for flexibility and group work, aircraft engineers anticipated later notions of high-speed, creative work settings.

This is the last of the three chapters that together form the core of this dissertation. Despite the broad range of activities in which project-based forms of organization and management were applied and theorized in the early twentieth century, this prehistory of project management disappears in later accounts. An executive with Consolidated Vultee noted in 1943 that “until about three years ago, aircraft were not mass produced in any sense of the word” and that, in the absence of mass demand, even when an order for two dozen or so planes came in, this effectively meant the production of two

¹⁴⁶ In this regard, there were and are industry-level temporal dynamics to which producers have become attuned or “entrained.” Ancona and Chong, “Entrainment: Pace, Cycle, and Rhythm in Organizational Behavior.”

dozen prototypes.¹⁴⁷ Since then, "the days when an engineer used to walk into the shop, find a foreman, and say, 'Make this for me, will you Joe?'" had passed. Instead, tooling and planning engineers were "doing scientifically what was done in hit-or-miss fashion a few years ago."¹⁴⁸ While it was correct that war had brought something very close to mass production to the aircraft industry, somehow by 1943 the war had already started to erase the past.

¹⁴⁷ C.W. Perelle, "Present-Day Manufacturing Problems of the Aircraft Industry," *Aero Digest* 42 (May 1943): 158, 340–

¹⁴⁸ Ibid., 158.

Chapter 5

Circuitry and Systems:

Making the Mythology of the Man-Month, 1940–1960

“Systems... have universally owed their origin to the lubrications of those who were acquainted with the one art, but ignorant of the other; who therefore explained to themselves the phenomena, in which what was strange to them, by those in that which was familiar; and with whom, upon that account, the analogy, which in other writers gives occasion to a few ingenious similitudes, became the great hinge upon which every thing turned”¹

The end is not so much an end as a reinvention. Following World War II, engineering management was translated into the languages of operations research, cybernetics, and system dynamics. In common, these fields revolved around mathematical models and philosophical notions developed through wartime and pre-war work in communications theory, network operation, and feedback control. Applied to human activity, these approaches informed behaviorist conceptions of individuals in terms of inputs and outputs. Applied to management problems, they extended sciences of system regulation in areas including statistical quality control and industrial automation.² In the case of the administration of engineering and scientific work, these tools allowed the coordination of complicated projects to be mapped in algorithms and network diagrams, ultimately in the form of Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) charts, both developed in the late 1950s. The mathematics behind these techniques and some of their philosophical implications distinguished these approaches from older ideas of systems and theories of regulation, but in their application to engineering management they were ultimately new ways of

¹ Adam Smith, *Principles Which Lead and Direct Philosophical Enquiries, Illustrated by the History of Astronomy*, in Adam Smith, *Works*, ed. by Dugald Stewart (London: 1811), quoted in Mayr, “Adam Smith and the Concept of the Feedback System,” 17.

² Statistical quality control methods predated the war, but wartime application helped train a generation of statisticians who dispersed to industry after 1945.

addressing old problems—that is, new languages for dividing work and then fitting it together.³ Considered historically, project management during the Cold War was a relabelling of older methods of managing builders rather than a *sui generis* response to new conditions.

But as with other eras of system building, the problems faced were new to new communities, and the rush of new technologies and divisions of labor in the electronics and aerospace engineering industries precipitated a wave of theorizing by engineers and managers in the late 1940s and through the 1950s. Practically, the complexity and uncertainty of the work forced recourse to general contracting for systems in which the interactions of the parts could not be entirely planned and divided according to known technical and social relationships. Calling this systems engineering, the major purchasers of engineering work in the United States in the 1950s—the military services and the defense industry as a whole—used it to both order and represent work. Like Gantt charts and basic engineering drawings, systems diagrams and metaphors projected linearity and order into uncertain futures and in so doing presented messy work in tidy packages. These tools shaped the nascent computer hardware and software industries.

Frederick Brooks's collected essays, *The Mythical Man-Month*, is a staple of the business school curriculum, particularly for those aspiring to manage information technology projects.⁴ Brooks was an engineer and manager at IBM during the second half of the 1950s and into the 1960s. The essay from which he takes the title to the book as a whole addresses the impossibility of task partitioning beyond some limit; in any work that involves communication between participants, the time-cost of communication will increase with the size of the team such that the time to complete a task will *increase* with the assignment of more workers.⁵ While Brooks's essay post-dates this chapter's coverage, borrowing from his title to head this chapter emphasizes the active myth-making that accompanied the use of project management during the Cold War.

³ David Mindell has shown how engineering groups in different company and institutional settings in the first half of the twentieth century developed particular conceptions of systems and that these distinctions had corollary implications for how human and technical components interacted. " 'Datum for Its Own Annihilation': Feedback, Control, and Computing, 1916-1945," unpublished Ph.D. dissertation, MIT, 1996. Peter Gallison treats the development of servomechanical information systems as marking a conceptual watershed that shaped the social sciences at mid century. Peter Gallison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision," *Critical Inquiry* 21 (1994): 228-266.

⁴ The full title is *The Mythical Man-Month: Essays on Software Engineering*, (Reading, Mass.: Addison-Wesley Publishing Company, 1972).

⁵ *Ibid.*, 13-26.

Focusing particularly on the electronics and computing industries, this chapter reviews years in the late 1940s and early 1950s in which conversations around engineering management coalesced around language and tools still used today. This chapter has three aims. First, it establishes kinships between issues in project management and systems engineering in the 1950s and those of earlier eras of system building. Second, it considers how project management was used to both direct and defend work during the Cold War. And third, it explains the renewed need for project-based organization as a corollary of a period of social and technical ferment in emergent engineering fields. As in preceding chapters, an overview of historical contexts sets the stage for a look at management practices. In closing, two case studies provide a sense of project management's ubiquity and the continued interrelations of social, organizational, and technical issues in engineering management.

Historical Contexts and the Politics of Systems Engineering

Relative to the history of management, World War II should be seen as more of a confluence of than a watershed. So many people from so many lines of work were brought together on so many different projects that the weave of conversations set out in preceding chapters was drawn ever tighter. Yet, perhaps because of the intensity and novelty of wartime experiences, many people believed they had experienced something unprecedented. The Manhattan Project (notably managed by the Army Corps of Engineers), work on Radar in MIT's Radiation Laboratory, and other research and development undertakings introduced a generation of engineers and physicists to working in teams on parts of much larger projects according to government contracting requirements.⁶ Allowing for the speed-up of wartime, these projects were managed according to typical contracting procedures.⁷ In studies of project management, these military undertakings are widely seen as

⁶ The "Manhattan District" name reflected the project's first home in a New York City office. The Manhattan Project was put under the direction of the Army Corps of Engineers at the suggestion of Vannevar Bush. General Leslie Groves directed the project, having earned a reputation as an able administrator as the officer in charge of the construction of the Pentagon. Stone & Webster was selected as the general contractor on the project, but ultimately DuPont more directly coordinated much of the work. Groves later described the sectioning of the Manhattan Project as "compartmentalization." "The A-Bomb Program," in *Science, Technology and Management*, edited by Fremont Kast and James Rosenzweig, 31-40 (New York: McGraw Hill, 1963), 35. See also Record Group 77, Manhattan Engineering District, National Archives and Records Administration, Archives I, Washington D.C. Leslie Groves, *Now It Can Be Told: The Story of the Manhattan Project* (New York: Harper, 1962) provides an overview.

⁷ Larry Owens has studied political struggles over contracting for research work by the Office of Scientific Research and Development during the war, showing that open-ended contracts were an innovation that solved legal conundrums. The basic accounting and reporting procedures under such contracts were nonetheless fundamentally akin to earlier practices.

original, but they represented more the intense exposure of two ascendant professions—electronics engineering and physics—to the environment of construction work.⁸ With the post-war growth of the engineering profession as a whole, World War II and the Cold War should be seen as an enormous exercise in imprinting that acculturated a generation to a way of doing things.⁹

Like the waves of system building in the early years of the century, the electronics and aerospace booms that followed World War II played out in light of the politics of efficiency. These politics took on a particular cast during the Cold War. The United States emerged from World War II with a double image of the kind of work that had won the war. While the craft of scientists and engineers in building *the* bomb, refining Radar, and taming malaria was widely acknowledged, and though such wartime innovations shaped post-war politics, assembly lines dominated the post-war imagination of work and production. Mass production had kept liberty ships, B-29s, and other materiel flowing to fronts near and far. Retooled to build refrigerators rather than weapons, factories would serve the material yearnings of returning G.I.s and their families. With the advent of the Cold War, mass produced goods would materially demonstrate the superiority of a way of life. Against this background, large technical projects continued to occupy the peculiar position that they had assumed in the 1930s: heroic and yet also backward. Articles on the construction industry in the 1950s puzzled at the oddity of the industry but detected its coming of age in the serial construction of tracts of suburban houses, exemplified by Arthur Levitt's eponymous town on Long Island. Articles on the work of scientists and engineers wondered at their wizardry involved but celebrated the promise of their products to consumers and the defense of the free world. In the politics of the 1950s, mass production remained the norm against which all labors could be measured. System regulation aimed at maintenance of economic and political equilibria remained *the* model of management.

Cold War military patronage helped define the electronics and aerospace industries and the professions these industries brought together. In the early 1950s, all three branches of the military

Larry Owens, "The Counterproductive Management of Science in the Second World War: Vannevar Bush and the Office of Scientific Research and Development," *Business History Review* 68 (Winter 1994): 515–576.

⁸ Searching for evidence of administrative techniques used to order project work, I have failed to find an example of a practice used during World War II that differed from those documented in preceding chapters except in some of the mathematical models and terminology applied.

⁹ Figure 0.7 in the introduction documents both the splinterings and overall growth of engineering as a profession in this period.

were spending vast sums developing new weapons and “platforms” for these weapons, physically expressed in aircraft, land bases, and submarines, and extending to the development of strategic doctrines and supporting technical and organizational infrastructures. Integrating weapons and their supporting social and technical infrastructures was the object of much-ballyhooed systems approaches to management. Despite often over-the-top rhetoric and claims surrounding systems engineering, the idea and its representation addressed real problems. Shortages of skilled labor, time pressure, and the constant threat or reality of outside scrutiny combined with uncertain technologies and evolving divisions of labor to make engineering management a problem. In response to multiple pressures, public and private organizations in defense-related industries adopted project-based methods of organization to portray the management of system building. The language of systems engineering served its creators and their patrons by explaining the often messy and inefficient working out of new technologies and relationships in rational, mathematical languages.

Excerpts from a representative article of the early 1950s help further set the context. In 1952, *Product Engineering* devoted most of its May issue to “Engineering Your Company’s Future.”¹⁰ In the lead article to the section, States Mead, a management consultant, indicated that the problems addressed in the issue had been driven by the combined effects of a boom in consumer markets, increased demand from the Department of Defense, and a resulting shortage of engineering talent. The solution could not be found “merely by employing greater numbers of engineers,” but by making “more effective use of engineering talent.”¹¹ Mead considered that “engineers have invited many of their troubles through negligence or reticence in applying to their own activities some of the principles of scientific management that have proven so beneficial to other functions of a business.”¹² Continuing, Mead noted that surveys had found, “that in only a minor percentage of industrial firms today is the engineering division or department organized and administered with adequate regard for acknowledged principles and practices of sound modern business management.” Such practices were necessary, Mead asserted, because “perhaps never in the industrial history of this nation” had there

¹⁰ *Product Engineering* 23 (May 1952): 151–223. Mead was educated in mechanical and electrical engineering and, at the time of writing, was a principal with Cresap, McCormick, and Paget, Management Engineers.

¹¹ *Ibid.*, 153.

¹² *Ibid.*, 152.

been a greater need for “engineering management of the highest order.”¹³ He emphasized the role of increased complexity in driving both limits to management understanding of “the engineering function” and complexity in coordinating different engineering disciplines.¹⁴

Mead’s comments, and the issue in which they appeared, are representative of a general outpouring of studies of the problems of managing engineering. In calls for engineers to act morally and patriotically to build the country’s military capability countless articles echoed Vannevar Bush’s 1945 *Science: The Endless Frontier* in associating technical progress with national purpose.¹⁵ These celebrations also raised a problem suggested by Mead: if scientific management helped keep new cars in American garages, should it not also help solve the manpower crisis in engineering?

Competing Languages and the Science of Regulation Redivivus

Given the different industries and traditions brought together in large technical projects during the Cold War, competing languages were used to describe and control engineering work. Stephen Johnson has discussed operations research, systems engineering, and project management as reflecting the approaches of mathematicians, aerospace engineers, and engineering administrators, respectively, with each approach embodying “the efforts of a specific knowledge community to cope with the complexities of large technological systems.”¹⁶ Johnson is accurate in pointing out that distinct groups of practitioners enlisted and applied different versions of systems rhetoric according to their needs and interests, but the boundaries among these groups were far from clear. Discussing Norbert Wiener, the MIT mathematician who coined the term “cybernetics” and popularized it through his 1948 *Cybernetics or, Control and Communication in the Animal and the Machine*,¹⁷ David Mindell notes that Wiener claimed full credit for transferring servomechanical theory to

¹³ Ibid.

¹⁴ Ibid., 152–153.

¹⁵ (Washington: U.S. Government Printing Office, 1945). In this vein see E. Tinley Carter, “Engineering Responsibilities in Today’s Economy,” *Proceedings of the I.R.E.* 36 (April 1948): 517–519; Jesse Hobson, “Men in Research,” *Proceedings of the I.R.E.* 36 (May 1948): 650–651; H.B. Richmond, “An Engineer in the Electronics Industry: Prospects—Preparation—Pay” *Proceedings of the I.R.E.* 36 (1948): 774–777.

¹⁶ Stephen B. Johnson, “Three Approaches to Big Technology,” 892. See also, by the same author, “From Concurrency to Phased Planning: An Episode in the History of Systems Management,” in Hughes and Hughes, eds., *Systems, Experts, and Computers*, 93–112; and, “Insuring the Future: The Development and Diffusion of Systems Management in the American and European Space Programs,” Ph.D. dissertation, University of Minnesota, 1997.

¹⁷ (Cambridge: Technology Press, 1948).

communications engineering.¹⁸ In a similar manner, Jay Forrester appears as the apostle of systems dynamics thanks to his role in spreading this language. Despite claims staked to particular turfs, and as Thomas Hughes has emphasized, these various languages shared basic models.¹⁹ Discussing "program budgeting," a means of allocating funds to component projects in a system building effort, Glenn Bugos calls this "a movement," which "was championed by a new breed of program managers dedicated to the science of creating new technological systems," and who "borrowed and experimented with any technique that served a technological system and its time economy."²⁰ Other approaches to engineering management were similarly hodge podges.

In the Cold War iteration of systems thinking, communication and network theory borrowed from electrical and electronics engineering were the chief lenses, and these lenses shaped views of management problems. In a 1954 article titled "An Informational Approach to Organization and System Engineering Design," Jerome Rothstein, with the Signal Corps Engineering Laboratories, characterized organizations using the language of his field, stating,

"We suggest the following general characterization of organization. Consider a set of elements each associated with its own set of alternatives. Let an entropy be defined for each set of alternatives as is done in physics or communication theory. We now define a complexion as a set of selections where one selection is made from each set of alternatives.

"There are, of course, as many ways of choosing a complexion as there are ways of selecting a representative from each set of alternatives. The set of complexions then has an entropy which is merely the sum of the entropies of the individual sets of alternatives so long as the elements do not interact. Complexion entropy is a maximum for isolated elements. Maximal entropy, i.e. zero coupling, will be said to constitute the condition of zero organization. On the other hand, it is possible that the coupling between elements is so strong that only one complexion is possible. In this case the set of complexions has zero entropy and organization is said to be maximal.

"In general, the interactions in which the organization consists serve to narrow the ensemble of admissible complexions. These interactions are of the nature of correlations, couplings, constraints, orders, or instructions which restrict the choices available to the given element in accordance with the choices made from the ensemble of alternatives associated with other elements. The entropy of the set of complexions is thus generally less than the sum of the entropies of the individual sets of alternatives.

"We define the amount of organization as the excess of the maximum value the complexion entropy can assume over the entropy of the set of complexions calculated with the correlations characterizing the organization taken into account. It is easy to see

¹⁸ Mindell, "Datum for Its Own Annihilation," 23–24.

¹⁹ Hughes and Hughes, eds., *Systems, Experts, Computers* and Hughes and Hughes, *Rescuing Prometheus*.

²⁰ "Programming the American Aerospace Industry," 210.

that organization measures how much information has been introduced into the ensemble of complexions because of the interactions.”²¹

In other words, organization could be measured relative to a hypothetical state of perfect chaos. From this building block, Rothstein introduced “system” as an organization with a function (or “task, program, behavior pattern, objective”) and cited Claude Shannon’s theories on the limits to transmission rates as applicable to the rate at which materials in a factory were “organized” into finished goods through “the input-output ensemble.”²² He noted the need in actual management to recognize that not all subsystems would be clear from organization charts. He also admitted that social gatherings and “bull sessions” could “contribute to a sense of being part of the team rather than a feeling of being a nameless cog, and so are good morale builders in addition to enhancing efficiency.”²³

Another expression of this general model came from decision theory, which similarly attached metaphors from technical systems to human organizations. Describing how this worked, David Hertz, an active participant in discussions of engineering management during the early 1950s, explained,

“When decisioning is removed from the conceptual area of flash of genius or automatic reactive process a new basis of analysis is available. It leads to the methodological dimensions in a multi-dimensional concept of action, in which other dimensions are (a) content, i.e., kinds of things, organisms, concepts, perceptions, etc., and (b) sequence, or position variable in a time stream. The process dimension... comprises a number of variables; the actual ‘instant of decision,’ which is usually considered to represent the process, can be no more than an interval separating specific elements.”²⁴

A more rudimentary application of feedback models to organizations appeared in a paper presented to the American Society of Testing Engineers in 1959:

“In discussing control of labor costs it is most important to have a clear understanding of what is meant by control. Otherwise, it is too easy to assume that control exists when, in fact, the basic elements of a true control system are not present. Control of any activity means that the activity is constantly being compared to a plan or standard and so

²¹ Jerome Rothstein, “An Informational Approach to Organization and System Engineering Design,” *Transactions of the IRE Professional Group on Engineering Management*, PGEM-1 (February 1954): 25–29, quote, 25–26. Rothstein was a physicist who had worked on radar modulators and transmitters during the war.

²² *Ibid.*, 26–27.

²³ *Ibid.*, 28.

²⁴ This quote comes from R.T. Livingston and D.B. Hertz, “Decision Theory,” ASME Paper 52A-106, presented to Management Division, ASME, New York, November 30–December 5, 1952. ASME Miscellaneous Papers, Linda Hall Library. Hertz was held engineering management positions with RCA and Celanese and later joined the business faculty at the University of Miami.

regulated that the performance of the activity meets the standard. Control of labor costs should be considered in the way that engineers look at the control of any function and that is to consider the control system as a servo-mechanism system and to design it so that there feedback to control variance.

"Figure 1 [below as figure 5.1] shows a simplified concept of a labor control system. One of the outputs of a shop, and the one in which we are primarily interested, is labor costs. In a servo-system we continuously measure the output to be controlled (in this case labor costs), compare the measured results against the plan or standard and measure the variance. This, in the control function, the measure labor costs are compared against the planned labor costs and any variance between the actual and planned labor costs is the basis for the next function in the system, regulation. The type and amount of regulation is dependent on the variance in the which has been observed in the control function and in the case of labor costs, regulation may be achieved by any one of many causes of action. Therefore, in any good control system, we have a constant flow of information from the measuring function to the control function where variance is noted. On the basis of this variance, the inputs to the activity are governed so as to achieve the desired outputs which, in turn, are measured and compared against the standard—resulting in further regulation if necessary."²⁵

Figure 5.1—Management as seen through the lens of control systems engineering. Source: Arthur F. Gould, Industrial Engineering Department, Lehigh University, "Control of Labor Costs," American Society of Tool Engineers technical paper 203, volume 59, book 1, presented to American Society of Tool Engineers, Milwaukee, April 18–22, 1959, 2.

The system and feedbacks needed to establish this regulatory function involved first determining appropriate job design by skill level and refining the human engineering or man-machine relationships. With these optimized, motion study, "flash observations," statistical methods, and queuing theory could then be used to organize a "complete control system."²⁶

²⁵ Arthur F. Gould, Industrial Engineering Department, Lehigh University, "Control of Labor Costs," American Society of Tool Engineers technical paper 203, volume 59, book 1, presented to American Society of Tool Engineers, Milwaukee, April 18–22, 1959, 1. Linda Hall Library.

²⁶ Ibid., 4–5.

The point here is not to emphasize the particulars of any one of these expositions but to observe system building in the 1950s was expressed in new and widely adopted technical language—one that updated older theories of control and of the position of the engineer at the controls.

Endless Frontiersmen

Though the electronics engineering field predated the war, after 1945 it passed through a period of redefinition. The profession and its work grew rapidly in the late 1940s and early 1950s as a consequence of government investment in weapons and control technologies. During this growth, the Institute of Radio Engineers was one of several anchors for technical and social exchange. Paul Edwards has described the building of a “Cold War world” as an exercise in the creation of expert systems and secret languages within a closed world and Donald MacKenzie has written “a historical sociology of nuclear missile guidance,” demonstrating the formation of a community of expertise around socially constructed definitions of the meaning and importance of accuracy.²⁷ These and other studies of military technologies of the 1950s have focused on the process of black boxing, in which technical and social choices reach closure and are set aside as givens. Edwards and MacKenzie give these processes a dark aspect, emphasizing a duplicitous relationship between realities and their representations, but the more mundane story is one of necessary closings and coalescings as part of the formation of professional communities, agreements on goals and standards, and day-to-day getting work done. Both Edwards and MacKenzie acknowledge that the 1950s was a formative period for systems and professions. During this as during other such periods, closure and accuracy were important in representing the messy work that went on inside inchoate organizations. In one researcher’s words,

“When a researcher starts an investigation or project, there is no assurance the he will obtain results that can be commercialized. The odds of doing so are probably somewhere between 1 in 10 and 1 in 100, depending on whether they are being quoted to management or among scientists.”²⁸

²⁷ Paul Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge: MIT Press, 1996). Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge: MIT Press, 1990).

²⁸ “Correlating the Philosophy and Practices of Research—What Westinghouse Says,” *Product Engineering* (May 1952): 174–177, quote, 175.

Discussing the development of PERT under a contract let by the Navy's Special Projects Office—a general contracting organization—Harvey Sapolsky describes the competitive advantage of this office in contests over funds if it were “perceived as possessing an extraordinarily effective management system.”²⁹ In Sapolsky's assessment, the Special Project Office built a mythology around expert management systems and “an alchemous combination of whirling computers, brightly colored charts, and fast-talking public relations officers.”³⁰

As Sapolsky notes, such mythology and alchemy served genuine purposes. Similarly, the “closed world” described by Edwards was necessary to representing expertise in uncertain times. As in earlier cases, the relationship between technical closure and the formation of thought collectives can be seen through the published engineering and computing literature. As during earlier eras of industry definition, new professions and industries nurtured and were nurtured by technical literatures. The classified nature of weapons-related projects meant that technical discussions of the particulars of these were walled off, a separation marked by the 1951 creation of the Armed Services Technical Information Agency to serve where commercial publications or professional journals could not³¹; however, the more general social construction of electronics and computers was readily accessible. Government or institutional bodies supported several of the most important early forums for the exchange of knowledge. The *Annals of the Computation Laboratory* of Harvard University and *Digital Computer Newsletter* (from the Office of Naval Research) helped disseminate early developments as N.A.C.A. and the Guggenheim Foundation had done for aeronautical engineering. With accelerating commercial development of computers in the mid-1950s, a swarm of electronics-related publications appeared (figure 5.2), and marked the progress of the industry and the formation of networks around an unstable technology.

²⁹ *The Polaris System Development: Bureaucratic and Programmatic Success in Government* (Cambridge: Harvard University Press, 1972), 95. Sapolsky treats PERT in 94–130, with his footnotes serving as a useful bibliography to the popular spread of the technique.

³⁰ *Ibid.*, 129.

³¹ Harold Wattel, “Diffusion of New Management Techniques as a Management Problem,” introduction to Harold Wattel, ed. *The Dissemination of New Business Techniques* (Hemstead, NY: Hofstra University, 1964), 3–26.

Figure 5.2—Patterns in journal formation in the electronics and information technology industries, 1880--1970. Note that this image includes some publications from the earlier history of telegraphy and radio engineering to emphasize the longer lineage of communications engineering, but that these earlier publications attended less to management issues.

Between 1952 and 1955, including professional journals, some eight computer or automation periodicals appeared. While these reflected increased attention to computing, the most active and important conversation on engineering management in electronics in this period occurred within the Institute of Radio Engineers (IRE). The IRE dated to the 1912 joining of the Society of Wireless Telegraph Engineers, a “social-technical club,” and the Wireless Institute, with the joined societies starting with fewer than 50 members and still numbering just several thousand in the late 1930s.³² These predecessor organizations had been formed by radio enthusiasts who felt left out of the “heavy current”-oriented American Institute of Electrical Engineers.³³ In the late 1940s and early 1950s, the IRE grew dramatically and, in the late 1950s, overtook the membership of the American Institute of Electrical Engineers—a development that ultimately precipitated the merger of the two associations into the Institute of Electrical and Electronics Engineers in 1962. In the early 1950s, a group of IRE members set up a Program Group on Engineering Management, publishing its first *Transactions* in 1954.³⁴ In its first issue, the Publications Committee of the IRE commented to readers that “the field engineering management is a relatively new one, and not by any means as exact of a science as electronics or many of the other fields familiar to IRE members generally,” but that the Committee hoped for contributions nonetheless.³⁵

Even before the establishment of the Program Group, management issues figured in discussions within the IRE. Several papers by Ralph Cole in 1950 and 1951 focused on the integrative role of the

³² A brief history is John L. Hogan, “What’s Behind IRE?” *Proceedings of the I.R.E.* 39 (April 1951): 340–341. See also A. Michal McMahon. *The Making of a Profession: A Century of Electrical Engineering in America* (New York: The Institute of Electrical and Electronics Engineers, 1984).

³³ Hogan, “What’s Behind I.R.E.”

³⁴ The group was started in 1951 to address “problems confronting engineering managers that especially require the combination of engineering and management know-how in the direction of engineering projects and programs.” Noted in *Proceedings of the IRE* 39 (July 1951): 842. Prior to World War II there was little attention to management topics in I.R.E. publications. The exceptions were an August, 1930 article on quality control (Virgil M. Graham and Benjamin Olney, “Engineering Control of Radio Receiver Production,” *Proceedings of the Institute of Radio Engineers* 18 (August 1930): 1351–1365) and several much earlier papers touching on “the operator problem,” notably including one of David Sarnoff’s first published papers (David Sarnoff, “Radio Traffic,” *Proceedings of the Institute of Radio Engineers* 2 (December 1914): 273–287, discussion 273–305). Sarnoff’s paper is interesting for likening radio traffic and its management to the traffic control function in large industrial firms, for addressing how accounts were handled in multi-firm, mixed landline and wireless message transmission, and for showing the relationships between incommensurable accounting practices and language difficulties during a period of uncertain relationships in international wireless telegraphy.

³⁵ Charles G. Cambridge, et al., “Message from the Publications Committee,” *Transactions of the IRE Professional Group on Engineering Management*, PGEM-1 (February 1954): 2.

systems engineer.³⁶ Cole espoused “system thinking,” under the “system engineer,” who brought together components functionally defined through research and development.³⁷ In Cole’s exposition, this man further had to manage the development of manuals, spare parts, the interfaces of the assembled component with other parts and with humans to “form master operational entities.”³⁸ In a subsequent article Cole asserted, “obsolescence of systems can be avoided only by tying together evolutionary equipment specifications with the encompassing systems ones.”³⁹ The twining of technical and managerial requirements was to be reflected in the coincident location of test points and demarcations between circuits in assigning work to engineers.

Reflecting the post-war movement of military officers into civilian management, the Chairman of the Program Group on Engineering Management was T.C. Rives, a retired army general who had joined General Electric. Introducing the first issue of the group’s publication, he described the “increasingly scientific” approach to the problems of management and, citing John Diebold’s then-recent book, *Automation*, the potential of digital computers as an aid to management.⁴⁰ With the growth of technology and the scientific approach, the engineer stood well poised to assume positions of leadership and to interpret the new language of machines:

“As our technology increases, as both the products and the processes of the industry become more complex, as we find greater use for automatism we necessarily must adopt a new language, a means of communicating not only with the machines, but with each other. This language essentially becomes a mathematical language, since it must not only bridge the gap between human and machine, but also between market place and factory, laboratory and market research. The engineer then seems qualified to speak this new language, and to interpret it for those unable to speak it.”⁴¹

But, despite this special position, Rives saw most engineers as not ready to manage because they lacked “knowledge of human engineering, of motivation, of capabilities, of business psychology.”⁴²

³⁶ Cole was a senior member of the I.R.E. then with Watson Laboratories, a research facility of the Air Materiel Command and later with the 351st Electronics Group at Griffiss A.F.B. in upstate New York.

³⁷ Ralph I. Cole, “Management’s Role in the Research and Development of Electronic Systems,” *Proceedings of the I.R.E.* 38 (November 1950): 1252–1253.

³⁸ *Ibid.*, 1252.

³⁹ Ralph I. Cole, “Management Aspects of Electronic Systems Engineering,” *Proceedings of the I.R.E.* 39 (December 1951) 1492–1493, quote, 1492.

⁴⁰ T.C. Rives, “Management and the Engineer,” *Transactions of the IRE Professional Group on Engineering Management*, PGEM-1 (February 1954): 3–7, quote, 3. John Diebold, *Automation, The Advent of the Automated Factory* (New York: Van Nostrand, 1952).

⁴¹ *Ibid.*, 4.

⁴² *Ibid.*, 5.

Further, some engineers fell under the influence of “a vocal minority... [that] professes that the theory of competition is a smokescreen for selfish industrial interests.”⁴³ Rives felt that the engineer needed to learn to “care for his ‘tools,’ these human beings, salary wise, in their environment and with praise and encouragement.”⁴⁴ From this beginning, subsequent articles and issues of the group’s *Transactions* set out variations on two themes: formal project controls and the role and social status of the engineer. Feedback loops and human relations were often mentioned in the same breath, with Claude Shannon and Harvard psychologist Jerome Roethlisberger quoted in immediate succession.⁴⁵ Article titles included “Engineers Can Be Managers,” “More Engineering Per Dollar,” and “Are Engineers People?”⁴⁶ Evaluations of variants on project-based organization appeared regularly.⁴⁷

While the IRE Program Group on Engineering Management’s publications form one of the richest veins of writing on engineering management in the early post-war period, they were far from alone. Interest in the problems of engineering management was widespread and in 1955 one-quarter of ASME’s 40,000 members were registered members of its Management Division. The AIEE invited a representative of ASME to speak on the work of the latter’s management division with an interest in beginning a similar group.⁴⁸

The *National Association of Cost Accountants Bulletin* had printed occasional papers on accounting for research through the depression and the war, but there was an outpouring of writing on the topic in the late 1940s and through the 1950s. A new journal, *Industrial Laboratories* (similar in spirit to *Research Laboratory Record* two decades earlier) provided some coverage of management.⁴⁹

⁴³ Ibid., 6.

⁴⁴ Ibid.

⁴⁵ See, for example, Melville Hopkins, “Human Relations in Engineering Management,” *Transactions of the IRE Professional Group on Engineering Management*, PGEM-2 (November 1954): 16–27. On the spread of human relations approaches note “Human Relations—A New Art Brings a Revolution to Industry,” *Time* (April 14, 1952).

⁴⁶ Respectively, Douglas Watson, *Transactions of the IRE Professional Group on Engineering Management*, PGEM-2 (November 1954): 28–40; Burgess Dempster, “More Engineering Per Dollar,” *IRE Transactions on Engineering Management*, PGEM-3 (March 1955): 1–15; and, A.M. Zarem, “Are Engineers People?” *IRE Transactions on Engineering Management*, PGEM-3 (March 1955): 39–50.

⁴⁷ Almost every description of engineering management discussed project organization. An example is C.F. Horne, “A Practical Approach Toward Intergration of Project and Group Theories in Establishing an Engineering Organization,” *IRE Transactions on Engineering Management*, PGEM-3 (March 1955): 22–33.

⁴⁸ Newman, Louis E., “An Engineering Society’s Responsibility in the Field of Management,” *Mechanical Engineering* (August 1955): 675. This paper was presented to the AIEE, New York, February 2, 1955. Notably the AIEE did not publish this paper—it appears only in the bound unpublished papers for 1955, LHL.

⁴⁹ S.C. Ogburn, Jr., “Research Management,” *Industrial Laboratories 2* (September 1951): 6–9.

Administrative Science Quarterly devoted one of its early numbers to the administration of research and many of the articles carried in the burgeoning academic management literature in the late 1950s concerned research or engineering management.⁵⁰ C.E.K. Mees's *The Organization of Industrial Scientific Research* was reprinted for the first time in a 1950 second edition. Beginning in 1952, Columbia University ran a series of annual conferences on research management that brought together practitioners and academics.⁵¹ In short, the coordination of skilled technical workers working under conditions of "target uncertainty" mattered across a wide range of industries, marking the development of new discourses around developing technologies.⁵²

Management Systems in Cold War Engineering

The 1952 3rd edition of Wallace Clark's *The Gantt Chart: A Working Tool of Management* registered the spread of the term 'project.' This edition included a newly written chapter on "the project planning chart." written by W.E. Camp.⁵³ This new chart was described as suited to work in which "the governing factor is simply *time* and where capacity (within practical limits) will be provided for the sake of completion of a piece of work in the shortest possible time."⁵⁴ The uses cited for this chart included aircraft overhauls, engineering development for military or industrial applications, plant construction, production equipment overhauls, and seasonal or style products "where temporary employment or sub-contracting is justified to ensure meeting the market."⁵⁵ The chart illustrated (figure 5.3) was distinct from the earliest Gantt charts in that it listed breakdowns of time requirements for subassemblies and their components making up a single unit of output—"a military device" in the label to the illustration—, but was otherwise undistinguished. A similar bar

⁵⁰ *Administrative Science Quarterly* 1 (December 1956). As noted in the introduction, *Administrative Science Quarterly*, the *Journal of the Academy of Management*, *Industrial Management Review* (now *MIT Sloan Management Review*), *California Management Review*, and *Business Horizons* were all started within five years of each other beginning in 1956.

⁵¹ David B. Hertz and Albert H. Rubenstein, eds. *Research Operations in Industry* (New York: King's Crown Press, 1953). This volume collected papers from the third of these annual conferences and reprinted selected papers from the first two meetings.

⁵² The idea of "target uncertainty" is a basic concept in cybernetics, referring to the relationship between the actual location of an enemy aircraft and its predicted location. The term appears in the engineering management literature in the 1950s and 1960s, providing an instance of the mapping of a community's technical language into management discourse.

⁵³ Clark had died in 1948; Camp was a member of Clark's firm.

⁵⁴ Clark, Wallace. *The Gantt Chart, A Working Tool of Management* (New York: The Ronald Press Company, 1922); 2nd ed. with a forward by B. Seebohm Rowntree (London: Sir Issac Pitman & Sons, Ltd., 1938); and 3rd ed. (London: Sir Issac Pitman & Sons, Ltd., 1952).

⁵⁵ *Ibid.*, 3rd edition, 60.

chart showing subassemblies making up a single object had appeared in *Industrial Management* in 1918 (see figure 4.16).

Figure 5.3—A “project planning chart for a military device” from W.E. Camp’s “The Project Planning Chart,” chapter 6 of Wallace Clark, *The Gantt Chart: A Working Tool of Management* (3rd edition, London: Sir Isaac Pitman & Sons, Ltd., 1952), 62.

The appearance of this chart in the Clark book marks not originality but the broadening relevance of project-based organization, both for new industries and for older industries in which military contracts had grown in importance. Project-based systems were used both to tackle real problems of size, risk, and complexity and to represent this work. This form was used both in systems-oriented work and in less fashionable branches of engineering.

In a 1947 article in the *National Association of Cost Accountants Bulletin*, a member of the research and development department of firearms manufacturer Remington Arms explained how a special Control Group had devised means of feeding up-to-date information on research progress to company management. In advance of setting up this reporting system research work was “already systematized on a project basis:”

“Each project stated the purpose and the scope of the work to be undertaken and the approximate completion date. Each project was reviewed in relation to the finished product for the purpose of determining anticipated return on investment. Moreover, the accounting department was doing exactly what we had been requested to do, namely,

accumulating all expenditures against each project and rendering a monthly report of the financial status of each project.”⁵⁶

This system was not unusual in itself, but the Control Group had gone beyond it instituting means of “continuous” (rather than monthly) controls. These new controls included daily labor reporting and weekly material and supply tabulations, which together were “a step toward fingertip control of research and development expenditures.”⁵⁷ To ensure compliance with the new controls, the Group had used a “sales promotion policy” to sell research personnel on the program and to “draw out their full cooperation.”⁵⁸ Having worked for some time to develop and install this new system, the Control Group—a special task force within the Research and Development Department—discovered to its surprise that “similar controls were [already] being kept on all construction projects, many of which were part of the development projects.”⁵⁹ Notably, this description valorized the Group’s accomplishment in making control over projects approximate systems of operating management as nearly as possible. A 1946 article in the *NACA Bulletin* described the form of management used in most research and development organizations simply as “control by projects.”⁶⁰

Projects and Systems

The role of projects and project managers in the electronics and aerospace industries in the 1940s and 1950s was an extension and elaboration of the liaison functions attached to these in earlier practice. Projects existed to coordinate resources across—and against—divisions within and between firms. As in the case of earlier waves of system building, orchestrating the integration of complex technical artifacts while working across boundaries and under time pressure meant designation of points and means of contact. In 1955, E.D. Gittens, Chief Engineer with the American Bosch Arma Corporation, an instrument maker, wrote a series of articles for *Automation* explaining the project-based organization of his department and its relation to new engineering challenges—guided missiles, supersonic aircraft, and modern industrial process controls. Gittens’s words are representative of the

⁵⁶ Glau L. Smith, “How We Developed Control of Research and Development Costs,” *N.A.C.A. Bulletin* 29 (Nov. 1, 1947): 279–289, quote, 280.

⁵⁷ *Ibid.*

⁵⁸ *Ibid.*

⁵⁹ *Ibid.*

⁶⁰ Ronald H. Robnett, “Control of Research and Development Costs,” *N.A.C.A. Bulletin* 27 (July 15, 1946): 1095–1109, quote, 1105.

genre. "The tools are at hand—and one of the most basic of these is a relatively new concept of engineering application and management called 'systems engineering,'" Gittens asserted.⁶¹ He explained further what he meant by this new concept, "'systems engineering' may be broadly described as a management means of producing a highly coordinated application of engineering effort to problems requiring large numbers of engineers having varying degrees of specialization," while at the same time, "the entire project is usually tightly bounded by time schedules and cost."⁶² As Gittens explained it, the need for this new way of thinking had arisen because of the increased specialization of engineering fields in areas such as servomechanisms, automatic controls, and electronics. While systems engineering was, in essence, a means of coordination of men and things, this coordination also needed to "provide an atmosphere of intellectual freedom for the creative professional man and an opportunity to develop his growth potential"⁶³ "The opportunity to maximum initiative and resourcefulness with responsibilities, scope, and authority clearly defined."⁶⁴

Gittens's firm used three broad divisions: Project Administration, Research and Development, and Product Design. The basic organization structure was functional, but Gittens noted that the formal organization and its operations diverged. "If one were to take this organization at face value and assume that projects would have to be broken down and assigned by the chief engineer according to function or specialty, such an organization would immediately be deemed unworkable. "However, it is possible for this engineering division to handle hundreds of different projects simultaneously and successfully through the concept and operation of a *project team* superimposed on the plan of specialized departments."⁶⁵ His description went on to explain the function of the project co-coordinator. In his case, the entire project effort served a control function in relation to manufacturing: once a system meeting the customer's requirements had been conceptualized, it was to be "reduced to manufacturing terms in the form of drawings and specifications."⁶⁶

⁶¹ E.D. Gittens, "Management of Systems Engineering: A New Challenge," *Automation* (February 1955): 35–41. Gittens exposition continued in the March and April issues, 49–55 and 55–64, respectively.

⁶² Ibid., 35–36.

⁶³ Ibid., 37.

⁶⁴ Ibid., 37–38.

⁶⁵ Ibid., 40.

⁶⁶ Ibid.

The result of this organization was to “arrive at a high degree of concentrated specialized knowledge and yet maintain flexibility of application through the project team operation.”⁶⁷ Gittens particularly emphasized the flexibility and creativity accommodated by Arma’s system. “At Arma, considerable effort has gone into the planning of engineering controls in an attempt to devise a complete set of mechanics for handling all non-technical phases of project operation in a systematic and uniform manner. Further, it was the aim of these mechanics to provide the project co-ordinators with direct aid and support in their ‘housekeeping responsibilities with regard to budgets and schedules.’”⁶⁸ Their reports went to a central engineering administration department containing an estimating section and a budget control section. The estimating section coordinated construction of time and dollar budgets for a prospective contract. These were built up from estimates for various subassemblies. Assuming the sale was made, this estimate then assumed a control function in relation to the execution of the contract. Monthly reporting of hours, dollars, and technical accomplishment was checked against the original estimate.

Subassemblies and Sectional Logics

David Mindell comments that prior to World War II “the political economy of military technology was built on the older model where systems were decomposable,” and that the contracting agency typically assumed responsibility for assembly.⁶⁹ Through World War II, the U.S. armed services contracted separately for component parts of weapons and for different steps in the development process. So, for example, in procuring aircraft, engineering was let as a contract separate from production, and production of different component parts were let as different contracts. The component parts were then provided to the assembling firm (typically the airframe manufacturer) as “government furnished equipment” rather than being produced or purchased by that firm. This logic was followed even where it involved extraordinary coordination costs, on the principle that such control was a necessary in the public interest. This intermediation was possible but extremely inefficient given the interrelatedness of weapons components in which system behavior and component design influenced each other. In Mindell’s words, “to embody their model in working

⁶⁷ Ibid., 41.

⁶⁸ Ibid. The term “mechanics” is used here in the sense of office system.

⁶⁹ “Datum for Its Own Annihilation,” 415.

systems... they needed a set of engineering techniques to complement institutional relationships.”⁷⁰ That is, tight organizational integration was needed to echo couplings in the systems being built.

In 1948, at the behest of a congressional committee, the Armed Services Procurement Act altered the procedures the Department of Defense used to acquire weapons. This act allowed the military to award single-source contracts for the development and manufacture of weapons. No manufacturer was then building entire weapons, so in essence this act transferred the integrating and coordinating function from the military services to a prime contractor, who gathered together subcontractors and assumed the responsibility and risks associated with making things and people work together. This act also shifted the temporal dynamic of development and manufacture, allowing initial engineering, manufacture, and subsequent modifications to be let in a single contract rather than incrementally.

In the early 1950s, the Air Force took this notion a step further by hiring the Ramo-Wooldridge Company to provide systems engineering services for the development of the Atlas intercontinental ballistic missile. The Air Force took this step on the grounds that the original prime contractor for the Atlas, airframe manufacturer Convair, lacked the technical expertise needed to pull together the disparate parts of the weapons system. Developments then underway included not just the missiles, but also an extended infrastructure of bases, communication systems, and training program.⁷¹ The Navy’s Special Projects Office served the same role in relation to the Polaris submarine program. In other words, systems engineering developed in response to the same problems that had encouraged the use of general contractors in municipal engineering work a half-century earlier. Contracts for complicated technical devices requiring the integration of different components created by different specialists involved assignments of risk for fitting the parts together. The systems engineering function provided expert coordination of parts given still-indeterminate technologies.

In a 1959 *Harvard Business Review* article, J. Sterling Livingston, commented on the complicated blend of technical and political integration and issues in the delegation of authority involved in these Cold War systems. “As weapon systems have become more and more complex,” Livingston stated, “the services have found that they did not possess the talent needed to perform all the functions

⁷⁰ Ibid., 415.

⁷¹ On procurement by the Air Force see John C. Lonquest, “The Face of Atlas: General Bernard Schriever and the Development of the Atlas Intercontinental Ballistic Missile, 1953–1960,” Ph.D. dissertation, Duke University, 1996; and Edmund Beard, *Developing the ICBM: A Study in Bureaucratic Politics*. (New York: Columbia University Press, 1976).

required of weapon systems managers, including the integration of the subsystems and components into compatible and balanced weapon systems.”⁷² Writing in the early 1960s, Fremont Kast and James Rosenzweig took a common view when they wrote that “the weapon system concept evolved from the recognition of a greater necessity for the timely integration of all the functions... into a coordinated and effective system for mission accomplishment,” and quoted a Senate hearing in which this was called “a new management concept.”⁷³ Kast and Rosenzweig used the Navy’s Special Projects Office and the Air Force Systems Command as instances of this new concept.⁷⁴

The Role of the Project Manager

As in aircraft engineering and construction contracting before, the project manager served as a go-between in the creation of Cold War systems. This was both a technical and social function, involving “integration factors”—that is, interfaces among subsystems—and “human factors.” “Liaison” continued to serve as a generic term for communication among different functions within firms and engineering departments, with the form of liaison coming sometimes through meetings and other times through forms or drawings. States Mead noted the double-edged quality of the go-between function assumed by “liaison engineers.” Use of such personnel was “a special though not uncommon means of maintaining a satisfactory working relationship between engineering activities,” and Mead considered it “the most direct and potentially effective method.” He noted, though, that it could be expensive and that it should not be overused, “lest it become organization habit in lieu of establishing clear definition of responsibility relationships and satisfactory work performance.”⁷⁵

Describing this function in an engineering laboratory, one author noted, “providing this ‘environment of organized research’ constitutes the research manager’s heavy burden of responsibility,” offered this author, “In a large laboratory, he must guard against breaking down projects into too minute and simple portions, as in a productive assembly line. In such

⁷² Livingston, “Weapon System Contracting,” *Harvard Business Review*, 83.

⁷³ “Weapon System Management and Organizational Relationships,” *Journal of the Academy of Management* 4 (December 1961): 198–204, quote, 200, citing *Procurement Study*, Hearings before the Senate Committee on the Armed Services, 86th Congress, 2nd Session (Washington: Government Printing Office, 1960), 100. See also Fremont E. Kast and James E. Rosenzweig. *Organization and Management: A Systems Approach* (New York: McGraw Hill, 1963).

⁷⁴ The Air Force Systems Command took over this role from the private Space Technology Laboratories, which had been spun-out of Ramo-Wooldridge Corporation.

⁷⁵ Mead, “Engineering Your Company’s Future,” 167.

overspecialization, a promising creative research worker might be whittled down into a routine laboratory tester.”⁷⁶ Mindell notes that in the design of anti-aircraft systems at Sperry, human operators served as “integrators” in the operation of the machines, linking balky and error-prone components, filtering noise, and increasing system-level reliability in order to enable prediction of target location.⁷⁷ Eric Rau describes how the integrative approach of operations research brought down walls between research and use, walls that had been erected through contracting practice.⁷⁸ Across technical and managerial aspects of the work and the systems being created, an increased need for such coordinative functions was remarked in the post war literature and marked in the adoption of general contracting forms.

Accounting Procedures

The boom in engineering work of the early 1950s created a boom in the business of supplying engineering firms with accounting and control systems. With the popularization of CPM and PERT, consulting services and aids to the application of these methods were widely touted. The “Pertometer,” the “Pert-O-Graph,” the “Planalog” were circular slide rules or nomographic aids to network analysis sold to project managers.⁷⁹ Engineers wrote articles sharing tools they had cooked-up independently.⁸⁰ Most of the methods offered in the 1950s and 1960s integrated some form of graphic control, usually in the form of a Gantt chart or network diagram accompanied by tabular forms for recording expenses. “Mechanized charts” with pegs, pulleys, and celluloid slots were offered, though the 1952 edition of *The Gantt Chart* disparaged these: “The appeal of the mechanical wall boards is that they are dramatic. The large, usually colourful, wall display is spectacular. Dramatics and showmanship have a useful purpose; they are frequently desirable features of a method of control in industry...” but the “orthodox Gantt Chart” can be similarly dramatized.⁸¹ Many

⁷⁶ Veal, C.B., “Research—Opportunity and Challenge,” *Mechanical Engineering* (September 1947): 759.

⁷⁷ 153. Regarding dynamic stuff See also “Automation’s Finest Hour: Radar and System Integration in World War II,” in Hughes and Hughes, 27–56.

⁷⁸ Eric Rau, “The Adoption of Operations Research in the United States During World War II,” Hughes and Hughes, 57–92.

⁷⁹ The several I have seen are in a collection of papers and books of Isadore Halzel, who worked in the MIT Instrumentation Laboratory in the 1960s, now in the possession of William Duncan, Lexington, Massachusetts.

⁸⁰ See, for example, W.E. Elder, “Keeping Track of Projects with Control Boards,” *Product Engineering* (September 1953): 141–142.

⁸¹ 3rd ed., 1952, 165.

examples of the craze for office systems that accompanies the systems engineering mania could be offered. A few will suffice.

A planning engineer with Reaction Motors, Inc. a maker of liquid-fueled rocket motors, tracked the bureaucratization of his company in its development of "effectivity rates" and overhead budgeting based on historical data.⁸² The company had existed from 1941, and did almost all of its work directly or indirectly on government contract. In developing a "Manual of Accounting Policies," in 1948, Reaction Motors sought a system that would both meet government requirements and be "coordinated with the other elements of the business."⁸³ The building block of this system was the "project budget" which was based on "an assigned task under a contract," which could include all work under the contract or breakdowns at the company's discretion. Project engineers, working in man-hours and material costs, were kept abreast of total charges with allowance for overhead and labor rates by the accounting department. In measuring work against budgets, the effort was complicated because the nature of the output varied from contract to contract. Early issues of the IRE Professional Group on Engineering Management's *Transactions* assemble a litany of similar systems (figure 5.4).

Many of these systems echoed the requirements of Department of Defense accounting requirements.⁸⁴ Given the monopsonistic position of the military in relation to much of the electronics industry, as it helped bring this industry into being it also impressed on it many formal procedures. Armed Services Procurement Regulations dictated how accounts were to be handled. WD Form 105—Cost Analysis, used in price negotiation, was ultimately based on a breakdown of the work to be performed. APSR Section 15 set rules for reimbursement on cost-plus contracts, but was also invoked for guidance when fixed-price contracts required renegotiation.⁸⁵ Legally, contractors' accounting systems were expected to comply with "generally accepted accounting practice," but they were so tied to the project-oriented reporting requirements that were written into government contracts that there was little general about them.

⁸² William Francis O'Brien, Jr. "Budgetary Control in a Research and Development Company," *N.A.C.A. Bulletin* (March, 1952): 838–860.

⁸³ *Ibid.*, 841.

⁸⁴ Section 1 of the *N.A.C.A. Bulletin* for May 1952 was entirely devoted to defense contract accounting. 33.

⁸⁵ *Ibid.*

**BUDGET AND EXPENDITURES, PROJECT NO E627-4
INSPECTION INSTRUMENTATION FOREIGN PARTS**

Figure 5.4—Budgeting diagram from H.J. Finison, "Control of Costs of Research and Development Projects," *Transactions of the IRE Professional Group on Engineering Management PGEM-2* (November 1954): 13.

Network Diagrams

The use of network diagrams where formerly Gantt charts had been used and the general extension of computers into engineering management are best marked by the simultaneous development of Program Evaluation and Review Technique by the Navy working with consulting firm Booz-Allen and Hamilton as part of the Polaris Program and that of the Critical Path Method by DuPont and Remington Rand Univac.⁸⁶ The possibility of such applications of computers to

⁸⁶ CPM is treated in more detail in one of the cases at the end of this chapter. A useful source for the state of the art in the early 1960s is Rocco L. Martino, *Project Management and Control*. 3 volumes: *Finding the Critical Path*, *Applied Operational Planning*, and *Allocation and Scheduling Resources*. New York: American Management Association, 1964–1965. CPM and PERT spawned a variety of derivative or imitative variants with acronymic names including SCANS, PEP, RAMPS, LESS, PACT, SPECTROL, and so forth.

engineering management—and particularly of network analysis to scheduling problems—had been earlier acknowledged; however, these methods were so heavily sold by consulting firms and forced on contractors by the Department of Defense that they came to be popularly equated with engineering management. The development and commercialization of computers provided both new work to be controlled and new means of controlling work. In an article written the early 1950s, a researcher at the University of California offered:

“If one reads either the popular press or the scientific literature at all, he cannot but be aware of the many dynamic applications in high speed electronic computers and of their application to the solution of engineering and scientific problems. There is also a rapidly growing discussion of their application to managerial problems. While these computers have been able to handle many of the basic and important scientific problems, to date they have been able to be applied only to the peripheral problems of management. This is due in large part not to any lack of ability on the part of the machines or their designers to fit them to handle many of the more interesting management problems, but rather the fact that these problem have not been reduced to a rigorously logical form.”⁸⁷

The solution for this author, and for many others, lay in the modeling of production in terms susceptible to the application of linear programming and other econometric tools. He noted the superiority of such techniques relative to “conventional” and “intuitive” use of Gantt charts to work through required steps in a production process because they offered “a synthetic numerical form of that intuition.”⁸⁸ While acknowledging limits to his approach, he hoped for “sympathetic cooperation” between managers and expert staff in the development of these models. This early consideration of the applicability of such models to scheduling in engineering work was not alone, with others looking at computing’s application in areas from road building and traffic management.⁸⁹ In 1951 and 1952, DuPont’s Engineering Department was working on applying operations research to balancing cut and fill in highway construction—an application that helps emphasize that these were new techniques applied to old problems.⁹⁰ By the early 1960s, CPM and PERT were being marketed as applicable to just about any kind of work. One text which admitted their faddishness nonetheless commented, “...both are equally applicable to *any* kind of project—R&D, construction, engineering,

⁸⁷ Melvin E. Salvesson, “A Computational Technique for the Scheduling Problem,” University of California Industrial Logistics Research Project, Research Report No. 15, May 5, 1953.

⁸⁸ *Ibid.*, 25.

⁸⁹ Joseph S. Kane, “Origin of CPM and PERT,” in Wattel, ed., *The Dissemination of New Business Techniques*, 37–64.

⁹⁰ Citation (*Ibid?*)

new product introduction, advertising campaigns, corporate planning, military tactical operations, and so on ...”⁹¹

A brief exposition of how PERT and CPM worked (and are used today) emphasizes the persistence of the underlying sectional logic of projects introduced in the first chapter. Like Gantt charts, PERT and CPM diagrams required first identifying and representing dependent relationships in the course of a production process. By linking steps in the process to predecessor and successor events and estimating the time costs and—in the case of PERT—expected variance in estimates of time cost, the “critical” path in a project could be identified (figures 5.5 and 5.6). That is, given a network of relationships in time, there was some path that determines the shortest possible time to overall project completion. This path became “critical” because speeding the project would require shortening the time to complete one or more of the tasks along the critical path. Simple networks could be analyzed by hand, but larger ones provided work for computers. The figure reproduced here as 5.4 comes from the later 1960s, but usefully sets out the common qualities between PERT, CPM, and many variants they spawned. The author of the document in which it appeared explained:

“A summary of the various steps involved in all current systems is shown in figure [5.4]. One must first establish his objectives and review all work involved in reaching the goal. This is described in step 1. Each job is then made part of a sequence that shows what must precede, what can follow, and what jobs can be done in parallel. This ‘roadmap,’ Step 2, is called a Network Diagram. Estimates of time, manpower, and data are then prepared, Step 3. Such data may be processed by either manual methods for simpler programs or by computer if the amount of data is large. Such alternates are indicated by the two steps No. 4. The results of this processing, Step 5, can then be translated into conventional bar charts, Step 6, showing the time each task must be performed to meet the goal date.

“While these are the basic steps in all current systems, there is a wide variation in the kinds of data and the depth of detail developed in Step 3. There are also many computational programs and computers from which to choose...”⁹²

⁹¹ Rocco L. Martino, *Project Management and Control*, vol. 1, 5, 14.

⁹² G.J. Fisher, “Scheduling the Elements of a Manufacturing Venture,” typescript in Accession 2004, E.I. DuPont de Nemours & Company, DuPont Reports on their Use of Computer Programs by the Engineering Department, Hagley Center for the History of Business, Technology, and Society, Wilmington, Delaware. Hereafter Hagley 2004. This document bears no date but is likely about 1967 given related documents.

Figure 5.5—Steps in developing a project plan. Source: G.J. Fisher, "Scheduling the Elements of a Manufacturing Venture," Hagley 2004.

Figure 5.6—Scheduling using a network diagram. Fully explaining the steps and symbols used in CPM or PERT is beyond the present scope but can be found in current textbooks on project management. Source: David M. Stires and Maurice M. Murphy, *Modern Management Methods: PERT and CPM* (Boston: Materials Management Institute, 1962), 177.

Cases

The first of the two cases here marks the use of project-based organization from the earliest days of the computer industry, looking at the use of this in the Eckert-Mauchly Computer Corporation and Engineering Research Associates, two early computing firms later absorbed into Remington-Rand Univac. Both of these firms were shaped by military contracting procedures directly and through the wartime experience of their staffs. The second case is based on accounts of the development of the Critical Path Method through a cooperative effort between DuPont's Engineering Department and Remington Rand Univac's Applications Research Center. Together these cases mark the essential continuity of conceptions of project-based organization relative to prewar practice even as this form was interpreted through the perceptual frameworks of evolving disciplines and modeled to suit the capabilities of new machines.

Univac

The development of the Univac Computer, among the first commercial general-purpose electronic computers, brought together a diverse collection of industrial and engineering firms. All of the firms in question organized engineering work around projects and most of the personnel involved had been in the military or had worked on military contracts during the war, and so War Department contracting terminology was a *lingua franca* to them as it was to most engineers after 1945. Univac development started as a project of the Eckert-Mauchly Computer Corporation (EMCC). The story of J. Presper Eckert and J.W. Mauchly, their wartime work on the ENIAC at the University of Pennsylvania, the untimely death of their major investor, Henry Strauss of American Totalisator, and the distressed sale of EMCC to Remington Rand has been chronicled by historians of business and computing, but the management practices of EMCC have not been chronicled.⁹³

Not long after Remington Rand bought Eckert-Mauchly, Remington Rand was itself acquired by Sperry Gyroscope, and Remington Rand Univac became a division of the Sperry Rand Corporation.

⁹³ The information available for this case is substantially thanks to a long legal battle over the intellectual property rights to general purpose computing. See Accession 1825, Sperry-Univac Corporation Records; Accession 1901, Technitrol Suit Records; and Accession 2015, Engineering Research Associates Company Records—all at the Hagley Center for the History of Business, Technology, and Society, Wilmington, Delaware. Hereafter Hagley 1825, Hagley 1901, and Hagley 2015, respectively. A valuable general account is James Cortada, *Before the Computer: IBM, NCR, Burroughs, and Remington Rand and the Industry they Created, 1865–1956* (Princeton: Princeton University Press, 1993).

Shortly thereafter, Remington Rand Univac acquired a second early computing firm, Engineering Research Associates (ERA) of St. Paul Minnesota. The 1955 creation of the Univac division was an effort to pull assorted organizational components into some coherence, uniting the people and facilities of ERA, EMCC, and part of Remington Rand's own engineering division. Going back to the immediate post war period at ERA and EMCC brings to light a story of a halting, complicated effort to manage systems development for a halting, uncertain market. Both firms desperately sought patronage wherever they could find it. In this light, both were essentially contract engineering companies looking for the job that would carry them to the job after that, like small-time construction contractors trying to keep crews together. A detailed account of either of these firms is beyond my scope and so the balance of this case provides snippets of organizational and contracting issues that show how the language and tools of projects were both ubiquitous and mundane in early computing.

The ENIAC had been developed at the University of Pennsylvania's Moore School under Contract W-670-ORD-4926. As an ordnance department project, it was governed by Army contract requirements for monthly accountings and progress reports.⁹⁴ The ENIAC Progress Report for Dec. 31, 1944, for example, notes:

"As of Dec. 31, 1944, virtually all thought and energy of the project group were concentrated on the achievement of a working model of the ENIAC. To this end intensive construction work was underway, but no complete units or parts of the ENIAC, with the exception of two accumulators, were finished. A large portion of the steel framework to receive the ENIAC panels had been erected; the ventilating system for the panels had been designed and was being installed; and a group of 40 to 50 wiremen, machinists, etc. were working at constructing the various parts."⁹⁵

Of interest in these records is an early mapping of the behavior of a difference analyzer in a manner closely akin to sequencing production using a Gantt chart (figure 5.7).

⁹⁴ Many examples can be found in Hagley 1825, box 5.

⁹⁵ Ibid.

Figure 5.7—Gantt-type chart used to represent a computing process in terms of stations and transformations akin to the sequencing of an assembly line. Note the list of operations at the right. Source: Hagley 1825-5, from project report of November 1943.

Following the war ERA and EMCC went after more or less the same group of potential patrons. In late 1946, ERA considered its major prospects to be the Office of Naval Research, the National Bureau of Standards, the U.S. Army, Prudential Life Insurance, and the University of Chicago and other schools⁹⁶ with potential also seen at United Airlines, the Civil Air Administration, and Sun Oil.⁹⁷ Early governance of EMCC was through a "Contract Committee" that met "at the usual beer parlor on Cliveden Avenue" to decide on how to court government and commercial work, including air traffic control, airline reservations, and insurance applications.⁹⁸ The various government agencies were themselves feeling their way toward what it was that they wanted to buy and how to specify the nature of that object. Discussing delays in the letting of an Office of Naval Research (ONR) Contract to ERA, a representative of the ONR explained that ERA's original proposal had been too specific—the contract at hand was for the nebulous task of technical assistance in defining the Navy's computing needs.⁹⁹

⁹⁶ C.B. Tompkins to W.C. Norris, October 8, 1946, Hagley 1901-6-7. Note the Prudential ultimately sponsored work at EMCC, but later abandoned the Univac for IBM's products.

⁹⁷ William C. Norris to Howard T. Engstrom, September 11, 1946, Hagley 1901-6-7.

⁹⁸ Memorandum, Isaac L. Auerbach to J.W. Mauchly et al., May 18, 1948, Hagley 1825-4a. Auerbach was the Chief Production Engineer.

⁹⁹ "Summary of Computing Conferences Held 9 October 1946," Hagley 1901-6-7.

The methods of ordering work in these companies once contracts were let echoed practice in the pre-war aircraft industry. The progress reports mandated by contracts were prepared by Project Supervisors and then used by "Contract Liaison Representatives."¹⁰⁰ The earliest computer contracts were functionally defined in terms of the behaviors of component parts and terms of exchanges of information among them, rather like specifications for power equipment in the nineteenth century. Describing the objective of "Project Goldberg," a special-purpose computer for the Navy, this was set out as a teletype tape reader, magnetic storage drums, electronic translators, electronic counters, mechanical printer, and control equipment, with specification of what each would do and how they would interact.¹⁰¹ In their business plan, Eckert and Mauchly were not too concerned about space since "an electronic computer is built mainly by assembling components manufactured by others," most of which were "standard radio parts."¹⁰²

Jumping forward to the later 1940s, Eckert-Mauchly set up more formal administrative controls and routines as Univac development got underway. Operations and planning committees were established in early 1949, with the Operations Committee set up "in the interest of expediting the speedy and effective dispatch of the various tasks before the Corporation" and to "occupy itself with interdepartmental relations, schedule work to be performed by the Corporation and follow up the progress of this work."¹⁰³ Meetings of the Planning Committee within Eckert-Mauchly set out work in terms of months and weeks relative to drawing releases and completion of preceding steps where work had to be sequential.¹⁰⁴ Scheduling was based on ballpark guesses of time required and expedition through such "operating and engineering compromises" as were possible without

¹⁰⁰ William C. Norris to Distribution, August 14, 1951. Hagley 2015-2-1.

¹⁰¹ Progress Report No. 1 Engineering Research Associates. September 1, 1947. Hagley 1901-5-17.

¹⁰² "Proposed Electronic Computer Company," n.d. but likely Spring 1946. Hagley 1825-4a. In this regard, Eckert-Mauchly aligned themselves with the Bureau of the Censuses pursuit of a practicable early model rather than a fantastic future possibility. J.H. Curtiss put this in terms of the contrast between a 1947 Buick and a 2001 private rocket ship. J.H. Curtiss to J.C. Capt, June 12 1946. Hagley 1825-4a.

¹⁰³ John W. Mauchly to J.P. Eckert Jr., et al., "Establishment of the Operations Committee," January [full date missing but likely January 2nd or 3rd of 1949 based on related documents]. Hagley 1825-4a.

¹⁰⁴ Eckert-Mauchly Operations and Planning Committee meeting records are in Hagley 1825-4a.

breaching contractual obligations.¹⁰⁵ Accounting followed the technical breakdown of the work, with man-months and material tracked by month by component by type of labor.¹⁰⁶

Jumping forward again, to after the formation of the Univac division within Sperry Rand, in 1956 Univac was shifting into production. Arnold J. Ryden, treasurer of ERA (and later a founder of Control Data Corporation), was addressing organizational hurdles to making this transition; incompatibilities between the administrative arrangements suited to building relative to those for operating began to develop.¹⁰⁷ Ryden observed, "Historically St. Paul [ERA] was an engineering organization. Quite logically, the accounting developed around projects and a job cost accounting system."¹⁰⁸ As a consequence, though, St. Paul lacked systematic cost control suited to production, particularly since "Engineers might also tend to be unduly concerned with equipment capabilities rather than total clerical function."¹⁰⁹ Discussing the administration of engineering work, Ryden felt that, "an important factor in this regard is a clear distinction, organizationally, between engineering and production."¹¹⁰ Ryden proposed a project-based control system involving authorization, charting, program development, cost reporting, and organization. This system was designed provide detailed, regular reporting, through use of a "project engineers planning chart" that integrated a cost summary, Gantt charts indicating progress against plans, and personnel information.¹¹¹

Further explaining this system, he indicated, "The organization of the department is primarily by project with each project being under the supervision of a project engineer."¹¹² These engineers in turn reported to a Project Coordinator, who held an integrative function with regard to both technical and administrative aspects of the work. "In short, the project coordinator will tell the project engineers what to build and by when it must be ready and will have the responsibility and authority to

¹⁰⁵ The rush to meet deadlines and budgets in early 1949 was in connection with the delivery of a BINAC computer to A.C. Nielsen. Quote is from Dr. Mauchly to Planning Committee, H.L. Straus, and M.C. Robinson, March 4, 1949. Hagley 1825-4a.

¹⁰⁶ Accounts for the Univac were kept by component for the Univac, Uniprinter, Unityper, Super Typer, Unitape, and Binary Computer. Hagley 1825-29.

¹⁰⁷ Ryden prepared a number of memoranda on organization in 1956 and 1957. Hagley 2015.

¹⁰⁸ "Review of Progress: Financial Planning and Control." A.J. Ryden? Hagley 2015-2, citing his own April 1956 report.

¹⁰⁹ Ibid.

¹¹⁰ Ibid.

¹¹¹ Hagley 2015-2-8

¹¹² E.E. Masterson to members of the Electro-Mechanical Development Department, February 24, 1956. Hagley 2015-2.

see that his directions are met.”¹¹³ Notably, he did not include how the engineers would build what they built. Intersecting the vertical project control was horizontal direction by Technical Coordinators for electrical and mechanical aspects of the work. The technical coordinators controlled “how.” While this scheme implied a very management-heavy department, individuals held multiple roles. A single person was both Project Coordinator and Technical Coordinator for electrical work and the department head also served as Project Coordinator for research work and as Technical Coordinator for mechanical work. Driving the complexity of the arrangement (at least when represented on paper) was that the firm was unable to find project engineers who could handle mechanical, electrical, and logical work. Further, this plan was expected to help coordination, which had been “admittedly weak in the past.” But, within this set up, the project engineer was to have “the maximum amount of control and responsibility for both his project and his men,” including both administrative and technical authority.

The project system itself worked along the lines of the sequence of requests and approvals akin to that at DuPont in the 1920s. A written description including preliminary considerations of schedules, budgets, and personnel requirements was to be prepared, including charts that could serve as controls on the work if approved. Weekly meetings and monthly reports would provide formal mechanisms, supplementing day-to-day contact. In May 1957, A.J. Ryden reviewed a proposed “Project Planning Chart” that Knight Pryor had developed for use in controlling engineering work at Remington Rand (figure 5.8). Ryden felt the charts were “excellent” and that they “must become a principal tool for the project engineer.” He also noted “the total of all individual Project Planning Charts must be used as the basis for evaluating new business alternatives in relation to capacity and projected capacity.”¹¹⁴ Interfaced with the finance and personnel departments, these charts would become part of an integrated engineering management system. The chart used consisted of Monthly and quarterly accounting and charting of dollar and hour costs against estimates.¹¹⁵

¹¹³ Ibid.

¹¹⁴ A.J. Ryden to K. Pryor, May 6, 1957. Hagley 2015-6.

¹¹⁵ Charts appear in Knight Pryor to F.C. Mullaney, “Project Planning and Control,” May 3, 1957.

Figure 5.8—Sample "Project Planning Chart" prepared either by or for Knight Pryor in the spring of 1957. Source: Hagley 2015-6.

The application of project-based controls at EMCC, ERA, and then the Univac Division of Remington Rand helps relate the generalities contained in the contemporary literature on engineering management to practical problems in the course of unfolding, uncertain technical development efforts in a bureaucratizing context; however, seen in relation to systems described in the contemporary press, reporting requirements set by these firms' military patrons, and the longer history of organizing contract engineering, they were utterly mundane. They do, though, mark one path by which these logics and their temporal dynamics shaped the modern computer industry.

E.I. DuPont de Nemours & Co. (3)

In the mid-1950s, DuPont's Engineering Department oversaw over 100,000 construction workers involved in projects ranging from Nylon plants to atomic energy installations. The Department was then working on retooling DuPont's facilities to enable continuous rather than batch production and was also doing work under contract to other companies.¹¹⁶ The Department had developed a complex bureaucracy to handle cost estimates, schedules, and accounting work, using a system of "blocks" of work that could be defined based on field experience, such that organizing a project meant arranging the blocks in a manner that best coordinated people, materials and tools. This was object-oriented programming well before the fact. In late 1956, Du Pont's Chief Engineer, Granville Read, set up an "Integrated Engineering Control Section" with the purpose of finding better ways of organizing engineering work. Morgan Walker, trained as an aeronautical engineer, joined this group and arranged the lease of a Univac to work on the problem.¹¹⁷ Interested in fending off IBM's entry into the computer market, Remington Rand Univac had set up a "Univac Applications Research Center" to develop uses for the machine, and John Mauchly assigned James E. Kelley, Jr., to help with the DuPont work. Kelley, a mathematician by training, had already been looking at the application of operations research to highway construction as a potential market for Univacs, so the construction-scheduling problem faced by DuPont fit his area of inquiry.¹¹⁸

¹¹⁶ John S. Sayer, "DuPont Engineering Department in the 1950s," *PMNetwork* (February 1989): 23.

¹¹⁷ According to Walker's account, the application of a DuPont-owned Univac to this problem had already been proposed by two mathematicians in the Engineering Services Division, but this proposal did not progress. See James E. Kelley and Morgan R. Walker, "The Origins of CPM: A Personal History," *PMNetwork* (February 1989): 7-22.

¹¹⁸ The first interstate highway bill was then recently signed into law, and so there was a prospect of a ready market. *Ibid.*

Applying network diagrams and linear parametric programming techniques of which the relevance “was obvious” to a mathematician.¹¹⁹ These conceptions made the scheduling problem amenable to network techniques developed to understand routing or traffic problems. In this regard, the contemporary but independent development of CPM and PERT registers the general awareness of and interest in such applications. There was some interaction between the people involved in CPM and those working on PERT, but reportedly this occurred late in the development of each and “little practical exchange of knowledge took place.”¹²⁰ With input from consultants including Jay Forrester, the CPM group conceived of a project flow system that “was based on the concept that engineering is essentially an information/data flow process,” that began with a problem statement and progressed through technical specification and execution.¹²¹ Despite meeting internal resistance to spending time and money working on a management system rather than revenue-generating contract work, development of this system was authorized in early 1957.

The DuPont method of arranging blocks had already created a set of relationships and movements over time, which made the problem into a flow diagram or algorithm, typified by connections and dependencies. The method developed by the CPM group applied network analysis to time and sequence relationships among steps in an engineering project to identify the “critical path,” that is, the sequence of activities that determined the quickest possible completion of the overall project. Activities that did not fall on the path carried “float,” or available time greater than required time. Because resources and accomplishments over the course of a project could change, the activities on the critical path could change. DuPont applied the method to the actual construction of a hydrogen and ammonia plant.¹²² Tested against traditional methods of coordinating plant maintenance downtime, the technique was adopted throughout DuPont and shortly marketed generally by Remington Rand and others.

¹¹⁹ Ibid. For a basic exposition of the problem see James M. Kelley, “Construction Scheduling Problem (Progress Report),” Remington Rand Univac, Univac Applications Research Center Report, April 25, 1957. A copy of this report is in Hagley 2004.

¹²⁰ John S. Sayer, “DuPont Engineering Department in the 1950s.”

¹²¹ Ibid., 24. The term Critical Path Method was only later popularized, so I use “CPM group” as shorthand.

¹²² To run the analysis, the tapes were taken to a Univac 1103A at Lockheed’s Palo Alto engineering operation, and then on a Univac 1105 destined for the Census Bureau but not yet complete at St. Paul, or to an Air Force Univac 1105 at Rome, New York.

While created for a particular kind of project, CPM was sold by its progenitors as having applications across a wide variety of business problems. A 1962 article included plant retooling, low-volume production scheduling, new product development, building construction, plant automation, organization change, and executive replacement among possible applications.¹²³ Extensions to the basic concept enabled least-cost determination and resource allocation. Mauchly left Remington Rand and formed Mauchly Associates, Inc., to sell CPM. Kelley went with him. They developed the “SkeduFlo” analog computer, specifically designed to run scheduling networks and identify critical paths, and marketed this and CPM applicable across a variety of technical and organizational projects. In a paper given at a conference on manufacturing automation and subsequently printed in *Automation*, Kelley and two associates illustrated the application of CPM to a manufacturing automation project, showing the coordination of layoffs, publicity, and the changeover of equipment (figure 5.9).¹²⁴

Figure 5.9—Critical path diagram for an automation project, incorporating steps from technical work to laying off displaced workers. Source: J.E. Kelley, L.D. Wilson, and H. Berman. “Using Critical Path Programming.” *Automation* 9 (November 1962): 92

¹²³ Kelley, James E. Jr., Louis D. Wilson, and Herbert Berman, “Using Critical Path Programming,” *Automation* (November 1962): 91. Use of projects in change management was a logical extension of their use in plant set up and retooling. The Army’s “Project 80” was a 1962 reorganization.

¹²⁴ *Ibid.*, 92.

Conclusion

In the 1950s, methods of managing short-term creative work coalesced in essentially the language around the tools that persist today. In this coalescence, older techniques were refashioned using new words. Novel mathematical methods provided new lenses on older problems. The uncertainty and complexity encountered in the post-war period were new to new disciplines that worked with new languages, but the novelty of these things blinded contemporaries to the old story that they were reliving. Some of this blindness was willful. As shown by Sapolsky and others, the heroics of Cold War management techniques were deliberately created mythologies, designed to portray rushed, uncertain work as expertly controlled.

Conclusion

Hiring Halls and the Information Age, circa 2001

The term 'project management' gained currency in the late 1950s and the early 1960s as part of the engineering heroics of U.S. missile and space programs. Its first conspicuous appearance in the business press was in a 1959 *Harvard Business Review* article, "The Project Manager," by Paul Gaddis, then an engineer with Westinghouse Electric, who opened this article observing that "in new and expanding fields like electronics, nucleonics, astronautics, avionics, and cryogenics, a new type of manager is being bred."¹ The first appearance of project management in the Harvard Business School's course listing came in the 1963/64 catalog, in the title of a course called "Defense Marketing and Project Management," that aimed to help students planning to join engineering companies understand how to sell to the Department of Defense.² By 1963, NASA and all branches of the U.S. military typically required that contractors use project organizations to manage hardware and software development efforts and, in early 1964, Secretary of Defense Robert McNamara made the use of PERT mandatory on large contracts.³ *Aircraft and Missiles* magazine rechristened itself

¹ (May-June 1959): 89-97, quote 89.

² The course was taught by J. Sterling Livingston, also the author of "Weapon System Contracting," *Harvard Business Review* 37 (July-August, 1959): 83-92. The course description was as follows:

"Defense Marketing and Project Management will be concerned with (1) the buyer-seller relationships of the national defense and space agencies and their industrial contractors, and (2) the management problems inherent in large, complex research and development projects. The course will deal with the marketing problems of weapon and space system contractors and the source selection problems of the Military Services and the National Aeronautics and Space Administration. The secondary objective of the course will be to develop an understanding of project management as it has been adopted by industry and government agencies. Various types of project organizations will be examined, and their strengths and weaknesses will be appraised. Consideration also will be given to the techniques used by project managers to plan and control schedules, costs, and technical performance in developing advanced military and space systems."

Official Register of Harvard University 60 (September 3, 1963), Harvard University Graduate School of Business Administration 1963/1964.

³ A text written before this requirement was formally in place suggests that as early as 1958 or 1959 presenting a "project organization" was necessary to winning large Air Force contracts. John Stanley Baumgartner, *Project Management* (Homewood, Illinois: R.D. Irwin, 1963), 6-7. The Air Force System Command codified its acquisition practices in a series of systems management manuals issued beginning in 1961 and collectively known as the "375 Series." These are treated in

Aerospace Management in 1961, with its editor promising readers information on setting up “technical planning and marketing activities to mesh with the procurement patterns of Air Force, Navy, Army, NASA, and the weapon systems managers.”⁴ He noted that the magazine’s shift in focus from technologies to their management had been prompted by reader demand.

Through the 1960s, the literature on project management continued to burgeon as part of a general wave of interest in the problems of managing innovation.⁵ In a 1965 *Administrative Science Quarterly* article, Victor Thompson observed “a growing feeling that modern organizations, and particularly the large, bureaucratic businesses and government organizations, need to increase their capacity to innovate.”⁶ In Thompson’s assessment, bureaucratic organizations faced limits because of monocratic production ideologies in which creativity and innovation were muted if not entirely suppressed. “Typically,” he wrote, “the introduction of technical innovative activities into modern organizations is by means of segregated units,” which segregation then had the undesired effect of preventing innovation from changing the status quo within the main body of the organization.⁷ Paul Lawrence and Jay Lorsch proposed a corrective in “the integrator,” a person or department that would tackle “the nonroutine, unprogrammed problems that arise among the traditional functions.”⁸ Other writers proposed complete abandonment of hierarchy. Tracking the electronics boom and the go-go stock market of the late 1960s, management theorists postulated a coming “post-bureaucratic” era and theorized the social characteristics of the knowledge worker.⁹

Johnson, “Insuring the Future,” 119–123; a useful overview is Edward J. Morrison, “Defense Systems Management: The 375 Series,” *California Management Review* 9 (Summer 1967): 17–26.

⁴ Tom MacNew, “Why—Aerospace Management?” *Aerospace Management* 4 (August 1961): 6–7. The first issue under the new title featured Robert McNamara on its cover.

⁵ The best single source for a sense of this proliferation and a guide to literature beyond my scope is Lee Dyer and Gary D. Paulson, *Project Management: An Annotated Bibliography* (Ithaca: New York State School of Industrial and Labor Relations, 1976). See also Association for Systems Management, *An Annotated Bibliography for the Systems Professional*. (2d ed., Cleveland: Association for Systems Management, 1976).

⁶ “Bureaucracy and Innovation,” *Administrative Science Quarterly* 10 (1965): 1–20, quote, 1.

⁷ *Ibid.*, 8.

⁸ Paul R. Lawrence and Jay W. Lorsch, “New Management Job: The Integrator,” *Harvard Business Review* (November–December, 1967): 142–151, quote, 142. See also *Organization and Environment: Managing Differentiation and Integration* (Boston: Harvard Business School, 1967).

⁹ Warren Bennis was the best-known theorist of novel forms while Peter Drucker popularized the notion of the knowledge worker. See Bennis, “Beyond Bureaucracy,” *Trans Action* 2 (1965): 31–35; “Organizational Revitalization,” *California Management Review* 7 (1966): 41–55; “The Coming Death of Bureaucracy,” *Management Review* 56 (1967): 19–24. For a counterpoint to Bennis, see Robert Miewald, “The Greatly Exaggerated Death of Bureaucracy,” *California Management Review* 13 (Winter, 1970): 65–69. Peter Drucker focused on the knowledge worker in his 1968 *The Age of Discontinuity* (New York: Harper and Row).

Unwittingly marking the apogee of this trend was the lavishly produced and short-lived journal *Innovation*.¹⁰ Carrying the tagline “*Innovation* is about the art of managing advancing technology,” this journal collected articles on organization theory, research management, and technology, threaded together by chatty editorial comment and artsy page design. Introducing the first issue in May 1969, its editor noted an impromptu theme: fluidity. “If you look at this issue of *Innovation* as a totality, it seems to be saying that as this country heads into the 1970’s it is in a state of such rapid and intricate change that to understand your society you must think of it as a liquid turbulent flow. You can’t rely on solid organizational structures; they’ll change. You can’t locate any useful boundary between your own area of responsibility and the turbulence outside; the outside comes flooding in.”¹¹ The magazine’s first article was Warren Bennis talking about “The Temporary Society.”¹² In this article, Bennis said that he had been introduced to the idea of temporary task forces while on the faculty at MIT’s Sloan School of Management and that “this pattern grew out of the war years when units like the Radiation Laboratory and Instrumentation Lab were established at MIT.” He had once asked Charles Stark Draper—director of the Instrumentation Laboratory—to sketch the organization of the Lab, and Draper had only been able to “sketch out a galaxy of these temporary teams.”¹³ In Bennis’s exposition, the pressures of the 1960s had required organizations with the fluidity of carnivals and a social dynamic of assumed identities and fleeting liaisons. For Bennis, the methods of group dynamics, sensitivity training, and encounter groups would help people cope with stresses accompanying unrelenting ambiguity through establishing collective truths.

In thought-pieces and more straight-laced studies alike, the new organizational form associated with this new time was the project team, whether woven across existing hierarchies or formed through clusterings in shifting networks. Studies of the effectiveness of project teams preoccupied much of the literature on engineering management. A number of individuals who subsequently helped define the study of technology and productivity as now taught in business schools published studies of project organization in the IEEE’s *Transactions on Engineering Management* in the late 1960s,

¹⁰ *Innovation* was published by The Innovation Group and edited by Robert Colborn. It survived from May 1969 to May 1972, then being absorbed into the much more modest *Business and Society Review*.

¹¹ “Says the Editor,” *Innovation* 1 (May 1969): 1.

¹² Also the title of a book Bennis had coauthored the year before (see footnote 8). “The Temporary Society,” *Innovation* 1 (May 1969): 3–11.

¹³ *Ibid.*, 5.

among them Thomas Allen and William Abernathy.¹⁴ Articles in the *Transactions* in the 1960s continued to apply the information processing language and models that typified the electrical engineering profession's approach to technical and social problems alike.

While electrical engineering occupied a particularly important position in relation to conversations of this period, the enthusiasm for project-based organizations and "dynamic," team-oriented work was general. These forms were also widely seen as new. John Mee, in a 1964 article, asserted that "the project concept evolved as a means for adjusting to the pressures applied to prime contractors and subcontractors of defense projects," most notably "the demands on time, cost, and performance in a rapidly changing technological environment agitated by increasing international tensions."¹⁵ Consulting firms including Booz-Allen & Hamilton set up practices to help firms adopt project-based organizing principles. Harvard Business School professor Paul Cherington ran a firm that worked with the Defense Department and advocated "projectization."¹⁶ Like Bennis, though in different terms, he noted the social problems accompanying temporary organizations. Cherington's work involved confronting the fact that "projectized" offices were plagued by uncertainty about job security when they were "deprojectized."¹⁷

The faddishness that attended project management in the 1960s dropped away in the following decade. With the economic crises of the 1970s, no one could afford carnivals. Commenting on the state of the project management literature in the mid-1970s, the authors of a bibliography on the subject found three types of nonempirical articles: fad-panacea, problem identification, and prescriptive. They observed of the first of these:

¹⁴ This was the updated title of the *IRE Transactions on Engineering Management* in the wake of the merger of the IRE and AIEE. Thomas J. Allen, "Studies in the Problem-Solving Process in Engineering Design," *IEEE Transactions on Engineering Management* EM-13 (1966): 72-83; William Abernathy, "Some Issues Concerning the Effectiveness of Parallel Strategies in R&D Projects," *IEEE Transactions on Engineering Management* EM-18 (1971): 80-89; William Abernathy and Richard Rosenbloom, "Parallel and Sequential R&D Strategies: Application of a Simple Model," *IEEE Transactions on Engineering Management* EM-15 (March 1968): 2-10.

¹⁵ John F. Mee, "Project Management," *Business Horizons* 6 (Fall 1963): 53-54, quote, 53.

¹⁶ Cherington's firm was United Research International. The coining of "projectization" is described in relation to Cherington's work for the Army in Raymond Snodgrass, *The Concept of Project Management* (Washington, DC: U.S. Army Materiel Command Historical Office, 1964), 113.

¹⁷ *Ibid.*, 179. In this vein see Arthur G. Butler, Jr., "Behavioral Implications for Professional Employees of Structural Conflicts Associated with Project Management in Functional Organizations," Ph.D. dissertation, University of Florida, 1969.

"The fad-panacea literature was most prevalent in the mid-1960s. Its tone is syllogistic: rapid technological and societal change is and will continue to be a fact of life; traditional bureaucratic structures are less capable of dealing with this change than is project management; therefore, bureaucracy is on its way out and project management is on its way in. For reasons that are apparent to informed readers, few articles of the fad-panacea type have appeared in recent years."¹⁸

In the 1970s, as during other downturns, management attention shifted from building new capabilities to driving operating efficiencies.

In the 1990s, a new gold rush brought a renewal of interest in the discipline and sociology of projects and knowledge work. This theorizing had its foil in the scientific management of the day—ideas of process "reengineering" and "total quality management" (TQM).¹⁹ Where the literature of the 1960s attempted to describe the uncertain and exploratory nature of change in terms of "stochastic networks," writing in the 1990s applied "chaos theory."²⁰ *Fortune* magazine claimed in 1995 that project management had become *the* management field as predictable and insular corporate hierarchies gave way to flexible, global multi-firm teams.²¹ *PMNetwork*, a magazine published by the Project Management Institute, called manufacturing "the final frontier" for project management as product cycles accelerated and the last bulwarks of mass production gave way.²² Another author celebrated the transition of firms from rigid hierarchies to fluid aggregations of projects.²³ Swedish-Swiss engineering firm Asea Brown Boveri, a project-oriented firm in a project-oriented industry during a boom in spending on projects, was held up as a talismanic example of a firm that managed to be both big and flexible.²⁴ In common, these writings heralded a world in which people would

¹⁸ Dyer and Paulson, *Project Management: An Annotated Bibliography*, vi.

¹⁹ Michael Hammer and James Champy championed the former in *Reengineering the Corporation: A Manifesto for Business Revolution* (New York: Harper Business, 1993). Quality management—a vast literature in itself—is associated with E.W. Deming, *Out of Crisis* (Cambridge: MIT Press, 1986). A review of these methods appears in Mary J. Benner and Michael L. Tushman, "Process Management and Organizational Adaptation: The Productivity Dilemma Revisited," unpublished manuscript, October 12, 2000.

²⁰ W.E. Hildenbrand, "On Stochastic Scheduling" and B.V. Dean, "Stochastic Networks in Research Planning," both in M.C. Yovits, et al., eds., *Research Program Effectiveness* (New York: Gordon and Breach, 1966), 217–234 and 235–266, respectively; Shona Brown and Kathleen Eisenhardt, *Competing on the Edge: Strategy as Structured Chaos* (Boston: Harvard Business School Press, 1998).

²¹ Thomas A. Stewart, "Planning a Career in a World Without Managers" (March 20, 1995).

²² Kelly McCowan, "Project Management for Manufacturers: The Final Frontier" (May 1999).

²³ Paul Dinsmore, *Winning in Business with Enterprise Project Management* (New York: American Management Association, 1999).

²⁴ Kevin Barham, *ABB, the Dancing Giant: Creating the Globally Connected Corporation* (London: The Financial Times, 1998).

experience work less in terms of day-to-day routines and corporate ladders than in terms of irregular work on temporary tasks and careers built on networks of inter- and extra-firm allegiances.

Despite the novelty of these developments to witnesses of the 1960s and 1990s alike, for some kinds of work these qualities are as they ever have been. The neologisms, acronyms, and systems discourse of the Cold War and, more recently, computer networks and electronic commerce obscure connections to earlier ways of managing and working. In the preceding chapters, these connections have been recovered by considering the underlying problems solved by project-based organizing and when and where these problems have obtained. Integrating the work of scientists, engineers, technicians, skilled tradesmen, and general laborers, building a railway or a hydroelectric plant or a chemical processing facility has required coordination across professional fields and firms. Again and again, the organization and management of the building of technological systems has required integrating diverse labors under uncertain conditions. The mapping of management techniques among these seemingly disparate worlds has in turn reflected these structural kinships between labor and communication processes. In this regard, the social order of construction work and the professional culture of high-technology enterprise have long been and are closely parallel. Participants in the ages of railroading, electricity, and aircraft all believed they had entered uncharted social as well as technological territory but, fundamentally, all needed to establish means of coordination in the face of uncertain futures and unstable divisions of labor. All relied on the evolving networks of relationships evinced by discourses in professional associations and journal literatures. All did their best to schedule work that could not be fully specified in advance.

Beyond marking the recurrence and persistence of project forms of organization, the evidence in the preceding chapters suggests several conclusions. First, it shows that there has been a subtle, problem-driven dynamic to the history of management thought that has been obscured in studies emphasizing shifting fashions in the administration of factory settings. Seeing this has required looking outside the haunts of people who have positioned themselves as management theorists. The pages of the *American Railroad Journal* from the 1830s, the *Journal of Industrial and Engineering Chemistry* from the 1910s, *Product Development* from the 1930s, or *Space/Aeronautics* from the 1960s at first seem to be windows onto industry-specific technical discussions, but within them are direct and generic confrontations with questions of how to get work done when speed is of the

essence, environments are uncertain, workers are more informed than managers, and organizations are evanescent.

Second, the preceding pages show that the ebbs and flows of theorizing on project-based organizing have tracked cycles of system building. Because both technical and social arrangements are formative during booms, understanding the nature of the productive processes underway has required attention to extra-firm associations, ambiguous thought collectives, entrepreneurial technical literatures, and other inter-project supports. Partly because periods of intense capital investment and technological change are irregular and occur only once or twice in a generation, structural similarities and historical links between management ideas during eras of system building have been clouded by shifts in language, tools, and industry settings. Complexity and uncertainty are relative terms and when technical systems have lost their novelty people have lost sight of the fact they once had these qualities. But from the perspective of a participant in any technological revolution, the outcomes of previous revolutions are givens, stripped of ambiguity that accompanied them into being. While projects are constants in many fields, this form has been remarkable where it has been new to new technical communities and, consistent with Lundin and Midler's observation, projects are disproportionately associated with periods of development.²⁵

Based on my evidence, a third general observation can be made in regard to the representations employed to direct project work. Over the period covered here, images of projects moved from literal, spatial mappings to increasingly time-based abstractions. With growing size and complexity, the extents of systems being built and the details of where and when one piece of work began and another ended could no longer be succinctly indicated in a scale drawing or left to known divisions of labor. At the same time, explanations of the nature of project work increasingly existed in relation to theories and practices in managing routinized work. As a consequence of these twin dynamics, abstract representation using timelines and Gantt charts and other forms have provided means of locating the interactions of disparate tasks in time and space and at the same time have allowed the inscrutable aspects of project work to be black-boxed and set aside, for purposes of both internal agreement and external representation.

²⁵ *Projects as Arenas for Renewal and Learning Processes.*

From these conclusions and the body of evidence that supports them, I note below two broad implications for present practice and some potential avenues for further research. The first implication I draw relates to the role of extra-firm networks in project work; the second to the double role of management tools in project environments. These comments are speculative. I base them only on impressions formed in the course of reading back and forth between recent discourse on project-oriented work settings and long-ago efforts to understand similar circumstances. Suggestions for further research follow these comments.

Contingent Work in the Information Economy

Non-hierarchical forms of organization accompany protean times and places. In efforts to define and refine new technologies and divisions of labor, people have actively sought means to organize and explain work in uncertain environments and toward ambiguous ends. In doing so, they have repeatedly theorized project-based, fluid, and externally linked communication patterns. These patterns connect individuals and institutions, help define evolving Fleckian thought collectives and thought styles, and eventually coalesce and acquire regularity in relation to dominant technical and organizational arrangements. Before such coalescings, organizational fluidity is associated with contingent working relationships.²⁶ Since entrepreneurial businesses are often short-lived and key technical information may come from anywhere in a loosely bounded network, in protean times keeping options open can have value for both firms and individuals.²⁷

²⁶ On contingent work see Gideon Kunda, Stephen Barley, and James Evans, "Why Do Contractors Contract? The Theory and Reality of High End Contingent Labor," unpublished manuscript, Center for Work, Technology, and Organization, Stanford University, April 1999; Kathleen Barker and Kathleen Christensen, eds., *Contingent Work: American Employment in Transition* (Ithaca: ILR Press, 1998); Paul Osterman, *Broken Ladders: Managerial Careers in the New Economy* (New York: Oxford University Press, 1996).

²⁷ In this regard, recent work in organizational economics built around notions of relational contracts and other informal enforcement mechanisms is apt for protean times and project-based industries. Drawing on game theory, relational perspectives on firm and individual behavior consider actions made where future, *ad infinitum* exchanges can be valued as part of immediate choices. Two parties to an exchange will repeat the game (that is, continue in the relationship) so long as the long-term value of the exchange is higher than that of alternatives less the ability of the each party to punish the defector for leaving the relationship. From this building block, studies of networks of producers and "relational assets" have been developed, wherein the value of each relationship to a firm is in the possibility that it will bring useful information, future business, and so forth. From this perspective, relationships are options on possible futures. In uncertain environments, hiring skilled workers with ties to universities, professional associations, and other firms becomes part of the search function by which a company keeps abreast of technologies and the market. Hence, non-economic relationships are particularly important during periods of technical flux. For examples in this vein see Bruce Kogut and Nalin Kulatilaka, "Operating Flexibility, Global Manufacturing, and the Option Value of a Multinational Network," *Management Science* 40 (January 1994): 123–139; Robert Gibbons, "Taking Coase Seriously," *Administrative Science Quarterly* 44 (1999): 145–157; Clayton

In her conclusion to *Regional Advantage*, Annalee Saxenian observes that the competitive disadvantage of Massachusetts's Route 128 technology community relative to that of California's Silicon Valley during the 1980s reflected Route 128's "social and institutional setting from an earlier industrial era." She typified the earlier era as one,

"When technology remained relatively stable over time, vertical integration and corporate centralization offered needed scale economies and market control. In an age of volatile technologies and markets, however, the horizontal coordination offered by interfirm networks enables firms to retain the focus and flexibility needed for continuous innovation."²⁸

While the notion that such a stable era ever existed is partly mythology, consistent with Saxenian's findings, literature on regional competencies or national systems of innovation has highlighted the role of non-firm institutions in supporting innovation and productivity growth.²⁹ I have not attached any quantifiable significance to the evidence I have presented, but the cyclical importance of social networks linked to academic or professional affiliations and of an entrepreneurial technical press noted here complements such findings. Institutions, government agencies, and technical journals have again and again created the media and meeting places that facilitate exchanges during times of ferment. Over the course of cycles of system building, networks of producers can succeed even as many firms within a swarm fail. As a corollary, the preceding pages also show that these networks are not *sui generis* but have been nurtured by government and institutional funds and forums.

Less emphasized both here and in much of the competitiveness literature is that contingent work also has costs. Bennis sought remedies for the destabilizations of carnival-like atmospheres. A running theme in my evidence has been the importance of regularity to both management control and

Christensen and Richard Rosenbloom, "Explaining the Attacker's Advantage: Technological Paradigms, Organizational Dynamics, and the Value Network," *Research Policy* 24 (1995): 233–257 and "Technological Discontinuities, Organizational Capabilities, and Strategic Commitments," *Industrial and Corporate Change* 3 (1994): 655–685.

The Fleckian perspective I emphasize is consistent with such ideas if non-financial aspects of membership in thought collectives are considered as part of the value exchanged. To put it another way, in emergent and unstable environments, individual allegiances and identities attach to conversations. In times of change, firms establish links to ambiguously defined communities through employees and, in hiring a skilled construction worker or an esteemed research scientist, a firm takes an option on the directed perception of the individual which, in turn, exists by virtue of his or her acculturation in a particular style of thought and participation in collectives external to the firm. In other words, aspects of firm behavior during periods of social and technical formation can be considered in terms of relational contracts with emergent thought collectives or communities of practice.

²⁸ 162.

²⁹ For example, David Mowery and Richard R. Nelson, eds., *Sources of Industrial Leadership: Studies of Seven Industries* (Cambridge: Cambridge University Press, 1999).

social stability—drifting, itinerant labors from engineering to agriculture have long been seen as anomalous if not deviant. Construction work can be a difficult, uncertain existence even with strong social supports. This is also true of other forms of building. The economic climate that sustained a world of insatiable demand for skilled workers and easy job switching in the boomtowns of the 1990s—the Palo Altos, Austins, and Cambridges—obscured the less attractive sides of such worlds. Gold rush economics eventually leaves behind ghost towns. Industries that stabilize around project-based organization evolve relatively strong extra-firm institutional supports. However imperfectly, hiring halls, unions, and professional and academic affiliations help individuals get along from project to project. But whether they are on a track toward “maturation” in the sense of firm-focused routine and stable markets or will remain in a permanent state of project-oriented churn (as discussed in relation to figure 0.3 in the introduction), evolving industries and networks have weaknesses.

In this light, depending on one’s point of view and the general state of the economy, an increasingly ‘projectized’ economy can seem liberating or terrifying. Opportunities for top-down managerial control of information in project environments are limited. Because of the irregularity and unpredictability of projects, external intervention can affect financial and political resources but the individuals and groups doing the work substantially control how the work is carried out. Executives oversee project portfolios rather than production lines. Individuals in the lower ranks of such environments enjoy latitude in determining how they do their jobs, but they must also manage their own careers to a greater degree than held in the paradigmatic industrial organizations of the mid-twentieth century. Recent writings on the new economy and the flexible corporation have varied as to whether they celebrate or bemoan the changes they describe, but they share acknowledgement that for individuals, firms, and governments, the prevalence of project-based enterprise has implications for how work is and can be experienced, organized, and governed.

Such environments require greater management awareness of the social aspects of creative work and, in particular, the need of individuals for extra- and inter-firm networks for both social support and technical information. In industries that are either new or undergoing substantial redefinition, it is not simply the environment of a particular project that is emergent, but also the communication channels, social and professional identities, and communities of practice or thought collectives of the industry as a whole that are forming.

Protean Times and Insulative Technologies

In describing what he calls the “project culture” of technocratic society, Jean-Pierre Boutinet sees projects as exercises in exploring the future in order to control it.³⁰ In Boutinet’s account, projects use rhetorics of certainty and transparency embodied in diagrams and other representations to exercise control. These images help establish organizational legitimacy by forcing bureaucratic structures onto problems, building conflict into a process in which project managers occupy a precarious position between projected certainties and unknown futures.³¹ Instrumentally, projects are used to reduce uncertainty about the likelihood of desired outcomes. But given environmental uncertainty, managers of builders need to balance formal and informal controls, relying on trust, personal and professional affiliations, and other forms of allegiance and loyalty external to the project and the firm as much as they invoke schedules and specifications. The insulative aspects of project management that I have emphasized reflect the fact that interpretive, creative, and collaborative aspects of project work are often best black-boxed and untouched. Ideas such as matrix organization, teamwork, knowledge management and so forth facilitate productive collaboration by creating literal or virtual spaces for interaction and by specifying temporal patterns of interaction, but they do not and cannot fully set out the interaction itself.

Constance Perin describes how the formal methods used in project management both order work and establish informal contracts among participants:

“Project management models are a technique for reducing uncertainty and managing risk in organizational activities. They are understood as self-evident, straightforward techniques for planning, tracking, controlling, and co-ordinating human, technological, and financial resources and tasks. Their formal structures, represented visually in PERT configurations, in Gantt charts and ‘waterfall’ or tree structures, can also be seen, however, as cognitive templates that set expectations of linearity, transparency and predictability. These models also carry implicit promises of helping managers and project

³⁰ *Anthropologie du projet.*

³¹ Boutinet speaks of « ...l’acharnement projectif; un tel acharnement, nous le rencontrons spécialement chez ces nouveaux professionnels que sont les conseillers a projet : lorsqu’ils s’adressent a des acteurs en position fragile et précaire, ces conseillers exigent de leurs consultants une lucidité et une transparence qu’eux-mêmes sont bien souvent incapables d’appliquer a leur propre devenir! », Ibid., 3.

participants to anticipate and reduce financial and technical mis-steps, and in turn they elicit promises from them.”³²

Perin describes the tools of project management as forcing linearization and mathematization that carry “mechanistic expectations of exactitude rarely fulfilled in practice ... these models tend to assume away the social and cultural dynamics of project work.”³³ In particular, she notes that in their focus on wringing time from every step of a process, these methods neglect necessary but inscrutable aspects of the work:

“Likely to be structured by schedules, milestones, and deliverables defined by clock and calendar time, project activities may overlook the business and scientific significance of work activities such as networking, reading, attending meetings... they may structure work believing that the time needed for resolving conflicts and for competing for resources, for example, is an interruption and not inherent in project-based organizations.”³⁴

The phenomena Perin describes can be cast in a slightly different light. Managers of project-based organizations are at least intuitively aware of the social dynamics of the work they oversee, and know that the work involves battles over resources, disagreements about outcomes, and the indirect contributions of networking. They also know that these aspects of the work will play havoc with the timelines and charts that have been created to manage the project. But they also know that to gain and maintain support for the work requires willful obscuring. Sapolsky’s description of PERT as alchemy acknowledges this dynamic operating at a large scale, but it also obtains in more day-to-day interactions in relation to project work.³⁵ The rhetorical flourishes, displays of expertise, and false certainties set out in representations of projects have been—and are—necessary lies in representing building to an operating world. The need to force conclusions may result in less than optimal results and can obscure the arbitrariness of outcomes, but assessing the implications and costs of such forcing is an uncertain exercise. As Donald MacKenzie notes, “shaping needs is not in itself wrong; the moral and political question concerns the character of those needs.”³⁶

³² Constance Perin, “Work, Space and Time on the Threshold of a New Century,” in Paul J. Jackson and Jos M. van der Wielen, eds., *Teleworking: International Perspectives from Telecommuting to the Virtual Organization* (London: Routledge, 1998), 40–55, quote 47.

³³ Ibid., 48.

³⁴ Ibid., 51.

³⁵ *The Polaris System Development*, as discussed in chapter 5.

³⁶ “Missile Accuracy: A Case Study of the Social Processes of Technological Change,” in Bijker, Hughes, and Pinch, eds., *The Social Construction of Technological Systems*, 195–222, quote, 214.

The insulative aspect of project-based tools and the duplicity that has often attended their use suggest a more complex set of organizational relationships between building and operating than is often recognized. Prescriptions for the support of innovation within projects and firms have emphasized the need to create isolated ventures or to buy up-and-coming firms as a means of effectively outsourcing innovation.³⁷ The evidence presented in the preceding chapters emphasizes that representations of engineering work in Gantt charts, CPM diagrams, organization charts, reports, and cost accounts have been means of limiting points and terms of contact—technologies for both insulating and ordering building in relation to operating. More recent use of the black boxes of Design Structure Matrices shares this quality.³⁸ Projecting closure and stabilization in advance of the fact is a basic means of managing projects. Though they operate at different scales, “skunk works” and the day-to-day tools of project management can be equally seen as insulative technologies, suggesting a more subtle spectrum of options for accommodating building and operating within single organizations.

Directions for Further Research

As noted at the outset, I arrived at the form and content of this dissertation by fumbling backward from the 1950s. The exploratory nature of my research reflects the dearth of historical studies of management theory and practice outside of factory settings. Given that project-based organizations are often short-lived and relatively few leave behind the volumes of archival materials that exist for many large corporations, gathering evidence of their histories can be hard going. Journal articles, the proceedings of professional associations, and other indirect sources have provided much of my evidence of such evanescent forms, and rich possibilities exist for both further gathering of qualitative

³⁷ For example, Christensen, *The Innovator's Dilemma*.

³⁸ A succinct exposition of the Design Structure Matrix is in Steven Eppinger, “Innovation at the Speed of Information,” *Harvard Business Review* 79 (January 2001): 149–158. See also Karl T. Ulrich and Steven Eppinger, *Product Design and Development* (2nd ed., New York: McGraw-Hill, 2000), which offers a textbook explanation. The basic procedure in setting up a DSM is to use a grid to code interdependencies between steps in a design process. Every identifiable step or decision that must be made in the course of design is identified and coded according to which steps must precede or follow others. Such dependencies form the basis for applying manual or computer-aided sorting algorithms. Where the design process involves feedback loops—that is, where a group of steps must be carried out iteratively—these are literally put together in a black box and set aside.

evidence and for more empirical testing of some of the propositions I put forth. I had little to guide my way and hope that the evidence here will provide markers for further research.

Potential for qualitative study is considerable. There are no extant synthetic studies of management in any project-oriented industry before 1950 and such secondary materials as exist appear scattered in studies of particular projects and firms. There are similarly no broad scholarly studies of the business behavior of the technical press in the United States. I have only scratched the surface of the several engineering and scientific conversations I have treated, and I have suggested more connections than I have established. For example, the imprinting of DuPont's administrative practices on General Motors in the 1920s is widely acknowledged, but movements of practices in research administration have not been closely studied. There are no biographies of a number of the individuals who figure in the history presented here. C.E.K. Mees and Halpert Gillette stand out in this regard. Further, in addition to the technical disciplines with which I have worked, there are other technical fields as well as discussions in relation to creative industries including filmmaking, radio, and other media, each of which has gone through periods of definition in the twentieth century. Again, there are no historical examinations of administrative practices in these industries.³⁹

The history of management in project-oriented industries has so far been overlooked not only as regards its intrinsic historical interest and also as it offers evidence that can enlighten current theory building. The ubiquity of project-based organizing in high-technology industries means that organization theorists seldom step back to ask if their findings are artifacts of an underlying labor process rather than of "unprecedented" conditions created by novel technologies.⁴⁰ I have drawn on

³⁹ I note an example of a description I picked up in the course of my research. The bankruptcy of Radio-Keith-Orpheum Corporation, a film studio, in 1931 and "a prevalent belief that the large losses sustained by this company and other motion picture concerns have been due in part to the uneconomical operation of the studios," prompted an accountant to write of the nature of the business in 1934. While the fact that the industry was not, and could not be, organized on a mass-production basis would seem obvious, the writer nonetheless felt obliged to state this and to explain the appropriation-based accounting system used by R.K.O. and other studios. The problems faced were closely akin to those of the construction contractor, involving the need to budget by picture in an industry subject to the whims of its labor pool and which brought together "companies"—in the sense of theatrical troupes—at remote locations. He stated, "no picture can be a successful box office attraction if it is ground out under the Taylor system or any scheme remotely resembling it. Originality must be fostered, not stifled." Again like construction, the basic problems were those of costly set-up time and scheduling expensive resources ("talent"). Charles W. Eiseman, "Cost Control in the R.K.O. Radio Studio," *N.A.C.A. Bulletin* 15 (August 1, 1934): 1351–1360, quotes, 1358.

⁴⁰ I have in mind here literature that looks at fast-paced, "virtual" settings without recognizing that the issues and conditions described are generic to workplaces characterized by environmental uncertainty and non-zero capital costs.

recent work to help distill common qualities from the disparate times and places I have studied, and further consideration of antecedents to now-fashionable organization theory may help point arguments and enable ideas to be generalized beyond particular times and industry settings.

Reflecting the idiosyncrasies of the path I have followed in developing this dissertation, I did not have in advance a clear definition of the phenomena that interested me or the best means by which to measure the patterns that emerged as I accumulated evidence. From the far side of my research, I can suggest possibilities for quantitative tests. A combination of analyses of patterns in the dynamics of discourses around project-based organizing and, within conversations, studies of their content might emphasize or debunk the associations between management theory and eras of system building that I have argued. In particular, population-level analysis of technical literatures (after the model of population ecology approaches to firms) and content analysis of selected publications could evaluate the patterns I have found inductively. A first step would be year-by-year analysis of the content of journals and transactions volumes, focusing on how content shifts between concern for building effectively and operating efficiently over the course of industry definition. By then dating conversations and their content relative to technical developments, "dominant designs," and "eras of ferment," such tests could further relate my findings to scholarship on organizational forms and the management of change discussed in the introduction.

Summary

Between the 1870s and the 1950s the organizational form now called "project management" was articulated and refined in the context of industries undergoing periods of formation, growth, and redivision of labor in relation to new technological systems. Though this form has been a constant in many industries and predates this period, discussions of project-based organization have waxed in time with periods of system building and associated technical uncertainty and waned as technologies have standardized and institutional settings have fixed. Returning to the illustration introduced as figure 0.2 (reproduced as 6.1), this cyclical quality can be seen as marking relationships between communication patterns, industry stages, and uncertainty.

Figure 6.1—The research, development and production process, seen in terms of applicability of different modes of control and shifts in the mode of communication.

But fully understanding how and why theories of project-based organizing have appeared and reappeared has required recognizing a further dynamic. In addition to providing means of directing work in settings characterized by complexity and uncertainty, project-based controls have again and again been used to explain irregular work in response to political and economic pressures associated with theories of operating efficiency, whether Taylorist scientific management in the 1910s or TQM in the 1990s. It has only been by contrast to systems of routinized production that project-based forms have needed explanation. In this regard, representations of projects in accounts, engineering drawings, timelines, and other forms of communication have historically been used to both control and insulate building work in relation to operating organizations and their logics.

It may be that project-based organization has genuinely become more relevant to more people in recent years, but recent attention to this form partly reflects greater awareness rather than greater salience. Neglect of the construction industry and of construction activities more generally was common to both sociological approaches to organizations and political economic approaches to industries and productivity for much of the twentieth century. Histories of business and management theory have shared this blind spot. This dissertation has shown that neither project-oriented organizational forms or theories of them new. As I write in the spring of 2001, the recent wave of interest in these forms appears to have crested. A drop-off in spending on information technologies and the onset of a recession have shifted the focus of management concern from building to operating. While theorizing team-based, iterative production processes may fall out of fashion, the tides will shift again—though they may wash on yet-unknown shores.

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This is a representative rather than exhaustive list of the sources that inform this study. Citations to particular journal articles are limited to those from which I draw directly or which I quote in the text. Where I cite the general run of a periodical, I have not studied every issue but have relied on individual indices, references from other publications, and citations in the *Engineering Index* and other periodical indices to guide me. Where I have found rich veins of evidence, I have used closer page-by-page reading to understand context and the actors in a particular discussion. Note also that the boundaries between primary and secondary literatures are inexact, particularly for the later periods of this study.

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