

INTEGRATING TECHNOLOGICAL AND ORGANIZATIONAL PERSPECTIVES
- AN APPROACH TO IMPROVE RAIL MOTIVE POWER MANAGEMENT

by

Chi-Kuo Mao

B. A. National Cheng-Kung University,
Tainan, Taiwan, Republic of China
(1971)

M. E. Asian Institute of Technology, Bangkok, Thailand
(1975)

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Massachusetts Institute of Technology

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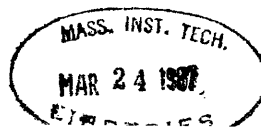
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Signature of Author
Department of Civil Engineering, October 10, 1982

Certified by
Thesis Supervisor

Accepted by
Chairman, Civil Engineering Departmental
Committee on Graduate Students



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ABSTRACT

This study is devoted to the development of a theory which fits the nature of transportation operations management. A dual-system paradigm is postulated. Following that paradigm, a transportation operating system is conceived of as a control system which consists of two complementary parts: 1) the controlling sub-system - the organizational aspects of the system which possesses the controlling capacity, and 2) the sub-system being controlled - the technological aspects of the system which defines the tasks to be controlled and their interrelationships. The performance of the total system is then determined by how well the controlling capacity of the organization units is matched with the characteristics of the tasks to be controlled stemmed from the underlying technological processes.

The key theme of this study is the development of theories and operational techniques which collectively enable us to 1) understand and describe the nature of both the controlling and controlled systems in the context of transportation operations management, 2) diagnose and analyze the strengths and weaknesses, and problems of total system, and 3) identify the desired directions of change and develop alternative change plans for improving the total system's performance.

To test the theories and methodologies, the management of the operations of railroad motive power - locomotive - is adopted as an empirical case. The data are collected from three major U. S. Railroads.

Thesis Supervisor: Dr. Marvin Lee Manheim
Title: Professor of Civil Engineering Department

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The acknowledgement in a thesis is the only place where one can say something non-academic, sensational and human. Given this opportunity, I decided to write a brief review of the process which produced this thesis with the following aims: to thank those who contributed to it, and to make concluding remarks for my years at MIT.

The study presented in the following pages finds its origin in my first days as a member of the MIT Rail Group four years ago. Joe Sussman set me off on the track, and before he became the head of the Civil Engineering Department two years later, he witnessed the transition of an engineering-minded analyst into a management-oriented researcher. I am indebted to his guidance and patience in allowing me to effect the transition. Carl Martland, the group director after Joe and also a member of my thesis committee, helped me in many ways to carry through this work. He furnished me with most of my knowledge on railroading and has always been supportive both intellectually and emotionally - particularly during my most difficult days, before I passed my General Exam. I am singularly indebted to his encouragement and kind consideration in giving me a free hand at the thesis developing and writing stages. Marvin Manheim has my gratitude for his enthusiasm for my study from the very early days when I produced the preliminary results on power cycle analysis. I am even more grateful for the fact that he accepted my request to chair both my General Exam and Thesis Committees. Marvin saw me go through the whole "labor" process of thesis-birth, and witnessed the evolution and sharpening of the key themes of this thesis. He significantly influenced the style of analysis in this study; I can hardly measure all the uses I have made of his advice, both intellectually and personally, along the way. Craig Philip gave me the benefit of his assistance and accelerated the transition of my cognitive style through his critiques and suggestions on my early research work when he was a Ph.D. student here. His dissertation in many ways provided ground work and perspectives for this study. As a thesis committee member, he kindly read most key chapters, patiently corrected my draft and made many valuable suggestions. I am indebt to his compelling kindness and friendship. I am grateful to Mike Meyer for serving on my thesis committee. My many discussions on methodology and conceptual framework with him helped me sharpen some of the key ideas in this study.

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This work is dedicated To my parents: Pau-Jen and Bin-Shi Mao. It was their high expectation on their only son that motivated and supported me to strive and persist through this very exhaustive process. I hope they will be proud of the outcome.

**INTEGRATING ORGANIZATIONAL AND TECHNOLOGICAL PERSPECTIVES
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Chapter 1

INTRODUCTION

1.1 Motivation

The history of science is the history of a human endeavor to describe the world in more precise terms and to improve it in a systematic way. Due to the fact that a coherent theory for the management of service operations in general and transportation operations in specific has not yet been developed, the need to conduct some substantive research in this field has emerged for a long time. This study is devoted to the development of a theory which fits the particular nature of transportation operations management.

1.1.1 Traditional Approach to Operations Management and Its Limitations

Until quite recently, operations / production management had been associated almost exclusively with manufacturing processes. Exhibit 1-1-1 summarizes some typical contents covered in most of production / operations management textbooks today. Briefly, in those books the subjects are basically structured along either of the following three key dimensions (or some combination of them):

1) decision categories - usually divided into three categories: input (human resource, materials, etc.), transform systems (process, facilities and equipment, etc.) and output (products), for instance, Starr [1972], Garrett and Silver [1973], Marshall, et al [1975], and Fitzsimmons and Sullivan [1982].

2) phases of decision process - including planning and design, operating control, and performance evaluations, for instance, Riggs

Exhibit 1-1-1 TRADITIONAL CONTENTS OF PRODUCTION/OPERATIONS MANAGEMENT

Methodologies Decision Categories	Task Phases PLANNING, DESIGN	OPERATING CONTROL	PERFORMANCE EVALUATION
<p><u>OUTPUT</u></p> <p>Product: Product Portfolio Demand Analysis Product Specification Engineering Design Product Logistics Life-cycle Management</p>			
<p><u>TRANSFORM SYSTEMS</u></p> <p>Process: Technology Planning: Method Analysis Job Design Performance Standards: Work Measurement Cost Standard Quality Management: Quality Control Quality Assurance Resource Scheduling & Dispatching: Manpower, Material Cost Responsibility</p>			<p><u>METHODOLOGIES AND TECHNIQUES:</u></p> <p>Schematic Models: Flow Chart, Assmeby Diagram, Routine Sequence Diagram, Gantt Chart, CPM, Organization Chart, Block Diagram, etc.</p> <p>Statistics & Probability: Statistic Testing, Sampling, Industrial Experiment, Regression Analysis, Reliability Theory, etc.</p> <p>Systems Analysis: Simulation Model, Analytical Models (LP, DP, Sequencing Model, Queuing), Inventory Control Theory, Decision Analysis (Expected Value, Utility, Probability Assessmet), Control Theory (Standards, Feedback, Corrective Actions), etc.</p>
<p>Facility & Equipment: Plant & Equipment Investment Location of Plant Layout of Facility Utilization & Cost Control Maintenance & Reliability Information Systems</p>			<p>Financial & Economic Analysis: Portfolio Planning, Capital Bugeting, Cash Flow Management, Make-Buy-Lease Analysis, Break-Even Analysis, Value Analysis, Spatial Economics, etc.</p>
<p><u>INPUT</u></p> <p>Human Resource: Manpower Level Ability and Training Labor Standard Human Factor in Job Design: Labor Performance & Work Condition Payment System & Job Evaluation Employee Relation</p>			<p>Information-Processing Technology: Information Systems Theory, CAD, CAM, etc.</p>
<p>Material: Requirement Forecasting Logistic Systems Procument Inventory Control Material Handling</p>			

[1970], and Buffer [1980].

3) methodology and techniques - various decision-aid tools which include schematic models, statistic and probability techniques, systems analysis, financial and economic analysis, and information technology, for instance, Bowman and Fetter [1967], Starr [1972], Groff and Muth [1972], and Constable and New [1976].

However, no matter which of the above frameworks was adopted, the prevailing emphasis was on techniques of analysis. Starr [1964] defended that "the study of production management is mainly concerned with questions of how to employ methodology to operate and administer [production] transformation systems with effectiveness." He even further argued that much of the uniqueness of the diverse domains of production endeavor "resides in their technology, suprisingly little in their methodology." Nonetheless, the above arguement becomes highly questionable beyond the domain of manufacturing oriented processes, e.g., the service operations.

A. Transferability of Traditional Approach

The first critical problem encountered in the application of the traditional approach of operations management to the transportation context is the problem of transferability. Since the traditional approach is primarily manufacturing process oriented in substance, many issues which are both unique and essential to the transportation process, such as vehicle (or resources) cycling and geographically dispersed but interconnected operations, cannot be properly addressed by such an approach. In other words, the transferability of the theories and techniques from one context to another is limited; therefore, to

satisfy the specific requirements of transportation operations management, we must develop a set of dedicated theories to deal with them. To elaborate on the above argument, in the outset of Chapter 2 of this study we present a synthesis of the general features of the service operations as well as specific characteristics of transportation operations.

B. Methodological Drawbacks of the Traditional Approach

The second problem with the traditional approach is methodological. As exemplified in Exhibit 1-1-1, the typical treatment of current operations management study bears technocratic bias, i.e., focusing chiefly on the modelling of the physical or technological processes but paying little attention to the organizational factors which in fact embody the performance of the physical systems. Moreover along such a line of thought, one usually tends to have a predisposition to fragment most problems into particular fields which are characterized by certain specific quantitative solution techniques, e.g., facility location, inventory control, project management, mathematical programming, etc. Processes such as description and diagnosis of problems receive little formal treatment. In effect, the constraints of the quantitative media usually force unfortunate compromises upon the models to oversimplify complex situations and reduce their ability to provide sufficient insights. Moreover, because of the solution's technique-oriented attitude, there is always a danger of solving wrong problems for such an approach.

1.1.2 Technology Determinism Approach and Its Limitations

Methodologically, an alternative to the above approach is the so called technology determinism found in the literature of organization study (e.g., Woodward [1965]), which emphasizes the importance of relating the organization structure to the underlying technology of the system. However, in this approach the nature of the technology is usually defined too generally and abstractly to have any practical meaning to transportation operating managers. To amplify, technology often means different things to different people; for instance, the concept of technology has been operationalized in terms of the extent of task interdependence [Hickson, et al, 1969], automation of equipments [Blau and Schoenherr, 1971], uniformity or complexity of materials used [Mohr, 1971], the degree of uncertainty in the task environment [Lawrence and Lorch, 1967], and degree of routineness of work [Hage and Aiken, 1969; Hickson, Pugh and Pheysey, 1969; Perrow, 1970], to name a few. Exhibit 1-1-2 is a summary of some researches in this school [Steers, 1977, pp.80-81]. The list can be expanded to include more recent studies, e.g., Poole [1977], Tushman [1979], Kiggundu [1981], and Randolph [1981].

The major drawback of this approach is that it is trapped in an attempt to find correlations between two sets of aggregated and oversimplified typologies: one concerns the nature of organization (in terms of centralization, decentralization and the likes) and the other concerns the nature of technology. In consequence: 1) due to the lack of unified definition of terms, the empirical findings are sometimes confusion [Reimam and Inzerilli, 1981, p.266], and 2) the opportunity to

Exhibit 1-1-2 Studies Relating Structure Variables to Technology

Source: Steers [1977, pp. 80-81]

Investigator(s)	Measure of Technology	Dependent Variable(s) under Study	Findings
Woodward (1958, 1965) 100 British manufacturing firms	Firms classified into small batch (unit), mass production, or continuous process, according to production process.	Structural variables (span of control, levels of authority, ratio of managers to other personnel); effectiveness measure (general level of organizational performance and success - see text for details).	(1) Levels of authority & ratio of managers to personnel increased with technological complexity; (2) labor costs decreased with technological complexity; (3) span of control was related to technological complexity as an inverted U-function; (4) successful firms tended to cluster at the midpoints on various structural continua (e.g., span of control), less successful firms clustered at the end points on such continua. In short, it is argued that effective firms employ structures that conform to their technologies.
Lawrence & Lorsch (1967) 10 industrial firms	Technical rate of change, information uncertainty, & feedback timespan.	Amount of differentiation & integration between departments.	Results interpreted as supporting a strong relation between technological variation & increased differentiation between departments.
Harvey (1968) 43 industrial firms	Firms placed on continuum of "technological diffuseness" (number of product changes, number of products produced).	Measures of internal "structure": (1) degree of specialization; (2) centralization; (3) span of control; & (4) program specification.	Organizations with more stable (i.e., less changing) technologies exhibited higher degrees of structure on all four dependent variables. Findings held with organization size and other variables held constant.
Meyer (1968) State & local departments of finance	Introduction of automated equipment.	Number of levels in hierarchy, span of control.	Introduction of automated equipment led to increased number of levels & span of control.
Hage & Aiken (1969) 16 social welfare agencies	Routineness of task.	Structural variables of degree of participation in decision making, amount of autonomy, measures of affect & distance between supervisors & subordinates, & formalization.	Significant negative correlation between routine technology & participation in decision making; positive relation between routineness and formalization; no relation between routineness and other structural variables.
Hickson et al. (1969) 46 service & manufacturing firms	Automation of equipment, rigidity of workflow sequences, interdependence of workflow segments, & specificity of evaluation.	Structural variables of span of control, ratio of managers to total personnel, specialization, standardization of procedures, formalization, centralization.	Weak relationship between technology and structure found. Data suggest that technology may affect structure & effectiveness in small organizations; in large firms, technological influence will be confined solely to production units & should not affect other units.
Fulani (1970) 3 Canadian firms (printing, auto, & oil); N = 149 subjects	Firms classified into craft, mass production, & continuous process (after Woodward, 1958).	Amount of perceived worker integration (i.e., co-worker & supervisory relations; labor-management harmony; company identification).	Workers in continuous process technology felt highest degree of worker integration, followed by craft workers; mass production workers felt least integration.
Zwerman (1970) 55 U.S. manufacturing firms	Firms classified into small batch, mass production, or continuous process (after Woodward, 1958).	Span of control, levels of authority, size & other structural variables. Firms classified according to success levels.	(1) No simple structural correlates of operating success; (2) replicated Woodward's findings concerning relation of technology & structural characteristics, except found no relation between technology & span of control (in contrast to Woodward). General conclusion that production technology closely related to structural characteristics.
Mohr (1971) 144 work groups in 13 local health departments	Uniformity, complexity, & analyzability of tasks	Structural variable (degree of supervisory participativeness), effectiveness variables (attitudes, innovativeness, work output).	Moderate relation found between task manageability and participativeness. However, it is argued based on the findings that no relation exists between the degree of congruence between technology & structure & resulting effectiveness.
Hrebiniuk (1974) 210 subjects in various departments of a major hospital	Jobs classified according to operations & materials technology (Hickson et al 1969), task predictability, task interdependence, & task manageability	Structural variables (job autonomy, participation, closeness of supervision, formalization, unity of control) & supervisory behavior	No clear relation between technology & structure, although certain technological variables were found to be significantly related to some structural variables when supervisory behavior was held constant.
Warshaw & Frost (1974) 27 organizational units in 17 business firms	Units classified into long-linked mediating & intensive technologies (after Thompson 1967)	14 facets of effectiveness (e.g. performance planning, reliability, coordination, development, etc. - see text for details).	No direct relationship between technology & effectiveness. However, regression analyses indicated different technologies were related to different facets of effectiveness. Authors suggest different models of effectiveness based on type of departmental technology.

establish more delicate linkages between the detailed technological processes and the profound organizational and human behavioral theories is lost.

1.1.3 Three Propositions

In response to the limitations of transferability and the methodological drawbacks of the traditional approaches, this study is aimed at the integration of both the technological and organizational perspectives and the development of a coherent theoretical construct which can be used in the conceptualization, diagnosis and performance improvement of transportation operations management. Specifically, this study adopts the following three general propositions: 1) production technology of a system can and should be studied in a more detailed and practical way than that conducted by the followers of the technology determinism school of method mentioned above, 2) organizational and human variables should be an inherent part of the theories of operations management, and 3) explicit linkages between the technological system and organizational system can be established and should be more delicate than a set of correlative relationships between two families of typologies.

1.2 Research Paradigm and Methodological Framework

Kuhn [1963] argues that science proceeds with a governing set of assumptions on the basis of which theories and models are developed; he uses the word "paradigm" to refer to these assumptions collectively. In response to the emerging research needs addressed above, the first step is to adopt a new paradigm to govern our conduct of inquiry.

1.2.1 Dual-System Control Paradigm

This study postulates that an organization is a goal-seeking mechanism which develops instrumental ends and means to pursue a certain tangible or intangible rationality of the organization. Using a two-subsystem notion, Simon [1981, p.141] explained the nature of a goal-directed total system as below:

Ability to attain goals depends on building up associations ... between particular changes in states of the world [system] and particular actions that will bring these changes about. ... goal-directed action depends on building this kind of bridge between the afferent [i.e., controlling] and efferent [i.e., controlled] worlds [systems]. [remarks added]

The rationale which underlies the above statement is the control cybernetics; therefore, what Simon was suggesting is a dual-system control paradigm. In such a paradigm, a control system is conceived of as being constituted of two complementary parts: 1) the controlling sub-system - organizational aspect of the system which possesses the controlling capacity, and 2) the sub-system being controlled - technological aspect of the system which defines the tasks to be controlled and their interrelationships. The performance of the total system then is determined by how well the controlling capacity is matched with the characteristics of the underlying controlled tasks.

The notion of control also suggests that we seek two-way linkages - action and feedback - between the elements of the controlling and the controlled sub-systems (or, in short, systems) (Exhibit 1-2-1) [*].

Compared with the traditional paradigms, the dual-system control framework provides us with the desired analytical instrumentality. Specifically, it indicates the specific focus of inquiry in order that we can understand the nature of the total system, i.e., to explicate the relationships between the controlling action and the state of the controlled system. Moreover, it is also flexible in accommodating the above inquiry at various levels of details - system-wide level, sub-system level and individual level, and allows us to integrate a variety of control-relevant theories (organizational, individual behavioral and system analysis) into a coherent construct[**].

1.2.2 Organizational Intervention Framework

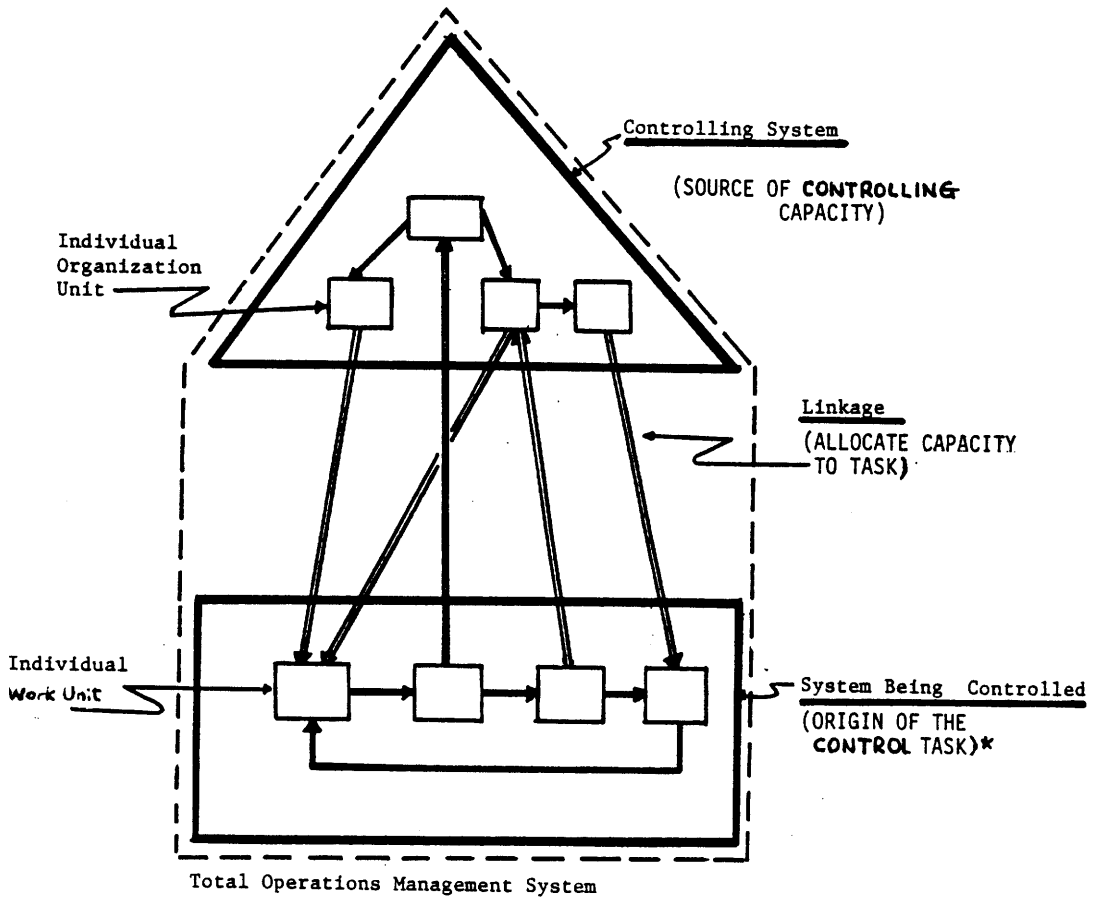
The analysis of the transportation operations management system (which consists of both the controlling and the controlled systems) in this study is aimed at improving the performance of the total system.

The endeavor of improving both the organizational and technological systems' performance can be put into an organization intervention framework which, according to Philip [1980, pp. 20-21], consists of

*: Also after M. L. Manheim, "Lecture Notes for the Seminar on Transportation Systems and Management", Taipei, Taiwan, Republic of China, January, 1982.

** : The notion of control here does not necessarily imply that the system under study is a closed system. Details see Chapter 2.

Exhibit 1-2-1 A DUAL-SYSTEM PERSPECTIVE OF OPERATIONS MANAGEMENT



*: The structure of the decision tasks in principle is also in hierarchical form; for simplification reason, it is represented as one dimensional.

three major intervention steps: 1) diagnosis and problem definition (a diagnosis stage), 2) unfreezing existing relationships, setting change objectives, and developing change plans (a prescription stage), and 3) implementation and institutionalization of change (an action stage). However to be more precise, Philip's framework can be further divided into two sets of interrelated activities [Exhibit 1-2-2] - one concerned with the substance of change or the technical dimension of intervention (defining the problems encountered and designing solutions, i.e., the tasks of 1, T-2 through T-7, and 8 in Exhibit 1-2-2), and the other the procedures of change or the behavioral dimension of intervention (identifying resistance of change, and designing and implementing strategies to overcome the resistance, i.e., the tasks of 1, B-2 through B-7, and 8 in the Exhibit). Successful organizational intervention must proceed back and forth between the above two sets of activities - substantive and procedural[*]. This study emphasizes mainly on the intervention activities regarding change substance [**], or more specifically, on the diagnosis and prescription stages and on the technical dimension's activities.

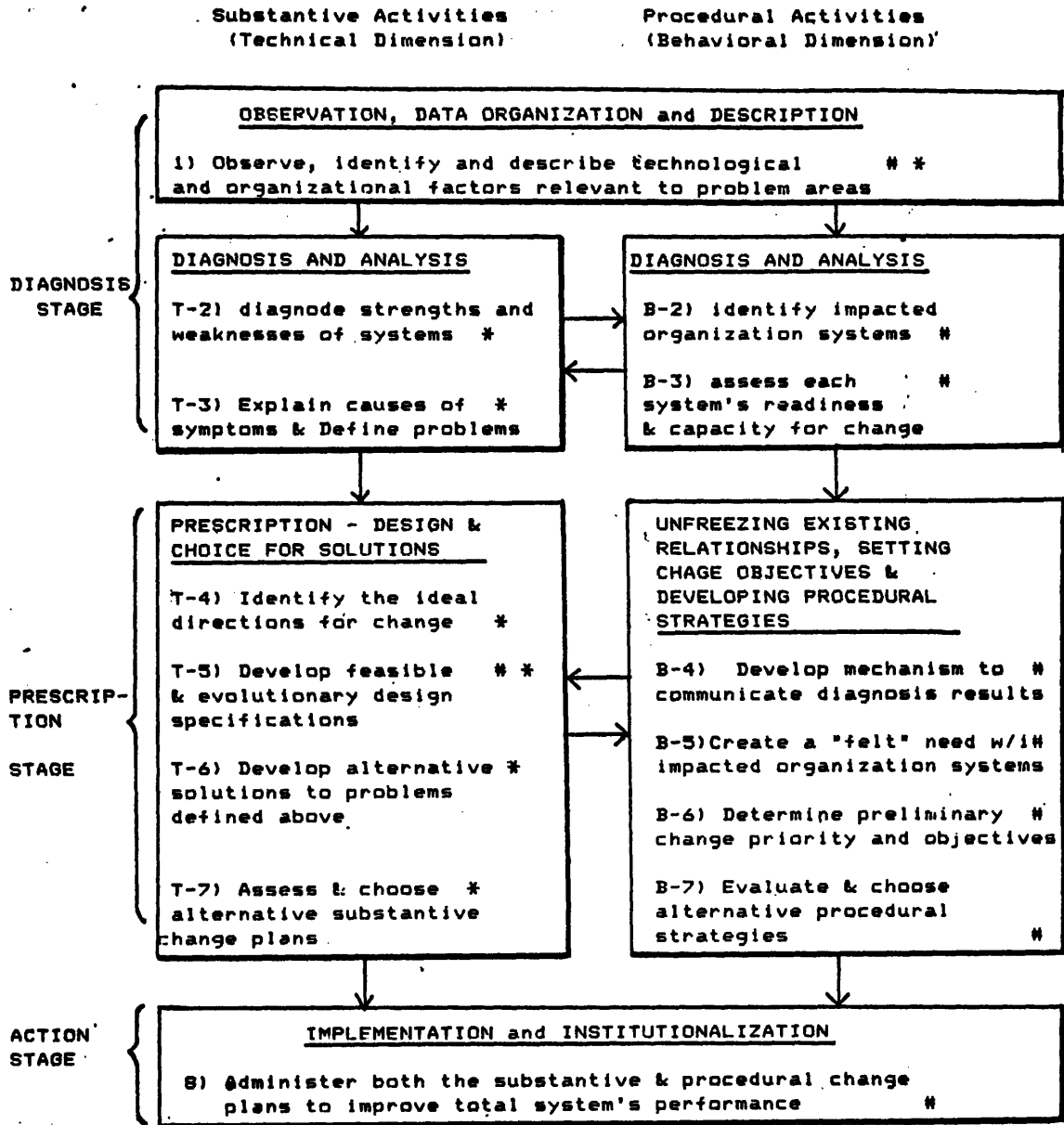
A. Key Themes of the Study

To accomplish a diagnosis and prescription task, Simon [1981, p. 110] argued that two sets of knowledge are required: a large body substantive knowledge and a few general processes - "the knowledge as

*: The potential feedback relationships among the activities shown in the Exhibit are omitted to simplify the representation. However, in practice feedback and iterations do exist.

** : Philip's major focus was on the change procedures (i.e., the management of change process).

Exhibit 1-2-2
GENERAL ORGANIZATION INTERVENTION FRAMEWORK
 (Refined from Philip, 1980, pp. 20-21)



*: treated in this study
 #: mentioned in Philip's Framework

organized in processes, instructing the expert how to proceed with the diagnosis." Following Simon's notion, in this study we first develop some theories which enable us to put the functions of both the controlling and the controlled systems into perspective and provide us with the substantive knowledge (conceptual) frame needed in an organization intervention process. Secondly, we develop a set of general procedures associated with certain operational techniques which can be applied, under the guidance of the conceptual framework, to the diagnosis of transportation operations management systems. In other words, the specific objective of this study is the development of theories and operational methodologies which collectively enable us to 1) understand and describe the nature of both the controlling and the controlled systems in the context of transportation operations management, 2) diagnose and analyze the strengths and weaknesses, and problems of the total system, and 3) identify the desired directions of change for improving the total system's performance, and develop alternative change plans.

B. Empirical Example

To test the theories and the analytical methods developed in this study, the management of railroad motive power (i.e., locomotive) operations is adopted as an empirical case. Three major U. S. railroads, disguised as Railroads A, B and C, were involved in the study. Due to the varying degree of details of the data, our analysis is primarily based on Railroad A, while Railroads B and C's data are used for reference purpose or as supplementary information.

1.3 Outline of Dissertation

This study consists of eight chapters. Except for Chapter 1, the relationships among the remaining chapters are as follows. Chapter 2 is devoted to the conceptualization of the dual systems; the theories and frameworks constructed in this chapter will govern the inquiry process in the rest of the study. Chapter 3 contributes to the development of operational diagnosis procedures and techniques so as to operationalize the key notions developed in the previous chapter; it also serves as a set of organized information collection strategies and tools which can be used to identify the state of the dual systems, to highlight their problematic symptoms, as well as to facilitate the design of improvement plans.

Chapters 4 through 6 are the application of the dual-system theories and diagnosis methodologies to the context of rail motive power operations management. These chapters provide background information about the dual systems in study, as well as pave way to the later stage's assessment of the systems' strengths and weaknesses. Specifically, Chapter 4 deals with the diagnosis and analysis of the task of rail power management as a whole. Chapter 5 concerns with one major functional area of power management: maintenance; this chapter also provides us with opportunities to observe the processes of interfunctional coordination. Chapter 6 focuses on the steering control of the motive power-related rail transportation function.

Given the above three sets of data, Chapter 7 gives the general assessment regarding the performance of the motive power operations management of the host railroads and outlines the recommended

improvement plans corresponding to some selected symptoms identified at various levels of the total management system. The methodological and empirical implications of the study and the areas for further research are summarized in Chapter 8.

THEORIES AND METHODOLOGIES

In the following two chapters (2 and 3), based on the dual-system paradigm as well as the organization intervention framework, theories (Chapter 2) and methodologies (Chapter 3) applicable to the analysis, diagnosis and synthesis of the characteristics of the technological and organizational components of transportation systems are developed.

Chapter 2

THE STRUCTURE OF TRANSPORTATION OPERATIONS MANAGEMENT SYSTEMS

In Chapter 1 we argued that the transportation process, as other processes in the service industry, are different in character from the manufacturing processes, and it is this difference which demands a new analytical framework for the study of transportation operations management. In this chapter, we shall elaborate on this argument from the dual-system perspective.

2.1. The System Being Controlled

2.1.1 The Characteristics of the Transportation Operating Systems

Following the dual-system paradigm, because the nature of the controlling decisions and the control tasks is derived from the characteristics of the underlying physical processes, to start our analysis we first discuss certain key common features of the service operations in general, and then proceed to the more specific characteristics of transportation operations.

A. Some Common Features of the Service Operating Systems

Transportation is a service in which the system utilizes its resources primarily to change the place utility of customers or customers' belongings (i.e., cargoes). In such a transportation operation, as in other service processes, the resources used are not normally substantially changed physically [Morlok, 1976, p.32]. More specifically, a key aspect which distinguishes a service process from

the classical manufacturing process is the nature of the input and output of its productive operations.

Service Output. In a service system, the output or the service is normally characterized by multiple intangible attributes. As suggested by Manheim [1979, Chapter 2], Fitzsimmons and Sullivan [1982, p.16], the service product is, in fact, a package of which the attributes are collectively determined by the supporting facilities (e.g., the vehicle in transportation service), the facilitating good (tickets, waybills, meals), the explicit service (e.g., the transit time and reliability of the intrinsic O-D movement), and the implicit service (the perceived psychological benefits such as privacy and a sense of status). The intangibility of the service output usually causes a serious measurement problem [Sasser, et al, 1978].

Service Input. In a service process, the presence of the customer or customer's belongings is essential. For instance, without the attendance of the passenger or cargo, a transportation function is actually not performed. In other words, in addition to the conventional input of an operator's resource, the service object or the user is also a necessary input for the accomplishment of a service process. Wild [1977, p.32] argues that the service process is activated by a user input (the customer exerts some push on the system), while in manufacturing, the customer acts directly upon output (he pulls the system). The presence of the user input further distinguishes service operations from manufacturing by two characteristics, that is, the simultaneity of the production and consumption processes and the

perishability of the product, i.e., the service cannot be inventoried [Sasser, et al, 1978, p.17]. There are at least three vital and interrelated consequences resulted from the above characteristics: 1) the inability to inventory services precludes the use of the traditional manufacturing strategy - in which the output inventory is established to serve as a buffer to absorb the fluctuation in demand - so as to maintain the production system at some optimal constant output level which maximizes the utilization of the capacity, 2) the uncontrollability of the user-input, incorporated with the perishability of the product, normally creates a serious capacity management problem in the service industry, i.e., due to the cyclic pattern of demand, the system is usually congested during the peaks and idled during the off-peaks, and 3) the simultaneity causes a difficult in quality control and this difficulty is usually further magnified due to the lack of proper measures of service quality as well as the labor intensive nature of the operation.

System Structure. In addition to the distinctive input/output properties, the structure of the service system is usually dictated by the location economy, i.e., the service must be produced where prospective user-input is generated. As a result, a service system is normally comprised of a large number of geographically dispersed local stations, and the scale economy through the centralization of production facilities usually cannot be enjoyed by such a system.

B. Specific Features of the Transportation Operating Systems

A key character which further distinguishes the transportation

operation from other service processes is the circulation of the service objects and the resources in the system. In other words, the transportation operating system is a system of circulatory channels in which customers and/or cargos flow from one point to another, or more simply, the transportation operating system is a system of flows. Associated with the flow of resources and service objects in such a system, a number of outstanding features can be observed.

Cyclicality and Directionality of Demand. Cyclic fluctuation is the common nature of any market. As addressed above, this cyclic pattern of demand usually causes great trouble in the management of a service system's capacity. However, in a transportation system, the demand is further characterized by strong directionality - for instance, the outward movement of the grains from the agricultural states during the harvest season, and the morning inbound traffic and evening outbound traffic of an urban highway - which escalates the difficulties to the management of system capacity in at least two ways. The first concerns the utilization of the infrastructure. That is, during the peaks, on the same route, the co-existence of under-utilization (in one direction) and the over-saturation (in the other direction) of the infrastructure. Special operating control devices are usually required so as to resolve this rather ironic situation and to increase the utilization of the capacity of the infrastructure, e.g., the reversible traffic lanes.

The second problem concerns the operator's rolling stocks. The directionality of demand usually creates considerable imbalanced distribution of transportation vehicles. This effect taking place in the normally geographically dispersed transportation network results in

a particular operating control issue in the transportation context - vehicle backhaul economy. More specifically, the problems involved in this issue include: 1) How to identify the surplus locations, 2) How to balance the vehicle flows, 3) How to minimize the empty mileages, and 4) How to use the vehicle backhaul movement more productively. The real challenge of this issue, in many cases, is that it occurs right during the peaks, and must be resolved during the peaks.

Joint Production Operations. In a transportation system, the movement of a service object between one particular O-D pair usually involves multiple facilities (e.g., terminals and roadways) and multiple processes (e.g., loading, unloading, etc.). Meanwhile, in most non-individual modes, one vehicle usually carries more than one service object with different O-Ds; and one facility normally serves more than one vehicle flow at the same time. Due to the above complicated operations, several rather unique problems are exhibited in the transportation sector. First, the system capacity can only be defined by associating it with a level of service quality [Manheim, 1979, p.271], or in economic term [Henderson and Quant, 1971, p.89], the amount of service objects handled by the system and the quality of the service are the joint products which can be produced in varying proportion by a single transportation process. Second, the interactions among the service objects which flow through the system at the same time usually result in an undesirable externality in service quality; in other words, in the joint production of service capacity and quality, the relationship of these two products is always an inverse one in a given transportation system. Third, the multiple facilities involved in

the process of servicing an O-D movement - which can be categorized as a typical long-linked production technology defined by Thompson [1967, p.15] - create a particular control issue, that is, the traditional responsibility center concept [Anthony and Reece, 1979, p.755] based on clear-cut local cost, revenue or profit responsibilities, is difficult to apply in the transportation industry, due to its high mutual-dependence among the local operating units. As a result, the decentralization strategy, which is usually advocated by the management control theorists, is normally not a practical solution for the improvement of a large transportation system's performance. This is also the reason why Drucker [1977, p.515] claimed that "there are ... service institutions for which we do not possess an adequate principle of organization." Fourth, in many transportation systems, due to the uncontrollability of demand as well as the potential chain-effect of the network-wide interdependence of operations, there is a general tendency to yield considerable variances between the planned and the actual performance. To cope with this largely intrinsic variability and to prevent chaos, in some transportation systems, the control of the real-time operations becomes a critical managerial activity.

Work Rules. The need to circulate resources to accomplish service makes the transportation industry a unique system in which a majority of its employees are working on a mobile work place (i.e., the vehicles). In consequence, because the predominant employees are working away from their supervisor, a complex of special rules not normally involved at the fixed work place are thus required, such as those concerning vehicle speed, route, manning, safety and emergencies [Dunlop, 1958, p.36].

These work rules represent a set of standard operating procedures which direct and confine the allowable discretion during the execution of the first-line operations that cannot be specified by predetermined operating plans but must be taken care of on a contingency basis.

In addition to the supervisory issues resulting from the mobility of the employees' work place, there is another set of work rules which imposes constraints on the management's utilization of labor force. Due to the variable demand and the geographically dispersed network, the nature of transportation operations is inherently heterogeneous, i.e., it is difficult to regularly assign all employees to specific runs or assignments. Therefore, to prevent personal discrimination and favoritism from occurring and to bring about a fair distribution of work, various work rules are developed, particularly in the unionized systems [Kaufman, 1981].

The problems concerning these work rules are the same as any other formal regulations: once they are established, certain rigidities develop. For instance, in the rail industry many obsolete rules actually become barriers to the improvement of productivity. However, in this study we are aware of the existence of this issue, but put no emphasis on it.

2.1.2 Conceptualization of the Transportation Process

Understanding the characteristics of the transportation operating system is the first step toward the conceptualization of the underlying transportation process, which in turn enables us to specify the tasks to be controlled and their managerial implications. This section (2.1.2) is devoted to the development of a conceptual framework for the transportation technological process, and in the next section (2.1.3), we shall discuss the managerial implications which can be inferred from the conceptual framework.

A. Emerging Operational Concepts

A key notion in the discussion of the above section (2.1.1) is that the delivery of transportation service relies primarily on the cycling of a number of resources (such as vehicles and crew) on some supporting facilities (e.g., guideways and terminals) [Manheim, 1979]. To translate the notion of resource cycle into a concept directly useful to the transportation operations managers, we need to further elaborate on the above notion and explicitly identify the fundamental elements to be controlled and their interrelationships in the transportation delivery process.

Resource Cycling and Flows of Work

A transportation operating system is primarily structured in accordance with the flows of work [Mintzberg, 1979, p.38; Steers, 1977, p.73], in which any act (operation) can be performed only after a successful execution of some upstream acts (operations), e.g., before the completion of car switching and assembling operations, no train can

be dispatched from the terminal. Following this line of thought, one operational scheme for analyzing the transportation operating system is, going one step further from the notion of resource cycle, to identify and differentiate between the various core operations and their interface buffers involved in the resource cycles which embody the flow of work [*]. More specifically, because there are natural orders of operations, which are dictated by the nature of the technology adopted by a transportation operating system, the resource cycles can usually be systematically fragmented into distinct status or time phases. Furthermore, these status or time phases can normally be related either directly to 1) the activities - core operations - which are essential to the delivery of transportation service, e.g., the loading, unloading, linehaul, maintenance, etc., or to 2) a function - interface buffer - of which the primary purpose is to provide a smooth connection between two interrelated activities, e.g., the schedule slack between two consecutive linehaul operations. In short, we argue that, from the operations management perspective, most transportation processes can be thought of as the transitions of various phases of resource cycles. Before going any further, because the notion of interface buffers is less obvious than that of core operations, we shall elaborate on it as follows.

[*] The resource cycle concept in fact can serve as a device for comprehending and specifying the distinct work flows engaged in the transportation process. Manheim [1979] identified functional components of vehicle cycle, given the fact that vehicle is one of the key resource engaged in the transportation processes.

Buffering Mechanism.

Uncertainty and interdependence are two essential factors which receive the common concerns of many organization theorists: March and Simon, 1958; Cyert and March, 1963; Thompson, 1967; Galbraith, 1977, to name a few. In the transportation context, the consequences of these two factors are vital. For instance, the times when demand for service arrive, as well as the volume of the demand per se are normally uncertain in a transportation system. The uncertainty of demand incorporated with the variability of the service-delivery procedures usually causes performance variation in each componential process. Moreover, the ultimate effect of performance variations in one process could be far-reaching across the network due to the chain-effect of operational interdependence.

In order to 1) cope with (i.e., reduce, absorb or avoid) task uncertainty and provide an "as if" certainty basis for action [Stout, 1980, p.17], 2) decouple the interdependence among operations so as to minimize the effort of coordination and the likelihood of conflict [Pfeffer, 1978, p.157], and 3) localize the chain-effect resulting from interdependence [Thompson, 1967, p.57], one effective strategy is to create various buffering mechanisms at the interface of two interacting processes.

In the context of transportation operations management, four types of buffers are of particular interests. The first is the physical buffer, i.e., the resources inventory created to absorb the uncertainty produced from adjacent processes. For instance, stand-by vehicles that are purposely deployed at certain strategic locations waiting to serve

unpredictable traffic generated in the neighboring area, represent the typical physical resources buffer. A key point here is that, although the transportation operating managers cannot stock their output service, they do inventory the input resources (empty freight cars, stand-by locomotives, extra-board crew) to protect the unpredictable fluctuation of traffic and to cope with the uncertain supply of resources due to operational variation. The second type of buffer is an informational one, e.g., the schedule slack time built into a transportation operating schedule. When taking a broad view, we may even conceive of the operating schedule, as a whole, as an informational buffering mechanism, because such a schedule provides a common guideline to a series of interrelated processes, and to a large extent these processes can act independently within that guideline. The third type may be called the procedural buffer. A typical example is the practice of the preventive maintenance. The purpose of such a buffer is to prevent the potential operating contingency (e.g., vehicle failure) from upsetting the smooth function of the transportation process [Miles, 1980, p.295]. Indeed, for certain controlling units, these procedural buffers are their core operations, such as preventive maintenance to the mechanical personnel. The fourth type concerns the interface between the organization as a whole and the environment. For instance, if we view the activities conducted by the operating department as the core operations, then the marketing activities becomes a system-environment buffer which is specialized to deal with the external uncertainty and enables the operations department to concentrate on the internal operating issues.

In short, the buffering mechanism is a device for coping with task

uncertainty and interdependence. Among the four types of buffers specified above, the first two are identifiable by the physical transportation process, while the last two are rather abstract. In the following analysis, we shall concern primarily with the first two types of buffers - physical and informational.

Elementary System Modules

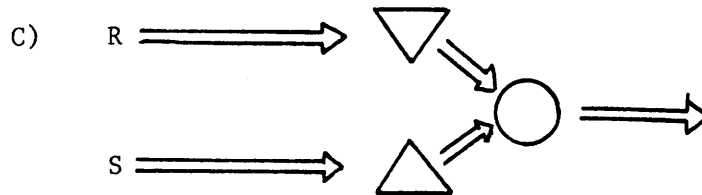
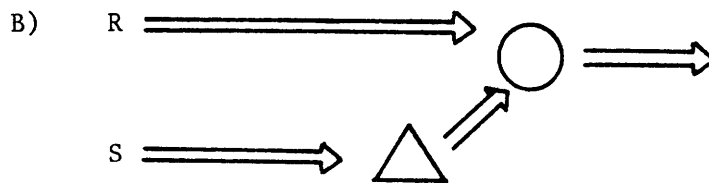
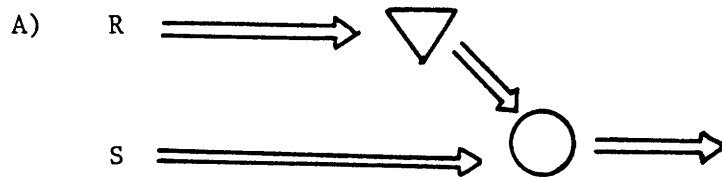
From the preceding discussion, we can summarize that the delivery of transportation service relies primarily on the cycling of various resources, and these resource cycles can be generally factored into status or time phases. These cycle components either function as core operations which directly or supportively contribute to the delivery of transportation, or serve as buffering mechanism to cope with task interdependence and uncertainty.





Given the above conception, and following Ray Wild's suggestions [1977, p.34], we argue that a transportation operating system is comprised of three elementary types of modules [*] as shown in Exhibit 2-1-1. Each type of module represents a different arrangement of the core operations and the buffering mechanisms. The first one utilizes a resource inventory to provide timely service as soon as the service object arrives. The second one reverses the structure and lets the service object await the arrival of the resource, while the third

*: Starr [1964] once argued that "there is an underlying pattern [for the input-output production system] that is divisible into some kind of modular units. These can be joined in different ways to form varying configurations of input-out systems."

Exhibit 2-1-1 ELEMENTARY MODULES OF TRANSPORTATION OPERATING SYSTEM

(After Wild, 1977, P.34)



- KEYS:  PHYSICAL FLOW
R : RESOURCE-INPUT
 RESOURCE BUFFER INVENTORY
S : SERVICE OBJECT
 SERVICE OBJECT BUFFER INVENTORY
 CORE OPERATION

one combines the above two structures and establishes two buffers in around of the core operations.

Two points must be noted. First, the service object mentioned above not only refers to the outside customers but also to resources of different categories. For instance, when the maintenance crew is viewed as the resource of concern, the vehicle to be maintained is the service object. This broader definition is necessary to make the above notion of elementary structural modules applicable to a more operational level. Second, a different type of module has inherent implications in its performance, in terms of the resource consumption and service quality. For instance, for a given operation, the first type generally consumes more resources than the second but provides better service quality, while the third type usually achieves more balanced performance, which is something in between the above two types. In short, each type of module may involve distinct technology and is suitable for certain specific operating contexts with different managerial emphasis. We shall return to this issue in Section 2.1.3.

Example of Resource Cycle - Vehicle Cycle

To gain more insights into the concept of resource cycle, an illustration of the application of this concept should be worthwhile. In the following, we choose the vehicle, among other resources employed by transportation carriers, to demonstrate how to construct an analysis framework based on the resource cycle concept.

The derivation starts from the identification of the types of cycles in which a vehicle is engaged. By categorizing the time-phases

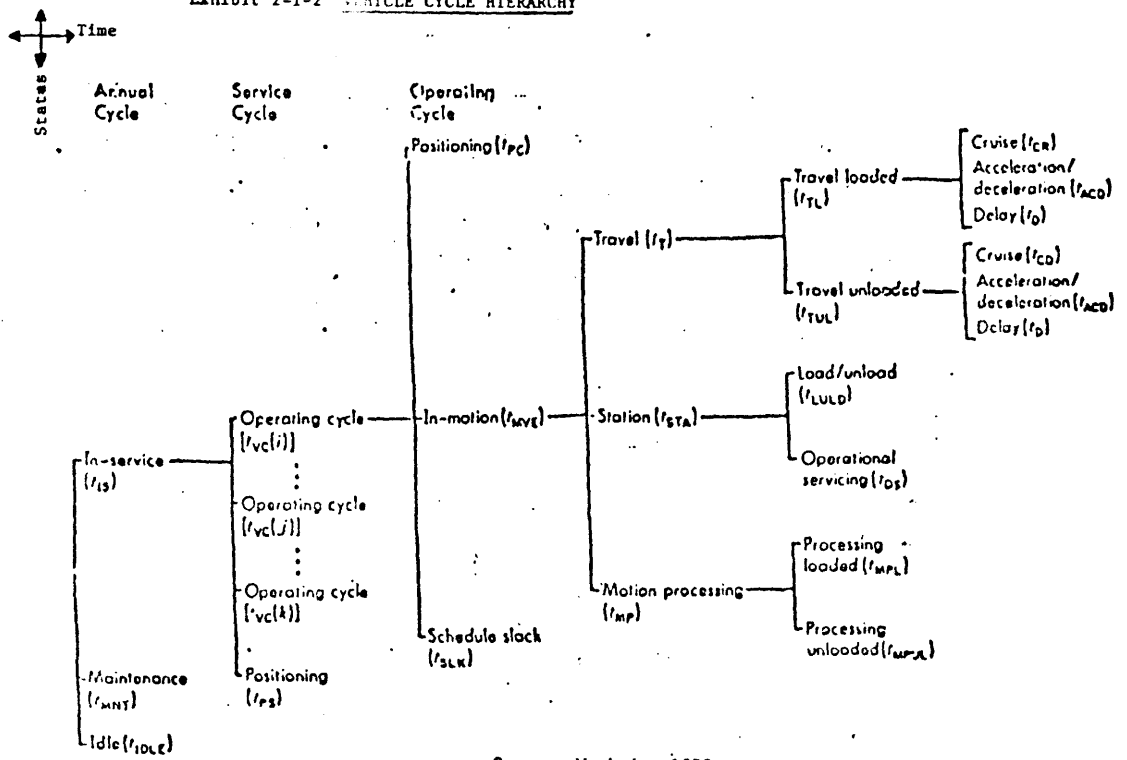
involved in the annual activities of a general vehicle, Manheim observed three types of vehicle cycles - the operating cycle, the service cycle and the annual cycle [1979, p.220]:

The operating cycle begins and ends at the operational base and includes positioning time, travel time while loaded and unloaded, load/unload time, operational servicing time, scheduled slack, and movement processing time. The service cycle begins and ends at a major maintenance base and includes one or more operating cycles as well as positioning time from and to the maintenance base. The annual cycle includes the service cycle, time spent in periodic maintenance, and time spent in idle status.

It is important to note that these cycles are hierarchically interrelated as shown in Exhibit 2-1-2. Several observations can be made from the above example.

- 1) The resource cycle can be specified in varying degrees of detail. However, their fundamental components are either core operation or operational buffer, or some collection of these two elements.
- 2) Within any particular level of the hierarchy, the cycle components specified above satisfy the mutually exclusive and collectively exhaustive criteria (although some of the components can be further factored into more detailed elements). In other words, to specify a set of cycle components which satisfy the above criteria along a particular resource dimension is not infeasible.
- 3) The interdependence of the components of a resource cycle can be specified through the analysis of the underlying cycling process.
- 4) Different cycle components involved in a resource cycle demand different analytical methods and measures for assessing the process, and different management skill and talent are required accordingly. For instance, the elements under the in-motion category (core operations) can be appropriately analyzed through the classical engineering approach

Exhibit 2-1-2 VEHICLE CYCLE HIERARCHY



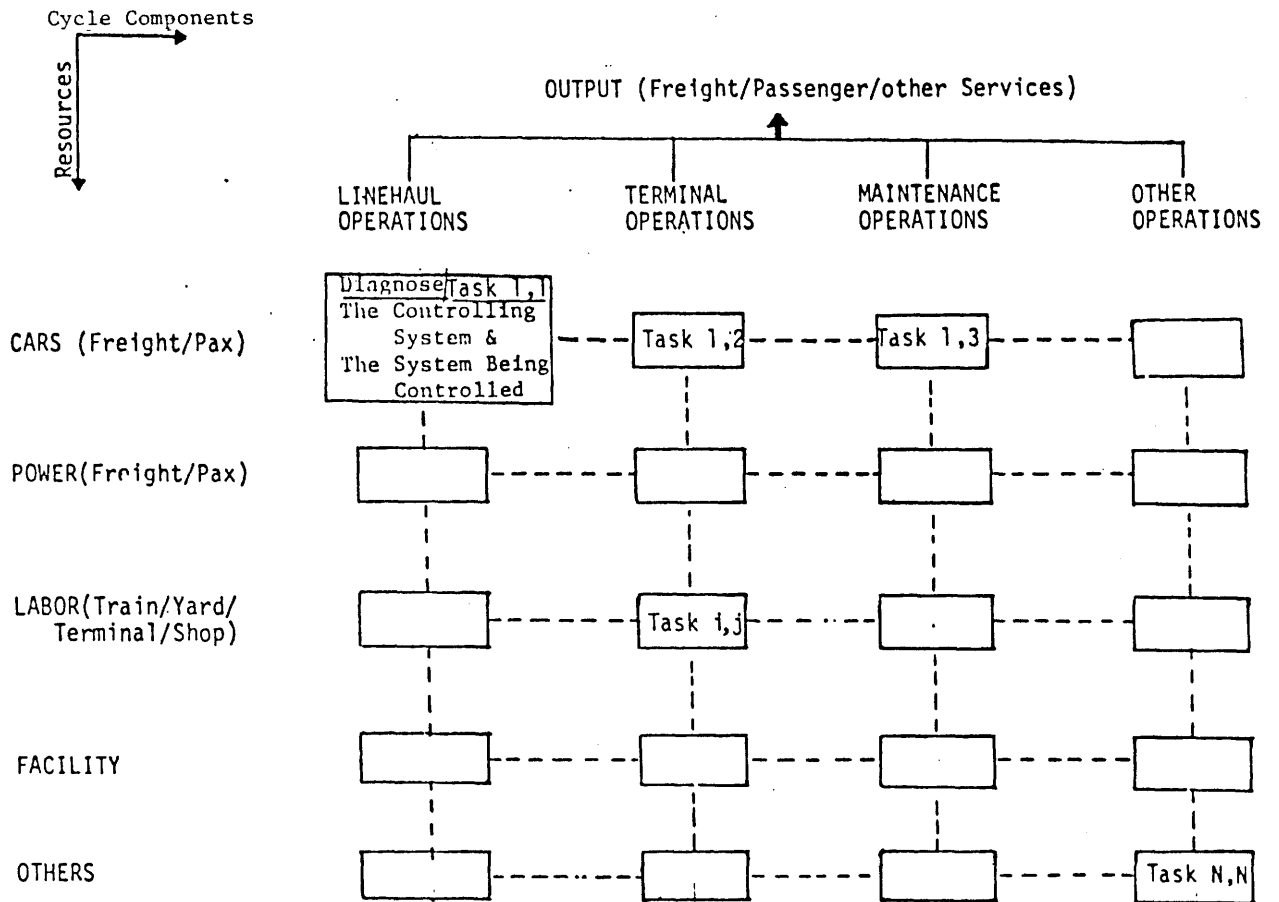
Source: Manheim, 1979, The vehicle cycle—variables and relationships.

- vehicle motion mechanics; while the analysis of schedule slack (an operational buffer) requires another set of knowledge, such as system operating reliability, trade-off between service level and resource consumed.

5) Because some of the components of a resource cycle may also be the common elements of other resource cycles (e.g., schedule slack could be a common components for both the vehicle cycle and crew cycle when the crew is assigned to the vehicle), it is possible to augment the scope of the analytical framework embodied on a elected resource cycle as needed by associating additional elements to the appropriate components (in the original cycle) which are a) also the cycle components of other resource of concern, or b) directly related to some other concerned issues. For instance, to address energy issues, some fuel consumption elements may be associated to the elements under the original in-motion category in Exhibit 2-1-2.

6) To predict the performance for a set of resources, one could predict the characteristics of the cycles for all resources of concern. Exhibit 2-1-3 depicts such an image - one may notice that the issues of interdependence among different resources cycles can be addressed through the analysis of the activities (i.e. blocks in the exhibit) where they intersect.

Exhibit 2-1-3 RESOURCE CYCLES AS ANALYSIS FRAMEWORK (RAIL CASE)



B. Defining the Object to be Controlled

Putting the preceding discussions into a control perspective, our concern is to translate the various conceptions specified above into a coherent framework which characterizes the control tasks underlying the system being controlled. In other words, we must define, in the controlled system, the object to be controlled which is assignable to some identifiable elements in the controlling system which have or should have the capacity to control the performance of the task. To do this, we should first examine the general managerial activities involved in the control of a resource cycle component.

Management Cycle

The management of a resource cycle component encompasses a wide array of activities which in principle constitute a cyclic process [Rathe, 1959, Anthony, 1965]. Such a cycle can be called management cycle which contains the following three distinctive but interrelated phases.

Planning - determining objectives as well as media such as operating goals, work programs and procedures, quality standards, and the like.

Execution - exercising control over specific tasks within the framework defined at the planning phase to assure the actions are carried out properly.

Review - measuring and appraising the performance, interpreting the effects and causes, as well as feeding back distilled conclusions for further planning.

One must note that, the management cycle comprised of the above three elements is not a closed loop. Successful implementation of the

planning and review functions usually involves certain analysis efforts characterized by 1) to which external information is an essential input [Anthony and Dearden, 1976, Chapter 1], and 2) of which the activity is usually conducted separately from the regular managerial routines [Rathe, 1959]. We consider both (above) types of efforts an auxiliary to the basic management cycle. To amplify, the purpose of this auxiliary is the feed-in of additional intelligence, i. e.,

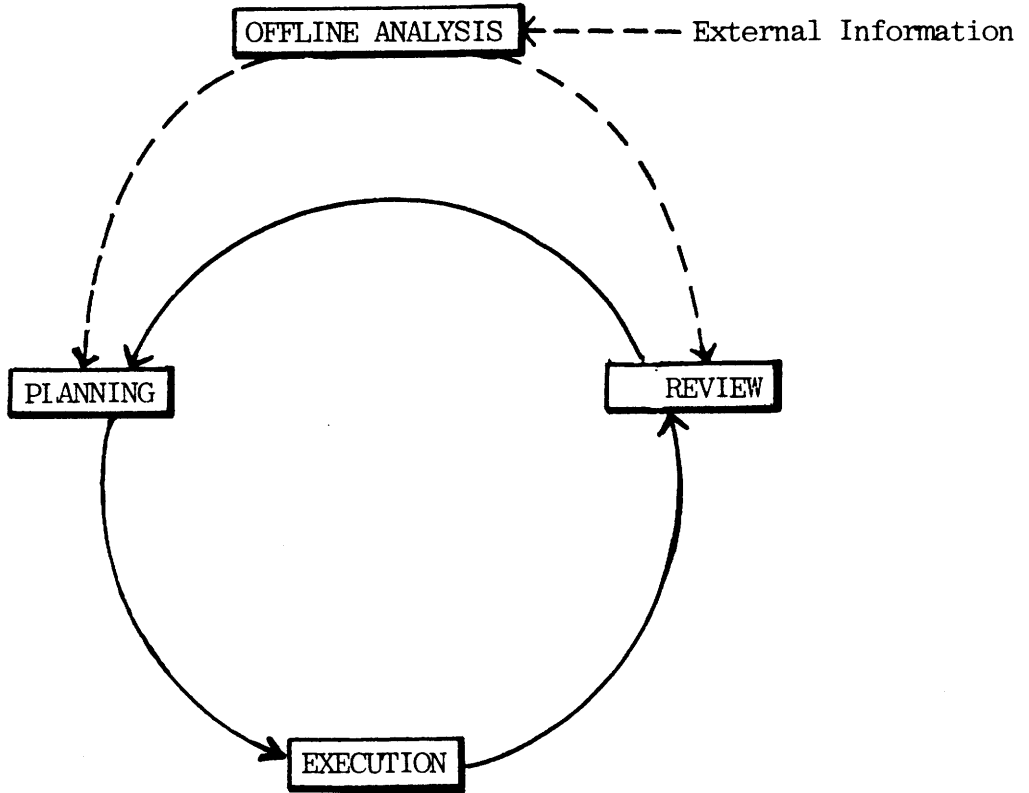
- 1) procuring supplementary information (external or internal) through surveys, etc.
- 2) processing existing data by enlisting the potential of statistical, mathematical and other information-processing techniques to gain more insights into a problem, and
- 3) searching for new knowledge which make it possible to crack old problems, to find new alternative solutions, and to discover reasons for previous failures.

In this study we call the above function off-line analysis. The notion of management cycle can then be summarized as shown in Exhibit 2-1-4.

Work Unit.

Given the notion of management cycle, we can then define the fundamental object to be controlled in the transportation system. In this study such an object is called work units. Because the management of any resource cycle component involves all three phases of the management cycle, we argue that each component of a selected resource cycle will generate three work units which represent the planning, execution and review tasks associated with the concerned component, respectively. Therefore, the work units generated from each cycle component of a selected resource collectively define the totality of the tasks to be controlled associated with the resource. Once the work units have been specified, they can then be related to the elements in

Exhibit 2-1-4 The Notion of MANAGEMENT CYCLE



the controlling system. By this token, organization diagnosis can be conducted concerning the strengths and weaknesses of the control function of the total system, according to the characteristics of the linkages between the work units and organization units.

Three points are worth noting: 1) The elementary work unit thus specified may vary in their degree of detail, depending on how detail we disaggregate the resource cycle; 2) Depending on the issues, analysis perspectives and the structure of the controlling system, the work unit actually assigned to the controlling organization unit may consist of one or more than one elementary units; 3) The work units are interrelated in two ways - one is the technological interdependence resulting from the underlying resource cycling process, and the other is the administrative interdependence resulting from the procedures of management cycle.

2.1.3 Totality of the Control Tasks

To conclude our conceptualization of the system being controlled, in the following sections, we like to put the notion of work unit into perspective and develop a typology of control tasks which embodies the nature of the system being controlled. However, before getting into the key theme, it is appropriate as a premise to first clarify the role of transportation operations management.

A. The Role of Transportation Operations Management

Conflicting Goals. The performance of a transportation system can be comprehended through two general perspectives - user's and operator's

[Manheim, 1979, Chapter 5]. From the user's perspectives, one puts the focus on the service level experienced by each individual load from origin to destination. The importance of understanding the service level is that it enables the management to predict how customers may respond to changes in the system performance; whereas, from the operator's perspective, one needs to care about the resources consumed and revenues from all services provided by the transportation enterprise simply because the financial viability of the system is determined by the costs associated with resources consumed together with the revenues generated from system users.

However, because higher quality service can normally be achieved only through larger amount of resources consumption, there is an inherent conflict between the service goal - which prefers higher quality, and the resource goal - which prefers lower consumption. In addition, it is not unusual that the goals of several resources may also conflict due to the potential trade-offs resulting from the complicated interactions among the resources or due to their inherent substitution relationships.

Management Roles. The need for transportation operations management stems from the fact that the operating system must contend with multiple objectives - satisfactory service must be delivered simultaneously with the achievement of efficient operations; either inefficient use of resources or inadequate service quality is sufficient to give rise to the failure of the operating system. Transportation operations management is concerned with the provision of both satisfactory service and resources productivity; one must be balanced against the other since

an improvement in one may cause a deterioration in some aspect of the other.

Inconsistency among goals - either service vs. resource, or resource vs. resource - exists usually because of a lack of clarity about how behavior in one subsystem affects that in others. In a transportation system, both service levels and resources consumed vary as the options specifying the system are varied and/or as the volume using the system is varied. To analyze system performance, one must be able to trace out how both vary[*]. The transportation delivery process itself involves not only the application of technology but also the adequate management of all the variables that can be controlled - these include the options open to both the controlled system and the controlling system. In short, the essence of effective operations management is seeing the interrelationships of all the variables and viewing the entire transportation delivering process as an integrated system.

*: In other words, the notion of balancing service level with resource consumed is vital to the design and application of the performance indices of transportation system.

B. A Typology of Control Tasks

As demonstrated by the example of vehicle cycle cited in Section 2.1.2A, the components of a specific resource cycle are normally hierarchically interrelated. Manheim argues that a hierarchy of decisions for transportation operations management can usually be specified [1981]. For example, it may begin with the short-range operations planning and control problem - effective utilization of vehicles, given fixed facilities and technologies - this includes service planning, producing an operating plan, determining maintenance policies, effective utilization of manpower and other resources within work rules and other constraints, etc.; then is the mid-range options of vehicle fleet acquisition or divestment; finally follows by the long-term options of major changes in facilities, including guideways, terminals, maintenance, and the like.

Putting the notion of work unit into a time perspective as suggested above and by taking into account the structure of the controlling system (which will be discussed in part 2 of this Chapter), we can categorize the work units (including both of those associated with the cycling resource and with the fixed resource) into three levels: steering control task, functional control task, and meta-control task [modified from Anthony, 1965; Mesarovic, et al, 1970; Newman, 1975; Kirkert, 1980]. By integrating these three levels tasks into one framework, a hierarchy of control tasks is constituted.

Steering Control Tasks. The steering control task, following Newman [1975], is simply the control of the operating schedule of a variety of

resource cycle components at various locations of a transportation network. The objects to be controlled at this level are 1) the amount of the physical throughput (e.g., resources, and/or traffic) which flows through the system, and 2) the timing of occurrence for the process. Referring to the vehicle cycle example, the steering control task is mainly concerning with the execution phase of the operating cycle, and the execution of the core operations or buffering functions of higher level cycle (e.g., maintenance operations). Indeed, the discharge of a steering control task may itself constitute a sub-management cycle and in this study we call such a cycle steering control cycle [more discussion see Section 2.2.1].

The nature of the decisions involved at this level's control tasks is usually routine, repetitive and well-defined. Nevertheless, as argued earlier, these tasks are not necessarily a straightforward implementation of some fixed blue-print; continual judgement is regularly required due to the ever changing operating contingencies, and timing is critical because these tasks are performed on a real-time basis. Due to the long-chained interdependence [Section 2.1.1B], on-line communication is essential to perform the task; however, the final decision is normally reached at the discretion of the individual who is in charge of the work unit. In other words, in real-time context, due to the mutual-dependence with rest of the system, the discharge of a single work unit demands information on a large amount of variables, and most of these variables are uncontrollables from the work unit's viewpoint; it is communication which renders the uncontrollable variables more certain and leaves the controllables at the responsible

individual's discretion.

Functional Control Tasks. Steering control is performed within a context defined by higher level control tasks. The planning as well as review (which provides information for replanning) of various operating schedules in a transportation enterprise are typical control tasks at this level. Because the physical flow is influenced significantly by the number of stages as well as the location of buffers involved in a system, changing the arrangement of operational buffers, in effect, is changing the arrangement of control points, and it is an effective way to intervene in the real-time performance. The Work units at this level at least contain the following two types of tasks: 1) specifying the timing of arrival/departure of physical flows (resource and/or traffic) to/from various core operations and operational buffers under some presumed operating situations; and 2) creating or eliminating operational buffers or even core operations without changing the infrastructure of the system.

Referring to the vehicle cycle example, the functional control tasks concern with both the planning and review phases of the operating cycle, the service cycle and the annual cycle. The work units at this level together with the steering control tasks complete a functional control cycle.

Decisions at this level are made less frequently than that at the previous level. A much larger array of controllables are included in the task at this level than in any steering control task; such an array usually contains the elements of a whole resource cycle (e.g., freight car management), a whole work flow (e.g., rail piggy-back service) or a

particular operating function (equipment maintenance). The uncontrollables, caused by task interdependence, are not as well-specified at this level as at the steering-control level. To deal with them, coordination and some form of collective decision are usually required so as to produce mutually consistent operating guidelines for the steering control tasks. The decision problems raised at this level are normally less well-structured than those encountered in the real-time context. Off-line analysis is usually essential to the successful discharge of this level's tasks.

Meta Control Tasks. According to our definition, both the functional and steering control tasks are performed in a framework with a given amount of total resources available, i.e., within the limit of a given capacity. Therefore, a natural level above the previous two is system-wide meta control tasks [Kickert, 1980] taking care of the capacity of the system. A general objective for this level's tasks is to match the system capacity with long-term demand. From such a capacity control point of view, the two lower levels' tasks are complementary, since their objectives are mainly to accommodate short-term and real-time imbalance between system capacity and demand volume. Meta control tasks provide both the procedural and structural operating contexts for the functional and steering control tasks. Not only the resources in cycling but also the non-circulatory (fixed) resources, such as terminals, plants, etc., are of concern at this level. In other words, it is this level's tasks to control the most appropriate combination of all options available to operations management in response to the changing environment. With more options

to explore and greater flexibility in finding a solution, the challenge is not simply to coordinate or to implement, but to develop in a manner that supports and enhances the ultimate goal of the system.

In terms of vehicle cycle, at this level the key issue is concerned with vehicle's life cycle, or more specifically the planning and review of vehicle life cycle as well as the vehicle fleet size. The work units at this level incorporated with the lower level control cycles form a meta control cycle.

The decisions involved at this level are generally novel and ill-structured in nature, and most of the uncontrollables are external-oriented. The problem concerns not only the technical uncertainty which can be dealt with through fact finding, but also political uncertainty which relates to the value consensus on the system's goals [Brightman, 1982, p.6; Stout, 1980, p.151; Thompson, 1967, p.134]. Because the problems to be dealt with are ill-defined, the source of information becomes an issue. The use of the conventional formal management information is usually very limited at this level, informal communication systems become more effective and in many cases ad-hoc information inquiry effort is required [Soelberg, 1967; Tuggle, et al, 1975; Mintzberg, et al, 1976]. In other words, off-line analysis must be conducted extensively and intensively so as to discharge this level's tasks successfully.

Hierarchy of the Control Tasks.

In summary, the control tasks derived from the nature of the system being controlled are hierarchical in character [*], ranging from the lowest well-programmed stimulus-response type of steering control tasks geared closely to the process of physical transportation flow, to the ill-defined system-wide meta-control tasks dealing with the design and redesign of the transportation system in response to the long-term trend of the external operating environment, with a level of functional control tasks in between to mediate the two extremes. The underlying mechanism which integrates these three-level control tasks is the cause-effect and ends-means interrelationship existing among the decisions involved at various levels' tasks.

In this study we argue that, in order to specify the characteristics of the transportation system being controlled, it is essential to specify the hierarchy of the control tasks, and only in this manner can the required controlling function - which provides a solid reference line for the diagnosis of the performance of the controlling system - be identified.

*: We follow Philip's term - hierarchy of control tasks [1980, p. 77], and further refine it.

2.2 The Controlling System

The controlling system in this study is primarily defined as the organization of a transportation enterprise. However, the knowledge of the static formal organization structure of a transportation enterprise does not allow us to understand how the organization structure works in practice. To attack this problem, some organization theorists propose to take a functional approach which "would first select appropriate components or sub-systems (e.g., decision areas), then show how the characteristics of these components (e.g., the way decisions are made) bring about some state of the system" [O'Shaughnessy, 1972, p.121]. As to the problem of how to specify the system components, there seems to be no standardized practice: different analysts may adopt different specification for different purposes. For instance, in one article [1973], Simon emphasized the importance of examining the information system in abstraction from the formal organization departmental structure; whereas after the review of various schools of thoughts, Galbraith [1977, p.31] summarized the following five variables as the key to the design of an organization: task, structure, information and decision processes, reward systems, and people. In a recent study on several transportation organizations' performance, Philip [1980] advocated the concept of seeking congruence among three elements - organization structure, information systems, and decision process - so as to appropriately support the transportation activities.

In this study, a comparison with Galbraith's framework, the task variable has been elaborated and expanded into the system being controlled as discussed in the preceding part of this chapter, and as a

first approximation, both the reward systems and people are considered as an integral part of the organization decision mechanism. Given these two premises, we are allowed to reduce our focus chiefly on the three dimensions as suggested by Philip in the study of the transportation controlling system. In fact, this reduced construct is consistent with Simon's proposal in which the key theme is arguing the importance of designing an organization in accordance with its underlying information processing structure - the essence of such a structure is determined by organization structure, decision process and information systems. To further operationalize the above concept, this study adopts a hierarchical analysis approach, i.e., the behaviors of a transportation controlling system are probed along the following three dimensions:

- 1) How the system as a whole behaves in response to an organization-wide problem?
- 2) How a group of organization units works together as a team to carry out a decision-making process?
- 3) How an individual behaves when he encounters a decision problem?

Our hypothesis is that, through such a segmented analysis[*], the results can collectively provide us with a sufficiently rich descriptive and analytical data to enable us to put the function of the controlling system into perspective, to conduct insightful diagnosis

[*]: The three levels of diagnosis, in practice, could be a multi-faceted iterative process with a variety of depth in each level. Detailed discussions see Chapter 3.

concerning the actual system performance, as well as to develop norms for organization change if needed. The following is the summary of our conceptualization of a transportation controlling system regarding 1) the macro-function of the organization structure as a whole, 2) the group decision-making process, and 3) the individual decision-making behavior.

2.2.1 Organization Structure - A Macro Problem-Solving Perspective

Organization is a mechanism developed to solve complex problems through organized effort to achieve some shared purposes. To put the function of an organization into perspective, in this study we conceive of an organization primarily as a problem-solving mechanism. In the following, we first elaborate on the above notion from two distinct viewpoints, i.e., mechanistic and open system (or organic) [Burns, 1963], and then integrate both viewpoints into a broader frame.

A. Mechanistic View

Means-ends Hierarchy and Work Division

March and Simon [1958, p.169] argued that the basic features of an organization structure and function are derived from the characteristics of human problem-solving processes. It is observed that when faced with a complicated issue, managers usually attempt to simplify the issue by decomposing one decision into many smaller sub-decisions and by trying to use standardized programs to deal with each problem [Alexander and Manheim, 1965]. The principal way to decompose a problem is to conduct a means-ends analysis [March and Simon, p.152]. Manheim [1966] has

illustrated how to solve a complicated problem by specifying a solution progressively from the level of very general plans down to determining the very detailed step-by-step execution tasks.

The decomposition of a large task into parts, according to March and Simon [1958, p.152], can be more elaborate for an organization than for an individual person, because in an organization context the means specified in the problem-decomposition process become subgoals which may be assigned to lower level organization units. In March and Simon's view the division of work can be explained by the cognitive limit of the human mind (an individual can attend to only a limited number of things at a time) [also see Section 2.2.3 of this study]; therefore, various aspects of the whole complex problem are being handled by different individuals and different groups of individuals in an organization, so that each organization unit only needs to take care of a manageable part of the whole problem and omits the others [March and Simon, 1958, p.151]; the resulting departmentation can be mapped to a means-ends hierarchy which relates the individual tasks to the organization purpose [ibid, p.31]. Along the same line of thought, Williamson [1979, pp.27-31] even specified a formula which equates the number of organization levels to a function of control span.

Mechanistic Bureaucracy

The image of the organization as a means-ends hierarchy allows us to gain insights into the classical bureaucracy, which is characterized by vertical and horizontal job specification, a proliferation of rules and regulations, formalized communication through the organization, as well as by the decision-making process following the formal chain of

authority [Mintzberg, 1979, Chapter 18]. In the context of operations management, when the operative end of an organization is to produce certain fixed outputs, such an end can usually be systematically factored into a family of simple, repetitive tasks - which stands for a set of empirically proven means to the intended operative end - and the mechanistic bureaucracy becomes a rational organization structure that maximizes production efficiency through the precise execution of various standard operating procedures (SOPs) associated with the individual tasks specified above. In other words, a classical mechanistic organization is an instrument or tool for achieving a given end through the functioning of the built-in hierarchical means-ends mechanism.

It is clear that the premise which determines the validity of a bureaucratic machine is the validity of the ultimate operative end - in terms of some effectiveness measures, such as the long-term survival of the organization. This argument highlights a major issue [*] faced by business bureaucracy, that is, an efficient instrument is not necessarily always effective in all situations and for all problems. In a stable and deterministic environment, a fixed operative end may remain valid and effective, as does the end-specific bureaucracy; while in an ever changing external and internal environment, the validity of any established operative end becomes an issue subject to review from time to time to the organization, so does the business bureaucracy which embodies the operative end.

[*] Specialization, a key characteristic of the bureaucratic organization, has recently come under attack by the proponents of job enlargement. They believe that the concern with task specialization has dealt only with the cognitive but not the motivational aspects of work. However, this is not the major emphasis of this study.

However, the need for organizational change should not make an organization as vulnerable if the signal of change from both internal and external environments can be well received by the organization. The key source of trouble stems mainly from the inward-oriented management attitude associated with the mechanistic organization. As argued by Mintzberg [1979, p.321]: "the managers at the strategic apex of these organizations are concerned in large part with the fine tuning of their bureaucratic machines ... just keeping the structure together in the face of its conflicts [usually] consumes a good deal of the energy of top management." As a result, they become insensitive to the change of environment and fail to respond to it in an entrepreneurial way.

B. Open-System View

Environmental Determinism

The mechanistic organization can only be trouble-free in a closed system with a highly predictable environment. However, the market and the internal constituencies of any business are normally in a constant state of flux; in response to this reality, there is a school of thought, i.e., environmental determinism [Steers, 1977, p.90], which argues that organizational rationality never conforms to close-system logic but demands the logic of an open-system, or more specifically, most effective organization design is determined as a function of external factors. For instance, Lawrence and Lorch [1967] emphasized the need for an organization to understand its environment and to structure itself accordingly. They concluded from their study that

environment does play an important role in the relation between structuring activities and organizational success. Moreover, Alfred Chandler suggested that there is a relationship among environment, strategy, organization structure and its success: "strategic growth resulted from an awareness of the opportunities and needs to employ existing or expanding resources more profitably. A new strategy required a new or at least refashioned structure if the enterprise was to be operated effectively" [1962, pp.18-19]. In short, environment determinism advocates that an effective organization must be structured organically with high flexibility and adaptability in response to environmental changes.

Structural Dilemma

The preceding discussion uncovers a structural dilemma faced by the operations management: on the one hand, to gain production efficiency, the organization should be maintained as a stable closed system and structured principally by following the chosen production technology; on the other hand, to cope with environmental uncertainty and to achieve system effectiveness, the organization structure must remain flexible and adaptive. The key issue is whether it is possible to design a single organization to satisfy both seemingly conflicting criteria. Thompson [1967, p.20] attacked this problem explicitly. He argued that:

Since the technological activities are embedded in and interdependent with activities which are open to the environment, the closed system can never be attained for the technological component...[yet] the technical core must be able to operate as if the market will absorb the product at a continuous rate and as if inputs flowed continuously at a steady rate and with specific quality. ... organizations

reveal a variety of devices for approximating these "as if" assumptions, with input and output components meeting fluctuating environments and converting them into steady conditions for the technological core.

Vertical Qualitative Differentiation and Three-level Concept

In other words, in order to operate smoothly without interruption, the technical level cannot tolerate much uncertainty, therefore a necessary buffer must be provided to separate the technical core from direct exposure to the external unpredictable environment. Steers [1977, Chapter 5] emphasizes the need to set aside and invest some resources in activities that will enhance the net worth of the organization in the future, because without such renewal efforts, organizational survival is easily threatened by short-term shifts in demands, resources and so on. Following Parsons' [1960] three-level system notion, Thompson suggested that such an organizational renewal effort is best accomplished by the senior management: "If the closed-system aspects of organizations are seen most clearly at the technical level (i.e., the bottom level of an organization), and the open-system qualities appear most vividly at institutional level [i.e., the top level of an organization]" [1967, p.12]. The remaining issue is how to mediate between the above two extremes. Thompson went on suggesting [ibid]: "If the organization must approach certainty at the technical level to satisfy its rationality criteria, but must remain flexible and adaptive to satisfy environment requirements, we might expect the managerial level to mediate between them, ironing out some irregularities stemming from external sources, but also pressing the technical core for modifications as conditions alter."

In summary, to appropriately balance the efficiency and effectiveness criteria, the controlling organization of an operating system should function like a three-level system[*], each level dealing with tasks which are qualitatively different - the low-level for physical process, the top-level for system-wide adaptation, and the middle-level for mediation and coordination. In other words, in the conventional business bureaucracy, the hierarchy of the organization is primarily a result of work division - the managerial energy at all levels is oriented toward the same instrumental (operative) end, i.e., looking into the procedures and processes of a given production technology. However, a properly functioning organization demands a qualitative break along the vertical dimension of hierarchy in terms of the orientation of managerial attention, particularly for the top level: its attention should focus not only on the achievement of the instrumental end but also on the validity of the instrumental end with respect to some effectiveness measures of the organization.

*: Parsons and Thompson's three-level notion is derived from a conception of an organization's structure and its function. Anthony's three-level notion, the notions of management cycle, as well as of the hierarchy of control tasks (Sections 2.1.2 and 2.1.3) are derived to conceptualize the characteristics of general management activities. The relationships between these two groups of typologies are discussed in the next subsection (2.2.1C).

C. Meta-Control View

To conclude the above discussion, the mechanistic system embodied in a specific means-ends hierarchy is an efficient structure for achieving production efficiency; however, it suffers from the drawback that, in time of change, the underlying operative end may no longer serve the goal of the organization, nor will the organizational structure; whereas the organic (open) system is effective in response to the environmental change, but has trouble in providing a stable operating context demanded by production efficiency. To resolve the above structural dilemma, a qualitative differentiation of the organization hierarchy is required, and in effect this leads to the notion of a three-level organization system as cited in the foregoing section. In the following, we shall illustrate the relationships between the three-level system and the organizational problem-solving processes, and then put them into a unified framework which characterizes the function of the organization structure as a whole.

Organization Problem-Solving Cycle

Generally speaking, problem-solving is a conversion process which transfers an open problem with unspecified ends and means into a closed problem with specific step-by-step action procedures (solution) which lead to a given end [Ponds, 1969; Lang, et al, 1978]. Associating this problem-conversion notion with the Parsons and Thompson's three-level system concept, we argue that, in an organizational context, the general responsibility of top management is to define and re-define organizational problems through the specification of either their ends or means; for first-line management, is to execute the solutions, while

for middle management, is to transfer the semi-open problems with unspecified means or ends into closed problems [see Exhibit 2-2-1].

Comparing the above three-level organizational problem-conversion system with the means-ends hierarchy implied by the classic mechanistic organization, one finds that the latter is only a partial structure of the former as indicated in Exhibit 2-2-1. Specifically, the classical bureaucratic system constantly defaults the first phase of the conversion process, i.e., defining problems; as a result, their problem-solving machines easily become obsolete when the predefined problems change.

Nevertheless, imposing a problem-definition element on top of the classical bureaucratic machine will not necessarily turn the system into an adaptive one. Although the problem-conversion phases commonly proceed downward from the open-problem to closed-problem - a process usually referred to as formalization or institutionalization [Tuggle, 1978, p.42]; for an adaptive system, the reverse process is equally important. That is, in certain situations, the system should be able to re-open the already institutionalized problem-solving machine - a process usually referred to as organizational innovation or development [Lawrence and Lorsch, 1967, p.90]. In other words, problem-conversion should function in a cyclic fashion, but not as a top-down linear one-way process.

Meta-Control Structure - Organization as a Problem-Conversion Mechanism

To conclude, from a functional perspective, an organization can be viewed as a macro problem-conversion mechanism. By applying such a notion, the principal roles (in terms of task authority and accountability [Philip, 1980, pp. 82-85]) of an organization's various

Exhibit 2-2-1
ORGANIZATIONAL PROBLEM SOLVING/CONVERSION TWO-WAY PROCESSES

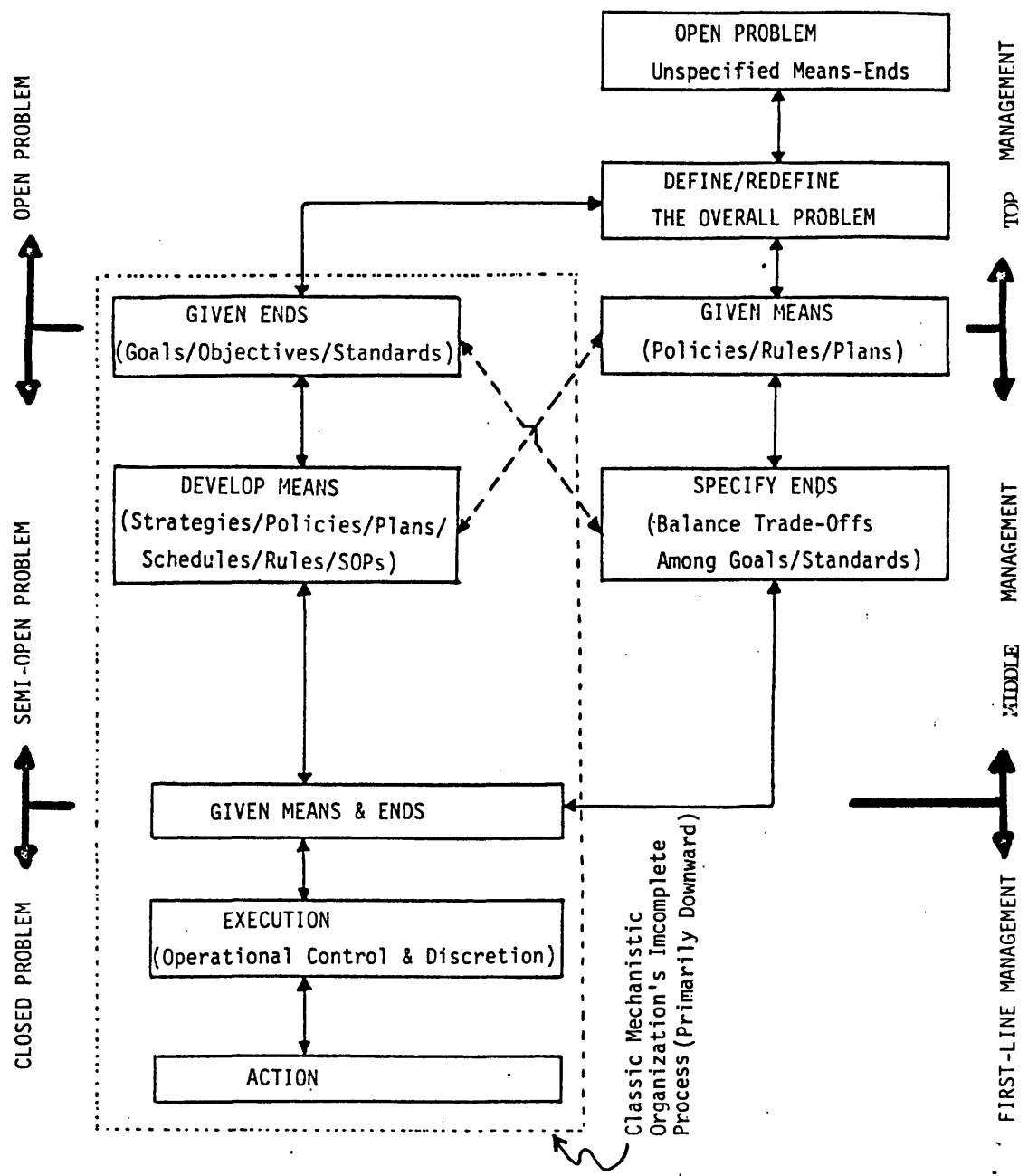
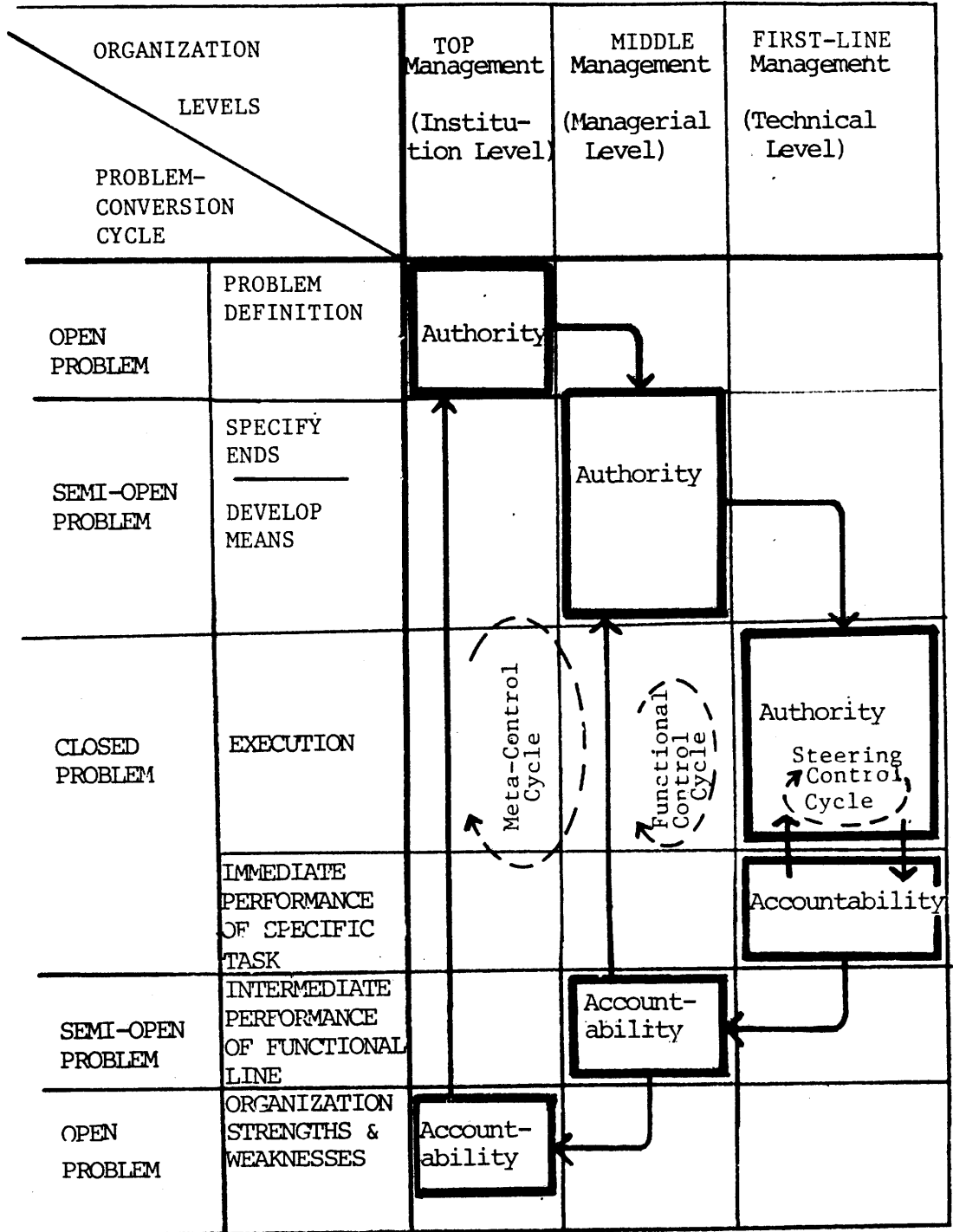


Exhibit 2-2-2 Meta-Control STRUCTURE



levels can be characterized by the relationships between the problem-conversion cycle and the three major organization levels (see Exhibit 2-2-2); and such relationships define the operational structure of an organization in managing a particular task. In this study, we call such a structure meta-control structure, which explicates the authority and accountability of all the involved organization units[*].

Briefly, the management of any particular task starts from the definition of the problem and development of planning premises, both of which are usually the responsibility of top management at the institutional level; then the problem is reduced to the planning phase: the middle management, based on the given premises, develops operating guidelines or action plans (schedules) for first line management at the technical level; and finally, first-line management executes the well-defined operating tasks, and based on immediate performance feedback, takes necessary corrective actions to assure the smooth operation of the controlled system. Moreover, over a certain period of time (e.g., a week, a month or a season), middle management may review the average performance of the controlled system and use the evaluation results as input for replanning of the responsible functional lines; while top management concerns itself with the performance of the system as a whole - in terms of overall competitive position, the relative strengths and weaknesses among various functional segments and so forth [Lorange, 1980, p.18]. These appraisals feedback and direct

[*] In this study, we define authority as the input or effort aspect roles of individual organization unit in accomplishing a specific task, while accountability concerns with the output or result aspect of individual roles.

the redefinition of the problem or the refinement of the total system (both the controlling system and the controlled system)[*].

Therefore, in a properly functioning organization at least three generic control cycles can be identified, which correspond exactly to the levels of control task hierarchy associated with the system to be controlled. To amplify, the first line manager is responsible for the steering control cycle which streamlines the physical operations. The middle management is responsible for the functional control cycle which guides the technical level's operations, provides necessary buffers to insulate the technical operations in a closed system, and exercises incremental adjustments within certain bounded limits imposed by the top level to enable the technical level operations to accommodate short-run fluctuations. The top management is responsible for the meta-control cycle which provides the ultimate buffer between the organization and the external environment and controls the systemic structure of the organization. It is the meta-control cycle which allows the organization to behave as an open (organic) system and to pursue effectiveness. In other words, the organization levels defined above are the most aggregated organization units which can be identified to be responsible for the performance of certain specific categories of work units in the underlying technological system.

*: In fact, the notion of the problem-conversion cycle is, by and large, compatible with and complementary to that of the classical management cycle, i.e., plan-execution-review cycle [section 2.1.3]. The problem-conversion notion underscores that an essential step in any updating of a present managerial practice is the re-examination of the planning premises - concerning problem definition and redefinition [Newman, 1975, p.113], while the management cycle notion highlights the cybernetic feature of the controlling mechanism - performance feedback is specified as a key information source for re-planning - which explicitly indicates that problem-conversion is a cyclic process.

2.2.2 Organizational Process - A Team Decision-Making Perspective

The conceptualization of the general function of an organization as a whole is a necessary step for diagnosing an organization's macroscopic controlling function. However, to gain more operational insights into the underlying causality of an organization's performance and to associate the work unit with the organization unit at more microscopic level, we should further probe into the group level's and individual level's behavior. In this section, we first focus on the group- (or team-) based organization decision-making processes.

A. Organizational Decision Environment

From the preceding section's discussion, it is clear that, even in a highly mechanistic organization, not all decisions are made at the top; decision authority is generally distributed throughout the organization [Simon, 1976, chapter 11]. More specifically, in an organization as complex as a transportation enterprise, decision-making is not an individualistic behavior but a process which usually involves more than one participant[*].

[*]: Most of the research on decision has mainly focused on single individual choice events, and is considered largely in isolation from the organizational environment. Conolly [1977] cited that "a similar isolation may be found in the literature on organizational communication. A ... review of the topic [Porter and Roberts, 1972] lists only one source (out of more than 150 references) in whose title the word 'decision' appears." The above assessment is generally agreed with the author's own observation. In other words, the decision-making process in a organizational context is currently a less than well-developed research subject.

The consequence of a decision to an individual decision-maker [*] depends upon both his own choice and the choices of others. Organizational relationships primarily grow out of the division of work and the delegation of responsibility and authority. The interdependence among the decision-makers in an organization stems from the interdependence of the underlying work units upon which the decision-makers exercise their controlling authority. Therefore, in an organization (such as a transportation enterprise) decision-making is characterized as a highly diffused process [Connolly, 1977, p.208] along various dimensions - multipersons, nontrivial physical distances, multi-organizational levels, and multi-time periods.

Interdependence of Decisions and Indirect Decision Makers

When taking a close look at the interrelations among the controlling decisions, one may find at least the following two categories of interactions [Neuberger and Duffy, 1976, p.57]:

1) Two decisions are interrelated in action, if a) the choice of a certain action in decision A eliminates the choice of some actions in decision B, or b) some action in decision A must occur for an act in decision B to be possible. The former type can commonly (but not only) be observed along the vertical line authority as a result of formal or informal regulation, while the latter one occurs commonly (but not only) along the horizontal dimension due to the sequential nature of work flow.

*: The term decision-maker here refers to individual person or a group of persons which can be viewed as a single unit to perform the decision making function of concern.

2) Two decisions are interrelated in consequences if the act chosen by one decision maker influences the consequences of another decision-maker's potential acts, either due to 1) the externality effect (e.g., line congestion), or 2) the built-in trade-offs (e.g, resource inventory cost and service quality), or 3) the effect of incentive systems (e.g., certain type of behavior is rewarded formally or informally).

From an individual decision perspective, the ultimate choice of a decision is not only determined by the decision-maker who directly makes the decision, but also influenced by some of indirect decision makers (along both horizontal and vertical dimensions of the organization hierarchy) who control the interdependent (upstream or downstream) activities or processes (e.g., the uncontrollables from the direct decision-maker's point of view) and the outcomes.

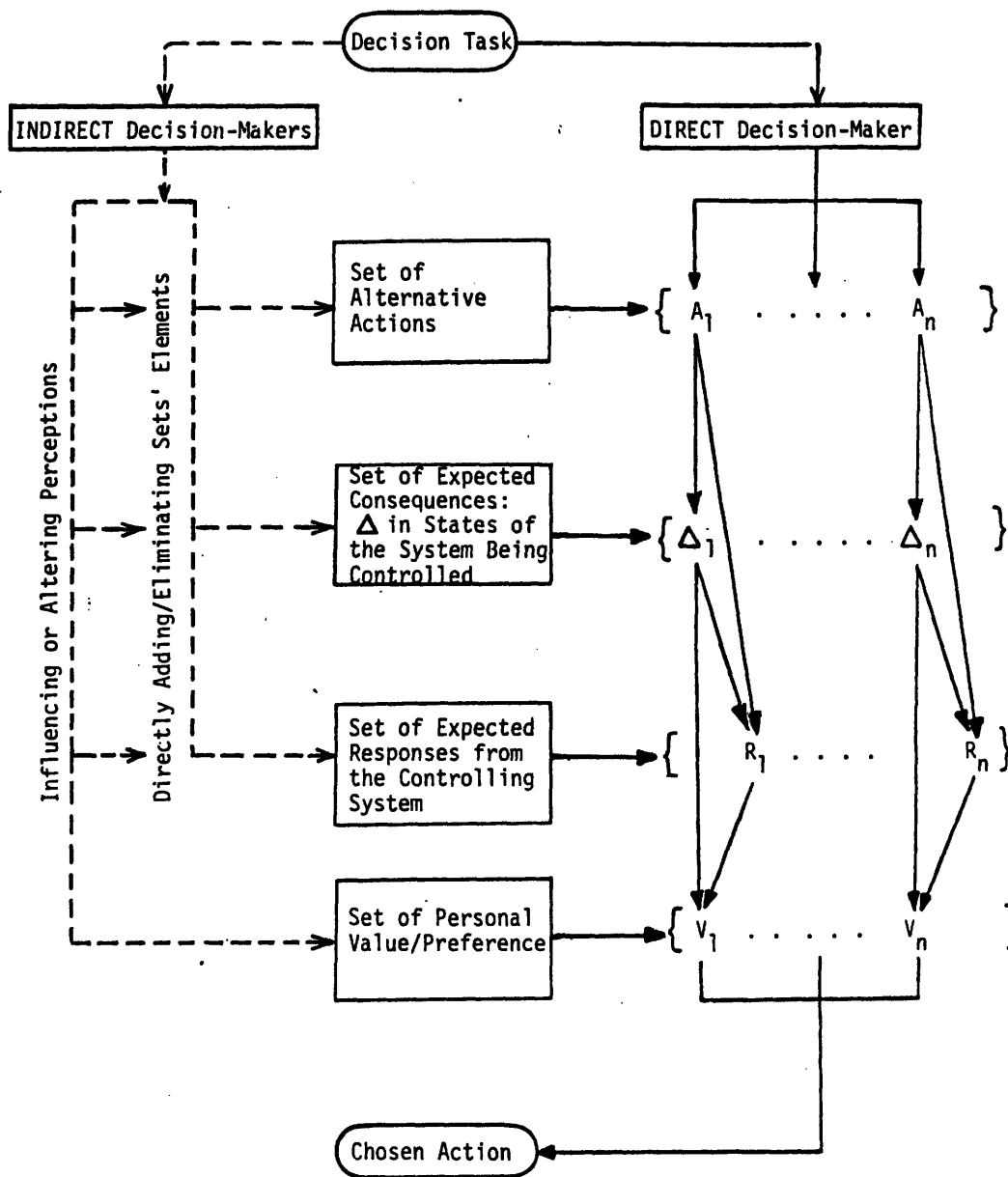
The interdependence upon other decisions and the existence of indirect decision-makers characterizes the decision environment of any organizational decision-making process. This decision environment constrains the search space of alternative solutions and manipulates the evaluation process as well as the choice behavior. Exhibit 2-2-3 illustrates such a notion.

B. Decision Base and Decision Net

The notion of decision environment summarizes the general features of organizational decision-making. Further insights can be obtained through the observation of 1) How a group of interrelated organization units are evoked to deal with a particular decision problem? and 2) What

Exhibit 2-2-3

DECISION-MAKING IN AN ORGANIZATIONAL CONTEXT*



* An integration of Decision-making Paradigm and the Expectancy Theory of Behavior.

is the actual process which leads to a final actionable decision?

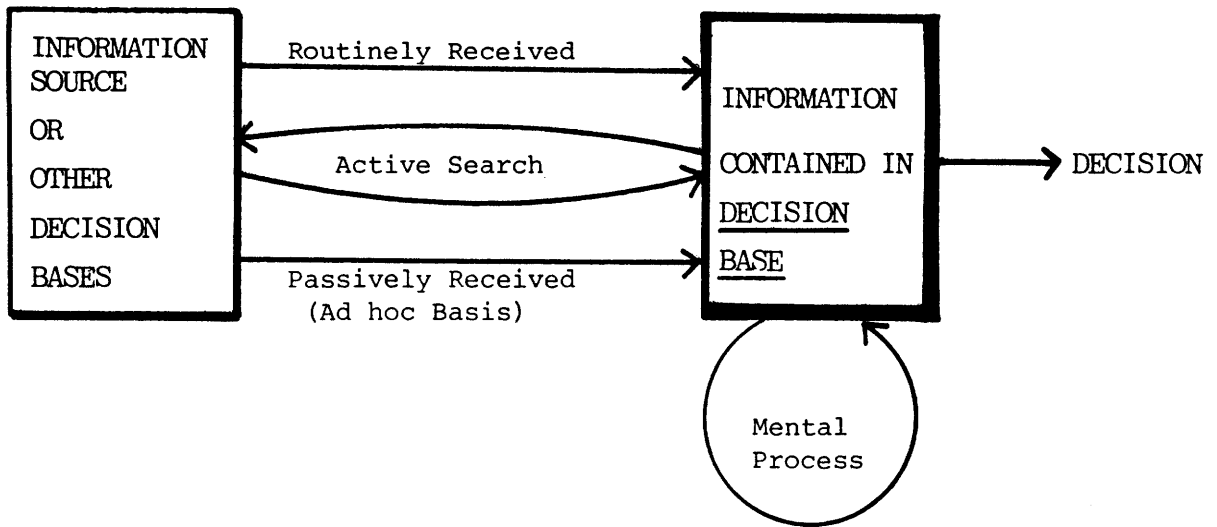
Decision Base

To answer the above two questions, we may start from the analysis of the information required by a decision unit (organizational unit evoked to play a decision maker role) in a decision process which is presented as the blocks lined-up vertically at the middle of Exhibit 2-2-3. In this study, we call this set of information the decision base: information required for making a decision including that related to goals, alternative actions and potential consequences of the actions. We argue that any decision unit in an organization must have a decision base of its own, and part of the information contained in the base is a result of organization design and is routinely received by the unit through formal information channels [Exhibit 2-2-4]. However, to accomplish a decision, the routinely received information is usually insufficient and more information must be furnished into the decision base of a decision unit. There are primarily two approaches to acquire the additional information needed in a decision. The first is through interpersonal communication, e.g., by way of decision-maker's active search via various communication channels (formal or informal), or his passive receipt of information from other initiative (or advocative) actors. The second is through decision-maker's intrapersonal mental process (operations of his decision heuristics) to generate the needed information. In other words, in an organizational context, a key to understanding the decision-making process is to focus on the input/output operations involved in the concerned decision bases. In the following, we shall further elaborate on the characters of the

Exhibit 2-2-4

INPUT/OUTPUT RELATIONS OF A DECISION BASE

- Indirect Decision-maker
 - Information Unit
 - Action Unit
- Communication Channel
- DIRECT DECISION MAKER



interpersonal approach, and leave the intrapersonal approach to the next section (2.2.3).

Decision Net: Participants and Role Set

An organization unit engaged in a team decision-making process can be distinguished by its role or contribution to the accomplishment of the decision task. Due to the functional departmentation, an organization unit may either have prescribed official task role(s) in a formal or well-structured decision net (e.g., train-dispatching process), or have variable roles in a less formal or unstructured decision net (e.g., ad hoc problem-solving meeting). In order to understand the task responsibility and performance accountability involved in the decision-net, in the analysis of task roles, we focus our attention on a) who initiates the process, b) who is being consulted, c) who is kept informed, d) who is authorized to make the choice, e) who supervises the process, and f) who implements the decision.

To accomplish a decision in an organizational context, a decision-net [*] that links the following units together can usually be identified:

- 1) direct decision-maker(s) - in case of collective decisions, the direct decision-maker could be more than one party,
- 2) indirect decision-makers - particularly the units which are either controlling the immediate upstream/downstream decisions (in terms of work flow) or performing an immediate supervisory function,

[*]: Connolly [1977, p.209] used a term "decision-specific communication net" to stress two roles involved in a net: decisional and informational. Other typology can be found in, for instance, Barker, et al [1979, p. 164], and Merrell [1981].

3) information units which provide information (due to the fact that they have access to certain information that forms in part the decision base of some decision units) but, in principle, perform no decision-making function, and

4) action units which perform the decision-taker's role and implement the decision when the outcome of the process is an actionable decision.

In short, the decision-net is a decision-specific team structure - embedded in the mutual-dependence of the underlying work units as well as the organization of the controlling system - which integrates several individual-based microscopic decision-making processes into a team-based macroscopic decision-making process.

Decison Net:Characters, Context and Integration Media

The nature of the decision net - in terms of the media which actually link the individual units into an integral net as well as the specific participants evoked in the macro-process - is basically characterized by the nature of the decision problem.

As mentioned in the previous section (2.2.1), the decision problems arising in an organization vary widely in nature, e.g., open problem, semi-open problem, and closed problem. The procedural strategy which is most appropriate for solving each of those problems also varies accordingly. For instance, for problems with a principal consensus on values (e.g., concerning the objectives, criteria, or outcome preference), the primary decision-making strategy either follows certain structured solution procedures (e.g., routine and repetitive tasks); or through professional judgement based on some prediction data (e.g.,

longer range factually uncertain planning tasks); while for the problem without agreement on the valuational premises, the solution must be reached through negotiation and compromise [Thompson and Tuden, 1959, Tuggle, 1978, p.78]. Another important dimension concerning the nature of a decision problem is the extent of time-pressure, i.e., whether it is a crisis problem awaiting an immediate response, or a routine operating problem able to be solved at a regular pace, or an opportunity exploring problem with no specific deadline [Brightman, 1982].

By and large, for the routine, repetitive operating problem, the participants involved in a decision-net are normally standardized, and formal information channels are developed as the integration media. Specifically, for real-time tasks, telephone calls (for geographically dispersed operations) and face-to-face conferences are essential, and usually the chronological sequence of the dialogue is also standardized. For daily routines, the morning report systems and daily operating conference could be effective [Eilon, 1968]. While for the crisis problem, conceivably the actors which are evoked in the decision-net depend on the decision issue encountered, and all available and most effective media (but not necessarily efficient, Galbraith, 1977, p. 3) will be employed in the communication process. As to the planning tasks or negotiation problems, the primary participants to perform the decision function are usually problem-specific, but the secondary participants - who act in a facilitative capacity, i.e., to gain or provide information, further technical expertise, or serve as a connector linking to other groups - could vary from time to time depending on the contingencies [Merrell, 1981, pp.297-302]. Effective

mechanisms for solving this category's problem (planning / negotiation) could be an interdisciplinary task force [Bass, 1975], collective bargaining meeting, etc. Finally, the opportunity-exploring type problems, in our opinion, basically refer to two kinds of tasks: the general R&D function, and the function of senior management's supporting staff who perform as a think-tank performing an off-line analysis function [section 2.1.3]. The decision-net for this type of problem is least-restricted, and the major media could be project reports, seminars, or result briefings.

C. Team Decision-Making Processes at Work

The utilization of the decision-net, from the individual decision maker's (individual person or group of persons) standpoint, is as a vehicle which facilitates its acquisition of information concerning uncontrollables; while from the organization controlling function's standpoint, the decision-net is an operational mechanism for achieving coordination among mutually-dependent decision units, because in principle through the functioning of the decision-net, each decision-maker can determine whether his intended action will enhance his contribution to the organizational goal, given the intended actions of other decision-makers. In practice, the process of coordination can be analyzed through two dimensions, i.e., 1) procedural - concerning the implementation of the process, and 2) substantive - concerning the rationale of the process. They are discussed in turn as follows.

Coordination: Role Influence

Simon [1976, p. 220] argued that "organizational behavior is a

complex network of decisional processes, all pointed toward their influence upon the behaviors of the operatives - those who do the actual ... work of the organization." March and Simon [1958, p.181] mentioned that a key effect of the group on the problem-solving process is the modification in the problem solution produced by direct social influence. Drucker [1977, chapter 30] pointed out that communication is subjective and perceptual, or more specifically, in the process of communication not only objective information is being transmitted, but also the contextual factors such as mutual perceptions between the communicating parties. Meyer [1978, p.44] summarized that interpersonal influence can be exerted through at least five strategies: persuasion, coercion, reward, personal authority (legitimate or referent), and expert power.

Emerging from the above arguments is the notion that the decision-making process embodied in a decision-specific communication net is in part a mutual influence process between the participants. Each task-role taker exerts, implicitly or explicitly, influence over others. This notion of role influence [Katz and Kuhn, 1978, Chapter 7; Barker, et al, 1979, p.166] is particularly important to the analysis of mutual intervention behavior across responsibility lines. To amplify, March and Simon [1958, p.179] pointed out that, if a decision-maker cannot find a feasible solution within the search space under his control, he tends to intervene in the uncontrollables so as to alter the solution' constraint set, the decision criteria, or to redefine the problem itself. In this kind of situations, the basis and strategies available to the decision unit in question through which he can exert influence on other actors in the decision-net become vital.

Coordination: Means Control and Ends Control

As to the rationale of the process which leads to the effect of coordination, there are at least two principal alternatives: one is to exercise influence to limit the feasible set of actions of the decision unit concerned; the other is to exercise influence to alter the consequences of certain given actions of the decision unit in concern [Neuberger and Duffy, 1976, p.26; Ouchi and Maguire, 1975; Miler, 1980, p.39]. The former can be called the means-control approach (relevant to those tasks interrelated in actions), while the latter can be called the ends-control approach (relevant to those tasks interrelated in consequences) [refer to Section 2.2.2A].

Means Control. To elaborate, the means-control approach requires the knowledge that reliably links the controlling activities to the controlled performance, because without such knowledge, means-control may fail to achieve the coordination goal. Operational practices in this category include, for instance, 1) general policies, or regulatory guidelines, 2) operating plans or schedules, 3) various standard operation procedures (SOPs), 4) on-line process monitoring, and 5) specific action orders [Miles, 1980, p.39; Hampton, et al, 1978, Chapter 9; Tuggle, 1978, p.42; Newman, 1975, p.6]. The allowable extent of discretion implied by the above means-control practices are different - ranging from relatively broad (e.g., policy guidelines) to virtually null (e.g., specific action order). A substantial amount of research and theory suggests that the performance of relatively routine tasks,

with relatively mechanistic technology, is facilitated by comprehensive means-control mechanisms that closely regulate the controlling behavior [Lawrence and Lorsch, 1967, Woodward, 1965, Perrow, 1970]. In a transportation controlling system, the means-control mechanisms are usually pervasive and comprehensive: higher level activities are generally coordinated through policy guidelines, operating plans and schedules, while lower level activities are closely coordinated through SOPs, on-line monitoring and direct action orders.

Ends Control. As to the ends-control approach, it includes at least two practical strategies: one is pre-action oriented, e.g., through the application of some motivational mechanisms that deliberately affect the intrinsic and extrinsic reward conditions of the person to be coordinated, so as to encourage him to pursue certain ends in common interest [Hampton, et al, p.539]; the other is post-action oriented, e.g., through the installation of cybernetic mechanisms that collect and feed back performance indices, so as to facilitate the self-correction of the unit to be coordinated in order to accomplish certain predetermined goals (which are represented in the same measures as the performance indices used). Formal goal-setting procedures, such as the MBO system, can be incorporated with this cybernetic mechanism, to ensure the goal acceptability as well as to inspire the motivation in achieving the goal [Tuggle, 1978, chapter 5]. In short, ends-control is most suitable to the situation where exceptions and unanticipated events are frequently encountered in the work process, or when a variety of means may be used to reach a desired end [Miles, 1980, p.40], or when creativity is critical to the success of the conduct.

D. Team-Support Systems - An Emerging Concept

The practical purpose of studying the organizational decision-making behavior is to improve the organization's controlling function. Emerging from the above discussion are two fundamental design issues: 1) how to better structure a task-team, and 2) how to enhance the process of coordination among the team members to improve the efficiency of the team decision process as well as the quality of the interdependent decisions as a whole.

The notion of decision base [Section 2.2.2B] gives us important clue to the issue, because conceptually the effect of communication can be measured by the difference between the information required and the information available (routinely received) in a decision-base. More specifically, the conceivable difference between the decision before communication and the decision after a specific stage of communication indicates the effect of communication. Given a decision task, to improve the efficiency of the decision process, one can 1) reduce the need for communication by increasing the information available (routinely received information) to the key decision unit to match the difference defined above, or 2) reduce the information required by re-arranging the relationships of the underlying work units to eliminate some of the above differences. By both tokens, the effective decision-net will become smaller due to the removal of certain information units or interdependent decision units in the net. However, the application of the first strategy - increasing the available

information in a unit's decision base - should be handled with care because it may involve the issue of information-overload (which is a subject of the next section 2.2.3).

The Design of Team Support Systems. The second strategy mentioned above is basically related to the design of decision net. More specifically, as discussed in the preceding sections, the performance of a decision net is a function of the following factors: 1) the organizational units included in the net and the task roles they played, 2) the nature of the integration media, 3) availability of mutual influence bases and influence strategies among the team members, and 4) the substance of information (means-related, ends-related, etc.) transmitted in the communication channels. The key to the design of a decision net is to match the performance of the net with the nature of the decision issue (e.g., routine or novel, operating or strategic, etc.). The systems with the capability to provide support for the above four factors so as to advance the coordination effect of a team-based decision-making process may be called team-support systems.

The structure of the lower level decision-nets is usually well-defined by the nature of the physical work, and the need to operate such decision-nets is usually well acknowledged. The issue left to this class of team-support systems is the efficiency of the communication media as well as the effectiveness of the interfunctional influence bases and strategies. However, for high level control tasks, the task per se is usually not well-defined; in consequence, the structure or even the existence of the corresponding decision-net may become highly

questionable, not to mention the decision-net-specific communication mechanism. Therefore, in the analysis of the high level control tasks, the real challenge is how to identify the control tasks (work units) in the first place, and how to specify the decision-making process as well as the underlying decision-net. Only after these two problems have been clarified can we then proceed to deal with issues concerning team-support systems: the analysis of the participants and their role sets, the associated communication media, the involved influence basis, and the information contents to be transmitted.

In conclusion, organizational process, to some extent, can be characterized by the team-based decision process which is composed of, but distinct from, the individual decision process. In a paper discussing the research perspective of the decision support system, Keen [1980, p.6] pointed out that compared with the personal support system, the group and organizational support systems "require a very different theoretical base which is so far lacking". This study, in part, represents an endeavor in this direction. In this section, we have analyzed the nature of organization decision-making process - in terms of its underlying rationale (the notion of decision base), its structure (decision-net, task roles), its function (mechanism and process of coordination and communication) - as well as synthesize various notions into a single construct, namely, the team-support systems, which may serve as an integral conceptual framework to guide the diagnosis and design of organizational decision-making processes. In Chapter 3, we shall further discuss some operational techniques which can be used, in association with the framework proposed above, to acquire specific data for the diagnosis and design of team-based decision support systems.

2.2.3 Individual Decision-Making

An individual person is an organization's fundamental unit for making decisions and exercising control over the performance of the organization. Therefore, an essential element in the diagnosis of the controlling function of an organization is to understand the individual decision-making behavior. Because our interest in studying individual decision behavior is with pragmatic aim of improving performance, the approach we take is to consider individual manager as a human information processor and to identify his strengths and weaknesses through the analysis of the cognitive process involved in his decision-making behavior. The eventual goal is to specify the principles necessary to the design of individual-based decision-aid systems for various decision issues and contexts.

A. Human Information Processing Systems

The notion of human information processor [Newell and Simon, 1972; Lindsay and Norman, 1977; Mayer, 1981] assumes that all humans come equipped with the same basic information processing systems. Based on Mayer's synthesis [1981, p.24], the main components of the human information processing systems (HIPS) include (as shown in Exhibit 2-2-5):

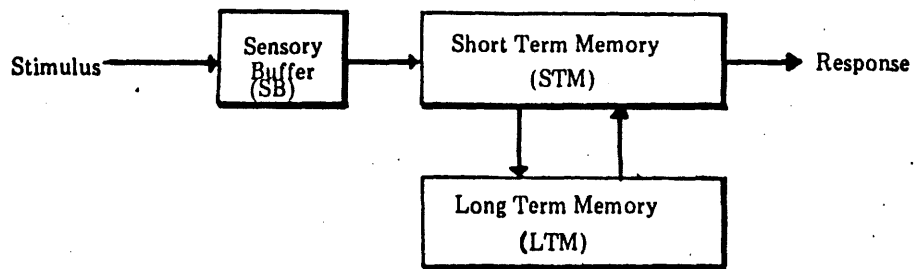
Sensor Buffer (SB). Information coming from the outside world impinges on our sense receptors and is first held (but fades very rapidly) in its raw physical form in a sensory buffer.

Short-term Memory (STM). This component may convert the raw sensory information into another modality (e.g., visually presented letters into sound, etc.). The holding capacity of STM is limited to about seven items. Items are lost from STM when they are bumped out by new incoming items (overloading) or when they are not actively rehearsed. STM can be thought of as conscious memory - it

Exhibit 2-2-5

HUMAN INFORMATION PROCESSING SYSTEMS

(Source: Mayer, 1981)



SB	STM	LTM
Capacity: Large	Capacity: Limited to About 7 Chunks	Capacity: Unlimited
Mode: Exact & Sensory	Mode: Echo	Mode: Organized & Meaningful
Duration: Brief	Duration: Temporary	Duration: Permanent
Loss: Time Decay	Loss: Displacement or Failure to Rehearse	Loss: Retrieval Failure or Interference

holds all that a person can be aware of at one time - and as a scratch pad on which we perform mental operations such as mental arithmetic.

Long-term Memory (LTM). If information is held in short-term memory, there are encoding processes that allow it to be transferred to long-term memory. LTM is practically unlimited in capacity, and does not fade with time. However, items may be lost because new information blocks the routes for retrieval of information from LTM. LTM can be thought of as an organized storehouse of information, in which each item must be found by following a search path.

Our interest is concentrated on the last two components: LTM and STM. In an analogy to the three-component machine information processing system - memory, processing unit and input/out device - the function of the STM is very much like the working storage space of the processing unit, while the LTM is the main memory component [Newell and Simon, 1972, p.808].

Limited Short-Term Memory

The practical implications associated with the notion of limited human short-term memory are primarily twofold. One is concerning with the principle of bounded rationality [Simon, 1955], the other is relating to the notion of information overload [Miller, 1956; Miller, 1960; Driver and Streufert, 1969].

Bounded Rationality. The principle of bounded rationality suggests that human is organisms of limited cognitive and computational capacity (basically referring to the nature of STM). In response to these limitations, simplification (heuristics) is deliberately introduced into the human search and choice mechanisms. To amplify, due to the restriction imposed by the capacity of short-term memory, we cannot generate all the admissible alternatives of a decision problem and compare their relative merits within practical computational limits; and

because we cannot see all of the potential choices, there is no way for us to recognize the best alternative. In effect, optimizing is replaced by satisficing - we satisfice by looking for alternatives in such a way that an acceptable solution can generally be found after moderate search effort [*].

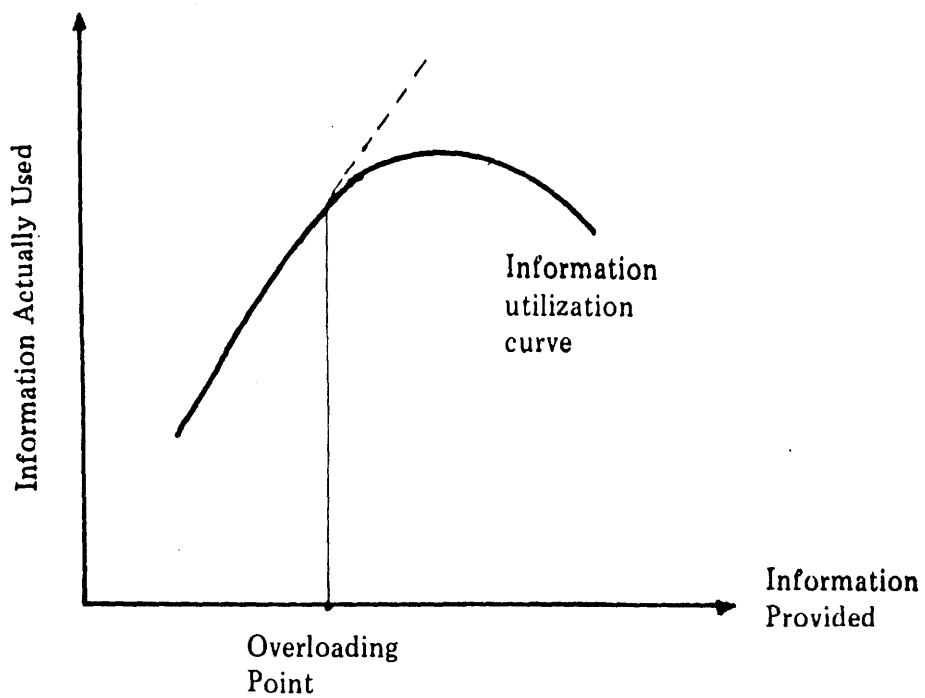
Information Overload. George Miller [1956] pointed out that the amount of information which a human can hold in short-term memory and process effectively has a common limit of seven chunks. James Miller [1960] indicated that, in case of overload of information input, many forms of dysfunctional behavior may occur, such as 1) omission - failing to process some of the information whose inputs are difficult to process but are really critical, 2) error - processing information incorrectly due to misinterpretation and inappropriate selective perception, 3) queuing or delaying the processing of information to ease the operation of the individual receiver, or 4) escaping from the task. Driver and Streufert [1969] observed that the relationship between the amount of information input and the amount of information actually used is an inverse U shape curve, i.e., beyond some maximum load point, the more information is received by the decision-maker, the less information is actually used in the decision [Exhibit 2-2-6]. Moreover, in an overloading condition, decision-makers will usually use not only

[*]: M. L. Manheim [1966] argued that "optimal process" is not equal to optimal action.

Exhibit 2-2-6

INFORMATION OVERLOAD PHENOMENON

(Source: Driver & Streufert, 1969)



less information, but will also lose their normal decision speed. Ironically, Driver and Mock [1975, p. 492] cited that "users invariably prefer more data even past the point of maximum level of information processing and conceptual abstract. Thus users' capacity and preference for information do not seem to coincide." Simon [1973, p.270] concluded that, in an information-rich environment, "the scarce resource is not information; it is processing capacity to attend to information."

Strategies to Break Through the Bottleneck. To summarize, we should nevertheless clarify a point: The notions of bounded rationality and satisficing behavior do not negate the desire to pursue a higher level of quality in human decision; nor does the notion of information overload preclude the possibility of using more complete information in a given decision so as to improve its quality. The key question is: Do we have any effective strategy to break through the bottleneck of human information-processing imposed by the limited capacity of human cognition? Fortunately, the answer is yes. There are at least three strategies which can overcome the limits: 1) use of organized human information-processing capacity through deliberate organization design to breakthrough the individual limitation 2) exploitation of the capacity and flexibility of human long-term memory, and 3) utilization of external aids [Lindsay and Norman, 1977]. The first strategy has been discussed in preceding sections [Sections 2.2.1 and 2.2.2]. The second and the third strategies will be elaborated on in the rest of this section.

Long-Term Memory: Structure and Function

Although there is an overload point of information input in the human decision process, the amount of information actually used in a given decision differs from individual to individual [Driver and Streufert, 1969; Driver and Mock, 1975; Libby, 1981]. More specifically, if seven chunks [Miller, 1956] are the maximum amount of information which can be accommodated by human STM, then the detailed contents (e.g., in terms of the most fundamental information unit - bite) in each chunk are different from person to person, i.e., some individuals can use the limited STM more skillfully and efficiently than others do. A key factor which causes the above difference is the degree of sophistication of human LTM with respect to the decision problem in question; in other words, this is the occasion where experience and knowledge come into play [Libby, 1981, chapter 4]. Two notions are essential to the understanding of the function and the role of LTM in the human cognitive process: one concerns with the theory of knowledge structure, and the other the process of cognition.

Knowledge Representation Frame. Minsky [1974] proposed a frame theory for the representation of knowledge, or more specifically, for the conceptualization of the general structure of LTM and its function in human cognition process. He suggested:

"When one encounters a new situation ..., one selects from memory a structure called a frame. A frame is a data-structure for representing a stereotyped situation ... [A]ttached to each frame are several kinds of information. Some of this information is about how to use the frame. Some is about what one can expect to happen next. Some is about what to do if these expectations are not confirmed." [see Winston, 1977, p.180]

Simon [1981, p.104] reinterpreted the same concept as follows:

"We can think of the memory as a large encyclopedia or library, the information stored by topics (nodes), liberally cross-referenced (association links), and with an elaborate index (recognition capability) that gives a direct access through multiple entries to the topics."

The practical utility of the frame theory is that it sheds light on the mental process of an expert, e.g., an experienced manager. Our interest is concerning with how he integrates his substantive knowledge with a few general procedures to move the decision process from the search for symptoms to the choice of alternative courses of action [Simon, 1981, p.110; Miller, 1975, p.64]. To elaborate this point, we can put the general knowledge-oriented frame theory into a managerial context to examine an experienced manager's decision-specific cognitive process, i.e., his decision heuristics.

Cognition Process. In this study, we conceive of decision heuristics as a decision-maker's pattern of organizing information contained in his decision base [Section 2.2.2B] and his process of transforming this information into a decision. Given the notion of the knowledge representation frame, we are allowed to investigate the intermediate stages of the decision process. Experiments in many different disciplinary areas [Gorry, 1967; Simon, 1981; Libby, 1981] suggest that the hypothesis-driven information search is a key characteristic of expert cognitive process. Based on Libby's synthesis [1981, Chapter 4], the decision strategy of an expert usually bears the following general characteristics:

- 1) He initiates the information search activities based on some standard lists of questions which lead to the development

of a general overall picture of the problem.

2) Through training and experience, he has developed a large complex associative memory (a well-developed frame of substance-specific knowledge) which relates symptoms and evidences (e.g., concerning sufficient or necessary conditions) to prototype problems - these relationship may take the form of models of causality between events and consequences.

3) A small number (usually less than seven) of hypothetical solutions - which most correspond to the prototypes formed during the standard "work-up" - are retrieved from memory.

4) These hypothetical solutions drive further information search which is aimed primarily at supporting and modifying the more likely applicable solution and eliminating the less likely ones. Such a hypothesis-directed search and adjustment process will continue until a satisfactory solution is reached.

In short, an expert's decision heuristics make complex tasks cognitively tractable; more specifically, well-developed decision heuristics enable the decision maker to reduce the information input as the decision process proceeds as well as to restrict the information seeking to promising areas. Both are essential characteristics of efficient decision-making, because they utilize the limited STM more productively and cope with the problem of information overload more effectively. Inexperienced persons are normally unable to organize the wide-ranging information into a coherent data structure, e.g., in terms of predetermined prototypes, and are usually forced to chunk the information into small portions which quickly lead to information overload and consequently, in most cases, yield poor quality decisions.

Technically speaking, for a given information-processing task (e.g., a decision), there is never a fixed rule as to what information must be stored within the memory and what actions must be performed by the processor. In general, there is a trade-off between 1) doing a lot

of processing and requiring little information to be stored within the memory, and 2) doing little processing but requiring a lot of information to be stored within the memory [Lindsay and Norman, 1977, p.595]. The application of the standard check list, prototypes and outstanding hypothetical solution set in an expert's decision process represents a strategy that uses the retrieval of processed or semi-processed information from the well-developed knowledge frame of LTM so as to save the otherwise demanded on-line processing effort as well as the huge working storage space (in the STM) associated with the processing unit in human mind. In this regard, Simon [1981, p.105] has made a comment on experienced intuition. He argued that most intuitive leaps are acts of recognition - when a familiar pattern is encountered, the expert recognizes not only the situation which he is in, but also the action which might be appropriate for dealing with it, because according to Simon's hypothesis, the information associated with familiar patterns (prototype problems) may include knowledge about what to do about them (stereotype solutions). In summary, the hypothesis-driven behavior exhibited in expert's problem-solving process is a strategy of applying semi-processed information stored in LTM so as to save the real-time information-processing effort.

The Limits of the Expert Decision Heuristics

However, an expert's decision heuristics are by no means trouble-free. One basic principle underlying an expert's heuristics is the retrieval of relevant patterns (prototype problems and the corresponding solutions) he encounters in a decision event. A conceivable problem is concerning the perceived availability of relevant patterns. Many studies [summarized in Slovic, 1982, p.162] indicate that intelligent individuals tend to overestimate the likelihood of the occurrence of imaginable and memorable events; in effect, many novel events may easily be perceived invalidly. Therefore, there is normally a systematic bias associated with a decision maker's perception of availability of prototypes and outstanding solutions for the decision task he is handling. This availability bias could yield retrieval failure which results in a wrong diagnosis of a situation and consequently an irrelevant solution to the problem. Conceivably, high level, innovative-in-nature, ill-structured strategic problems are particularly vulnerable to this type of bias.

Furthermore, after the retrieval of the relevant pattern (assuming it is valid to the situation encountered), the search for a final solution is started from the set of hypothetical solutions anchored to the retrieved pattern, and this anchor is then adjusted to accommodate the implications of additional information. According to many studies [summarized in Slovic, 1982, p.163 and Libby, 1981, pp.65-68], there is typically a tendency for insufficient adjustments, given the decision-maker's state of knowledge; in effect, an anchoring bias occurs. Practical implications of this type of bias are 1)

decision-makers usually exhibits regressional behavior [Bowman, 1963] regarding a given category of decision task, therefore systematic bias may be associated with each individual's decision in that particular category, i.e., constantly overresponse or underresponse as compared with a certain norm, and 2) it is possible that decision rules (including both solution's design specifications and consequence's evaluation criteria) applied by the decision-makers are inflexible to the contingencies of the individual decision task.

In conclusion, long-term memory is an effective resort for breaking through the limitation of human information processing capacity restricted by the capacity of short-term memory. Experienced decision heuristics, which are characterized by hypothesis-driven information search and utilization of semi-processed information, are valuable assets in solving problems. However, to attack a complex decision problem, the human information-processing systems alone - even equipped with experienced or educated decision heuristics - may still suffer from various rationality bounds, e.g., the availability bias and anchoring bias as mentioned before. And in many decision instances, although trained heuristics could reduce HIPS' work load significantly, the remaining information processing requirements, e.g., complicated computations pertaining to a rational intelligence, design or choice behavior - may still be too much a burden to be handled as a mental process. Therefore, to further breakthrough the rationality bound, in the domain of individual decision-making, one effective (but may be not the last) resort is the external aids to the human information-processing systems [Bailey, 1982].

B. External Decision Aid Systems

Following the notion of decision base [Section 2.2.2B], to reach a decision for any given task, the decision-maker should bridge the gap between the information requirement [*] and information available. To do so, he can request more needed information 1) outwardly from other persons, and/or 2) inwardly through the transformation of the information available in his own decision base with or without external information-processing aids. The approaches concerning the outward-oriented process and the inward-oriented process without external aids have already been discussed in the foregoing Sections (2.2.2 and 2.2.3A), respectively. In the following section we shall examine what external decision-aid systems can specifically do to support a human to accomplish a decision task.

External aids to the human information-processing systems range widely from simple tools such as the paper-and-pencil to a highly sophisticated machine such as a general or special purpose digital computer. In the following section, our interest is focused on how to integrate the power of modern computer-based information technology with the strengths of human heuristics to enhance the individual decision-maker's capability and to advance decision quality.

[*] Many studies, e.g., those summarized in Ungson, et al, [1981], suggest that human heuristics are specific to the task or problem encountered. For instance, the less understood the problem is, the more speculative and wide ranging is the search for clues that might have some relevance to the problem; while the more the problem is understood, the more selective is the information search. In other words, the perceived information requirement varies with the nature of the decision task.

Types of the Computer-based Information Systems

A computer-based decision-aid system represents a concept of the role of computer within the decision-making process [Keen, 1980, p.1]. To define the share of role a computer can play in a man-machine collaborated decision process, Mason [1969] suggested a typology. He first identified five key elements of a total information processing system: source, data, prediction and inference, value and choice, and action, then according to the inclusion or exclusion of the above five elements, he defined four distinct types of computerized information systems [Exhibit 2-2-7] as well as their corresponding application arena:

- 1) Databank: for ill-defined open problems
- 2) Predictive System: for problems with known causation but lack of preference consensus
- 3) Decision-Making System: for routine, closed problems but with wide-range variable operating contingencies
- 4) Decision-Taking System: for routine, standardized problems with stable operating environment

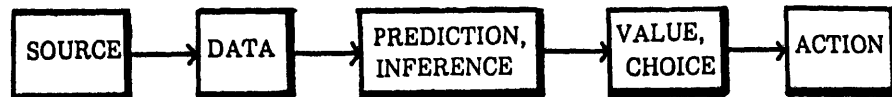
Although Mason failed to include one essential element of the decision process - the alternative search or solution design phase, his typology does shed light on two critical issues. First, it indicates the need to recognize the limits of the computer role in various decision contexts. These limitations stem primarily from the inherent nature of computer operations: it cannot tolerate any ambiguity in its operating instructions nor any unspecified premises needed by the subsequent operations; therefore, in a decision process, for those phases which are characterized by insufficient knowledge or controversial preferences (or both), the human role is indispensable for carrying through the process

Exhibit 2-2-7

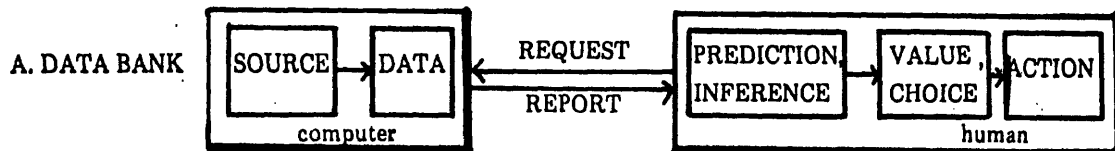
COMPUTER ROLES AND MANAGEMENT DECISION CONTEXTS

(Source: Mason, 1969)

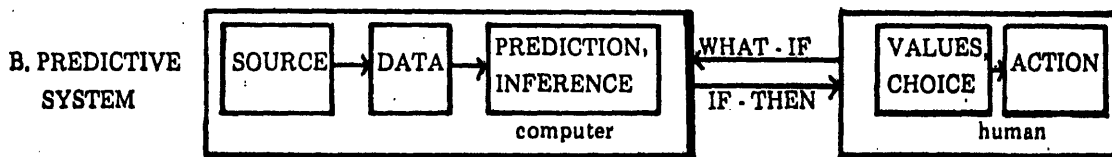
1) Information Processing Systems' Design Elements:



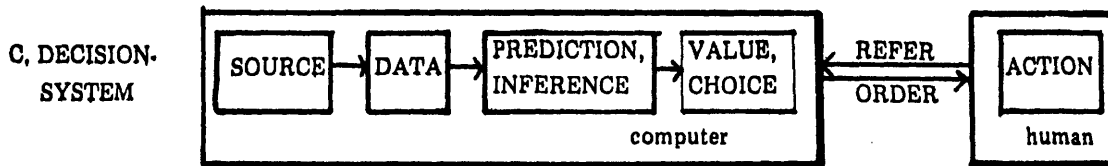
2) Alternative Designs:



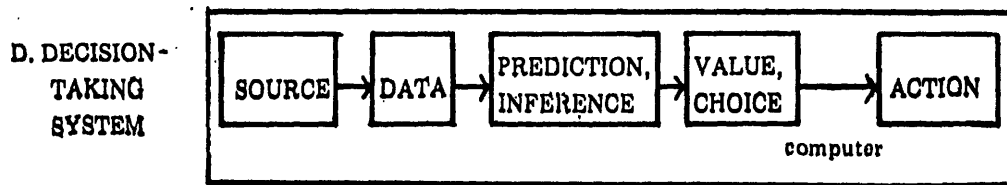
Decision Context: Ill-defined Open Problems, Strategic Decisions, ...



Decision Context: Factually Certain but Valuationally Uncertain Problems



Decision Context: Routine, Standardized Jobs with Variable Operating Contingencies



Decision Context: Standardized Jobs with Stable Operating Environment

[*]. Second, it implies that a different type of decision has its intrinsically different information-processing requirements and consequently demands a different type of information-processing system (i.e., different share on the roles of computer and human). In other words, no single type computer-based information system can satisfy the information processing requirements for the decision tasks at all organization levels, because, as argued in Section 2.2.1, each organization level is taking care of qualitatively different decision tasks.

Decision Support Systems

Specific Utilities of Computer. Mason's typology is useful to differentiate the roles of human and computer in accordance with their relative strengths and weaknesses in various decision contexts. As to the specific function the the computer should perform in computer-based decision-aid systems - i.e., decision support systems (DSS) - Sprague and Carison [1982, Chapter 4] summarize the following four user-oriented utilities :

[*]: Along a similar line of thought, Keen and Morton [1978, Chapter 4] argue that the tasks that need to be supported by computer-based decision-aid systems are those "semi-structured" in nature. By semi-structured tasks, they mean those decisions which are ill-structured in solution procedures as well as those which are structured in procedures but with a difficult to manage context [p.94]. However, in this study we consider the terms "structured" and "semi-stucutred" confusion and observe that, even for a task with structured procedures as well as with managible context, external decision support is sometimes still needed - not only due to the volume of information to be processed but also the variable and uncertain information contents. Exploring, testing and probing are indispensible activities to such a decision task. Therefore, we tend to define the role of computer played in a man-machine collaborated decision system directly by the underlying characteristics of the decision task to be supported rather than the notion of "problem structure".

1) Representation: the provision of contexts to facilitate the conceptualization of the information available and the communication of the emerging ideas, problems or proposals as well as to invoke or stimulate further search action.

2) Memory aids: the provision of a) an indexed database of internal or external information sources, b) working storage for saving the information in process, and c) linking function for cross-reference of various working storage and databases.

3) Operations (analysis and information manipulation): the processes concerning intelligence (diagnose and define the problem), design (specify ends and develop means) and choice (predict consequences and determine preferences).

4) Control Mechanism (of the decision aid systems): the mechanism allows the user to dictate the operating and interaction of the above three capabilities of decision support systems to fit his own decision need, such as style, skills and knowledge.

Conceivably, the emphasis of these utilities in a system will differ according to the nature of the decision task to be supported by the system. For instance, for systems designed to aid the resolution of ill-defined problems, the memory and representation functions would be the two most important utilities, which allow the decision-maker to be exposed to a wide-range of sources of information in various forms and combinations, so as to stimulate his imagination, bring forth ideas and help him gain insights into the problem. For systems installed to aid well-defined routine tasks, all utility components can be designed as task-specific, e.g., the control mechanism should be geared exactly to the decision-maker's grand heuristics, the analysis and information manipulation component should be the core of the system to efficiently enhance the task-specific search-and-choice process of human mind, and the representation and memory aid components should be tailored primarily to facilitate and support the core search-and-choice process.

As to the semi-open problem [Section 2.2.1C], the decision-aid systems should be equipped with powerful representation and operation (analysis and manipulation) components to facilitate communication among concerned organizational units and to provide efficient analytical feedback for further discussion and refinement of decisions.

Components of Decision Support Systems. The technological components - required to support the representation, memory, operations, and control functions - of decision support systems, according to Montgomery and Urban [1969] and Sprague and Carlson [1982], can be categorized into the following three parts.

1) Data Base and Data Base Management Systems: A set of data (historical, user generated, or model generated) relevant to the decision task; and a battery of computer programs used to a) create, maintain, access and update the data base, b) subset, combine and aggregate data, c) support the memory requirements regarding the operations of the system.

2) Model Base and Model Base Management Systems: A collection of modelling subroutines (cut-and-dried, ad hoc, user-built, operational / tactical / strategic modles, etc.); and a calling mechanism for invoking the model base which allows the user to develop a solution process composed of a sequence of primitive modles (modules).

3) Dialog Interface and Dialog Management Systems: A system of representation and control mechanisms which enables the user to communicate with data and model and supports the

interactive modeling by which decision maker analytically explore, test, and probe the nature of a problem and its solution; and systems which are able to generate and modify the dialog interface.

Ideally, the dialog component should be designed operationally flexible to support a variety of hypothesis-directed search processes involved in and facilitate the preparation of standard lists of questions for various decision environments. The model component should enable the user to formulate and test hypothetical solutions efficiently, to interrupt the modelling operations to examine the intermediate results of the computer operations, run model segments in a variety of sequences to suit the nature of the decision problem, and change parameters (factual and valuational) to accommodate subjective judgement as the user's perception about the problem changes. The data base should be designed in accordance with the notion of decision-base, and its management systems should enable the user to examine and manipulate conveniently both information contained in the decision base so as to link symptoms and evidences to prototype problems or to gain new insights into the relationships among data through data formating and display operations.

C. Integrating Human Information Processing Systems with Computer

Decision support systems are computer based external aids to the human information processing systems (HIPS). The foregoing discussion indicates that DSS may support HIPS in a decision making process in following ways: 1) augmenting the limited capacity of the human STM (mainly through the computer's memory aids, operations and representation capacities), 2) enhancing the utilization of LTM and supporting the intermediate stages of a decision process (mainly through the representation, control and operations capacities of computer), 3) saving human effort in the mechanical calculation and representation activities (e.g., graphing) and allowing the decision-maker to manipulate both processes (calculation and representation) more accurately and efficiently (through computer's operations, representation and control capacities), as well as 4) indexing and cross-relating the information both in-process and in-memory more systematically and precisely (through the memory aids capacities).

The above four major functions collectively enable decision-maker to be released, to a large extent, from the original bound of human decision rationality, and allow him to 1) have more time spending on the creative part of decision process - exploring more alternatives, 2) consider more subtle interactions and trade-offs among alternatives and consequences, and 3) cumulate the understanding of fragments of a whole problem by embedding these fragments in a more comprehensive and better structured conceptual frame.

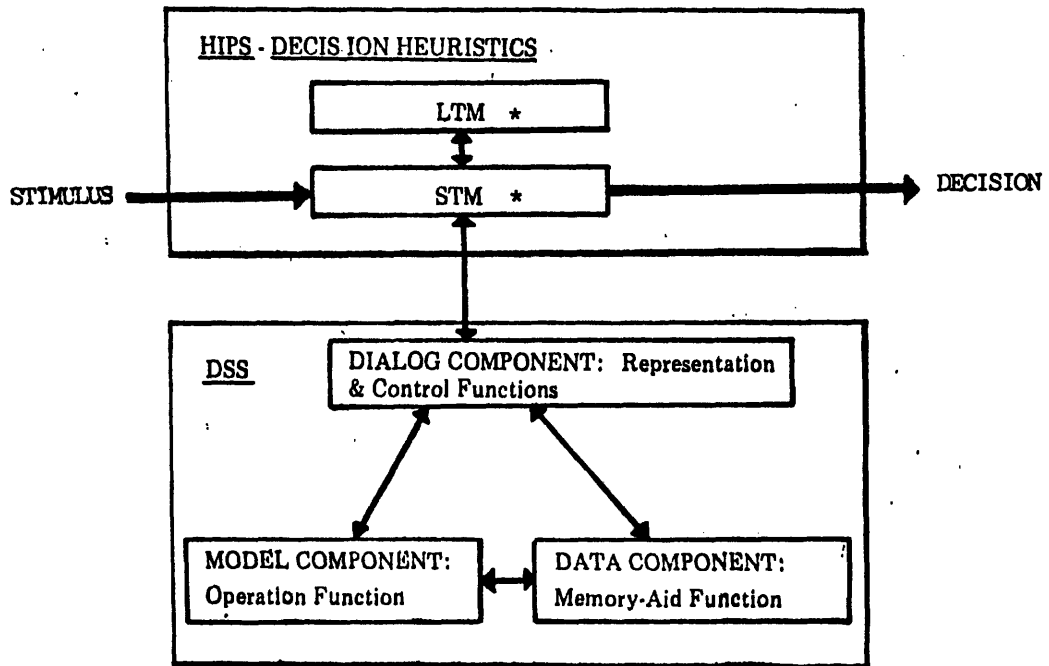
To effectively integrate the power of computer technology with the strengths of human mind to match different information processing needs

involved in various decision contexts, the design of DSS must begin with an analysis of the decision-maker and of the decision-making process that the DSS is to support. Ideally, DSS should also be designed to avoid or minimize the potential bias of human heuristics (e.g., the availability bias and anchoring bias) through the functioning of certain built-in bias detection (prevention) elements which are able to flag pitfalls for the decision-maker during the decision-making process. For instance, if a first-line manager is diagnosed as having a tendency to overlook a particular consequence in his decision (e.g., work-in-process inventory cost), then higher level management may refine the choice module (which supports the evaluation of solution's consequences) of the first-line manager's DSS which will highlight automatically the performance indicators of that overlooked area. As a result, the first-line manager is forced to consider the usually neglected consequences in such a the computer supported decision-making environment and the quality of the resultant decision is hopefully to be improved.

In conclusion, decisions can only be as good as 1) the quality of information on which decisions are based, and 2) the quality of the decision heuristics applied in the decision-making process. The function of decision support systems is to enhance the capability of the human information-processing systems so as to improve the quality of the above two determinants as well as ultimately the quality of decisions in a variety of decision contexts [Exhibit 2-2-8].

Exhibit 2-2-8

DECISION SUPPORT SYSTEMS AND MAN-MACHINE DECISION SYSTEMS



* LTM: Long-term Memory
STM: Short-term Memory

2.3 Summary of Chapter 2

The purpose of this chapter is to conceptualize both the controlling system and the system being controlled to provide us with the needed substantive knowledge frame for the diagnosis as well as the subsequent presentation of the performance of transportation systems.

Following the dual-system notion and the organization intervention framework, a key function of the theory of the system being controlled is to define a set of control objects which, on the one hand, characterize the underlying technological nature of the controlled system; on the other hand, can be explicitly assigned - in terms of decision responsibilities and performance accountabilities - to some identifiable organization units of the controlling system. These organization units comprise of individual persons or groups of persons which have or should have the capacity to control the performance of the control objects. In this study such control objects are called work units. In other words, in the conduct of transportation performance diagnosis, the work units and the organization units as well as their relationships (both between the two sets of units and within the same set of units) are our focal points.

2.3.1 The System being Controlled

The delivery of transportation service relies primarily on the cycling of a number of resources (e.g., vehicles and crew) on some supporting facilities (e.g., guideways and terminals). This notion of resource cycling can be further elaborated into a series of concepts which will eventually allow us to specify the work units, as well as their interrelationships and managerial implications.

Resource Cycle, Core Operations and Interface Buffer. A transportation

operating system is primarily structured in accordance with the flows of work, in which any operation can be performed only after a successful execution of some upstream operations. More specifically, because there are natural orders of operations, which are dictated by the nature of the technology adopted by a transportation operating system, the resource cycles (which embody the flows of work) can usually be systematically fragmented into distinct status or time phases. Furthermore, these status or time phases can normally be related either directly to the activities which are essential to the delivery of transportation service, or to a function of which the primary purpose is to provide a smooth connection between two interrelated activities. In this study, the former set of activities is called core operations, and the latter one is called interface buffers. Thus, from operations management perspective, most transportation processes can be thought of as the transition of various phases of resource cycles which consist of core operations and interface buffers. The notion of resource cycle possesses the following features:

- 1) The resource cycle can be specified in varying degrees of detail; however, their fundamental elements are either core operation or operational buffer, or some collection of the above two elements.
- 2) The interdependence of the cycle componets derived from a resource cycle can be specified through the analysis of the underlying cycling process.
- 3) Different componets involved in a resource cycle demand different analytical methods and measures for assessing the process, and different management skill and talent are required accordingly.

4) Issues concerning other resources can be addressed by adding appropriate components to the original resource frame so as to broaden the analysis scope if needed.

The resource cycle framework highlights the cyclic nature of transportation work flows and the systemic mutual-dependence among various core operations and operational buffers. Such a framework provides not only the analysis with perspective, but also effective heuristics in deriving the hierarchy of performance areas along a particular resource dimension as well as the control issues concerning other interacting resources cycles.

Work Unit. To translate the resource cycle components into work units, we introduce a new term - management cycle, which is comprised of three distinctive but interrelated phases of activities - planning, execution and performance review. We argue that the control of individual resource cycle component involves all three phases of the management cycle. Therefore, to specify the work units involved in the management of a selected resource, we can construct a work unit matrix with resource cycle as the vertical axis and management cycle as the horizontal axis. The entries of the matrix represent the elementary work units which collectively define the totality of the tasks to be controlled concerning a particular resource.

The notion of work unit possesses the following characters: 1) The elementary work units thus specified may vary in their degree of detail, depending on how detail we fragment the resource cycle; 2) Depending on the issues, analysis perspectives and the structure of the controlling system, the work unit actually assigned to the controlling

organizational unit may consist of one or many elementary units; 3) The work units are interrelated in two ways - one is the technological interdependence resulting from the underlying resource cycling process, and the other is the administrative interdependence resulting from the procedures of management cycle.

Control Task Hierarchy.

Putting the notion of work unit into a time perspective, and by taking into account the structure of controlling system, we can categorize the work units identified above into a three-level hierarchy of control tasks: 1) steering control tasks concerning with the execution of the cycle components, 2) functional control tasks concerning with the planning and review of resource cycles (other than the life cycle of resource), and 3) meta-control tasks concerning with the planning and review of resource's life cycle as well as issues relating to the non-circulatory (fixed) resources. After the hierarchy of control tasks has been specified, the required controlling functions - for controlling very disaggregated work units to aggregated macro level control tasks - can then be identified.

2.3.2 The Controlling System

The work unit's counterpart in the controlling system is the organization unit. Individual person is indeed the most fundamental unit in an organization. However, to understand the behavior of a controlling system, in some instance, it is required to study the performance of more aggregated object than individual person. Therefore, in this study, we analyze the controlling system through

three different but interrelated perspectives with gradual disaggregation, i.e., organization as a whole, work team and individual person. Three sets of questions are intended to answer: 1) How the system as a whole behaves in response to an organization-wide problem? 2) How a group of organization units works together as a team to carry out a decision-making process? 3) How an individual behaves when he encounters a decision problem? Our hypothesis is that, through such a segmented analysis, the results can collectively provide us with a sufficiently rich descriptive and analytical data to enable us to put the function of the controlling system into perspective, to conduct insightful diagnosis concerning the actual system performance, as well as to develop norms for organization change if needed.

Macro Organization Structure. The first perspective views the system as a whole. According to March and Simon [1958], the basic features of an organization structure and function are derived from organization's problem-solving process, and the departmentation of an organization can be mapped to a means-ends hierarchy which relates the individual tasks to the organization purpose. Incorporating the above concepts with Thompson's [1967] three-level notion of organizational function, this study considers an organization as a three-level problem-conversion mechanism which performs three major types of controlling functions (control cycles) respectively: 1) steering control - at the lowest level, which streamlines the physical operations and pursues production efficiency, 2) functional control - at the middle, which guides and provides necessary buffers to insulate the low level operations in a closed system and exercises incremental adjustments (within the bounds

imposed by the top level) to enable the lower level operations to accomodate short-run fluctuations, and 3) meta-control - at the top, which provides the ultimate buffer between the organization and the external environment and controls the overall systemic structure of the organization. It is this control cycle which the organization to behave as an open system and to pursue the effectiveness of the total system. Failure in the above control cycles indicates malfunction of the controlling system.

Organizational Team Process. The second perspective empahsizes the organizational decision-making process. Due to the interdependence of the transportation process, individual organization unit can rarely have direct access to all the information needed or control of all the factors involved in a concerned decision. As a consequence, decision-making in such a context is not an individualistic behavior but a team process. To accomplish a decision in a transportation organization, a decision-net that links the following units together can usually be identified: 1) the direct decision-maker: the organization unit which executes decision-making function that directly determines the performance of the underlying work unit; 2) the indirect decision-makers: those units which are either controlling the immediate upstream/downstream decisions (in terms of work flow) or performing an immediate supervisory function; 3) the information units: those units which provide information to support the direct decision-maker's decision, but in principle perform no decision-making function; and 4) the action units: those units which perform the decision-taker's role and implement the decision when it is actionable.

The performance of a decision net is a function of the following factors: 1) the organization units included in the net and the task roles they played, 2) the nature of the communication and coordination media, 3) availability of mutual influence bases and influence strategies among the team members, and 4) the substance of information transmitted in the communication channels. The systems with the capability to provide support to the above factors so as to advance the coordination effect of a team-based decision making process is called team-support systems.

Individual Decision-Making Behavior. The third perspective concerns individual decision-making behavior. The notion of human information-processing systems is applied. The key theme here is to identify the strengths and weaknesses of an individual decision-maker through the analysis of the cognitive process involved in his decision-making behavior. Two issues of particular interest are 1) the problems associated with the limited human cognitive capacity - specifically, the major concern are two phenomena: information-overload and bounded rationality, and 2) potential biases of individual decision heuristics.

Computer based decision-support systems (DSS) can provide four primary functions to support decision-maker: representation, memory aids, operations and control mechanism. A properly designed DSS should be able to effectively integrate the strength of human information processing systems with the power of computer technology, and enable the decision-maker to: 1) expand his cognitive limits and the rationality bounds, 2) detect and offset the potential biases of his decision

heuristics, 3) save his effort in mechanical computation and allow him to spend more time on creative part of decision process, e.g., exploring more alternatives, and 4) consider more subtle trade-offs among alternatives and consequences.

Chapter 3

INTERVENTION PROCEDURES AND TECHNIQUES

The conceptual framework developed in Chapter 2 for both the controlling system and the system being controlled provides us with the needed substantive knowledge frame to govern the organization intervention process. To complete the development of a diagnostic system, following Simon's two-components notion (knowledge vs. procedures) [1981, p. 110], the next task is to specify a set of general procedures which can be applied, under the guidance of the conceptual framework, to the diagnosis and analysis of transportation operations management systems.

3.0 General Framework

In an analogy to the medical diagnosis [Gorry, 1967], the organizational diagnosis is an information search and a judgement process in which the search for relevant information, the structuring of the information into a useful frame, and the association of particular symptoms with possible system states are vital. To do so, a set of systematic procedures which outline the step-by-step sub-tasks to be undertaken in the organizational diagnosis process is essential. Moreover, because it is difficult to establish and maintain an appropriate structure for all the information relevant to the diagnosis task, certain tools - analytical techniques - are demanded to facilitate the documentation of the diagnostic information, to highlight the symptoms and the potential causes of problems, and to enhance the

generation of the subsequent alternative solutions to problems. This chapter, as a complement to Chapter 2, is devoted to the development of methodologies, i.e., the procedures and related techniques for supporting the diagnosis process.

General Procedures. Organization intervention which aims at improvement of the organization's performance can be carried out through individual- or/and organizational- oriented approaches [Michael, et al, 1981], and along any (or some combination) of the following dimensions:

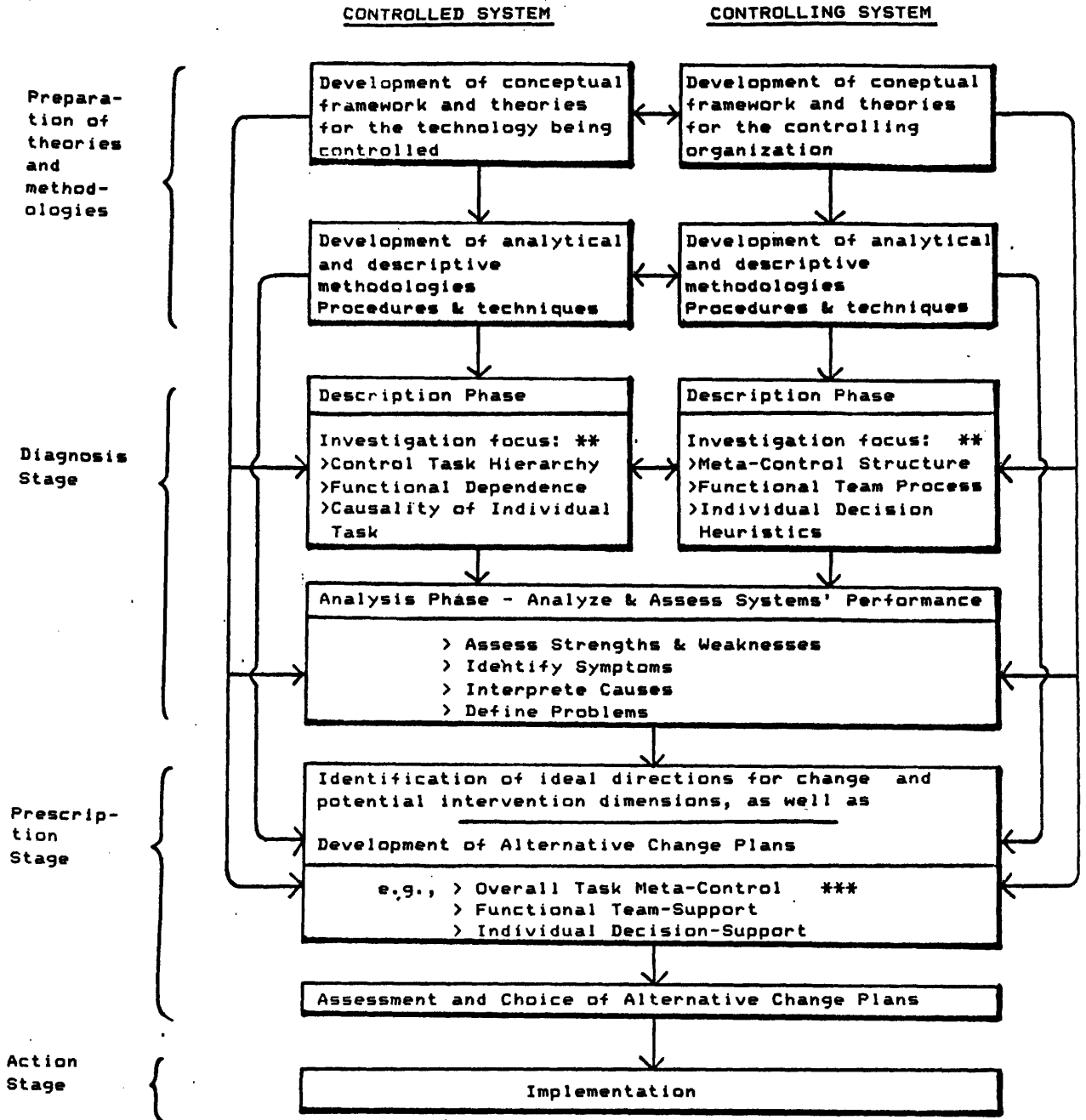
- 1) structural - e.g., creating or eliminating an organization unit, or redefining the role of a unit,
- 2) procedural - e.g., refining the process of decision-making or control,
- 3) informational - e.g., changing the information flow pattern or media of communication,
- 4) behavioral - e.g., modifying the decision-maker's attitude,
- 5) technical context - e.g., providing delicate decision-support devices, and
- 6) substantive context - e.g., changing the underlying technology of the system to be controlled.

Due to the complicated dynamics involved in the organizational process, effective intervention usually demands multi-dimensional strategies that are capable of creating the desired momentum to bring about an organization change [Huse, 1980].

In the transportation operations management context, following the dual-system notion and given the knowledge about the two systems, we propose a dual-system organization intervention process as shown in Exhibit 3-1-1 [*]. To amplify, due to the distinguishing

*: This exhibit is an elaboration on the substantive part of activities of Exhibit 1-2-2; procedural activities are included.

DUAL-SYSTEM ORGANIZATION INTERVENTION FRAMEWORK *



*: Substantive activities only, procedural ones not included - See Exhibit 1-2-2.
 **: Ideal diagnosis covers organization, team, and individual three levels' performance.
 ***: Ideal improvement plans may cover organization, team, and individual three levels' activities.

characteristics of the controlling system and the system being controlled, as indicated in the exhibit, the diagnosis will be carried out along two parallel but interactive lines, and consequently two sets of methodologies are required.

Due to the hierarchical nature of the control tasks pertaining to transportation systems, as well as to keeping the process manageable and systematic, a three-level - organization, team and individual - intervention strategy is proposed. Each level implies a different but interrelated approach to improve the organization performance, namely, 1) refining or improving the macro task management structure, 2) enhancing or improving the integrating mechanism for multi-functional team processes, and 3) installing or improving the support systems for individual decision. In ideal situation, the diagnosis in either system may be carried out progressively from general to specific. That is, in both systems, we first intend to sketch a macro picture concerning the whole system; then we proceed to examine some more detailed interdependence among functional activities and the interactions among organizational units; and finally, we get into micro analysis on the causality of individual decision tasks and the behaviors of individual decision-maker.

However, the three levels of intervention, in practice, could be a multi-faceted iterative process (rather than a simple linear sequential process without feedback or iterations), in which all three foci - organization, team and individual - are first examined in a preliminary way, then all three or part of them are examined in more detail. The actual emphasis of intervention will depend on the

following factors:

1)the characteristics of the organization problems in study - a typical scenario might be: there is a symptom which brings us into the situation; we first look quickly at all levels around the symptom; we then redefine the problem, or maybe focus on different individuals and different team processes when we shift to more detail.

2)the nature of the intervention process, e.g., the entry point (level of organization hierarchy and functional area), the organization's capacity to change, the intervenor's resource constraints (time, knowledge, skill, etc.).

3)the strategies of intervention, e.g., whether a pilot project is necessary to establish the intervenor's credibility through the quick feedback effect of the project.

Techniques. Since the information search at each diagnosis stage varies in its scope and degree of details, to serve the wide-ranging diagnosis requirements, we need a variety of methodologies - it is like the telescope and microscope that have their respective strengths and cannot replace each other - which collectively are capable of providing us with both macroscopic and microscopic information.

In the following sections, we shall first propose procedures which are applicable to the intervention activities - which cover both the diagnosis and analysis phases in the diagnosis stage of organization intervention - for each of three levels mentioned above, and secondly, present various techniques which could support us to proceed the intervention process.

3.1. Diagnosis and Analysis Procedures

3.1.1. Macro-Level Diagnosis - Getting A General Picture

The general procedures for describing the macro-level transportation operations management systems are proposed as follows.

A. Controlled System

The macro-analysis of the system being controlled is aimed at developing a general conceptual framework for the systems in analysis. The procedures are proposed as follows.

1). Anatomize the System Being Controlled

a) Conceptualize the physical process of the specific systems under study in terms of key work flows [Section 2.1.2A].

b) Translate the work flows into resources cycles [Section 2.1.2A] (in terms of selected resources particularly relevant to the task in analysis).

c) Break down the resources cycles into components, identify core operations and operational buffers, and identify the hierarchical relationships among the cycle components.

2). Understand Interactions Among Components of Resources Cycles

d) Examine the interactions among cycle components of a particular resource class, from both perspectives of the individual unit (e.g., individual vehicle, or employee) and the resource class as a whole (e.g., a whole particular vehicle fleet, or a whole class of crew), through the following two analyses:

d-1) Conduct ends-analysis: identify the purpose of each cycle

component in analysis - from one particular resource perspective; and identify the ultimate contribution of this resource to the overall transportation enterprise's goals.

d-2) Conduct means-analysis: identify the controllable means (options) available to the management of each cycle component in analysis to achieve the above identified ends.

e) Examine the interactions among different resources classes, e.g., the interactions between vehicle and crew, vehicle servicing and dispatching, etc.

3). Construct the Control Task Hierarchy

f) identify the work units [Section 2.1.2B] based on the knowledge of resource cycle components' interrelations, their managerial implications (drawn from means and ends analysis), and the notion of management cycle [Section 2.1.2B].

g) classify the work units identified above into a control task hierarchy [Section 2.1.3]. This hierarchy stands for a strategic conceptual framework concerning the nature of the system being controlled in study.

B. Controlling System

The macro-analysis of the controlling system is aimed at identifying the meta-control structure [Section 2.2.1C] which is the counterpart of the control task hierarchy in the controlled system.

1). Identify Relevant Organization Units

a) identify the relations between the components of resource cycle to

functional departments of the organization: the result represents the general roles (direct or indirect responsibilities) of each department for managing the task in analysis.

b) Analyze the formal structure of the directly responsible departments, and understand the specific role of all position holders in each department in analysis.

c) Identify specific actors: relate work units to specific actors (organizational units) at various levels in each department.

2). Identify and Describe Task-Actor Relationships

d) identify the authority and accountability (relate them to specific actors in the organization) for each work units in the control task hierarchy defined in Section 3.1.1A. This authority/accountability relationship represents the management structure for the task in analysis.

e) analyze the actual formal and informal processes of planning, execution and performance review (evaluation), i.e., the procedural aspect of the above authority and accountability structure.

3). Diagnose the Actual Function of the Task-Actor Structure

f) develop a normative task-actor structure and its desired functioning pattern based on the knowledge about the nature of the underlying work units, the problem context, and general organization theories.

g) compare the actual structure and function of the task-actor relations with the normative ones, identify and document their incongruence, and explain the reasons causing the incongruence.

h) identify the potential intervention dimensions for improving the macro controlling performance of the system.

The above diagnosis may serve two purposes: 1) highlighting the symptoms of deficiencies and malfunctions of the controlling system for the overall task in analysis, and 2) providing a context for the diagnosis of detailed functional-level and individual-level controlling behaviors, if needed.

Summary. One may notice that the analysis and diagnosis procedures described in Sections 3.1.1A and 3.1.1B are interrelated, specifically, second set (controlling system) procedures are primarily based on the results from the first set (controlled system). (Indeed, sometimes one can learn things in the other direction too.) The underlying hypothesis is that proper controlling functions must be congruent with the nature of the process being controlled. Chapter 4 of this study provides an example in which the above-described procedures together with certain techniques (which will be discussed in the second part of this chapter) are applied to a particular rail operating context.

3.1.2 Functional-Level Diagnosis - Understanding the Detailed Mutual-Dependence

The purpose of functional diagnosis is to gain more operational insights into certain selected areas concerning the underlying causality and decision processes. More specifically, the objects in the functional diagnosis are the components of the resource cycle rather than the whole cycle (or a set of exhaustive work units), and the focus of the analysis at this level is the detailed mutual-dependence (in

terms of both the physical processes and the associated controlling behaviors) among some selected work units, i.e., some subset of the total task-actor relationships identified in the macro-analysis. The procedures for analyzing and diagnosing the interdependence of functional activities are proposed below.

A. Controlled System

The analysis of the system being controlled at the functional level is aimed at 1) identifying and documenting the mutual dependence among the key performance areas in terms of detailed causality of the controllable and uncontrollable variables involved, and 2) refining the content of work units identified at macro level analysis.

1). Refine the Relevant Work Units

a) From the total control task hierarchy developed from macro analysis, identify the relevant work units which pertain to the functional area of interest.

b) Augment, if needed, the above selected set of work units with new elements which are not part of the original resource cycle hierarchy.

c) refine (from the results of macro analysis) the controllable variables and uncontrollable variables for each work unit, and examine the causality among the controllables and uncontrollables of each work unit.

2). Relate Functional Causality to Overall Control Task Hierarchy

d) Translate the cause and effect factors identified above into specific functional control tasks, i.e., operational strategies or policies, as well as in terms of contributions or constraints to the

overall task goals.

e) Integrate the above functional control tasks into the overall control task hierarchy.

B. Controlling System

The diagnosis of the controlling system at the functional level is aimed at: 1) identifying the decision-net [Section 2.2.2B] which takes care of the interrelated functional work units in the controlled system, and 2) identifying the actual team process in terms of the processes of communication and coordinat actors involved.

1). Identify the Relevant Actors

a) Relate the functional work units to organizational units.
b) Identify the formal relationships among the actors, in terms of authority and responsibility.

2). Identify the Communication Relationships Among the Actors

c) Identify the decision-net enacted for handling the routine and emergency control tasks in daily operations.
d) Identify the decision-net for high level control tasks with longer time horizons (e.g., weekly, monthly, annual processes) and the task roles [Section 2.2.2B] for each actor engaged.
e) Identify the information exchanged as well as the nature of the mutual influence basis [Section 2.2.2B] in the team process.

3). Diagnose Team Performance

f) Evaluate the task team's performance, in terms of degree of coordination, efficiency and effectiveness, based on the knowledge of

underlying work units, the problem context and general management theories.

g) Identify (informed by theories) the potential intervention dimensions for improving the team performance.

Summary. The practical purposes in conducting the functional-level diagnosis are: 1) to understand the managerial leverage available in the functional area under study, in terms of the potential contribution to the general task goals as well as the specific actions required to produce the contribution, 2) to examine the coordinability of the team process in the controlling system - e.g., whether the controlling process is compatible with the underlying interdependence of the physical process, whether the team process is properly supported in terms of communications media and mutual influence mechanism, and whether the controlling activities are coherent in the concerned functional area, and 3) to provide a context for the diagnosis of individual decision-making behavior. Chapter 5 and Chapter 6 (in part) of this study demonstrate how to conduct the functional diagnosis in two different selected areas concerning the management of rail locomotive operations.

3.1.3 Individual-Level Diagnosis - Examining the Individual Decision issues and Expert Decision Heuristics

Individuals in an organization are the ultimate elements determining the performance of the organization; therefore, organizational diagnosis ideally must end at this most elementary level. Once again, the proposed diagnosis process at this level is carried out along two parallel lines - the controlled system and the controlling system.

A. Controlled System

1). Analyze the Individual Decision Task

a) Single out the individual decision from a team-based macro-process which is embodied by a decision-net.

b) Analyze the potential cause and effect relationships underlying the decision.

2). Specify the Controllables and Uncontrollables of the Decision

c) Differentiate between the controllable and uncontrollable factors involved in the above specified causality, in terms of both intrinsic (e.g., uncontrollables due to lack of knowledge) and organizational (e.g., uncontrollables beyond the authority limits) characteristics of the factors.

3). Conceptualize the Decision Task in Means and Ends Terms

d) Define the individual task under study in terms of its ends and available means, where the means should include two sets of variables: one is controllables, the other is uncontrollable but can be intervened

in through organization communication or coordination channels.

B. Controlling System

1). Identify the General Decision Procedure of the Individual Decision-Maker

a) Describe the decision-making procedure adopted by the individual decision-maker for the task under study, in terms of the general input and output, as well as key intermediate steps, e.g., major trade-off considered, or core calculation efforts.

2). Elaborate on the Detailed Search and Choice Heuristics Applied

b) Identify the step by step intermediate search and inference process which transforms the input information into decisions, i.e., transforming an incomplete decision base [Section 2.2.2B] into an complete one. For routine repetitive tasks, this phase of diagnosis can be further split into two sub-phases:

b-1) Specify the search-and-choice heuristics [Section 2.2.3A] which are used to develop the routine working plan. Many modules may be involved.

b-2) Specify the search and choice heuristics which are used to handle the emergencies or to modify the routine working plan in response to operating contingencies.

3). Diagnose the Potential Pitfalls of the Heuristics Described

c) Identify the likelihood of information overload, premature decision due to insufficient information, heuristic biases and other potential pitfalls concerning the decision behavior under study.

Summary. The aim of the analysis of the system being controlled at this

level is at developing a prescriptive model concerning the nature of the decision of the task under study, while the diagnosis of individual decision-making behavior is aimed at identifying a descriptive model of the decision-making process. The differences between these two models indicate the existence of potential problems which result either 1) from insufficient diagnostic information, indicating that more detailed diagnosis should be carried out so as to refine both models and re-do the comparison, or 2) from actual incongruences which are the real symptoms of our concern. The latter half of Chapter 6 in this study demonstrates the diagnosis of the individual-level decision.

3.2. Analysis and Diagnosis Techniques

The conceptual framework derived in Chapter 2 is built upon several theoretical constructs, e.g., resource cycle, management cycle, control task, work unit, meta-control, decision-net, decision heuristics, etc. The diagnosis techniques, as explained earlier, are information collection tools which provide 1) operational definitions to the key theoretical constructs which embody the conceptual framework; and 2) practical analysis methods which support the diagnosis procedures in the inquiry for information. (One point worth noting is that we have not attempted to inventory all possible techniques rather those we proved useful in the case study).

The diagnosis techniques together with the diagnosis procedures proposed in the previous section enable us to bring the state of the system into focus. Because the techniques suitable for analyzing the system being controlled are different in nature from those for diagnosing the controlling system, our discussion again will proceed along the two lines.

3.2.1. The Controlled System

On the controlled system side, the key operational questions are:

- 1) How to anatomize the flows of work into work units?
- 2) What is the role of the resource cycle?
- 3) How to represent the interdependence of work units? and
- 4) How to differentiate controllables and uncontrollables?

In the following, we shall present the approaches which lead to the answers to the above questions.

A. Anatomize Work Flow into Work Units

The term work flow, depending on viewpoint, can refer to either macroscopic throughput of the system, or a microscopic process performed at a local point, e.g., terminal operations. In this section (3.2.1A), we are mainly concerned with the macroscopic system work flow and leave the discussion of local work flow to the next section.

From System Work Flow to Resource Cycle

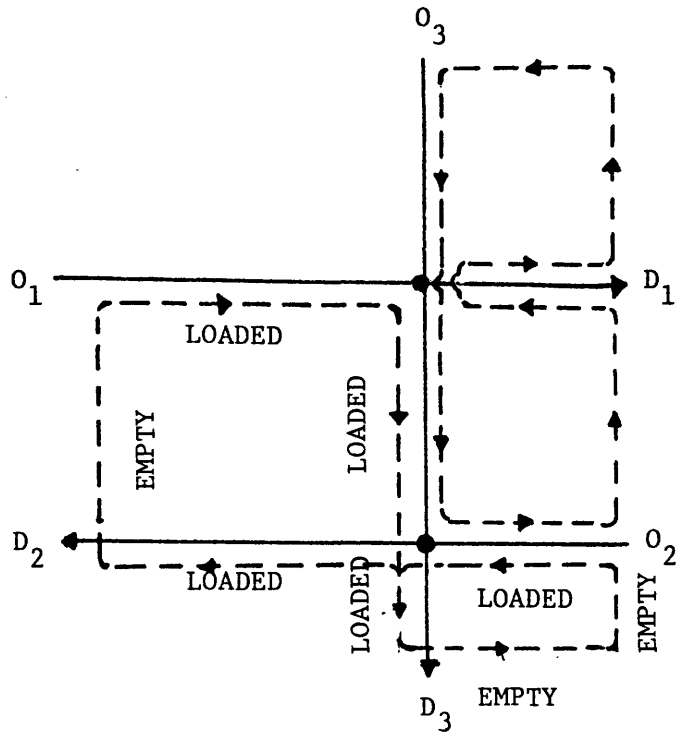
In this study, system-wide work flow is defined as the O-D traffic movements, and as argued in Chapter 2, such traffic movement is normally supported by various resource cycles [Exhibit 3-2-1]. The role of transportation operations management is to balance the goals of resource productivity and service quality. Nonetheless, to control service quality is equivalent to controlling the loaded portion (e.g., work flow) of a resource cycle, and to achieve productivity goal implies controlling the total cycle, therefore along this line of logic, we advocate that the transportation operating managers should perceive the control of resource cycle as their primary task, i.e., a properly controlled resource cycle will perform balancedly in terms of cost and service quality.

The notion of resource cycle is not only a substantive concept concerning the nature of the transportation process, but also an analytical approach which enables us to systematically construct a general analysis framework for the controlled system and to examine the detailed operations performed in the system.

In practice, the notion of resource cycle is not concerned with the

EXHIBIT 3-2-1

ILLUSTRATIVE RELATIONSHIP OF WORK FLOWS AND RESOURCE CYCLES



---> RESOURCE CYCLE (INCLUDING BOTH LOADED AND EMPTY COMPONENTS)

—> WORK FLOW (IN TERMS OF O-D TRAFFIC)

● WORK FLOW TRANSFER POINT

physical trajectory of movement of the resource, but with the transition pattern of status phases of resources. Moreover, resource cycle can refer either to the cycling pattern of individual units of a particular class of resource [Manheim, 1981] or to the average cycle pattern for a class of resource as a whole [Mao, Martland and Sussman, 1980]; macro-level analysis puts more emphasis on the latter.

The first step in applying the resource cycle approach is to select one particular type of resource among those which are circulated around in the transportation system. This selection is depended on the nature of the issues to be dealt with. However, in most transportation modes (except the pipeline and conveying-belt system), because the vehicle is the resource most fundamental to the delivery of transportation service (the other key resource is crew) and furthermore, because vehicle cycle is a relatively well-developed concept and has already been applied successfully in various contexts, e.g., AAR [1977], Manheim [1979], Mao, Martland and Sussman [1980], Mao, Philip and Susman [1980], and Mao and Martland [1981], it is convenient to select the vehicle cycle as the basis for constructing the general analysis framework.

From Resource Cycle to Cycle Components

As an analytical tool the utility of the resource cycle is that it can normally be systematically fragmented into distinguishable components. The example of vehicle cycle hierarchy given in Chapter 2 [Section 2.1.2B, Exhibit 2-1-2] indicates clearly that, given the knowledge of the transportation physical process, the breakdown of a resource cycle is relatively straightforward. Furthermore, the breakdown scheme of a resource cycle is flexible in terms of the degree

of details of the components specified in the cycle. For instance, in the preliminary phase of analysis or high level diagnosis, one can specify the components in relatively aggregated terms ,e.g., using the dichotomy - in motion and detention - to represent the whole cycle and leave the elaboration to the later phase of the analysis or lower level diagnosis. Given the fragmented cycle components, by putting them into a time perspective, we can then arrange them into a resource cycle hierarchy, e.g., life cycle, annual cycle, maintenance cycle, operating cycle, etc.

From Resource Cycle Component to Work Units

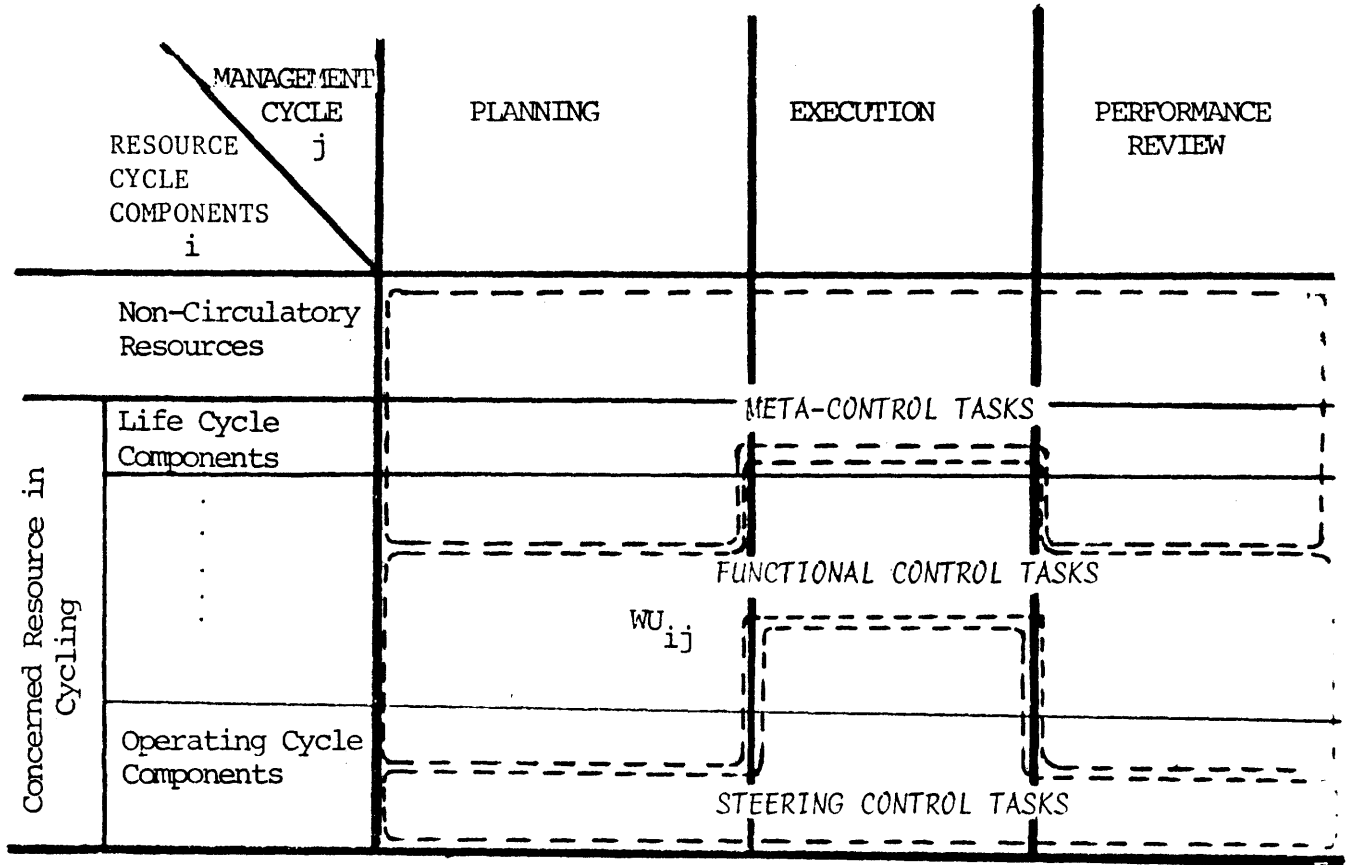
In Chapter 2, we argue that managerial activities, in principle, constitutes a cycle which can be primarily categorized into three interrelated phases - planning, execution and review. The control of individual resource cycle components involves all three phases of the management cycle. Therefore, to specify the wrk units involved in the management of the selected resource, we can construct a matrix as shown in Exhibit 3-2-2; the elements of the matrix collectively respresent the totality of control tasks (work units). The elementary control tasks specified in the resource cycle vs. management cycle matrix may vary in their degree of detail, depending on the degree of detail of the fragmentation of the resource cycle.

From Work Units to Control Task Hierarchy

To put the work units identified in the previous step into managerial perspective, we may further categorize them into various levels of control tasks - steering contorl, functional control and

Exhibit 3-2-2

IDENTIFYING WORK UNITS
- RESOURCE CYCLE VS. MANAGEMENT CYCLE MATRIX



$$\text{TOTAL CONTROL TASKS} = \{ WU_{ij} \} \text{ FOR ALL } ij$$

meta-control - as illustrated in Exhibit 3-2-2. There is a general correspondence between the control task hierarchy and the organization hierarchy [Section 2.2.1C].

B. Analyzing Interactions Among Work Units

The purpose of macro-level analysis is at least two-fold: 1) to gain an overall picture of the system; and 2) to provide a general analytical skeleton for detailed analysis - either still probing within the originally selected resources dimension, or probing some multi-resource issues, i.e., the interaction of various resources in the terminal area. In other words, the add-on to the original analytical skeleton is taking place at this level's analysis. In this subsection, we shall discuss some techniques which can be used in more detailed analysis of the interactions among work units (either within or between resource classes) and of the local work flows.

1). Schematic Techniques

Schematic model is a widely adopted tool to carry out systematic analysis and synthesis in a variety of disciplines, e.g., operations research, industrial engineering, information-processing engineering, organization study, etc. A schematic is a convenient starting point for setting up the more formal model, e.g., a quantitative model. In many situations, the schematic model represents the principal tool available for use in problems which involve "the analysis of methods by which people perform work which is not machine-oriented" [Bowman and Fetter, 1967, p. 64]. A schematic - which may be very simple or elaborate depending upon its intended use - can show qualitatively the

logical structure of a complex system in study and the relationships among its elements within a relatively small space.

The use of schematic methods are basically three-fold. First, they can be used descriptively in the documentation and explanation of the processes and performance of an existing system. Secondly, they may be used to diagnose the existing system by incorporating with some normative theories or other relevant arguments. Thirdly, they can be used prescriptively in the design, analysis and representation of the characters of a new system.

We have no attempt here to catalog all the schematic techniques developed in various disciplines. In the following, we shall only discuss briefly two major types of schematic models, namely, flow diagram and causal diagram.

Flow Diagram. A family of techniques can be categorized into this type, for instance, the flow process chart, the multiple activities chart, and the work place chart used by industrial engineers [e.g., Bowman and Fetter, 1967, Chapter 2; Marynard, 1971, Section 2]; the system logic flow chart, the data flow diagram, and the block diagram used by computer system analysts or management scientists [e.g., Gane and Sarson, 1979; Shannon, 1975], to name a few. In this family of techniques, two subcategories can be further differentiated into two sets. One is material-based, that is, of which the order of occurrence of the events which constitute completion of some desired objective is directly associated with some flow of physical objects - vehicle, crew, passenger, cargo, etc. The flow process chart, which portrays the sequence of steps of a production process, applied by industrial

engineer is a typical example. The other is logic-based, that is, the step-by-step details of a process (which is actually performed or anticipated to be performed) portrayed by the schematic is primarily concerning the logic structure of the process, e.g., the interrelations among decisions. The system logic flow chart and the various block diagram models used by computer system analyst and management scientist are typical example of this category. Some of the elements specified in a logic-based flow diagram as well as in a causal diagram (which will be discussed later) may pertain to the "performance" of the process in study rather than the sole "action" elements which characterize the material-based flow diagram. Although the logic-based flow diagrams are more abstract than the material-based ones, the logic specified by the former diagrams are usually embedded on microscopic work flows involved in the physical process. Both types of flow diagrams are useful in our analysis. During the systematic manipulation of schematic models toward understanding and improvement of a system, it is usually fruitful by concentrate on work which is of the interface buffer type. It is also worth to note that, in many cases a typical conventional flow diagram, takes little account, if any, of the structure of the controlling system; sometimes, a single decision-maker is implied. In this study, we emphasize the importance of breaking down the process in such a way that each sub-process can be explicitly assignable (and is assumed to be assigned eventually) to a specific organization unit (individual or group of individuals).

Causality Diagram. Another commonly used technique in conventional system analysis is the causal diagram [e.g., de Neufville and Stafford,

1972; Forrester, 1968], which uses arrows (as well as some auxiliary notations, e.g., positive or negative signs) to indicate how a change in one variable may generate changes to other variables - the portrayed interactions among variables could be empirical or hypothetical informed by theory or other arguments. Causality implies regularity (necessary, contributory or contingent relationships) between pairs of events [O'Shaughnessy, 1972, p. 64]. In a complex system, such as the transportation operating system, the causality involved usually constitutes a complicated network - any effect has its recognizable immediate, intermediate and remote causes. Because in principle, cause does not mean all necessary and sufficient conditions, and the length of the causal chain is not fixed [ibid, pp. 69 - 70], the key is that as far as management control is concerned, the cause of certain problematic situations must be traced back to the actionable condition. More specifically, in a management context, there is an issue concerning with the controllability regarding the causes - for any particular manager, a causal explanation should be able to help him to solve his problem (i.e., problem concerning the work unit he is in charge of). In other words, in constructing a causal diagram, the analyst should have the structure of the controlling system in mind, and the causal diagram developed should facilitate the identification of controllable and uncontrollable factors for those work units of particular concern. One point worth noting concerning the schematic models discussed above is that these techniques are not only applicable to the analysis of the system being controlled, but also very useful to the analysis of the controlling system.

2). Quantitative Analysis Techniques

Any quantitative analysis technique, e.g., simple data manipulation, statistical analysis or formal mathematical models applied by researcher, has its strengths and weaknesses, and consequently has its most appropriate application domain. In the following, we shall mention two different types of analysis which are applicable to the system being controlled at macro-level and lower levels.

Aggregate Analysis. Macro-level analysis of the controlled system can serve two major purposes: 1) as a preliminary or pilot study which paves the way for further detailed analysis, and 2) as an approach to enhance senior management's conceptualization of the process being controlled.

The general context for this level's analysis is normally characterized by one of two cases: 1) detailed knowledge concerning the system process is insufficient, or 2) operational details are not the real issue of concern. Given the above situation, at this level the development of sophisticated models is not only inefficient (time-consuming) but may merely be masking confusion (due to insufficient knowledge). Therefore, a legitimate and effective approach to be adopted for this level's analysis should be to construct some simple but informative aggregate models. In a sense, many financial-performance-indices based interactive decision-aid systems, such as the IFPS (Interactive Financial Planning Systems), are typical aggregate models. In Chapter 4 of this study, we present an aggregate policy analysis model [also see Mao and Martland, 1981] based on a set of operational performance indices of the vehicle cycle components as

well as on certain hypothesis concerning the technological process. In short, for macro-level analysis, aggregate models are shown appropriate because they are characterized by 1) simple to develop and easy to communicate, 2) explicitly identifiable assumptions, 3) providing insights into the trade-offs among policy variables, and 4) assignable controlling responsibilities of the policy variables specified in the model.

Detailed Process Analysis. To carry on a preliminary analysis or to operationalize the policy formulated at the senior level, more detailed analysis should be conducted. Various conventional operating planning and system analysis techniques can be adopted for this level's analysis [e.g., de Neufville, et al , 1972; Hillier and Lieberman, 1978]. We make no attempt to review these techniques here. The only point we like to note is that organization analysts should be willing and able to borrow applicable and relevant techniques and knowledge from any field of scientific endeavor.

3.2.2 The Controlling System

The diagnosis of the controlling system, according to our conceptual framework, focuses on three sets of issues: 1) the meta-control structure for the totality of the tasks in study, 2) the performance of the functional task-team which collectively takes care of a set of mutually-dependent work units, and 3) the performance of individual decision heuristics concerning specific individual decision issue. The techniques which are suitable to support the analysis and diagnosis of the controlling system can also be categorized into three

groups.

A. Techniques for Analyzing and Diagnosing Meta-Control Structure

To diagnose the meta-control structure, there are three information collection issues: 1) the identification of relevant actors in the organization, 2) the understanding of the controlling roles of these actors, and 3) the documentation of the meta-control structure. We discuss them in turn below.

1) Identify Relevant Actors - Structural Roles of Actors

Analysis of Organization Chart. The analysis of an organization can normally start from the analysis of the organization chart which is available (although updating may be needed usually) in most transportation enterprise. According to Stieglitz [1964], information which can be read from an organization chart primarily includes: 1) division of work, 2) grouping of work 3) superior-subordinate relations, 4) levels of management in terms of successive layers of superiors and subordinates, and 5) general nature of work performed by various components. However, as pointed out by Stieglitz, there is a lot more information an organization chart cannot show, such as: 1) the degree of responsibility and authority (delegation and allowable discretion), 2) staff and line relation (who supports whom), 3) status or importance (organizational power), 4) lines of communication, and 5) the informal organization through which things really get done. In other words, what an organization chart can show is the formal and static but not the dynamic and operational aspect of data.

In short, the analysis of the organization chart alone is insufficient to generate all the needed data concerning the controlling structure of an organization, but it is a practical first step which provides us with a "road map" and facilitates our further probing process.

Job Description. Job description is a supplementary technique to the analysis of organization chart. It provides us with detailed data concerning the content of the job (authority, accountability, task, or function) of the individual position holder [Steward 1976, p.121]. In practice, job description data can be collected through the formal organizational documents (if available), or through personal interview, or both. Although the data obtained from job description is still basically limited to the formal aspect of the role of the individual organization unit, when it is used with the general knowledge from the organization chart, we are usually able to identify a set of first cut relevant actors.

Summarizing the Structural Roles of Actors

To specify and summarize a list of relevant actors, there are at least two techniques: 1) constructing a control task vs. organization-level matrix, and 2) extracting a subset of the organization chart and relating it to the control tasks [Exhibit 3-2-3].

Resource cycle vs. Organizational-Level Matrix. The application of this technique is flexible. For instance, in the preliminary stage, the organization levels can be generally classified into three levels, and the actors identified (i.e., the element of the matrix) can be a group

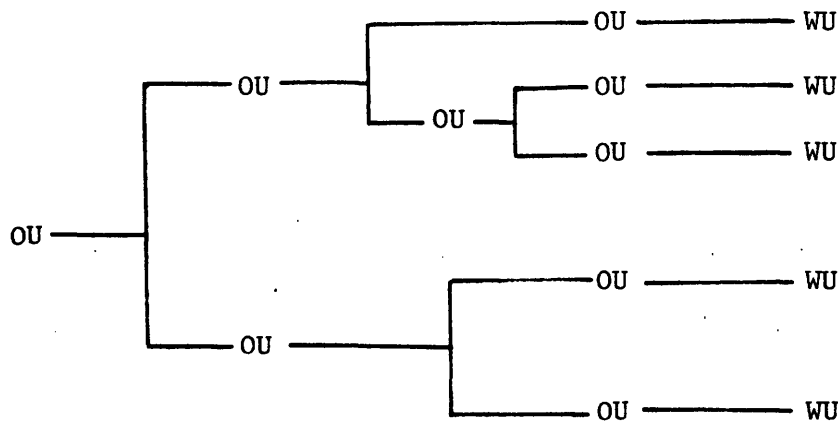
Exhibit 3-2-3
IDENTIFYING RELEVANT ACTORS

A. CONTROL TASK VS. ORGANIZATIONAL LEVEL MATRIX

ORGANIZATION LEVELS <i>j</i>	TOP	MIDDLE	FIRST-LINE
CONTROL TASK <i>i</i>			
⋮		A_{ij}	

TOTAL TASK TEAM = { A_{ij} } FOR ALL *ij*

B. LINKING ORGANIZATIONAL CHART TO CONTROL TASKS (WORK UNITS)



OU: Organizational Unit
 WU: Work Unit

of officers rather than specific individuals. During the later phase of diagnosis, as more knowledge is accumulated, the breakdown scheme can be gradually made more elaborate and the entries of the matrix can be more specific.

Linking Organizational Chart to Control Tasks. This technique is an alternative to the previous method. Its advantage is that the formal structural relationship of the identified relevant actors is explicitly shown. However, when the control tasks have been specified as a hierarchy, this method may encounter some technical problems - the need to link two hierarchies (one is the hierarchy of control tasks, and the other is the organization units). In this case, unless the representation can be made sensibly readable, the previous matrix technique is suggested.

In summary, the above two techniques basically serve as vehicles to facilitate the documentation of the formal roles of the relevant actors and to force us to search for relevant actors if there are "holes" of unassigned control tasks. The aim of this stage's analysis is to generate a reasonably comprehensive list of relevant actors. The collection of data follows two principles: 1) gradually getting into details as diagnosis progressing, and 2) not necessarily to be uniform in details across the organization but issue-focused.

2) Understand Procedural Roles of Actors - Analysis of the Formal and Informal Organizational Process

To identify the specific authority and accountability of the actors, information about their formal structural role is far too superficial and insufficient. The next step is to understand the

functional roles of the relevant actors, i.e., the procedural relationships among the actors. The techniques enumerated below are alternative methods which can be applied to acquire the above needed information.

Clarify the Authority of Individual Organizational Unit

Any organization, in order to perform its controlling function, must develop various system-wide mechanisms to assist in the integration of work, in monitoring the actual achievement and in dealing with problems for which no existing procedure is adequate [Weisbord, 1978, p. 44]. It is these mechanisms which make an organization function. To uncover the nature of these mechanisms and to probe into the actual roles of the actors in the organization-wide process, we may focus our information search effort in the following areas.

a) the planning and replanning processes which produce and change the operating schedules (e.g., service schedules, preventive maintenance schedule, crew assignment schedule, etc.),

b) the budgeting and auditing procedures (e.g., corporate budgeting, departmental budgeting, divisional budgeting, local terminal budgeting),

c) the institutionalization and adaptation of operating policies and rules (e.g., various work rules, decision rules),

d) routine operating conferences (e.g., daily, weekly and monthly operating conferences),

e) ad hoc problem-solving meetings which the organization or individuals devise spontaneously to solve problems not envisioned by the formal mechanisms (e.g., the handling of emergent operating contingencies, the management of departmental conflicts).

The key to understanding the above processes is to describe: a) the general agenda and the key issues of the process, b) the participants and their roles, such as who leads the process, who initiates proposals, who is consulted, and so forth, c) the decision mechanism, e.g., democratic, authoritarian or some mixture, d) the relations of the input and the output of the process to the rest of the organizational processes, e.g., on the output side, whether or how the decision is implemented. In short, the above analysis should enable us to gain a clear image of the actual responsibility of each individual or group of individuals in the overall organizational controlling structure.

Clarify the Accountability of the Individual Organization Unit

To understand the accountability relationships, we should understand the performance review system of the organization. In principle, the review of performance must rely on certain performance measurement systems [Drucker, 1977, Chapter 31]. Therefore, one operational approach in analyzing the accountability is to analyze the performance indices adopted by an organization and their relations to the formal and informal reward and sanction practices. The formal reporting systems are the major source of information for accomplishing this end. The focus of the analysis should be on:

a) What are the performance indices available and used in the

systems?

b) How are these indices filtered and aggregated through the organization levels?

c) Who receives what performance feedback?

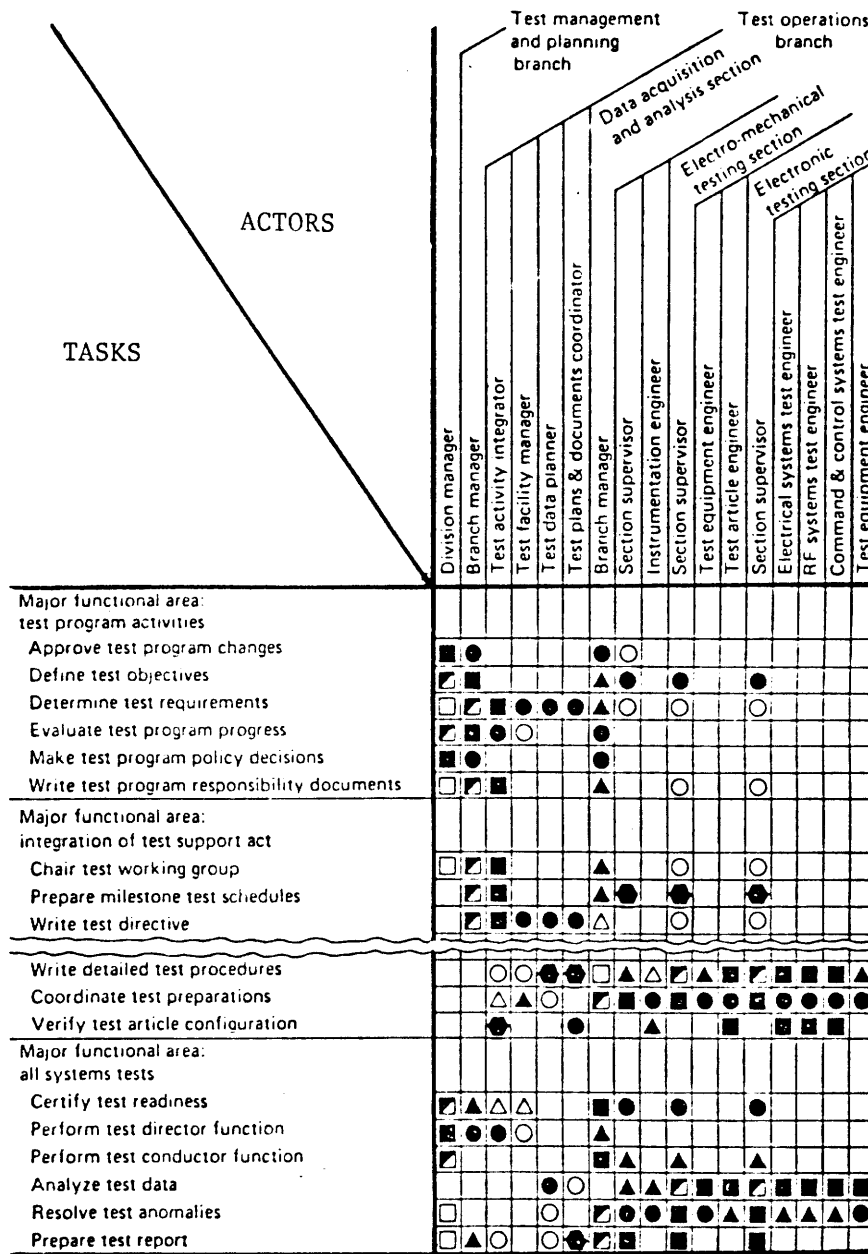
d) How does an individual use the performance feedback ? (e.g., for evaluation purpose? supervision purpose? self-correction purposes?)

To summarize, the analysis of the actor-specific controlling roles may result in adding or deleting actors from the original list. Given the explicit responsibility and accountability knowledge, the next practical problem is how to summarize and represent the potentially profound findings in some systematic way to facilitate our diagnosis - identifying problematic symptoms and systemic malfunction. The techniques proposed in this study to resolve the above problem are presented below.

3) Documenting Organizational Meta-Control Structure - Task-Actor Matrix

In response to the drawbacks of the traditional organization chart, Larke [1954] suggested a technique called the Linear Responsibility Chart (LRT) which represents the relationships between managerial tasks and individual actors in a matrix form as shown in Exhibit 3-2-4, and in an LRT, the roles of each individual manager can be explicitly described. In this study, we consider this matrix formation as a helpful technique for documenting the relationships between the controlled system and controlling system, because the tasks on the far left column of the matrix are the specific work units derived from the

TASK-ACTOR RELATIONSHIP - LINEAR RESPONSIBILITY CHART



Key to symbol titles

- Work is done
- ▲ Occasional intertask integration
- Direct supervision
- Intertask coordination
- General supervision
- Occasional intertask coordination
- ▲ Intertask integration
- Output notification mandatory

SOURCE: CLELAND AND KING [1972, p. 358]

nature of the controlled system, and the organization units on the top row of the matrix directly correspond to the relevant actors identified in the controlling system, while the entries of matrix cells describe each individual actor's task roles - in terms of authority and accountability.

However, Larke's technique only highlights the responsibility or authority aspect of the task and overlooks its potential to include the accountability elements into the matrix by assigning review phase's work units to organization units. To amplify, Larke's matrix can be perfectly associated with our notion of meta-control structure [Section 2.2.1C].

According to the notion of the management cycle (planning-execution-review) mentioned in Chapter 2, there are, in principle, inherent relations between authority and accountability - specifically, they constitute control cycles. Thus, in our opinion, the linkages between the work units (i.e., tasks) and organization units (i.e., actors) are by no means linear - due to the existence of cycles. It is for this reason that we change the name of the matrix as task-actor matrix, and refine the procedures for constructing the matrix as follows.

A) systematically rearranging the organization units (actors) along the top horizontal axis basically in accordance with their positions in the organization hierarchy;

B) lining up the work units identified along the vertical axis according to the following order: 1) planning tasks first and review tasks last, 2) among the planning and execution tasks, meta-control

tasks first and steering control tasks last, 3) among the review tasks, steering control tasks first and meta-control tasks last, and

C) filling in the authority, accountability and actor's task roles into the cells of the matrix.

By above token, in principle, the entries of the matrix will emerge some particular pattern as shown in Exhibit 3-2-5.

Moreover, we also argue that the task-actor matrix is not limited as a descriptive documentation tool, but also has normative utility. For instance, based on the nature of the work units and their underlying interdependence, we may prescribe the ideal authority and accountability structure which should embody the controlling system. The practical importance of this prescriptive task-actor structure is that it can be used to make systematical comparison with the descriptive structure and to identify the problematic symptoms accordingly (e.g., whether authority is matched with accountability).

In summary, the task-actor matrix is a useful tool for providing us with an explicit image of the controlling system's meta-control structure. The information contained in the matrix can be either prescriptive or descriptive. Furthermore, this technique can be applied to the analysis of the controlling structure of either organization-wide or function-wide missions.

Exhibit 3-2-5

TASK-ACTOR MATRIX

Control Task \ Actor		TOP Management (Institution Level)	MIDDLE Management (Managerial Level)	FIRST-LINE Management (Technical Level)
		PLANNING	PROBLEM DEFINITION	Authority
SPECIFY ENDS DEVELOP MEANS			Authority	
EXECUTION				Authority
PERFORMANCE REVIEW	IMMEDIATE PERFORMANCE OF SPECIFIC TASK			Accountability
	INTERMEDIATE PERFORMANCE OF FUNCTIONAL LINE		Accountability	
	ORGANIZATION STRENGTHS & WEAKNESSES	Accountability		

B. Techniques for Diagnosing Functional Task Team Process

The analysis of the meta-control structure provides us with an overall picture of the totality (at least along one selected class of resource) of the operations management system, i.e., the controlling system and the system being controlled as well as their linkages, in terms of the task roles of the actors. Given this knowledge, we are able to conduct a more detailed diagnosis, i.e., taking some subset of work units and their corresponding controlling organization unit from the totality of the system, and investigating the detailed processes taking place in the selected sub-system. By this token, three purposes can be served: 1) to elaborate on the knowledge concerning the overall system, 2) to diagnose and improve the performance of the selected functional sub-system, 3) to provide a context for the analysis of individual decision-making behavior.

One point worth noting is that the diagnosis techniques described in the preceding section (3.2.2A) and the schematic techniques discussed in Section 3.2.1B are not only applicable to the macro-level analysis or to the system being controlled, in many cases they are equally effective to be used in the diagnosis of the functional level of the controlling system - as demonstrated in later chapters (4 through 7). Given this understanding, in this section we shall concentrate on those techniques which were not covered previously but are particularly useful at the functional level diagnosis.

Operationalize the Notion of Decision-Net

In this study, we define the decision-net as a sub-set of the meta-control structure, e.g., some sub-set of the overall Task-Actor Matrix, which stands for a controlling structure for some selected functional work units. Moreover, given a collection of some functional work units, the actually enacted decision-net is dependent on operating contingencies, e.g., the decision net for handling emergency may be different from that for routine operations.

The key themes of the decision-net analysis are: 1) explicating the informational inputs on and outputs from individual decision-makers, 2) understanding the role of decision variables on communication events (i.e., how they drive the information search and exchange processes), and 3) the communication and coordination connections between multiple decision-makers in a team-based decision processes. In short, our focus is on the flows and transformations of information as well as the role influences associated with the team decision processes.

Communication Locus Analysis. Samuel Eilon [1968] proposed a method for coding messages in a communication network to identify and analyze control mechanisms in an administrative system. In his own words: "Although one often speaks of the 'flow' of communications, in fact, this flow consists of a series of discrete messages of different length, form or content. These messages are transmitted through certain channels which make up the communication network." Eilon argued that these messages could be coded and displayed in a communication chart as shown in Exhibit 3-2-6 - in which the actors are lined up horizontally

COMMUNICATION LOCUS ANALYSIS

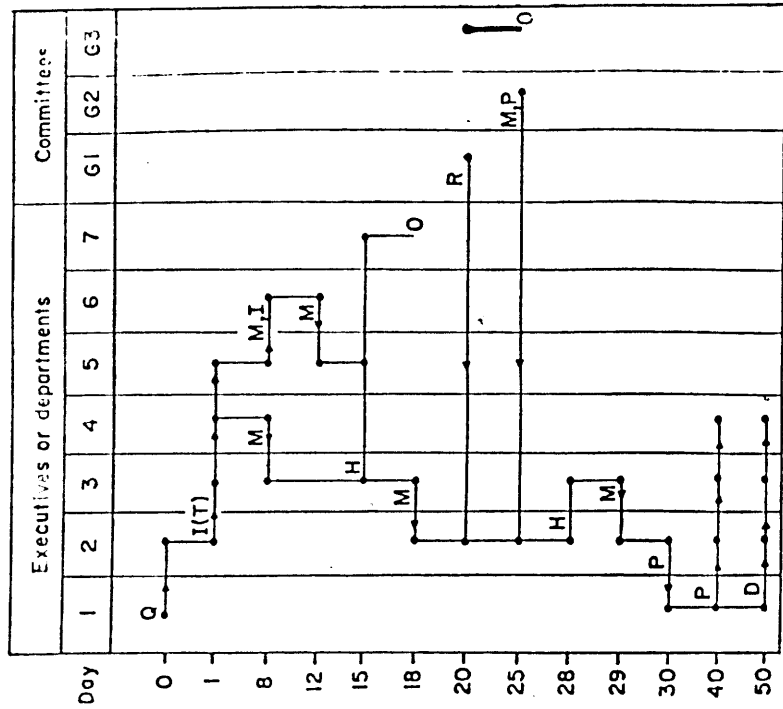
Table 1. Coding scheme for messages.

General coding	Detailed coding
R	R-1 Time triggered report R-2 Event triggered report
M	S Statement, following an inquiry or event triggered C Comment Details on data collection and processing can be added as follows: ^a 1—data from available records 2—ad hoc data collection 3—routine data processing 4—ad hoc processing
I	I-1 Inquiry covered by standing procedures I-2 Inquiry about a novel situation
Q	Q-1 Query about problems covered by regular procedures Q-2 Query for novel situations, or to clarify ambiguities and inconsistencies
P	P-1 Proposal about procedures or recurrent events P-2 Proposal on an ad-hoc issue
D	D-1 Decision on procedures affecting recurrent events D-2 Decision on ad-hoc issues
H	Meeting, the outcome of which may be any or several messages above; if the meeting fails, the result is denoted by O.
T	Telephone discussion

^a The particular kind of memorandum may be coded in this way, such as S-1, C-3, etc.

Source: Eilon [1968]

Table 2. Communication chart.



at the top of the chart, while the vertical axis stands for the time, and the lines drawn in the chart represent the communicaton locus of a specific decision process. Codes can be annotated alongside the communication lines to indicate the nature of the transmitted messages.

Eilon's method is an efficient tool to amplify the dynamics and time-dependent relationships of a task team. However, in Eilon's original specification, the codes employed in the analysis are basically the forms of messages (e.g., routine report, memo, personal contact, etc.); in fact, this practice does not fully exploit the power of the technique. According to our experience, the analysis of the communication locus can exhibit at least the following descriptive data:

- 1) the decision-net evoked in the decision process in question,
- 2) the chronological order of the process,
- 3) specific types information transmitted in each step of the process, e.g., state-related, alternative-related, outcome-related, criteria-related, etc.,
- 4) the task roles of the actors, e.g., Who are the primary decision-makers? Who are the informational supporters? and When should a person play the role of an information supporter at one time, and a decision-maker at the other?
- 5) How does a decision-maker search for new information? and How does he accumulate the information available before making a decision?
- 6) by studying the same decision task in different contexts, e.g., routine situation vs. emergency, we can observe in which case certain indirect decision-makers or supportive actors will be evoked.

A well-documented communication locus greatly enhances the analysis of the coordinability of a decision task because it can 1) show whether means-control or ends-control is properly applied, 2) facilitate our probe into whether an effective influence basis is provided between two interrelated decision-makers, and 3) even allow us to prescriptively examine the potential consequences of new scenarios [O'Conner, 1978] concerning the characteristics of the communication locus.

Decision Base and Communication Locus. The decision base [Section 2.2.2B] in this study is defined as the information available to and used by a particular individual in a specific decision. Because the information contained in an individual decision base is either passively received or actively acquired, a well documented decision-specific communication locus can enhance the identification of the contents of an individual decision base. The vertical line in the communication chart, in fact, represents an actor's internal cognitive process - for a decision-maker, it stands for the functioning of his decision heuristics (either with or without external aid) - by now it is still a black box subject to be analyzed by more microscopic techniques as shown below.

C. Techniques for Diagnosing Individual Decision Behavior

Techniques available for the study of the individual manager's behavior include: working diary study, the analysis of critical incidents or sequences of episodes, and problem portfolios, to name a few [Mintzberg, 1973; Stewart, 1976]. In this study we are particularly interested in the analysis of the individual behavior exhibited in a specific decision-making process. This knowledge allows us to specify

the decision heuristics employed by the individual and to identify their potential pitfalls. The eventual practical aim, based on the above information, is to develop effective decision-aid systems.

Protocol analysis. The analysis of verbal protocol is a typical approach to constructing descriptive models of managerial decision behavior [Newell and Simon, 1972; Winston, 1979, Chapter 5; Libby, 1981, Chapter 4]. The general procedure is to encode the verbalized ("think-aloud") step-by-step processes applied by a decision-maker in the course of solving a specific problem. The key is to construct a data base which enables us to uncover the intermediate inferences that lead to the final decision. This information normally is not transmitted or revealed in the ordinary decision-making process.

Protocol analysis is a structured experiment and is particularly powerful in the study of human information processing in solving well-defined and limited problems. A sensible protocol normally requires complete and precise detailed information - in an ideal case, the data base should be capable of supporting the development of a computer program which is able to replicate the behavior of the decision-maker [Newell and Simon, 1972].

Decision-Maker Introspection. In order to understand a decision-maker's heuristics, an alternative to the protocol analysis is the analysis of data collected from a decision-maker's introspection about the generalized sequences of episodes involved in his decision process. This method allows a manager to describe what he knows best about his usual performance of a specific task, and leaves the interpretation of

data and the development and test of theories to the analyst [Mintzberg, 1973, p.222]. Practical issues involved in the application of this method are the need to: 1) systematically examine the decision-maker to ensure the consistency between what he says and what he does, and 2) validate the analyst's inference and conceptualization derived from the decision maker's introspection. The analysis of a decision-maker's introspection is a flexible approach compared to formal protocol analysis; it can be helpful (as illustrated in Chapter 6) to sort the decision-maker's introspection into the following categories: 1) the general problem-solving frame of a specific decision task in terms of the general relationships among decision's premises, key decision variables and contingency factors, 2) search-and-choice framework associated with the key decision variables, and 3) detailed algorithms employed in the search-and-choice process. By doing so, we are allowed to examine the likelihood of information overload and the potential of heuristic biases. The influence of non-measurable (intangible) decision criteria can also be observed through the detailed breakdown of the choice procedure.

3.3. Summary of Chapter 3

3.3.1. Organizational Diagnosis Procedures

A diagnostic system consists of two primary components: a large body of substantive knowledge and a set of systematic procedures. The theoretical constructs presented in Chapter 2 provide us with the needed substantive knowledge which enables us to:

- 1) observe and organize relevant information about the dual-system in study,
- 2) identify problematic symptoms of the system through the normative ideals informed by the theories,
- 3) generate explicit hypothesis of desired states to be achieved by the system, and
- 4) develop alternative change plans.

The methodologies presented in Sections 3.1 and 3.2 provide operational techniques and procedures which instruct us how to proceed with the diagnosis. The three-level diagnosis strategies - organizational, team and individual - imply three different but interrelated approaches to improve the organizational performance: 1) refining or improving the macro task management structure, 2) devising or improving the integrating mechanism for multi-functional team processes, and 3) installing or improving the support systems for individual decisions.

The three levels of diagnosis, in practice, could be a multi-faceted iterative process, in which all three foci - organizational, team and

individual - are first examined in a preliminary way, then all three or part of them are examined in more detail. The actual emphasis of diagnosis will depend on the following factors:

1) the characteristics of organization problems in study - a typical scenario might be: "there is a symptom which brings us into the situation; we first look quickly at all levels around the symptom; we then redefine the problem, or maybe focus on different individuals and different team processes when we shift to more detail".

2) the nature of the intervention process, e.g., the entry point (level of organization and functional area), the organization's capacity to change, the intervenor's resources constraints (time, knowledge, skill, etc.).

3) the strategies of intervention, e.g., whether a pilot project is necessary to establish the intervenor's credibility through the quick feedback effect of the project.

3.3.2. Analysis and Diagnosis Techniques

Controlled System. The notions of resource cycle and work unit are operationalized through the following procedures: 1) translate work flow of a transportation process into resource cycles, 2) select one class of resource (each time) and break its cycle into components, specify the hierarchical and horizontal mutual-dependence (inherent in the nature of core operations and operational buffers) among the components of the resource cycle, and 4) construct the work unit matrix through the identification of the managerial tasks involved in the planning, execution and review for each component of the resource cycle.

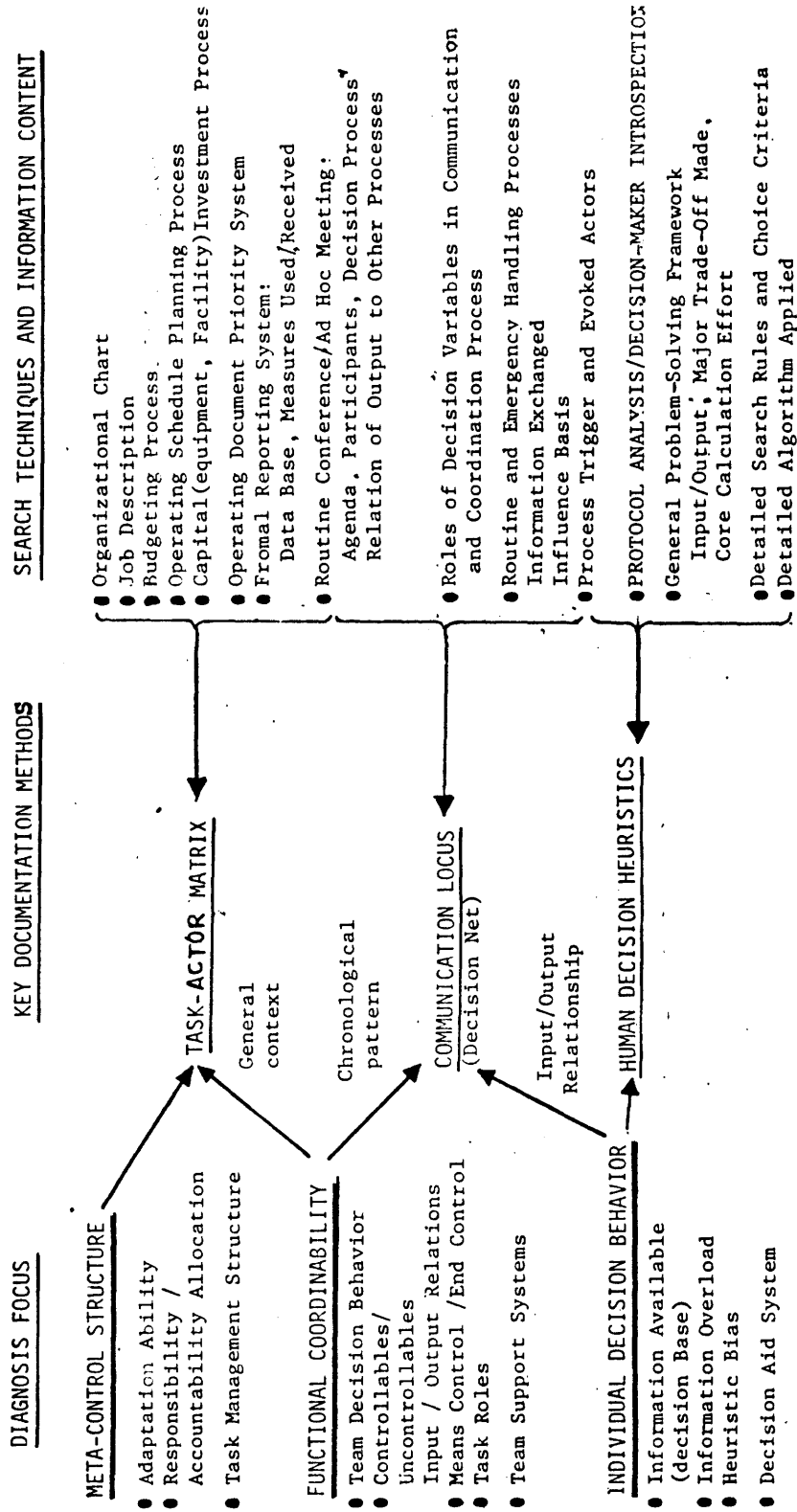
Controlling System. Operational procedures and techniques are developed in this study to support the diagnosis of the controlling performance from each of the following three perspectives - organization-wide, team, and individual. The technique suggested for examining the general linkages between the dual systems is the construction of a Task-Actor Matrix [Exhibit 3-2-5] which displays the relationships between the work units and the authority / accountability of the organization units as well as the three management control cycles. Inadequate linkages will be explicated through such an analysis.

The diagnosis of team-based decision behavior is conducted through the analysis of communication locus [Exhibit 3-2-6] and the decision base of individual actor involved in the process. These analyses allow us to examine the adequacy of communication and coordination process.

Decision heuristics are the focus in the diagnosis of individual decision behavior. Protocol analysis and introspection analysis are two alternative techniques. The key theme is to specify the requirements of the external aid system which is capable of improving individual decision quality.

The organizational diagnosis procedures and techniques mentioned in this chapter can be summarized into a single sheet as shown in Exhibit 3-3-1, which by an organizational diagnostician as a kit of tools, provided he is interested in transportation operations management issues.

Exhibit 3-3-1 DIAGNOSIS OF CONTROLLING SYSTEM: FOCUS, DOCUMENTATION AND TECHNIQUES



3.3.3. Post Diagnosis Intervention Tasks

Identifying Potential Dimensions for organization Intervention

In theory, organizational diagnosis is only one of the steps in a more general organization intervention and change framework in which the organization diagnostician can be viewed as a change agent, who could be either an external analyst or internal manager [Philip, 1980]. Bennis [1966, Chapter 7] pointed out that a change agent may intervene at different structural points in the organization (person, group, intergroup, etc.) and at different times. He listed the following nine major kinds of interventions which facilitate the organizational performance:

- 1) discrepancy: to call attention to a contradiction in action or attitudes,
- 2) theory: research findings or conceptual understanding which helps the system gain perspectives,
- 3) procedural: a critique of the existing method of problem-solving,
- 4) relationship: to focus attention on intergroup relationships,
- 5) experimentation: to set up comparisons and to test several actions before a decision is made,
- 6) dilemma: to identify choice points, understand assumptions and search for alternatives,
- 7) perspective: to provide situational or historical understanding through detached study,
- 8) organization structure: to identify sources of problems bound in the structure and organizational arrangements,
- 9) cultural: to focus on an examination of traditions.

The above list suggests the following two important points: 1) an organizational diagnostician should be sensitive to issues in a variety of dimensions, such as behavioral, informational, structural, procedural, contextual as well as technological, and 2) to improve the performance of an organization, there exist multiple approaches (also see the quotation from [Michael, et al, 1981] in Section 3.0), although

each approach may imply a different degree of effectiveness to the improvement of the performance. In short, because there is usually more than one way to treat the same symptom identified through the application of substantive knowledge and the diagnosis methodology, during the course of intervention, the organization diagnostician should collect information in a way which will facilitate the selection of the most effective intervention (prescription and treatment) approach from all available dimensions.

Behavioral Dimension of Organization Intervention

According to the planned change paradigm, the successful implementation of an organizational intervention program depends essentially on the acceptance and commitment of management [Philip, 1980]; therefore, to develop an effective change program (in terms of the substance of change rather than the change procedures)[*], management's participation is critical in the process of defining the problems (e.g., the interpretation of symptoms and the identification of the underlying causes of the symptoms) and of determining the change goals (e.g., to what degree the causes of the symptoms should be treated, which intervention dimension should be selected, etc).

In this study, we recognize the empirical importance (in terms of eventual implementation) of management's acceptance of and commitment to an organizational planned change process; nevertheless, our key theme is limited to the demonstration of how to establish a logical linkage to

*: Successful organization intervention will proceed back and forth between two sets of activities, i.e., substantive (technical) and procedural (behavioral) [see Exhibit 1-2-2].

integrate the following elements: substantive theories, diagnosis methodology, symptom identification and specification of improvement plans; therefore, management participation is not emphasized in this study.

C. Emerging Actionable Improvement Plans

The eventual objective of organizational diagnosis is to develop actionable and effective performance improvement plans. To do so, it is important to integrate the potentially profound diagnostic information into a coherent intervention perspective. Chapter 7 of this study demonstrates how to identify problematic symptoms and to sketch actionable plans to improve the macro-level, functional-level as well as individual-level performance, based on the background information (Chapter 4 through 6) and the theories derived in Chapter 2.

APPLICATION

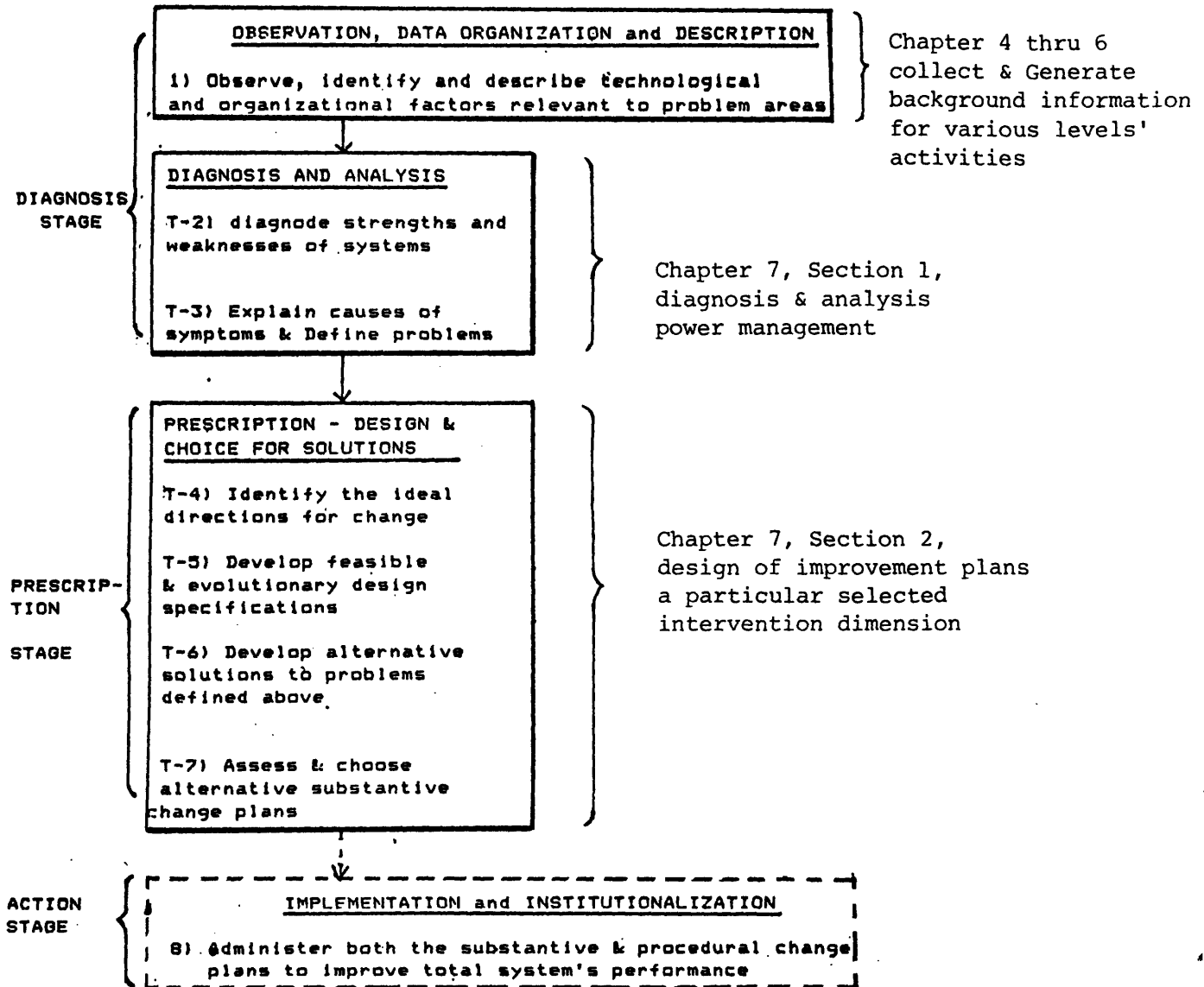
Introduction to the Application Chapters

In the following four chapters (4 thru 7), we shall demonstrate how to apply the theories and methodologies developed in the preceding chapters to the context of rail motive power operations management, and illustrate how specific theoretical and practical insights into the technology being managed can be used explicitly to describe, diagnose and improve the controlling system. We shall also illustrate how the various notions developed or adopted in this study (such as work flow, resource cycle, work unit, control task, meta-control structure, decision net, decision heuristics, etc.) can be applied to a real world context, and how important it is in terms of the insights gained.

By referring to the general organization intervention framework, the materials covered in Chapter 4 through 6 basically pertain to the first phase of the diagnosis stage in an organization intervention process as indicated by the top block of Exhibit 4-0-1, i.e., concerning with the provision and description of background information about the technology being controlled and the related organization system.

Chapter 7 covers those tasks pertaining to the second phase of the diagnosis stage as well as the prescription stage as indicated by T-2 thru T-7 in Exhibit 4-0-1. More specifically, the first part of Chapter 7 deals with the diagnosis of the strengths and weaknesses of the systems in question, the identification of problematic symptoms and the definition of problems, while the second part deals with the

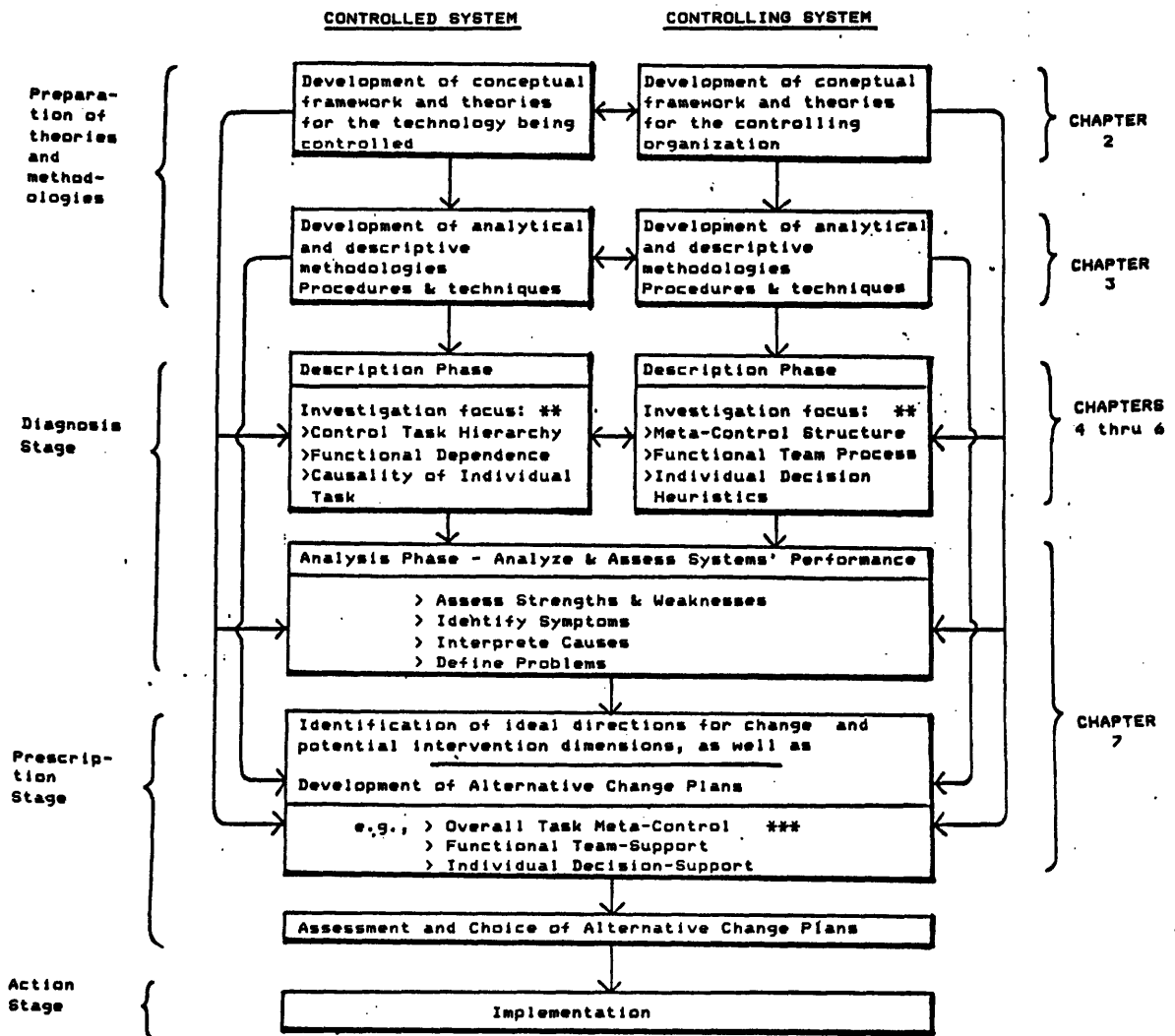
Exhibit 4-0-1 Contents of Chapters 4 thru 7
- Intervention Process Perspective



identification of ideal change directions and the development of some preliminary design specifications for the improvement plans. However, we should note that the purpose of this chapter is demonstrative - in terms of how the theories and methodologies developed in this study can be applied to guide the design of change plans - therefore, some of the tasks listed above (T-2 thru T7) are done partially or implicitly. For instance, we have no attempt to identify exhaustively all possible directions for change, or all possible alternative solutions to the problems defined. Nevertheless, this token should not be critical to the purpose this chapter is intended to serve.

From dual-system perspective, based on the theories and methodologies developed in this study, the specific foci of the following chapters are as below [see Exhibit 4-0-2]. Chapter 4 devoted to the identification of the control task hierarchy and the meta-control structure of rail power operations management as a whole. Chapter 5 highlights the functional dependence between maintenance and transportation operations, and functional team processes associated with the above operations. Chapter 6 concentrates on the analysis of one specific decision's (locomotive dispatching) underlying causality and heuristics applied by the decision maker. Finally, Chapter 7 deals with the overall diagnosis and proposes three interrelated sets of plans to improve the performance of the overall task, the coordinability between functional lines and the quality of individual decision.

Exhibit 4-0-2 Contents of Chapters 4 thru 7 - Dual-System Perspective



- *: Substantive activities only, procedural ones not included - See Exhibit 1-2-2.
- ** : Ideal diagnosis covers organization, team, and individual three levels' performance.
- ***: Ideal improvement plans may cover organization, team, and individual three levels' activities.

Chapter 4

THE GENERAL TASK OF POWER OPERATIONS MANAGEMENT

The purpose of this chapter is to understand the general nature of railroad motive power operations management and to draw an overall picture concerning both of the controlling and controlled systems through the application of the theories and methodologies developed before. The knowledge and insights gained in this chapter are essential to the diagnosis of the macroscopic performance of the systems, moreover, they may also serve as a general reference frame for the more microscopic inquiry into the systems.

4.1 The System Being Controlled

4.1.1 Conceptualization of the Railroading Process

A. Special Features of Railroad Technology

The railroad technology is characterized as well as complicated by the following factors:

1) Railroad vehicles can only maneuver one-dimensionally along their confined guideways. The advantage associated with this character is that high capacity of vehicle flow as well as safety in all weather can be attained via a deliberate traffic control system that keeps its vehicles in proper relation to each other. However, there is also a disadvantage, e.g., this character limits the accessibility of the service network and the flexibility of operation in picking up and delivering cars.

2) Railroads enjoy a high degree of operational freedom in creating various sizes of freight carrying capacity of its vehicle - the train. The advantage is that vehicle capacity can be tailored exactly as traffic demands - in Morlok's term [1978, p. 103], a rail freight train is a typical "fully differentiated vehicle." The conceivable disadvantage is that it is uneconomical to operate single car, thus considerable effort must be spent to form train of cars.

3) Freight cars are detachable from the motive power; locomotives can be utilized even while the cars are being processed (loading, unloading, or switching).

4) The motive power on a rail train can be closely tailored to the actual speed or travel time requirements of the train, or the gradients and speed restrictions of railroad lines. From operating point of view, the last two characteristics create a particular managerial task in the rail industry - the management of motive power operations. There are normally two power fleets in a railroad: one is for linehaul operations, the other is for yard switching. This study focuses on the linehaul (or road) power fleet.

B. Analysis Perspectives of Railroad Operations

The analysis of the railroading process can be put into a variety of perspectives. The first is from a carrier's viewpoint. "The business of the railroad is the selling and delivery of transport. From an economic stand point, it is the ability to assemble and move a large number of coupled cars as a unit that distinguishes the rail systems: so the real name of the game is running trains" [Armstrong, 1978 p.79]. However, the nuances of train scheduling are important to the railroad,

but the shipper does not care how the trains move. The important thing is when the carload will be delivered at the consignee's plant [ibid, p.172]. In other words, from the customer's point of view, the quality of dock-to-dock service is the most essential attribute of rail freight transport.

To integrate these above two potentially contradictory view points, a more disaggregate and subtle conceptualization of rail operation is necessary - a carload movement perspective. The railroading of freight cars consists primarily of the following elements:

- 1) local pick-up switching
- 2) departure-terminal classification and assembling
- 3) linehaul movement and intermediate yard reclassification (if any)
- 4) receiving-terminal set-out
- 5) local delivery switching

Exhibit 4-1-1 [modified from Wyckoff, 1976, pp.24-26] schematically describes the typical railroading process in terms of its physical work flow and its associated controlling information.

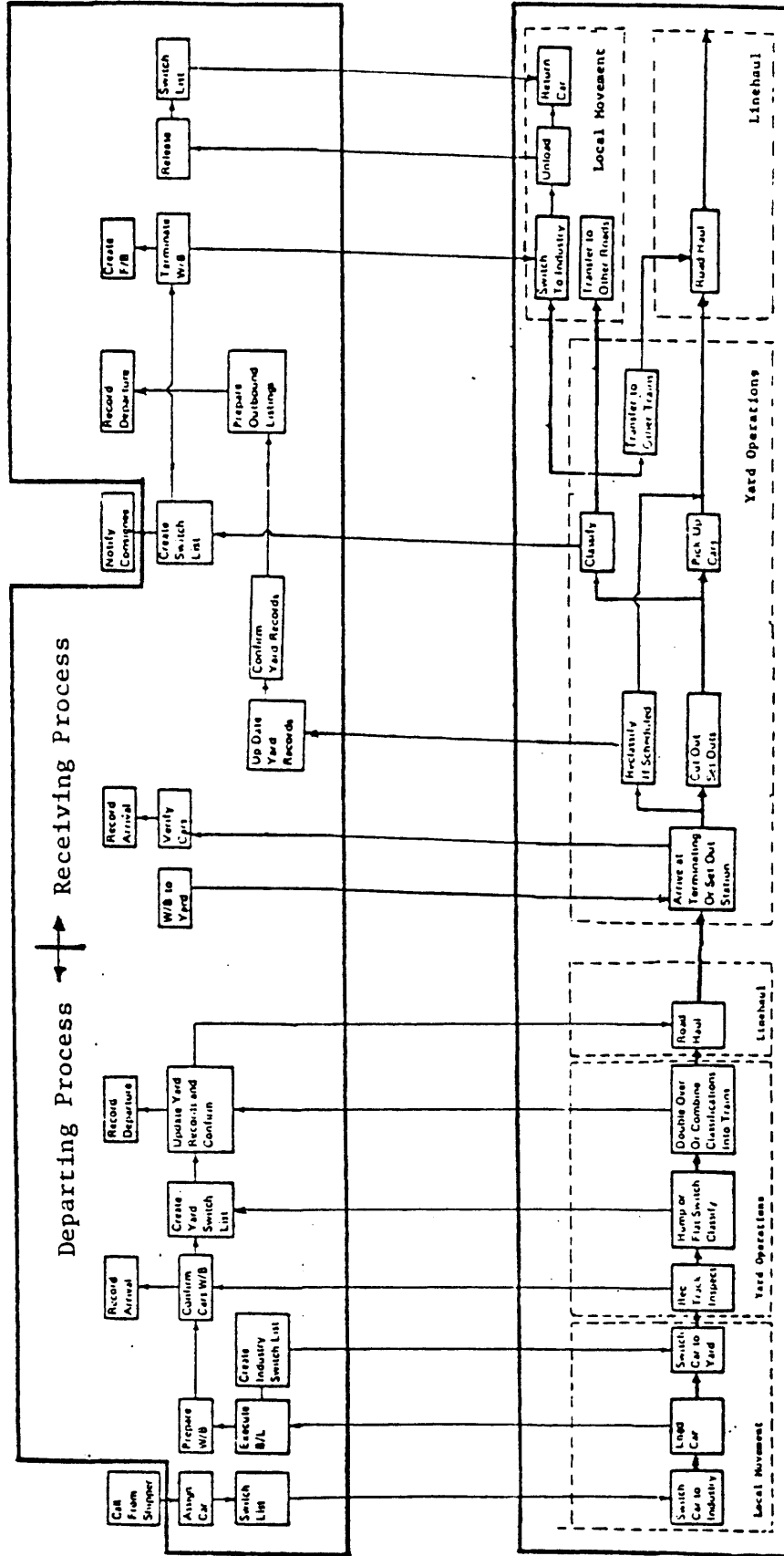
To translate the above notion of carload-movement into a framework which can directly serve our purposes, we must further analyze the flows of resources which result in car movement. From vehicle flow's perspective, the railroading process can be reduced into two complementary work flows: 1) the main flow of cars and trains, and 2) the supporting flow of power. Exhibit 4-1-2 depicts such a view of the railroading process which underlies the analysis of this study.

EXHIBIT 4-1-1

THE RAILROADING PROCESSES --- PHYSICAL WORK FLOWS AND CONTROL INFORMATION FLOWS

(Modified from D. D. Wyckoff, 1976, "RAILROAD MANAGEMENT", Fig. 3-1,2, pp. 24,26)

Control Information Flows



Physical Work Flows (System Being Controlled)

Note: Heavy lines indicate physical movements of cars and freight.
 Light lines indicate information flows.
 W/B = Waybill.
 B/L = Bill of Lading.
 F/B = Freight Bill.

EXHIBIT 4-1-2

CONCEPTUALIZE RAIL OPERATIONS --- INTERRELATED WORK FLOWS

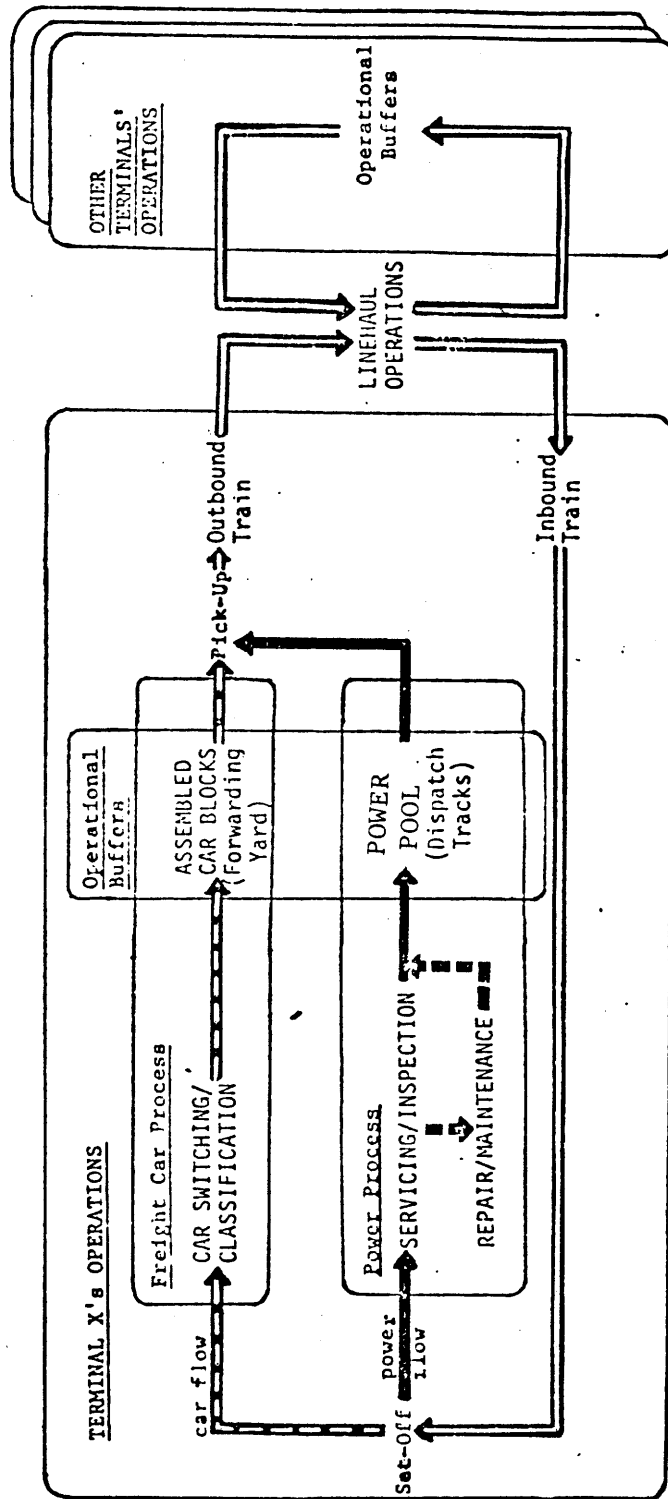
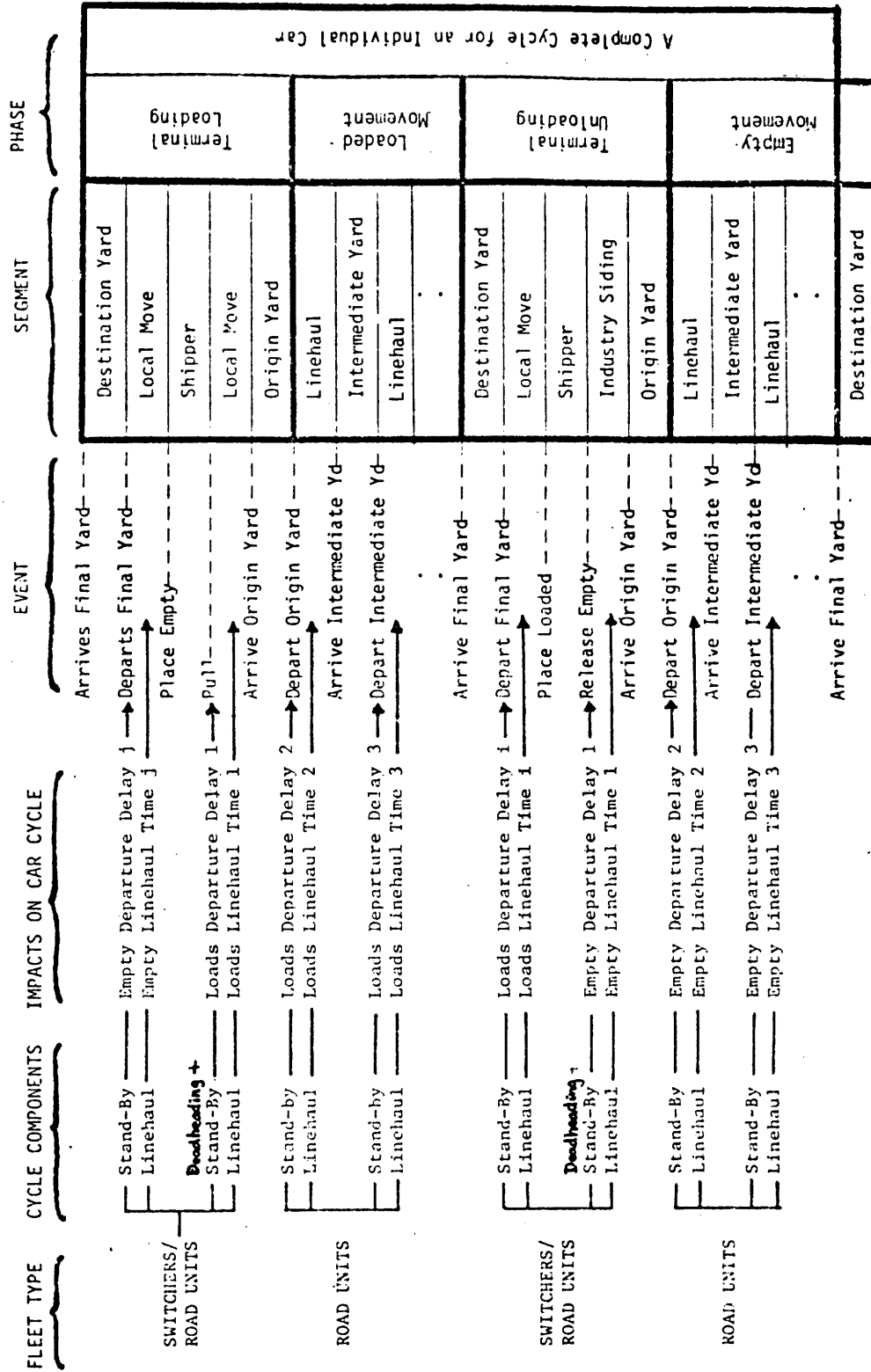


Exhibit 4-1-3 THE INTERFACES OF POWER CYCLE AND FREIGHT CAR CYCLE

COMPONENTS OF POWER CYCLE RELEVANT TO CAR CYCLE

COMPONENTS OF CAR'S CYCLE*



* Source:

M.G. Messner, 1980, "A SYSTEM FOR CONTROLLING A RAILROAD'S ON-LINE FREIGHT CAR CYCLE", Unpublished Master Thesis, C.T.S. MIT, P.29.

C. The Interplay Between the Power Flow and Car Flow

Since we conceive that the management of power plays primarily a supportive role in rail operation, it is important to have a general picture regarding the fundamental interplay between the processes of power and freight car movement. The cycle of a freight car can be basically divided into four categories: terminal loading, loaded movement, terminal unloading and empty movement. If we put these components into a car cycle framework, they constitute a sequence as shown on the right hand side of Exhibit 4-1-3.

To deliver freight cars, first there must be power available on the scene, and then power and freight cars must be assembled into a train. Thus, in the process of power operation, there will be some components directly associated with the movements of freight cars. There will also be some components primarily devoted to be awaiting (or distributed without any load - usually called deadheading - to certain industrial sidings and then awaiting) the call for service at rail yards or industry sidings. In other words, there are two primary components in the process of power operation which are linked with car cycle: we may refer to them as the linehaul and the stand-by (or deadheading plus stand-by) components of the power cycle. Exhibit 4-1-3 depicts the relationships discussed above.

The practical implications of the above relationships are two-fold. The first is that it highlights the degree to which the management of power affects the ultimate service of rail operation. In linehaul operations, both power and cars (either loaded or empty) are locked together; therefore, the performance of the freight car is determined by

the performance of power. For the other interface elements (on the car side, the departure operation; and on the power side, the stand-by components), the interactions are more complex. By and large (as we will discuss in detail in Chapter 6), the interrelation is basically a compensatory one: shorter (average) car departure delay can be attained only at the expense of longer (average) power stand-by time.

The above trade-off between the flows of power and cars entails another important operating concept, the notion of the physical operational buffer. Referring back to Exhibit 4-1-2, at the interface between the car flow and power flow, two respective operational buffers can be identified. One is the assembled car blocks in the departure yard and the other is the power pool on the ready (dispatch) tracks. From a power management point of view, to protect on-schedule train performance and to absorb unexpected demand, it is necessary to maintain a pool of slack resources (locomotive) standing by for service. However, an oversized power pool is simply in conflict with efficient utilization of this resource. Therefore, in this study, we argue that a key to controlling power performance is to control the operational buffers in the power process since, to a very large extent, they represent the pivot point on which the balance of service quality and power utilization relies.

4.1.2 The Power Cycle Hierarchy

A. Factoring the Power Cycle

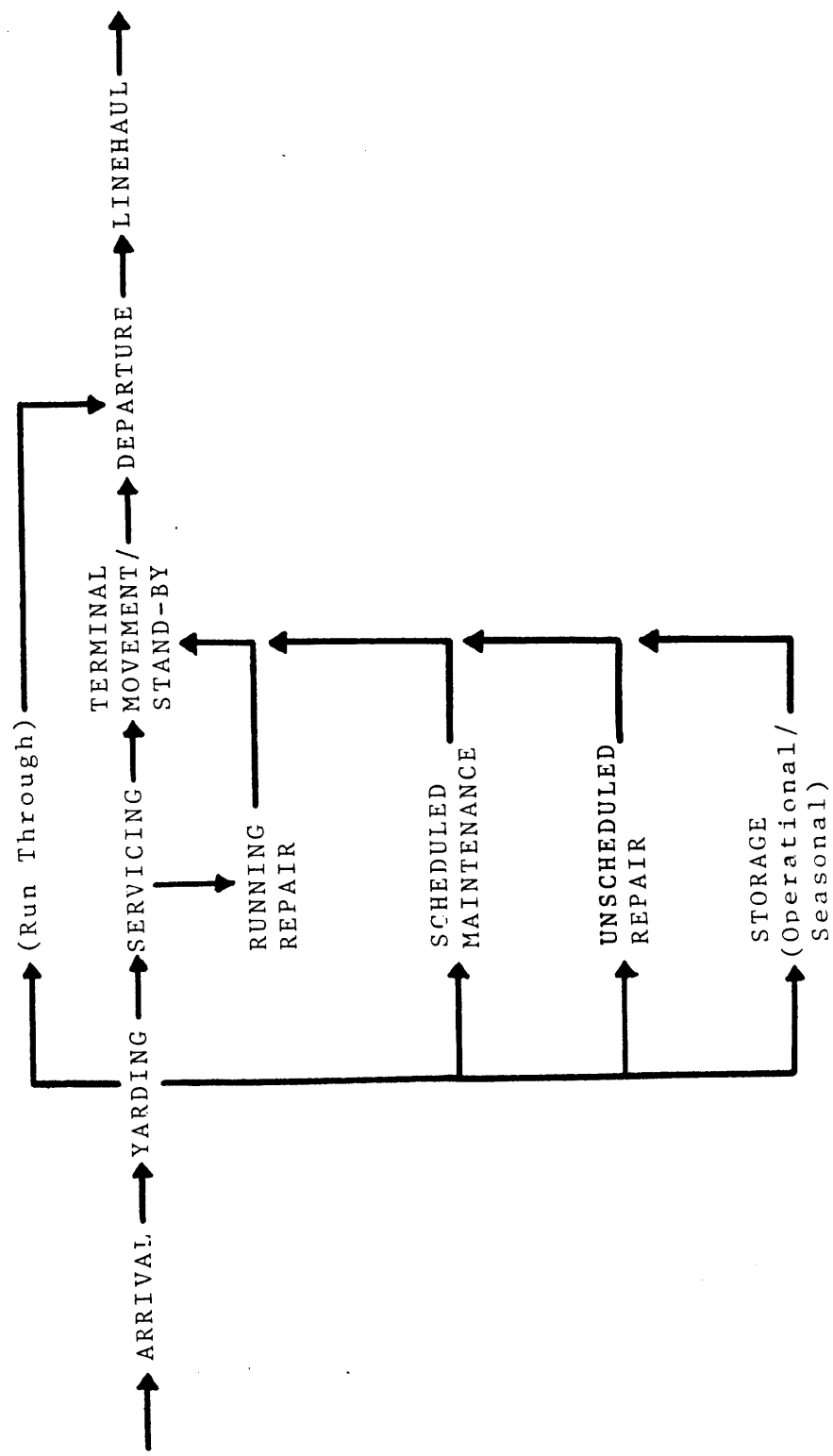
According to the dual-system paradigm presented in Chapter 1, the analysis of the system being controlled involves defining the control tasks and the interrelationship among them. In Chapter 2, we suggested that vehicle cycle is a useful analytical concept. To specify the cycle of motive power (which is the vehicle of major concern in this study), the power flows identified in the preceding section must be factored into components. Exhibit 4-1-4 gives a typical set of componential processes arranged in their normal sequences (a more elaborated fragmentation can be found in Chapter 5) which a road-locomotive (or engine) regularly undergoes. Briefly, as soon as it enters a terminal from its linehaul journey, an engine may experience one of the four processes:

- 1) retaining at the main track - run through power,
- 2) servicing (fueling, sanding, watering, inspection) or performing running repair, if needed, at service station,
- 3) scheduled maintenance or unscheduled repair at engine shop, or
- 4) storage (tentatively or seasonally) at the storage tracks.

After the completion of servicing (or repair, or storage), an engine will be sent to the dispatch tracks awaiting linehaul service. Finally on receiving the service call, the designated engines will be moved to the forwarding yard and be coupled to an outbound train. A linehaul journey for those engines will then begin and the whole process will start over again [*].

*:Road units in certain cases may be assigned to assist terminal work - used as yard switchers. Nevertheless, we consider this a minor practice and exclude it in the above flow break-down.

EXHIBIT 4-1-4 FACTORING POWER FLOW INTO COMPONENTS



B. Power Cycle Hierarchy

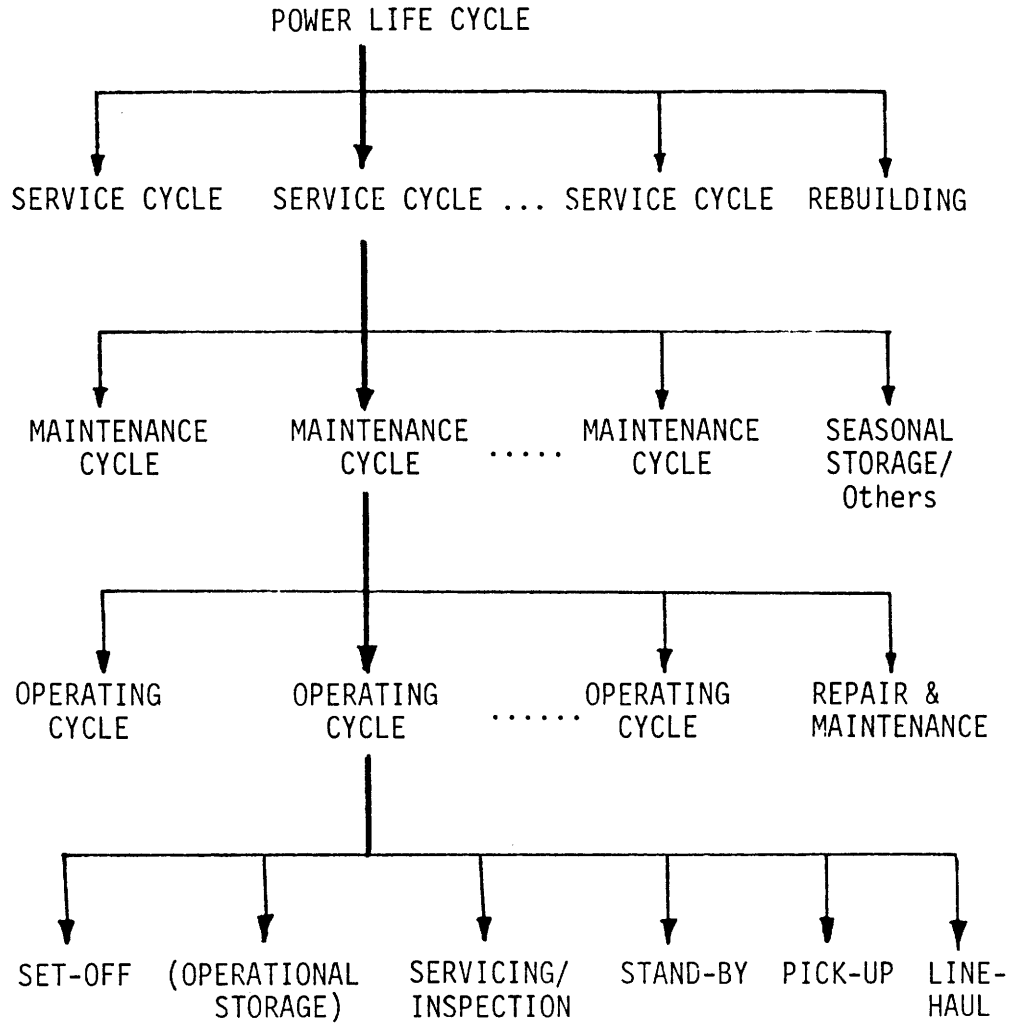
Since at any point in time, an engine cannot appear in more than one of the locations (i.e., sub-processes) specified above, the factored power flow diagram (Exhibit 4-1-4) can be viewed as a road engine's state-transition diagram. It is possible to observe some regularity regarding the transition pattern of an engine's operating status when the pattern is put into a time perspective. The process of power cycling, constitutes a hierarchy of status (see Exhibit 4-1-5).

At the lowest level, linehaul operation, daily inspection and servicing (including minor running repairs) at service station, stand-by at dispatching tracks, temporary storage, as well as the pick-up and set-off operations, are the five elementary components which a normal road unit undergoes consecutively on a daily basis. They may be called collectively the OPERATING CYCLE of a road unit.

On a periodic basis, namely, every 45-day[*], 90-day, semi-annual, annual, and biennial, an engine is subject to scheduled maintenance. In addition, an engine may accidentally break down and need to be fixed, not in accordance with the maintenance schedule. Before being engaged in any major maintenance operation (scheduled or unscheduled), a road unit normally will have already served several operating cycles. The series of operating cycles between two consecutive major maintenance (or repairs) including either maintenance (or repairs) can be called the MAINTENANCE CYCLE of motive power.

[*]: The monthly procedure (it is actually and legally implemented every 45 days in most U. S. railroads), which mainly covers running gear, controls and breaks, is usually supplemented by such diagnostic tests as a chemical analysis of the lube oil to detect early symptoms of unusual engine wear or internal leaks.

Exhibit 4-1-5 POWER CYCLE HIERARCHY



For some units, in addition to maintenance/repair, various off-line activities may be involved, such as seasonal storage, leasing to other railroads or to commuter rail agencies. The series of maintenance cycles in conjunction with the subsequent off-line activity comprise the SERVICE CYCLE of an engine.

After a series of service cycles, depending on the severity of the service to which it has been assigned, a unit will be ready for a major overhaul - this could entail rebuilding trucks, replacing a power assembly, or other major work - which usually calls for a "project" for that unit. Complete rebuilding may be in order at the end of a unit's life (20-30 years), at that time a unit could be 1) traded in for new units, 2) remodeled (by the railroad's own shop or by a contract rebuilder), or 3) cannibalized for parts to keep sister engines in service. These actions either technically renew or eventually terminate the LIFE CYCLE of an engine.

In summary, the major components of the power cycle can be specified as: 1) linehaul, 2) inspection and servicing (including running repairs), 3) standing-by, 4) set-off and pick-up, 5) operational storage, 6) maintenance and repair, 7) seasonal storage and other off-line activities, as well as 8) overhaul or rebuild. There is a hierarchical relationship among the above components. The notion of power cycle refers to a hierarchy of cycles: operating cycles, maintenance cycles, service cycles, and life cycles.

C. Interaction Among Power Cycle Components - Individual Unit

While there is no single measure that adequately describe the multi-dimensional management implications of the power cycle, time is

one practical performance criterion. A systematic evaluation of how a unit spends the time of its life cycle provides many prospects regarding the characteristics of power cycle.

For an average unit in the power fleet, the total amount of life time can be fragmented in accordance with the power cycle components as shown in Exhibit 4-1-6. Within the pie of the power cycle time split, a change in any one component will affect other component, in terms of their respective share. Moreover, the characteristics of the individual cycle components could feedback and determine the life cycle of a power unit. For instance, a constant heavy work-load may shorten an engine's life cycle, while high quality maintenance may prolong the cycle. These mutually dependent relationships among power cycle components have vital implications for the management of motive power.

For demonstration purpose, Exhibit 4-1-7 displays some principal trade-offs among various elements of the power cycle: a) to the extent that faster maintenance will not jeopardize its quality, less time in maintenance means more time will be available in the operating cycle; b) given total operating cycle time, less time in detention indicates more time used in linehaul operation; c) given total detention time, less time in the servicing process denotes longer time available in stand-by for service. These trade-offs have significant implications for power management and the key is to specify the underlying decisions that will result in these particular relationships and to identify alternatives to modify or improve decision behaviors. However, our discussion so far is individual unit oriented. Before we get into the issue of translating power cycle into actionable control tasks, we must further examine some

EXHIBIT 4-1-6

POWER CYCLE TIME SPLIT

* A CHANGE IN ANY ONE COMONENT WILL AFFECT OTHER COMPONENTS

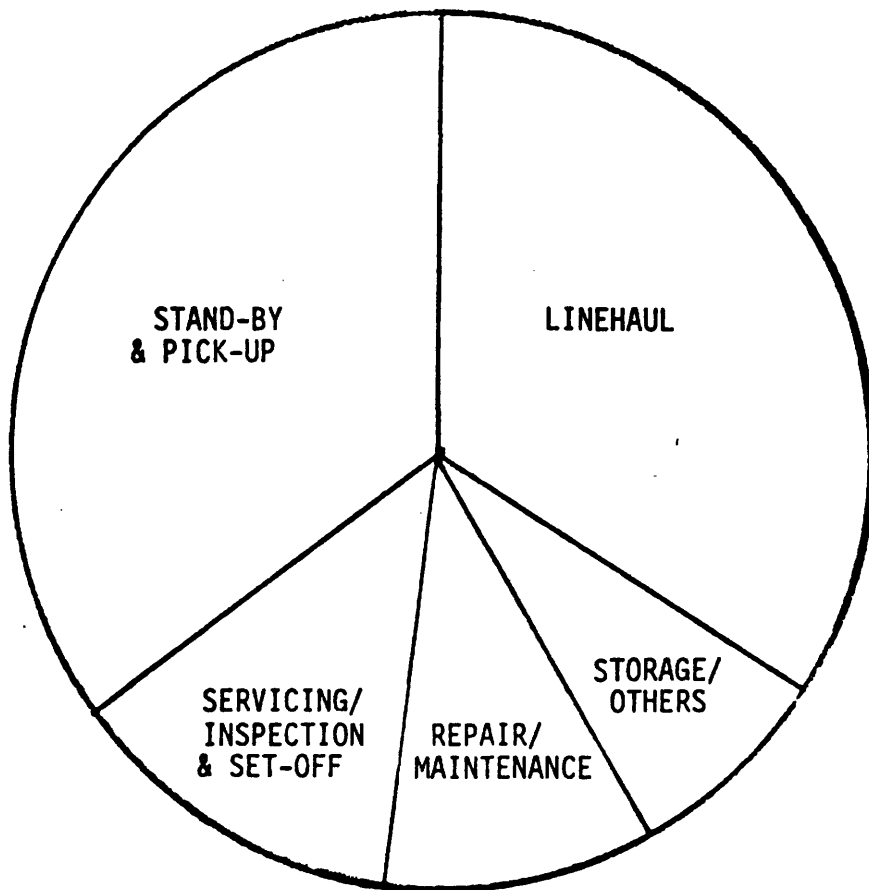
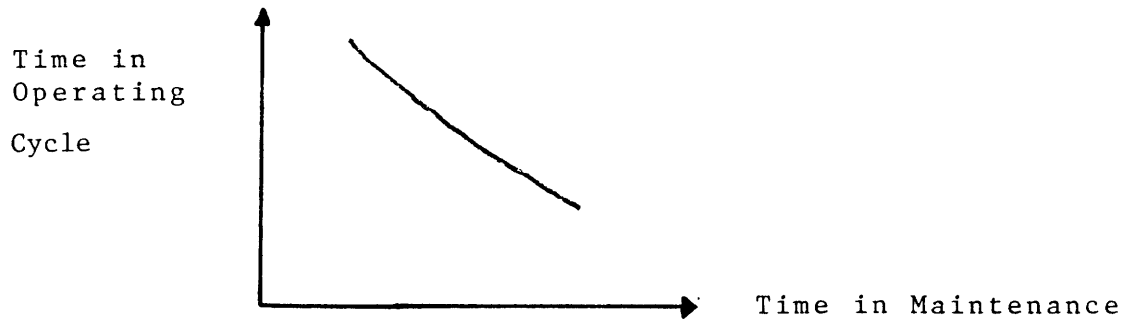
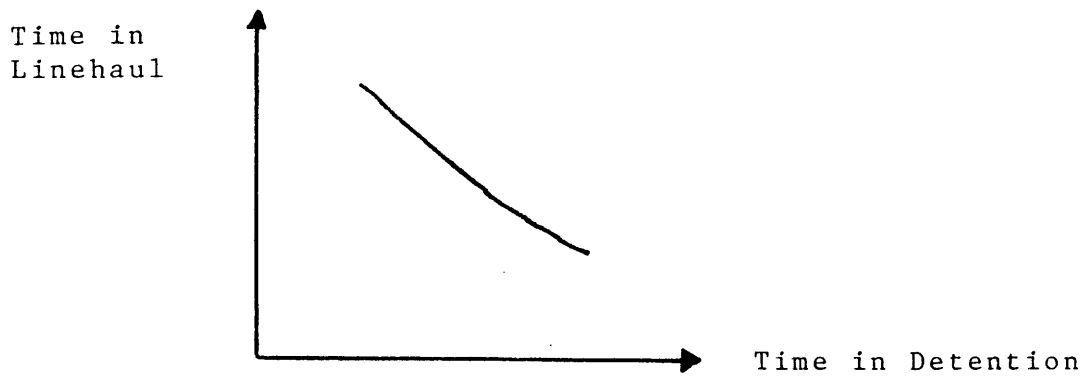


EXHIBIT 4-1-7 TRADE-OFFS AMONG POWER CYCLE COMPONENTS
(INDIVIDUAL UNIT)

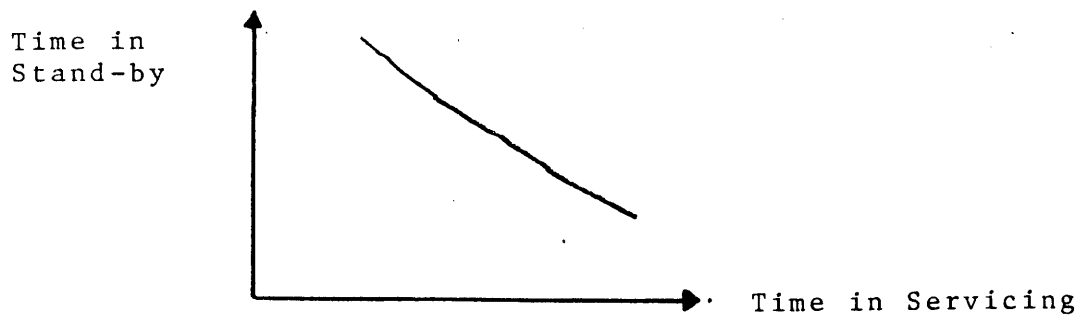
A. Given Maintenance Cycle Time
(to the extent faster maintenance
would not deteriorate its quality)



B. Given Operating Cycle Time



C. Given Detention Time



fleet-wide aggregate effects of power cycling.

4.1.3 The Aggregated Effect of Power Cycling and Its Ultimate Service Impact - Total Fleet

In this section, for each level of the power cycle, some performance indices are specified to illustrate the interactions among the cycle components as well as their impact on service. The material is extracted from Mao and Martland [1981], Mao, Sussman and Philip [1980].

A. Aggregate Effect of Power Cycling - A Power Availability Measure

The performance indices specified here for each level of power cycles are as follows [1].

life cycle: total fleet (number of units, denoted by N) and composition - mixture of various models (measured by average horsepower per unit, denoted by P) [2];

service cycle: active fleet size (total fleet excluding off-line units),

maintenance cycle: serviceable fleet size, i.e., active fleet excluding the out-of-service units (the effects of off-line activities and maintenance are collectively represented by a multiplier F),

operating cycle: ton per horsepower ratio, speed, time utilization (denoted by R, S and U, respectively).

To measure the collective effect of various levels' power cycle components, a "Power Availability (PA)" formula was defined. [details see Mao, et al, 1980, 1981]:

$$PA = (N * P * F) * (R * S * U) \text{ (ton-mile / time-unit)}$$

1: We don not claim they are the only relevent indicies to this issues, but they are convenient ad informative.

2: The flexibility of being able to use the power fleet interchangeably to provide total power for each train is an important factor in achieving efficient locomotive utilization.

The most important policy implication of this fleet-wide formula is that, given a certain desired level of power availability, there exists a set of multidimensional strategies which can be implemented at various levels of power cycle to achieve that desired availability. In order to increase the total power availability (PA), for instance, one may increase the static capacity: serviceable power fleet or the average horsepower/unit, or alter the dynamic operating factors: operating speed, ton-per-horsepower ratio or improve the time utilization rate. The optimal PA level and the choice of strategies for achieving that level will be determined by the operating and economic implications of the strategies [Mao and Martland, 1981, p. 309]. To assess the appropriateness of the PA level, we should further probe into the impact of different PA levels on rail service. To serve this purpose, based on the queueing theory, an aggregated service impact model was developed.

B. Ultimate Service Impacts - An Aggregate Service Impact Model

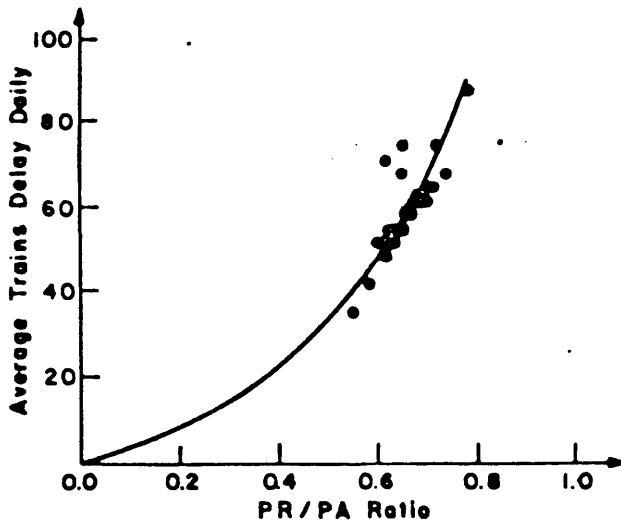
In queueing theory, there are three fundamental measures: capacity, system-load and service quality. To apply this paradigm, we may refer to the collective power availability as the system capacity. As to the system load, an operational definition called "Power Requirement(PR)" was specified, which is a function (also in product form) of the following factors: the number of car-loads, average car weights, average length of haul, empty-to-load ratio. The interactions between power availability and power requirement can be reflected by the service quality which was defined as the train delays due to power (both in terms of frequencies and the total elapsed time) [details see Mao, et al 1980,1981]. Exhibit 4-1-8 illustrates some results of the aggregate

Exhibit 4-1-8 AGGREGATE SERVICE IMPACTS ANALYSIS

Source: Mao and Martland [1981]

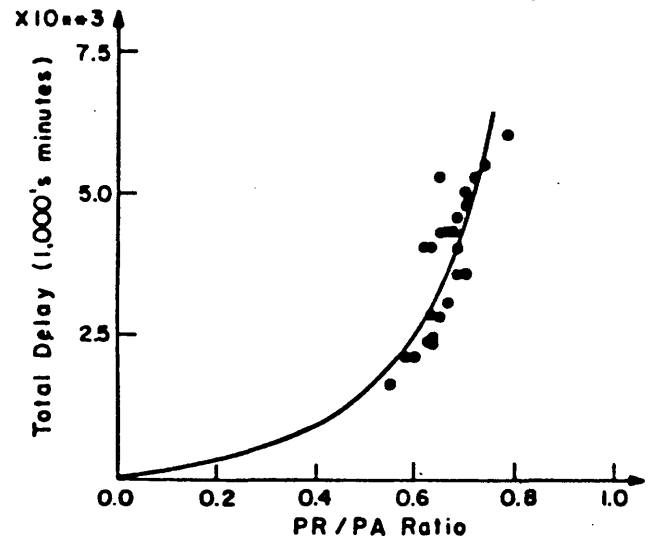
(A)

The Calibrated Relationship Among the Average Number of Trains Delayed and the Power Availability Ratio



(B)

The Calibrated Relationship Among the Total Minutes of Train Delay and the Power Availability Ratio



Remarks:

In Exhibit A, a scatter diagram is portrayed with the fitted curve of the number of train delays vs. the PR/PA ratio. From this figure, we learn that delays increase nonlinearly with the increase in the PR/PA ratio:

$$\text{Number} = 133 (\text{PR/PA})^2 + 3.6 (\text{DUMMY})$$

In this equation, NUMBER is the total number of delays caused by mechanical or operating factors, as summarized in Exhibit 3. The dummy variable is included to account for a major change in operations in June 1979; for earlier months, DUMMY is one, while for later months it is zero.

Exhibit B illustrates the parametric relationship between the train delay time and the PR/PA ratio. We find a steeper curve in this case than the previous one — the power of the PR/PA term is 4 instead of 2:

$$\text{DELAY} = 18600 (\text{PR/PA})^4 + 3190 (\text{DUMMY})$$

In this equation, DELAY is the total minutes of delay for the approximately 5000 trains operated each month.

From the above analysis, one can show that changes in the PR/PA ratio (which range from .6 to .8) relate to changes of up to 4000 minutes/day in train delay time (against a mean of 4000 minutes) and 40 trains delayed (against a mean of 60/day). The interdependence between the PR/PA ratio and the freight train delays is significant, as hypothesized in Exhibit 1.

service-impact model by using a set of data collected from Railroad A.

The aggregate service-impact analysis provides insights into the trade-off between power operations and service quality. It indicates that given the level of power requirements, train performance varies with power availability. When power requirements are high relative to power availability, both the number of train delays and the total delay time increase. In addition, in Mao, et al [1980], using a different set of data obtained from another major U. S. railroad, a relation was found between car O-D trip time and power utilization. Most importantly, it highlights the importance of balancing the cost of power availability against the service quality (the latter could not only be directly translated from car utilization into customer satisfaction, but also into car utilization costs).

In summary, power availability analysis represents a means-analysis endeavor. The power availability formula, in fact, produces a suggestive framework for controlling power availability, which transfers the problem of power management into several key control tasks as we will see in the next section. On the other hand, the service-impact analysis represents an ends-analysis. It integrates the effects of the complicated interactions among operating strategies, system traffic condition and ultimate service quality. The results of such an analysis greatly enhance the clarification of the overall task goals as well as the linkages between power operating procedures and the more general operating environment. Based on the knowledge obtained thus far, we are ready to define the totality of the control tasks concerning power management.

C. Task Goals of Power Management and General Strategies

Due to the fact that without goals, there can be no control, to define the control tasks engaged in power management, we should start with the identification of the task goals as well as the general strategies which can be applied to achieve those goals.

Task Goals. Due to the supportive role played by rail motive power, the primary goal of power management is to support train operations so as to pursue desired service quality. The task of power management is an endeavor to match power availability to power requirement at both system and terminal levels, with an aim to balance service quality and other resources' (e.g., car, crew, etc.) costs against power cost.

General Strategies. There are at least two distinct sets of general strategies that can be applied by power management to attain the above task goals. The first, by taking the power availability level as given, is through the changes in power requirement to 1) improve the service quality, or 2) improve utilization efficiency of power. Specific strategies within this category include: 1) reducing the empty-to-load ratio through well-designed car distribution plans, so as to accommodate more car loads (and less empty car) in each engine's linehaul journey (By the same token, shorter dock-to-dock transit times can be attained), 2) encouraging shippers and consignees to ship on a regular and continuous basis even during off-peak periods (e.g., low seasons of year, or slack days of week), so as to make better use of available power. This set of strategies usually requires the cooperation of marketing forces in the organizations. Effective coordination with

certain corresponding marketing programs is the key to the success of this strategy.

The second set of strategies is, by taking the power requirement as given, through changes in power availability to 1) improve the service quality, or 2) reduce power cost yet maintaining the same level of service quality. The identification of the specific strategies under this category, is one of the key themes of this study. In the following sections, we will first use the power cycle hierarchy to elaborate the control issues involved in each level of the power cycle as well as the inter-cycle relationships. Then we will translate them into a hierarchy of control tasks which represent the totality of the task of power management.

4.1.4 The Control of Various Power Cycles

The strategies to control power performance can be conceptually categorized into two classes. One is through the control of various fleet sizes, which are relatively long-run or mid-run oriented, including total fleet ownership, active-fleet and serviceable fleet. The second is through the real-time control of power utilization which includes the control of terminal power pools and network distribution, coordinating train/power dispatching as well as the scheduling of train and service operations. The following presents a detailed discussion of the above control tasks. (The material presented below is basically a synthesis from Mao, Sussman and Philip [1980], Mao and Martland [1981 and 1982], RSMA [1964], Emerson [1975], and Armstrong [1979]).

A. Fleet Ownership Planning

The control of an individual power unit's life cycle can be aggregated and transferred into issue of fleet ownership planning. The decisions on power fleet ownership mainly deal with the acquisition, disposal, rebuilding and retirement of power units. The determination of the size and type of locomotive to be contained in the power fleet has a direct bearing on the ability of power managers and the railroad to effectively discharge its service responsibilities.

In the process of planning the fleet ownership, it is essential to know the current motive power utilization, work performed and fixed requirements (e.g., maintenance); so that this data can be related to the prediction of traffic growth, the estimation of minimum base ownership, the identification of the need for specialization and standardization in matching power to tasks, and as a result the appropriate number of locomotives can be provided by purchase, rebuilding, and retirement programs.

Changes in service design can have considerable impact on motive power requirements. For example, changes in ton/hp ratio and ton/car ratio will change the horsepower required for a train; changes in train running time affects the required linehaul locomotive-hours, and so forth. Total fleet size is the general decision premise for the downstream fleet sizing (active fleet and serviceable fleet) and fleet utilization. The performance of the lower level decisions, in turn, feeds back to the total fleet sizing decision. The performance indices for this task should include, for instance, total horsepower available; GTM per available horsepower-day; and average car O-D transit time -

ideally the portion of time delayed by power should be specified.

B. Active-Fleet Sizing

The control of an individual power unit's service cycle can be put into the control framework of active fleet sizing. The control tasks at this level include decisions on the number of units to be stored, units to be leased in or out, the appropriate net balance with foreign roads. The incentives to reduce (store or lease out) active fleet size are several-fold:

(1) Maintenance Cost Savings. Fewer units to maintain requires less parts inventory, as well as less maintenance crew - about one man can be reduced due to the reduction of one unit [RSMA, 1964]

(2) More Control on Maintenance Schedule. Fewer units to maintain could result in better maintenance quality; well maintained units would perform better with lower failure rate.

(3) Less Fuel Expense. Due to the temperature-related engine efficiency reason, a current industry-wide practice is to keep the engine running during detention. For a 1000-unit fleet, fuel consumed during engine detention could cost millions of dollars in expense [Mao and Martland, 1982]. As long as it is mechanically desirable to sustain this practice, smaller power fleet could imply remarkably lower fuel cost.

In other words, to serve the same level of traffic, a smaller fleet implies higher power productivity and less short-run operating costs as well as long-run capital commitment (but at cost of less slack). In response to the changing pattern of traffic level, it is usually desirable to store units - particular those perceived as "odd ball",

expensive to run, or performing poorly - during the low seasons of the year. Another way to treat the surplus units during off-peak seasons is to use them as a shop margin allowance for maintenance operation, which will be discussed later. In effect, active fleet sizing provides a context within which maintenance activities will be both planned and controlled.

Active fleet sizing refers to the task of cutting the total fleet during off-peak periods down to the size which is most economical to operate but without jeopardizing the service quality. Thus, the performance indicies for this task may include: total power operating expense (or total power expense / ton-mile), GTM per active horsepower-day, amount of horsepower stored, etc.

C. Serviceable Fleet Sizing

The individual unit's maintenance cycle can be aggregated into the serviceable power fleet. The primary decisions involved in serviceable fleet sizing include decisions on the fleet shop margin (units out of service due to maintenance or repair), the quality and reliability standards (e.g., tolerable en-route failure rate) as well as certain maintenance logistics related issues (e.g., policies on parts inventory, home-shop assignment, manning-level, etc.).

Mechanical reliability determines the rate of unscheduled maintenance, and in conjunction with the scheduled maintenance operation, also determines the serviceable fleet size. The serviceable fleet should be sized to have all possible engines available during the peak seasons. If unavailability is reduced to the lowest level during the peak months, and is allowed to go higher during the remaining

periods, effective fleet can be reduced to a remarkable extent.

Maintenance and repair policies must establish the targets for peak period shopping, maintenance and servicing. The allowances for off-peak unavailability must be planned. Moreover, reliability of power in the fleet affects the amount of power assigned to trains. Horsepower will be added to the locomotive consist as an insurance against failures occurring en-route. as a result, "insurance" horsepower requires more engines in the fleet to handle a given service requirement and is also costly in terms of fuel consumption.

The daily measures of maintenance performance should include the number of units out of service (shop margin) compared to the targeted ratio for that period of the years, the train delays due to power enroute mechanical failures and, ideally, the number of units made available during each shift with respect to certain standards. The periodical performance statistics to be reviewed should include the ratio of scheduled maintenance versus unscheduled repair, mean elapse times of servicing, various categories' scheduled maintenance, unscheduled repairs and ideally, mean-time between road failures. The effect of mechanical reliability on power assignment is critical to the size of the serviceable fleet. However, the measure of this effect conceivably could be very controversial because all overpowered assignments do not necessarily result from reliability considerations. The assessment of this effect should be an integral part of power productivity control which will be discussed next.

D. Steering Control of Power Utilization

The control of the power operating cycle refers to the around-the-clock task regarding assignment and dispatch of serviceable engines to trains, as well as the balance of power distribution over the rail network. To this task, the general decision premises are train schedules, tonnage assembled to haul, as well as the maintenance schedule (which indicates when and where a unit is subject to shopping). All power operating related policies, such as ton/hp ratio, speed requirements, deadhead policy, helper-service, will be executed at this level. The major sub-tasks involved include maintaining power pools at each terminal, dispatching power in accordance with train dispatching operations, coordinating servicing schedule and train schedule as well as controlling power detention time.

The daily indices of performance should include: time utilization of power (linehaul horsepower-hour versus serviceable horsepower-hour), GTM per serviceable horsepower-day as well as the number of trains held and train-hours delayed for power. More ideally, records such as dragged trains (trains which are run with power level below that for normal operation), cancelled trains (cancellation of train due to lack of power) and tonnage removed from trains (in order to run the trains with available power) should also be summarized, both in terms of frequency and equivalent car-hours delayed, as gadgets to signify the operating effectiveness of the road freight fleet.

4.1.5 The Control Task Hierarchy of Power Management

To put the above seemingly complicated control tasks into perspective, a hierarchy of power management options can be summarized as illustrated in Exhibit 4-1-9 - which indicates that the control of power operations constitutes two interrelated sets of options: the management of power fleet size and the steering control of real-time operations; the former includes the control of engine's life cycle, the sizing of active fleet and the serviceable fleet, the latter includes the control of terminal power pool and network distribution pattern, the coordination and scheduling of train and power dispatching operations. To further amplify the above notions, we should differentiate the management options at each level into three major phases: planning, execution and performance reviewing, i.e., translate them into control tasks. In addition, to highlight the nature of the control context, certain major control premises should be specified at each level. Exhibit 4-1-10 summarizes the control tasks and their premises discussed in the preceding section into a control task hierarchy in a matrix form. Generally speaking, the high level control tasks create contexts for lower level operations, while equally important to note is that the lower level's performance in certain situations will indicate the need to alter the higher level control practices - for instance, the lower time utilization ratio during off-peak seasons can primarily be resolved by cutting down the active fleet size, but not through the improvement of real-time dispatching. To effectively and efficiently utilize motive power, a railroad should seek a "balanced" set of strategies to guide the control of the management of power through different periods of the

Exhibit 4-1-9 Key Strategies of Power Management

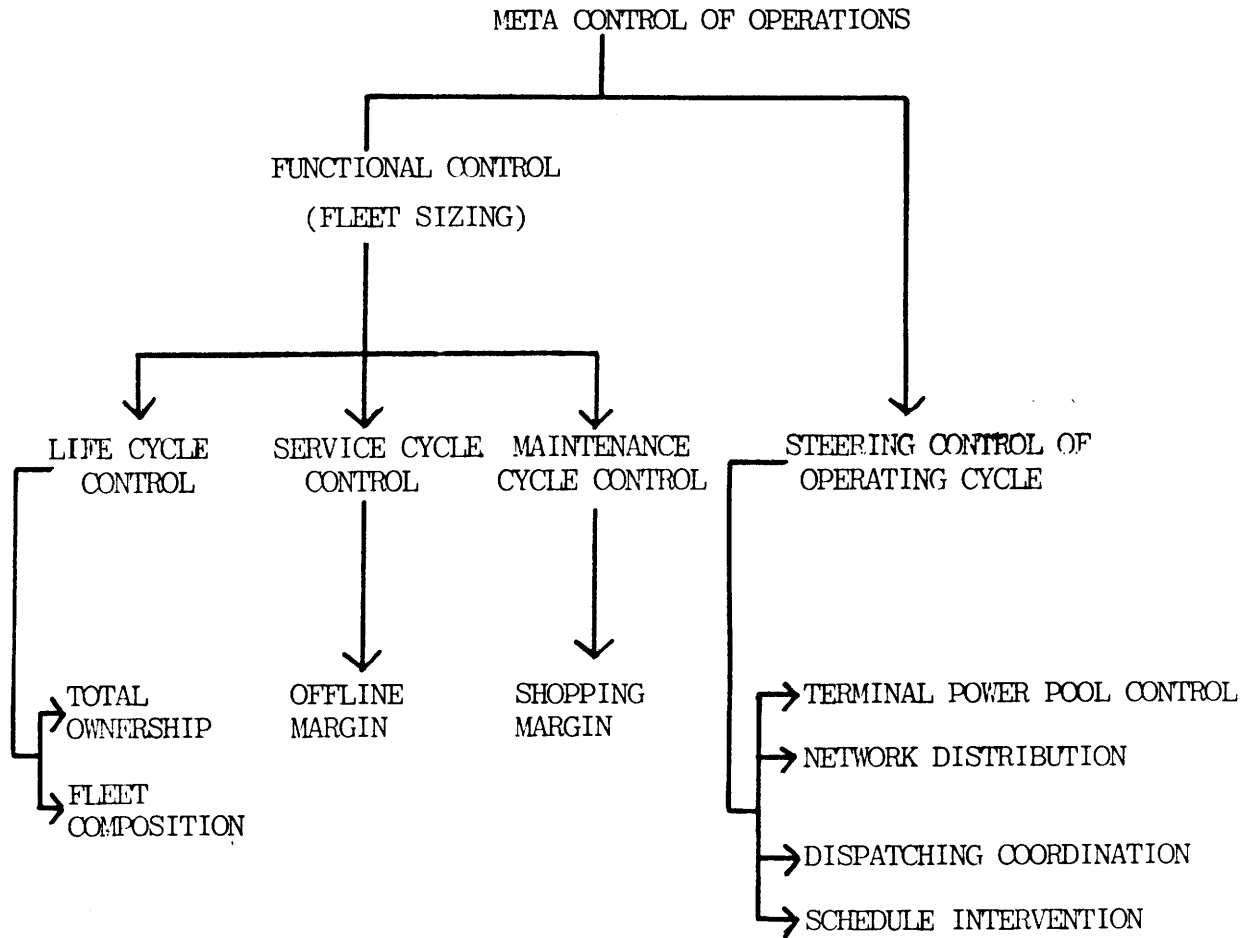


EXHIBIT 4-1-10 TOTAL CONTROL TASKS OF POWER MANAGEMENT

Power Management Cycle	Life Cycle	Service Cycle	Maintenance Cycle	Operating Cycle
(Promises)	power requirement (traffic level and pattern) desired service quality, system operational profile (efficiency indices of the lower level power cycling)	power availability level	power active fleet	train schedule, tonnage, maintenance schedule
Planning	power availability level	active fleet size, storage margin, storage policy guide	shopping margin (units out-of-service for maintenance), maintenance schedule, serviceable fleet sizing (annual profile)	hp/ton policy, to be hauled, utilization standard
Execution	overhaul rebuilding, acquisition/disposal plans; control of power service cycle	storage assignment, maintenance cycle control	shopping assignment, mechanical reliability monitoring, shop operations supervision	working plan development - power pool for each train, W/P assignment, detention time control, power dispatching - coordination among power dispatchers, train dispatchers and power servicing foremen; mechanical servicing supervision
Review	efficiency indices (total fleet, fleet composition, total power available) quality indices (total service quality)	efficiency indices (active fleet, productivity) quality indices (aggregate train performance account power)	efficiency indices (achieved serviceable fleet) quality indices (carriage failures)	efficiency indices (actual W/P ratio, speed achieved, time utilization); quality indices (train performance account power)

year.

These strategies indicate a way to coherently structure the tasks to be controlled, and provide a basis for management to identify: Which task at what level is the emphasis of their operations at a particular period? Which task is for continuing? Which task is only subject to periodical review? Due to the fact that, once the strategy is established, certain rigidities will develop, it is important to integrate a self-check function to signal the timing to shift from one set of strategies to another and to revise the control premises at various levels. For instance, during peak periods, the real-time control of power operations should be the emphasis of the management - all available power units should be mobilized to serve the traffic promptly. However, during the non-peak season, active fleet sizing becomes critical to reducing power operating cost. Off-peak periods are also the time for heavy repairs and the completion of deferred maintenance work, if any.

4.2 The Controlling System

4.2.1 The General Organizational Settings

In the context of rail motive power management, many functional departments play various roles and collectively contribute to the ultimate performance of power operations. These departments include:

a) Transportation Department. It controls the utmost utilization of power in the handling of trains through developing power pools which will bring the units back to servicing and maintenance points at the proper intervals.

b) Mechanical Department. It exerts efforts to reduce out-of-service time, speedily advancing locomotive units through servicing and repair facilities by close coordination of supervisors and the crafts so that the units are being continuously progressed. The most important thing is the provision of dependable repairs and servicing to eliminate delays and engine failures while the power is in service.

c) Finance Department. It assists the operating department (which is usually on top of both transportation and mechanical departments) in evaluating the effect of maintenance costs, depreciation and taxes, and the appropriate time to trade old power for new, to reduce or increase ownership.

d) Engineering Department. It is responsible for assisting in the development and provision of adequate and efficient facilities which will reduce out-of-service time and maintaining track to reduce wear and damage to equipment.

e) Personnel-Labor Department. It renders great assistance in the

employment and training of qualified employees and development of efficient and effective supervision. The economical use of crafts in servicing and repair and the elimination of conflicting work rules will reduce this cost and justify faster release of power from those facilities.

f) Marketing Department. It encourages shippers and receivers to ship on a regular and continuous basis to make better use of available power during slack periods of the week, the month and the year.

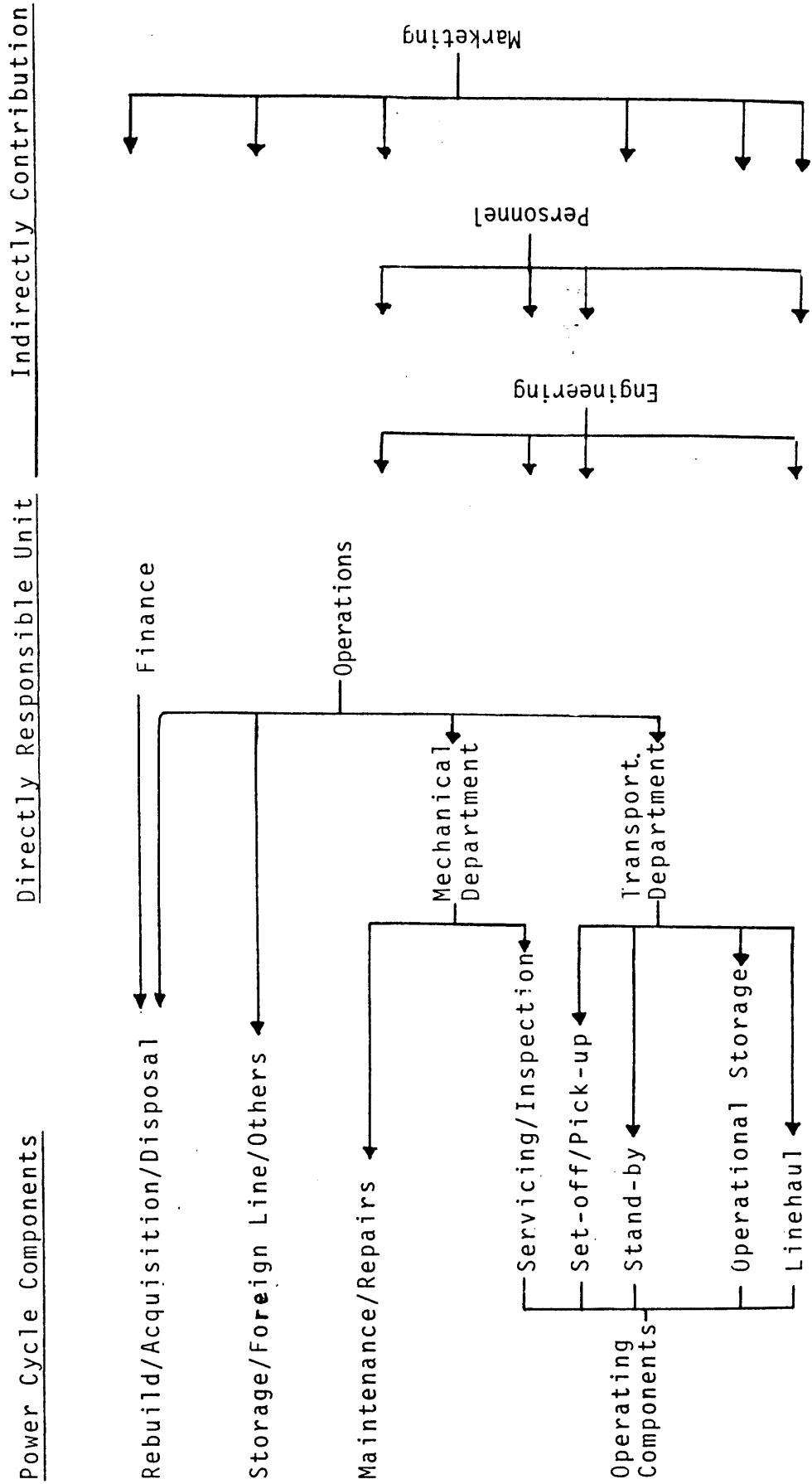
The most important thing is the integration of all these departmental functions toward the economical and effective utilization of motive power. A measure of the strength of a railroad's power management is its ability to coordinate people with all the necessary experience and responsibility working together as a team.

Exhibit 4-2-1 summarizes the relationships between the power cycle components and the responsible departments of a railroad. However, a general description at departmental level is insufficient from the diagnosis point of view. We need to specifically identify who is responsible for what on a more disaggregated basis, and to concentrate our attention on the task-roles played by each engaged individual organization unit. In the following section, to serve our purposes, the focus of the detailed structural and functional analysis will primarily concentrate on the Operations Department - the key department in charge of power operations.

4.2.2 Anatomy of The Operations Department

The variability resulting from the complexity of technology and geographical dispersity of the network makes the control of daily

Exhibit 4-2-1 GENERAL DEPARTMENTAL ROLES IN MANAGING POWER OPERATIONS



operations an overwhelming task of railroads, thus, "about 85 of every 100 railroaders work in the operations department"[Armstrong, 1978, p. 211]. Their utmost task is to run trains. Exhibit 4-2-2 is a condensed organization chart (by leaving out many staff and support positions at various levels) of the operations department in railroad A. (For smaller railroads, like Railroads B and C, some consolidation of positions and simplification might occur). Further explanation is deserved for both the transportation and mechanical departments. The key issue is to reveal the underlying task role of relevant individuals in each of the key departments.

A. Transportation Department

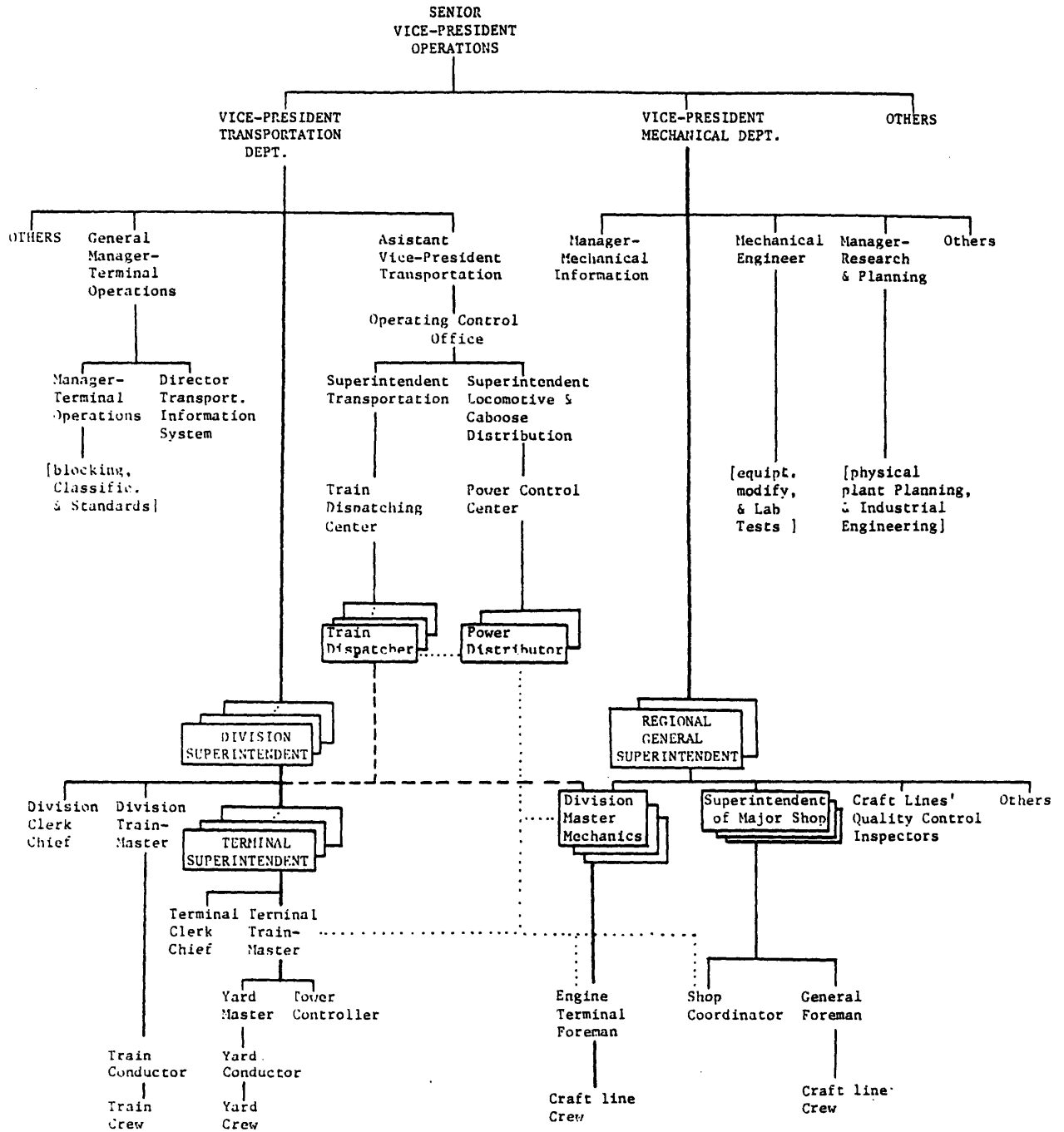
A-1 Headquarters Organization

Operations Control Office (OCO), headed by the AVP of the department, is the nerve center of the day-in-day-out operations of the rail system. Both movements of train (directly controlled by Train Dispatching Center, supervised by the General Superintendent-Transportation) and power (directly controlled by Power Control Center, supervised by the General Superintendent-Locomotive Distribution) in the system are coordinated by this office. OCO is usually equipped with various aids of status display (e.g. CTC board, power status board, etc.), and communicates with divisions and local officers through dedicated telecommunication lines.

The General Manager-Terminal Operations is primarily a trouble shooter and technically plays a back-up role to the AVPT because he is one-step back from the operating fire-line. Usually all the incremental adaptation concerning train schedules and other operating plans (e.g.,

Exhibit 4-2-2 THE CONSOLIDATED ORGANIZATION CHART OF OPERATIONS DEPARTMENT

(Railroad A)



— Formal authority line
 - - - - - Technical authority line
 Key: Power Dispatching Communication Net
 [] Observed function

blocking plans) is initiated and proposed by him - in many cases, this kind of adaptation is the planning function of Railroad A. For comparison purpose, Exhibit 4-2-3 gives the organization chart of railroad C's transportation department.

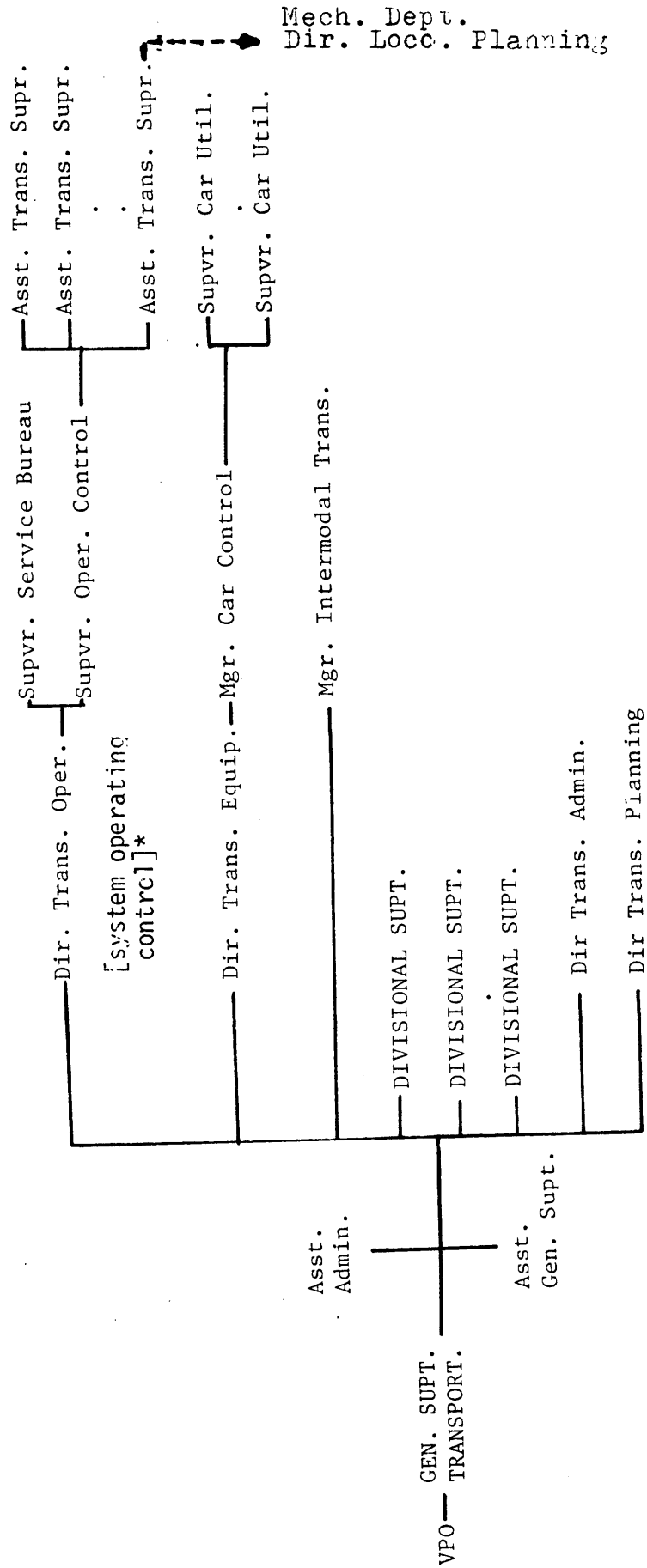
A-2 Divisional Organization

Division Superintendent is responsible for the train and car movements within the division limits and divisional budget. For the host railroad A, both the divisional master mechanics and the divisional engineer (primarily under Engineering Department which is not shown in Exhibit 4-2-2) should technically report to him. Therefore, he is also responsible for the coordination of maintenance of equipments and of roadways within the division boundary.

Division Trainmaster is the transportation staff of the division superintendent responsible for determining (guided by the system train schedules) the arrangement of carblocks into trains, and for scheduling and supervising the train crew to move trains over the division line. Once the train is beyond the limit of a terminal territory, the train conductor will directly communicate with him.

Division Train Dispatcher is responsible for the steering control (i.e., authorizing and directing) all movements of trains over the division. He issues train orders to the train crew via the terminal tower operator before the train has departed, and afterwards via the signal system within the CTC territory, or radio communication system directly. All division train dispatchers are physically housed at the headquarters and are the fundamental members constituting the OCO. Like master mechanics and the divisional engineers, they are another typical

Exhibit 4-2-3 RAILROAD C's TRANSPORTATIONS DEPARTMENT



* : Observed Functions

example that railroad employees are usually responsible to different chains of command for various parts of their duty - in a sense, this is a task-oriented matrix structure.

A-3 Local Terminal Organization

Terminal Trainmaster is Terminal Superintendent's transportation staff who supervises yardmasters, yard crew, switcher tenders and hostlers in making up trains, getting locomotive to the trains, switching cars to local industries, and moving trains into and out of the terminal limits.

Terminal Tower Operator (Terminal Dispatcher) is a messenger to transmit information from 1) yardmaster, 2) terminal trainmaster, and 3) division train dispatcher to train crews concerning their on duty time, train orders and etc.

B. Mechanical Department Organization

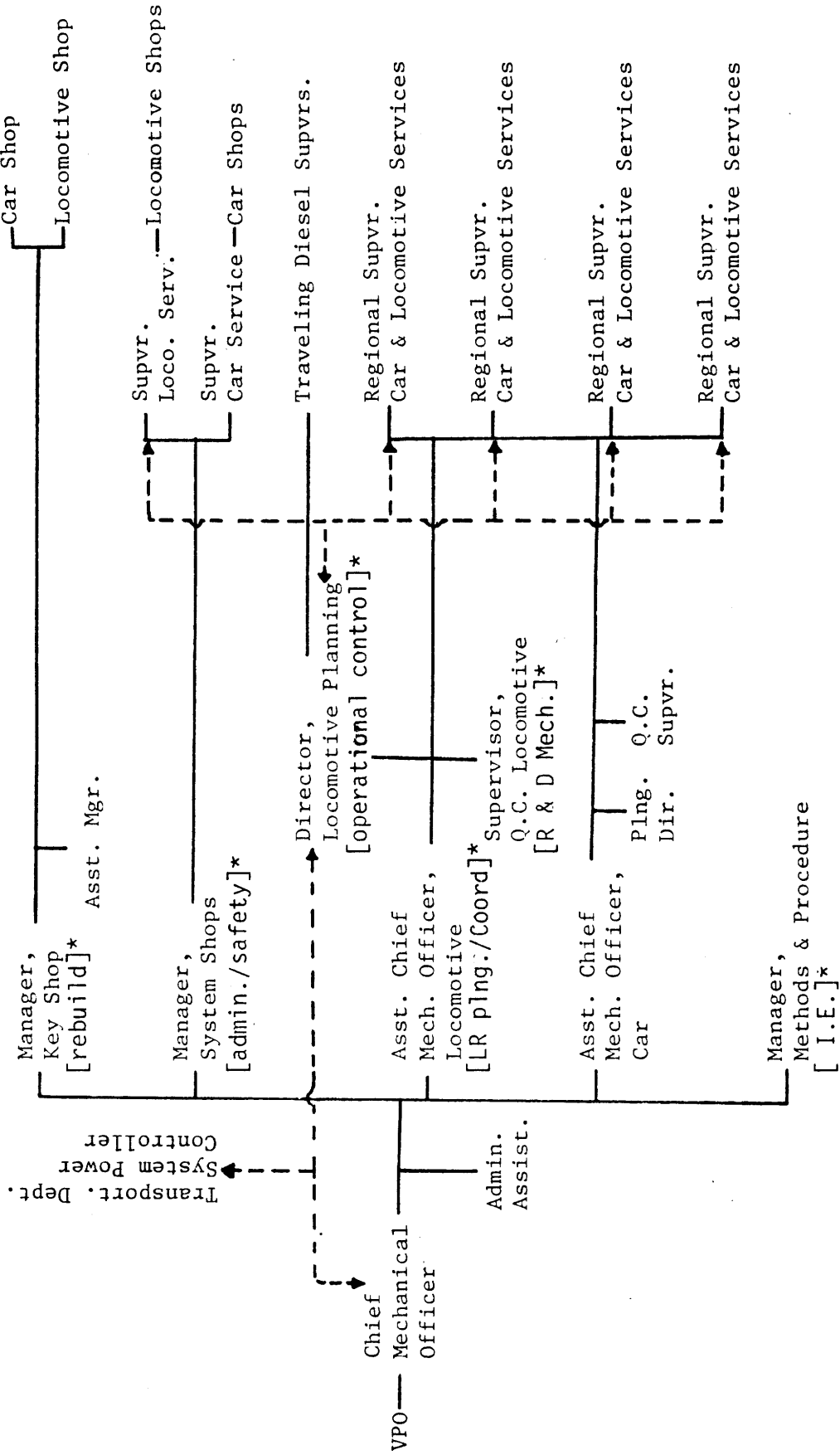
The Mechanical Department of a railroad is responsible not only for the maintenance and servicing of cars and locomotives, but also for upgrading or modifying them and for improving maintenance precedures. Therefore, we can usually find some equipment design and industrial engineering units in the mechanical headquarters.

Heading up mechanical department organizations at the local level are the Master Mechanic. They are the principal supervisors in charge of the daily mechanical operations and coordination with transportation personnel. For major system shops, which take care of heavy repairs, overhaul or even rebuilding work, Shop Superintendents are created to be in charge of the operation, they are at the same level as the master mechanic.

The annual or long-run planning responsibility for locomotive maintenance is not quite identifiable in Railroad A, except up to the VPM level. Regional General-Superintendents primarily play operating role to coordinate division master mechanics and shop superintendents. The Manager-Information System literally generates the schedule of the mandatory inspections due for each locomotive. Except for certain modification projects, no deliberate power maintenance planning effort can be identified in Railroad A.

For railroad C, although the organization chart is quite complicated, the observed function of each unit and the managerial process seem more clear (Exhibit 4-2-4). The system-wide coordination and control of daily operations of power is supervised by the Director of Locomotive Planning; while the ACMO-locomotive is responsible for annual and long range scheduling and planning and is supported by some research staff.

Exhibit 4-2-4 RAILROAD C's MECHANICAL DEPARTMENT



— : Published organizational relationship

- - - : Operational Control Relationship

* : Observed Functions

C. Document Relevant Organization units

Given the knowledge concerning the jobs of the key organization position holders at various levels and departments, we are ready to identify the relevant organization units as well as to specify their task roles, i.e., who is responsible for what particular power cycle component. Such a probing process will force us to take a closer look at the organization than we would have been done otherwise.

To generate a list of relevant actors, a power cycle vs. organization level matrix is constructed as shown in Exhibit 4-2-5 (following Exhibit 3-2-3). Taking the control of the power life cycle as an example, the formulation of general policy is an integral part of corporate strategy, thus this responsibility would be taken by the chief executive officer; while Senior-Vice-President of Operations, of Marketing and of Finance would usually provide proposals or recommendations concerning fleet size and compositions of the system. Finally, according to the nature of the issue, the decision would be executed by either VPT (utilization of power), VPM (maintenance modification or rebuilding of power), or VP-Purchase (acquisition of new power).

As to the control of the power operating cycle the General Superintendent-Locomotive Distribution as well as General Superintendent-Transportation jointly determine, in coordination with mechanical officers (regional mechanical-superintendents or division master mechanics), the power change locations on the system - where locomotive consists will change (in whole or in part) due to interchanges, grade conditions, system classification yards, fuel

Exhibit 4-2-5 Identified Relevant organizational Units

Organizational Level Power Cycle Component	General Control	Functional Coordination	Operational supervision Execution
Life Cycle	General Management	SVPO SVPMkt SUP Finan.	VPT VPM VP purch.
Service Cycle	SVPO	VPM VPT	DOT DOM staff
Maintenance Cycle	VPM VPT	DOT staff DOM staff	General Supt. - Mech.
Operating Cycle	Gen. Supt. Tran Gen. Supt. Power Gen. Supt. Mech	POWER DISPT. Train DISPT. Master Mech.	Terminal Supt. Train Master Engine Shop forms

consumption policy or other logical points of operating change. These locations will constitute the primary supply and demand points for road freight power distribution and assignment of units. The power dispatchers at the Power Control Center, working together with Division Train Dispatchers as well as Terminal Trainmasters and terminal engine foremen, control the real-time distribution and assignment of power operations, while the Division Trainmasters and Division Master Mechanic control system-wide train operations and engine's terminal operations respectively. They jointly provide a context in which the power dispatchers perform their duty.

4.2.3 Functioning of the Controlling System - Operating Document Priority

To put the above knowledge concerning the roles of relevant organization units into perspective, the understanding of a particular controlling mechanism applied by rail operations management is essential, that is the priority system of railroad operating documents.

Although many people today perceive the railroad industry as characterized by a lack of creative adaptability, believing that "many of the practices still based on technologies of a bygone era" [Kerr and Kornharser, 1980, p. vii], and by theory X's management style [Ellen, 1982], the organizational structure of railroads used to be highly creditable [e.g., Chandler, 1976]. According to Wyckoff [1976, p.57]:

"As the management tasks of the [railroads] shifted from the financial promotion and construction to the operating and administration phases, substantial creativity in organizational design occurred. ... In many respects, the railroads were pioneers in designing organization structures to manage large enterprises.... not being able to rely on ... developed organizational theory, ... the early railroaders innovated. Since they were designing organizations to cope with specific situations,

... they were actually applying the contingency organization theory (that was not to be articulated until nearly a century later)."

To provide the needed flexibility required by the real-time operations, while still confining these operations within an overall managerial frame, railroads have developed a particular administrative mechanism - the priority of operating documents [Armstrong, 1978, p.220]. The core of this mechanism is the Timetable-and-Train-Order (T&TO) system [Armstrong, p.95], in which responsible operating manager, normally the Division Train Dispatcher as described precedingly, may issue train orders to change - in effect, supersede - the instruction given in the predetermined timetable in case of operating contingencies or for the benefit of the system goals; while except on receiving such a train order, the train enginemen have no authority to disobey the timetable.

When putting the T&TO system into a broader document priority framework, we will obtain a result as shown in Exhibit 4-2-6. Power operations is essentially operated within the framework of train operations. Therefore, in line with the above train-oriented document priority system, there is a power counterpart which embodies the controlling structure for managing power operations. More specifically, in the power management context, there are various predetermined policies (e.g., maintenance schedules) which - derived principally from railroad's overall operating strategies - are general operating reference lines to be followed in normal situation; while in case of operating contingencies, except the mandatory ones (e.g., bridges' axle limit, federal regulated test due dates), they are subject to being

Exhibit 4-2-6 THE PRIORITY OF RAIL OPERATING INSTRUCTIONS
 (Modified from J.H. Armstrong, 1978, Fig. 21-1, p.220)

Instruction, Document	Example of Contents	Governed Objects	Typical Time Span	Issued Under Authority of: by: via:
Real-time Instruction/ Train Order	"Hold Train M1 until required power is available." "Train C2 take siding and meet Extra 3231 East at K"	Train Dispatcher, Train Conductor	From issue to Fulfilled (Minutes to Hours)	Supt. Transport. Div. Train Disp. Term1. Trn. Disp.
Bulletin Order/Notice	Temporary slow order location Schedule modifications Other Notices	Train Service Employees All Div. Employees	From issue to terminat. or incorporation in Timetable (days-weeks)	Supt. Transport. Div. Trainmaster Term1. Trainmaster
Employees Timetable	Schedules: Time/Class of Train Blocking Plan: preblocking/ switching plan Special Instruction: Speed, signal, supvr. direction	All system & Division employees concerned with train operation	From effective date & time until next Timetable (1-6 months)	VP Transportation Supt. Transport. Div. Supt.
Book of Rules	General Rules: Conduct of employees Operating Rules: Timetable Train order Signal Duty of employ	All Employees in Operating Department	Until Modified (Years)	SVP Operations General Management

↑ CAN SUPERSEDE ↓

superceded by the instructions issued by certain on-line officers through some specific authorization processes. Moreover, as to the time-span of these power operating policies and schedules, some of them (e.g., ton-per-horsepower) would usually be updated, piece by piece, in accordance with the revision of corresponding timetable and train orders; full-scale revision, in some railroads, will be implemented periodically - e.g., Railroad C revises its power special operating instruction (see Chapter 6) on a semi-annual basis.

In summary, the practice of document priority system, which exemplifies railroads' general problem-conversion-processes, in a sense stands for the rule of the game of railroading. Anyone who fails to recognize this rule might either lose himself in the operating details without acknowledging the existence of the broader contextual issues, or oversimplify the railroading process and fail to appreciate the subtlety of the control practices involved. Given the above knowledge concerning the controlling system, we are ready to identify the specific linkages between the controlling system and the controlled system, which will be discussed below.

4.3 Linkages between the Two Systems

4.3.1 Task-Actor Matrix

To explicitly identify each actor's roles and the interrelationships among the actors, we can construct the Task-Actor Matrix [section 3.2.2] - which relates the control tasks derived in Section 4.1.5 to the task-relevant actors specified above - as shown in Exhibit 4-2-7 (based on data from Railroad A). The Task-Actor Matrix

TASK-ACTOR MATRIX FOR POWER MANAGEMENT

ORGANIZATIONAL UNITS	GENERAL MANAGEMENT	SVPO	VPT	VPM	TRANSP. DEPT.	MECH. DEPT.	TRANSP. DIVISION SUPT.	MECH. REGIONAL GENERAL SUPT.	TRAIN DISPATCHER	POWER DISPATCHER	TERMINAL SUPT.	LOCAL ENGINE TERMINAL	ENGINE SHIOP
CONTROL TASKS													
SYSTEM-WIDE PR	DEC.												
SYSTEM-WIDE PA (FLEET SIZING AND COMPOSITION)	DEC.	Exec	Exec										
SERVICE CYCLE (STORAGE)					TRM.								
MAINTENANCE CYCLE (SCHEDULE)				DEC.		CRP.		Exec					
OPERATING CYCLE (TRAIN SCHEDULE)		APP.	DEC.	TRM.	TRM.		SUP.		Exec				
TRAIN DISPATCHING									Exec		Exec		
POWER DISTRIBUTION										Exec			
TERMINAL POWER POOL										Exec	Exec	Exec	Exec
POWER MAINTENANCE								SUPT.				Exec	Exec
SHIOP PERFORMANCE								REV.				ACCOUNT	ACCOUNT
POWER IDLE/TERMINAL					REV.					ACCOUNT			
TRAIN PERFORM./ TERMINAL DUE TO POWER					REV.					ACCOUNT			ACCOUNT
SERVICEABLE FLEET				REV.		REV.		ACC.					
POWER PRODUCTIVITY		REV.	ACC.										
POWER SERVICE QUALITY													

planning execution perform. review

explicitly describes who plays what roles in each sub-task at different phases. It summarizes the authority/responsibility and accountability relationships, the initiation and input-output characteristics, the interactions among actors, and the general direction of information flow. It is clear that in a task as complex as power management, the relationships among the actors should not be "linear". This upward feedback function should not only be viewed as a mechanism to assess lower levels' performance, but also as a internal source which amy signal the need for adaptation concerning higher levels' strategies, policies and plans.

4.3.2 A Meta-Control Interpretation

An organization can be conceived of as a problem-conversion mechanism, and in such a context power management is a process which gradually converts a relatively open and abstract system-wide power availability planning problem into a very specific real-time power dispatching problem. Applying this meta-control notion to the task-actor relationships identified in the task-actor matrix, we can reintepret their relationships as follows.

At the lowest level is the steering control of physical power dispatching and distribution in line with the execution of maintenance work and train dispatching. At the next level the role is primarily derived from the need to plan and monitor the operations of the rail service delivery processes. This function includes 1) the review of the performance of physical operations, 2) development of power operating polices and maintenance schedules, as well as 3) the review of train schedules. The latter two jointly determine the power service cycle.

In other words, this level exercises typical ends-control over the lowest level, as well as imposing constraints on the means that the first-line managers are allowed to practice.

At the top level, its function is the meta-control. That is, on the one hand, this level adjusts the system-wide power availability to pursue efficiency goals for power management; on the other hand, it maintains sensitivity to environmental influences on effectiveness of the task. The key issue to this level is the re-examination of key planning premises on which the various task strategies and tactics are based. These premises include system power requirement, meta-control structure (section 2.2.1) per se, power related key cost estimates, reward/incentive system (if any) and the basic infrastructure.

To summarize, the above described meta-control structure is a conceptualization concerning the overall task of power management. From a diagnosis point of view, such a conceptualization provides an analytical perspective concerning the nature of the controlling system and directs our attention to problems, not organizational hierarchy. To complete the diagnosis, the last step left is to identify symptoms of problems and rooms for improvement. However, in the following chapters (5 and 6), we shall continue our analysis on the operations concerning power maintenance (which is a key functional area of the overall power operations management task) and the control of real-time power dispatching (of which major emphasis will be on individual level decision behavior), respectively. All the diagnostic assessments regarding various levels' performance as well as some corresponding change proposals will be discussed later on in Chapter 7.

4.3.3 Summary of Chapter 4

This chapter devoted to the general description and analysis of the characteristics of railroad motive power operations management. We first analyze the technological aspect of the systems in question. The work flows involved in the railroading processes are analyzed, the power cycle hierarchy is identified. To analyze the interdependence among the cycle components as well as the impacts of power operations on the rest of the systems, a power availability measure and an aggregate service impact model are presented. Based on this knowledge, we discuss the issues involved in the control of various power cycles. We then summarize the findings into a work unit matrix (power cycle components vs. management cycle phases) which identifies the totality of the control tasks of power management.

In the analysis of the controlling system, we first identify the general roles of various departments in the host railroads, then focus on the key actor - operations department, and anatomize its two major sub-units - transportation and mechanical departments. Given the above analysis, we document the relevant organization units (individual or group of individuals). To gain more insights into the actual functioning of the controlling mechanism, the system of operating document priority adopted in the railroading processes is reviewed.

Based on the knowledge gained through the above analysis, the linkages between the two (controlling and controlled) systems can be identified through the construction of the task-actor matrix as shown in Exhibit 4-2-7. The data obtained in this chapter is not only essential to the diagnosis of the macroscopic performance of power management, but

also a general reference frame for the more microscopic analysis and diagnosis into the systems to complete a thorough organization intervention [*]. For instance, the analysis conducted in Chapters 5 and 6 can be viewed as an elaboration on some subset of the work units and organization units identified in the general task-actor matrix - more specifically, Chapter 5 amplifies the maintenance module of the matrix, while Chapter 6 highlights the interface between the mechanical and transportation departments' steering control tasks as well as the work units taking care of by individual power dispatcher.

[*]: For some limited intervention endeavors, the diagnosis may be terminated at the macroscopic level - they only have the chance to see the "woods" but not the "tree"; or the other way. However, this is not the case for this study.

Chapter 5

THE MAINTENANCE FUNCTION

In this chapter, we amplify the maintenance module of the system. The reasons to select this area are 1) maintenance is a key functional activity which supports as well as constrains power utilization, 2) the relationships between maintenance and transportation operations provide an opportunity to observe problems concerning interdepartmental coordination. The analysis of the maintenance function is basically following the above two lines, i.e., on one hand, the total control tasks and the control structure of the maintenance operations are analyzed; on the other hand, the mutual-dependence between the maintenance and transportation function is highlighted.

5.1 The System Being Controlled

5.1.1 Operations of Individual Shop and Engine Terminal

The elementary unit of a power maintenance system, depending on the equipment installed, will consist of various facilities which range from an engine terminal furnished only with minimum servicing equipments to a power shop which is capable of performing heavy repairs. Power maintenance facilities can be characterized by: 1) physical characteristics - track, facility layout, etc., 2) procedural characteristics - standard operating procedures, job contents and job priority for each craft, etc., 3) personnel characteristics - craft class, number of men for each craft class in each shift.

For a typical power maintenance base, the principal components include: 1) servicing facility which contains stations for fueling,

watering and sanding operations, bays for inspection as well as pits for running repairs, 2) repair facility comprised of a wheel shop, engine shop, as well as an electric and control equipment shop, 3) cripple and dispatch tracks for placing out-of-order units and lining up ready units respectively [see Exhibit 5-1-1]. In the following, we shall examine the servicing and maintenance activities in detail.

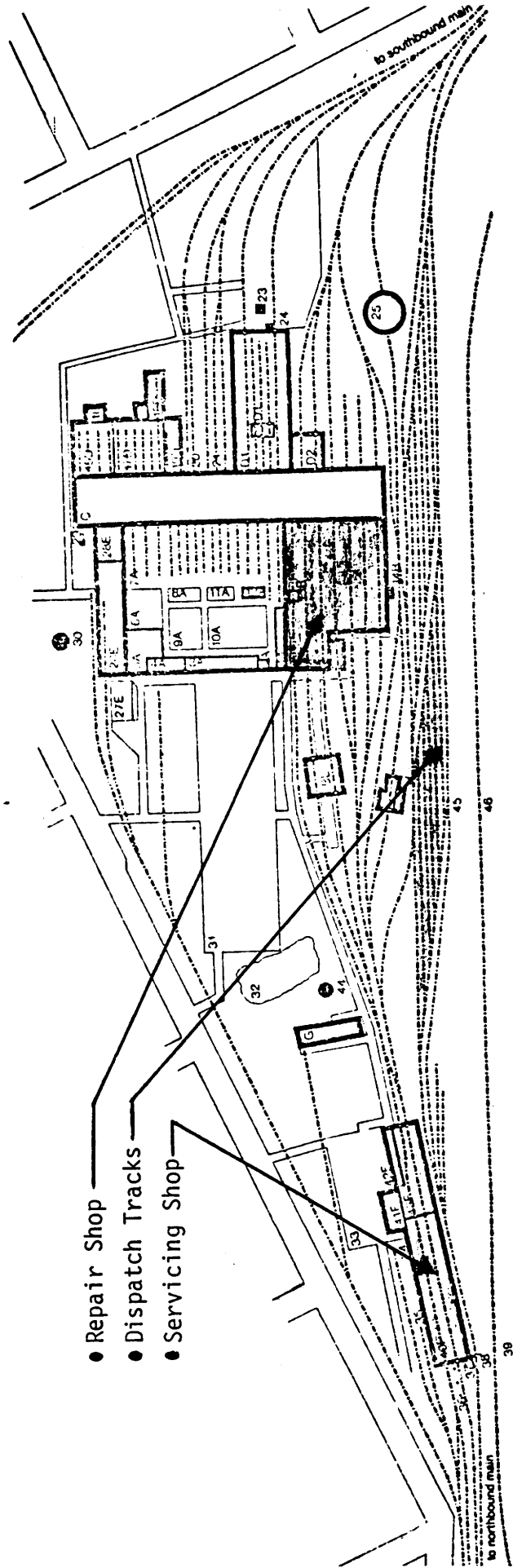
A. Servicing and Running Repair

General Nature of Servicing. In case of minor defects, running repairs may be performed during servicing. Servicing and running repair are maintenance activities operated at the "fire line". Their task is to turnaround an inbound engine in serviceable condition as soon as possible so as to assure maximum power availability and thus support real-time transportation needs. The out-of-service time in the servicing area is measured on a minute basis, while in the repair shop the time measure is locomotive-days.

Servicing is an interface activity between the transportation and mechanical operations. Typical jobs that take place in the engine servicing process are: fueling, sanding, watering, safety inspection, and occasional lube oil testing [*].

[*] Oil spectrographic testing: if the sample results are unfavorable, e.g., some symptoms of malfunction of engine such as fuel leak/ water leak/ air filtration/ etc., a history of samples for that locomotive will be transmitted to the lab technician for his decision concerning whether to issue an oil call - which lists the reasons for the call and what actions should be taken. The corrective actions may 1) add a treatment substance, 2) perform an inspection, 3) be an order for the immediate shutdown of that locomotive.

Exhibit 5-1-1 EXAMPLE OF RAILROAD MAINTENANCE FACILITIES



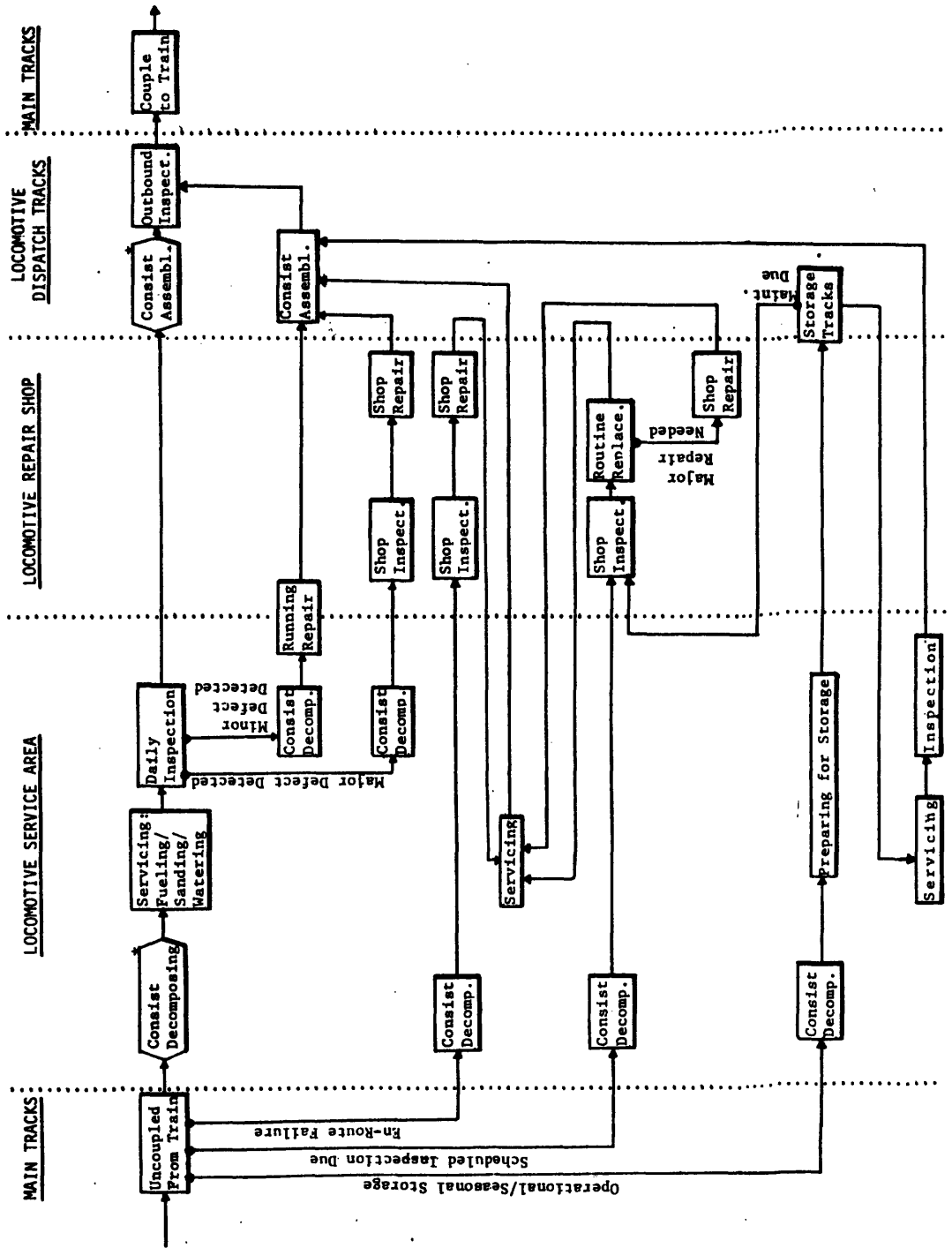
- Repair Shop
- Dispatch Tracks
- Servicing Shop

- | | | | |
|---|---|--|--|
| <ul style="list-style-type: none"> A Locomotive and Car Department Shop/Building A 1A general office 2A radio shop 3A air brake room 4A lathe room 5A power house 6A electric shop area 7A repair tracks 8A tool room 9A glass and wood mill area 10A pipe/tin boiler area 11A work area 12A tool room B Locomotive Run-Through Shop/Building B 13B wheel-truing machine | <ul style="list-style-type: none"> 14B shop coordinator's tower C 250-Ton Capacity Transfer Table/Building C D Paint and Upholstery Shop/Building D 15D spray and drying shop 16D paint storage 17D paint shop 18D sandblast shop 19D upholstery shop 20 passenger car tracks 21 electric suburban car tracks D1 Truck Shop/Building D-1 D2 25-ton drop table D2 Wipe-Down Building D-2 23 lye vat 24 material storage | <ul style="list-style-type: none"> 25 100-foot turntable E Material Stores/Building E 26E storeroom 27E truck dock 28E signal department 29 75-ton track scale 30 water storage tank 31 parking/382 cars 32 pond 33 parking/94 cars 34 oil unloading track 35 sand unloading track 36 alcohol stills (3) 37 sand tower 38 outside fueling and sanding point | <ul style="list-style-type: none"> 39 fuel storage tank F Locomotive Service Building F 40F servicing section 41F crews' service building 42F pump room 43F laundry section G Waste Water Treatment Plant/Building G 44 waste water storage tank H Load Test and Search Building H BL Blow-Out Building BL 45 locomotive dispatch tracks 46 track 17/ Yard A |
|---|---|--|--|

The decisions - which shall be made whenever an engine arrives the engine terminal - include the following three major categories: one must determine whether 1) the engine is on its inspection or project due, 2) an en-route failure is reported, or 3) the engine is on the storing unit list. If neither of the above is the case, then the engine will be switched to servicing station, otherwise, the engine will be sent to maintenance shop first. However, to serve a train, there are usually more than one engine coupled together - which is called a power consist - to provide enough horsepower; therefore, before the servicing operations, one has to decide whether the consist shall be decomposed into individual units. (Mechanical man-hours could be saved if this decision could be coordinated with the later power assignment decision. That is, if the same consist can be used in a later outbound train, then it may be preferable to retain the consist as it is during the servicing process.) During the daily inspection process, one should determine whether there is any identifiable minor or major defect and what to do about the defect. For instance, one may choose to send the defected unit to undergo a running repair, or if the defect is a minor one and there is a high demand for power, then one may choose to defer the repair work and send the unit back to service as soon as possible. Exhibit 5-1-2 shows the typical power flow pattern exhibited in a rail engine terminal. Exhibit 5-1-3 gives a distribution of power servicing time [exerpted from Mao and Martland, 1982].

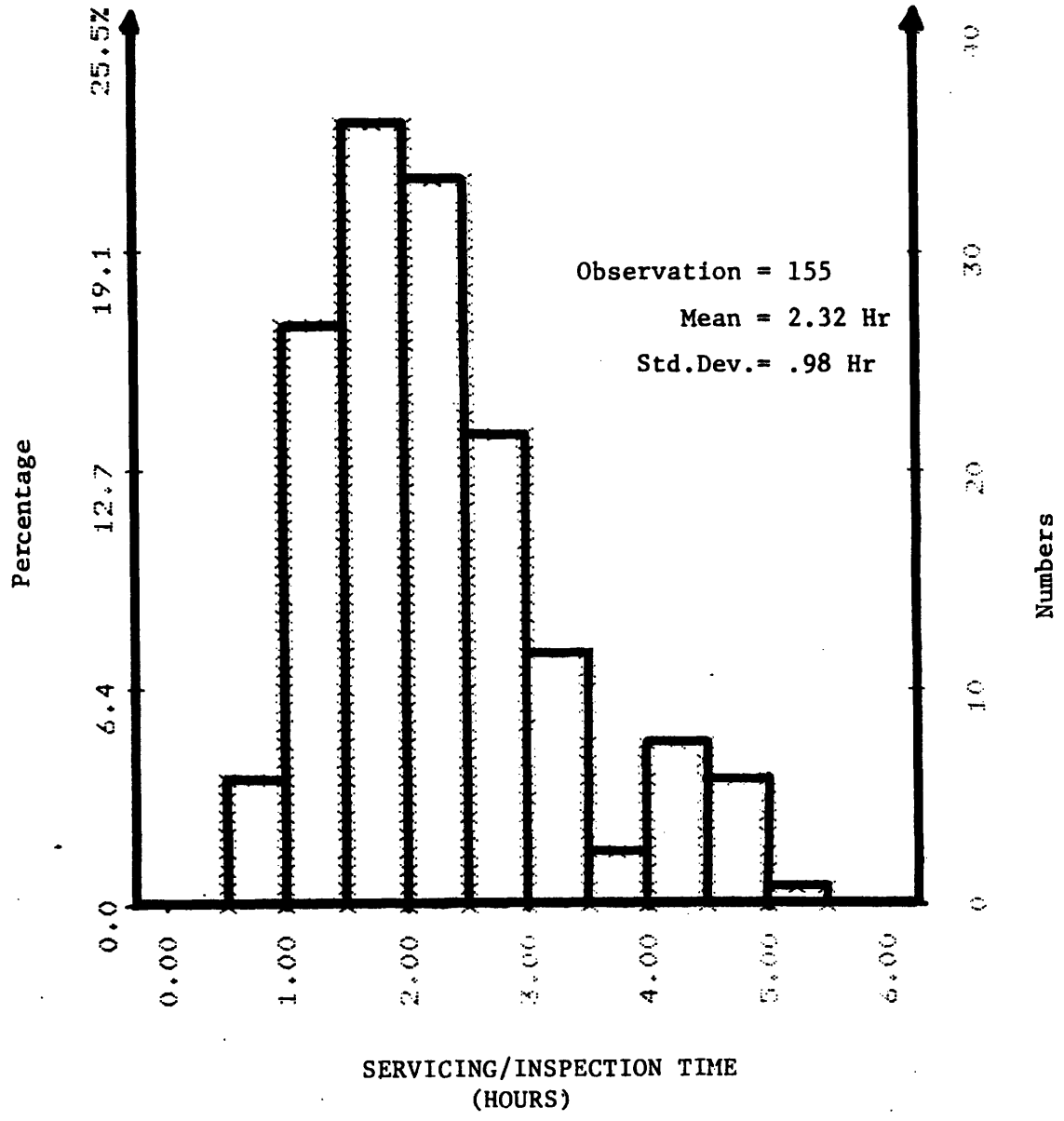
Procedural Characteristics of Servicing. The procedures and the rules by which the various decisions are made with respect to the servicing and movement of units in the service area are crucial to the efficiency

Exhibit 5-1-2 TYPICAL LOCOMOTIVE FLOWS IN A TERMINAL AREA



* Whether to decompose an inbound consist or to re-assemble an outbound consist will depend on the requirement of engines' next assigned tasks.

EXHIBIT 5-1-3
Distribution of Servicing/Inspection Time



of engine servicing.

Personnel Characteristics of Servicing. According to Kaufman [1980, p.7]: "Because of the fact that railroad operations are highly irregular, ... it is quite evident that all men cannot be regularly assigned to specific runs or assignments ... personal discrimination and favoritism might well arise ... For this reason many rules in the railroad agreements are designed to prevent favoritism and to bring about a fair distribution of work ..." To protect against any arbitrary or capricious action of management, the craftline distinction of maintenance workers is one of the major rail work rules which determines the crew utilization patterns [*]. Exhibit 5-1-4 gives a typical craft class and their engaged work in power servicing and terminal movement. One may view this exhibit as an amplification of the execution phase's maintenance - related elements in the general Task-Actor matrix.

B. Scheduled/Unscheduled Maintenance

The electrics, the diesel, the truck and the wheel are among the components of a locomotive whose condition is mandated by the federal government to be inspected periodically. Exhibit 5-1-5 is a sample of a partial readout of two inspection schedules - one is on chronological basis, the other is on an engine roster basis.

[*]: These work rules aim primarily to stabilize the conflicts in crew utilization rather than to economize the utilization.

Exhibit 5-1-4

MAINTENANCE TASK AND CRAFTSMEN DISTINCTION

CATEGORY OF JOBS CRAFT CLASSES	RUNNING SERVICE				SHOP MAINTENANCE			INBOUND/OUTBOUND & MOVEMENT			
	Fueling Sanding Watering	Washing *1	Trip Inspection *2	Running Repair	Periodic Inspection *3	Shop Repair *4	Consist Uncoupling	Consist Assembly	Outbound Inspection	Turn-around & Movement *5	
General Laborer	V	V									
Mechanist			V	V	V			V			
Electrician			V	V	V			V			
Carman			V		V		V	V			
Sheet-Metal *0			V	V	V			V			
Hostler										V	
REMARKS	*0: Pipefitter/Boilermaker/Blacksmith *1: In some terminals there is no washing facility. *2: 24-hour inspection or end-of-trip inspection *3: Monthly, quarterly, semi-annual, annual inspections. *4: Shop repair is conducted by a separated (from servicing/inspection activities) work force, in general. *5: Movement within the service area. Beyond the boundary, engine is moved by either road crew or the same hostler in terminal area, depending on the practices and rules of the railroad involved.										

There are two kinds of unscheduled maintenance. The first is engine's unexpected defects, either occurring as a road failure or detected during inspection. The second is, from the shop's point of view, any engine assigned to a shop but not according to the shop's original assignment schedule. This is in effect an unscheduled work load to the shop. Unscheduled shoppings 1) reduce the actual availability to a level lower than that calculated by a planned maintenance schedule, 2) force shops to maintain an inefficient level of work force [*] and material inventory. They will generally disrupt the scheduled shop work process as well as material supply. In one road surveyed, these unscheduled shoppings account for about one-half (sometimes even up to two-thirds) of all the locomotive shoppings. This implies that work loads and material supply cannot be consistently planned for more than half the work performed by the shop forces [Mao and Martland, 1982]. As a result, many locomotive-days of scheduled maintenance may be lost awaiting materials and shop forces because a large share of these resources are absorbed by the unscheduled shoppings. Exhibit 5-1-6 shows time distributions of scheduled and unscheduled maintenance operations (exerpted from Mao and Martland, 1982).

[*] Though the work force is separated, the craft classes of a repair shop is basically the same as those of servicing stations - see Exhibit 5-1-4.

Exhibit 5-1-5 EXAMPLE OF MAINTENANCE SCHEDULE

(A) BY DATE

MECHANICAL DEPT.

REPT NO. 2176 FRA INSPECTIONS DUE FROM SEPTEMBER 02, 1980 TO SEPTEMBER 09, 1980

NEXT INSP	CWNER	UNIT	TYPE	NEXT CNTRL	TYPE	MAINT. CYCLE
09-02-80	C1	1222	S			45
09-02-80	C1	2005	Q			45
09-02-80	J1	2022	C			45
09-02-80	C1	7716	M	10-19-80	B	45
09-02-80	C1	7913	M	10-15-80	C	45
09-02-80	G1	7972	A			45
09-02-80	C1	8073	M	10-19-80	S	45
09-02-80	C1	8100	M	09-05-80	Q	45
09-02-80	C1	8187	M	09-04-80	A	45
09-02-80	C1	8273	B			45
09-02-80	C1	8357	Q			45
09-02-80	C1	8461	C			45
09-02-80	C1	8740	M	10-19-80	S	45
09-02-80	C1	9420	S			45
09-02-80	C1	9540	M	10-19-80	3	45

TOTALS

MAINTENANCE	7
QUARTERLY	4
SEMI-ANNUAL	2
ANNUAL	1
BI-ANNUAL	1

(B) BY UNITS

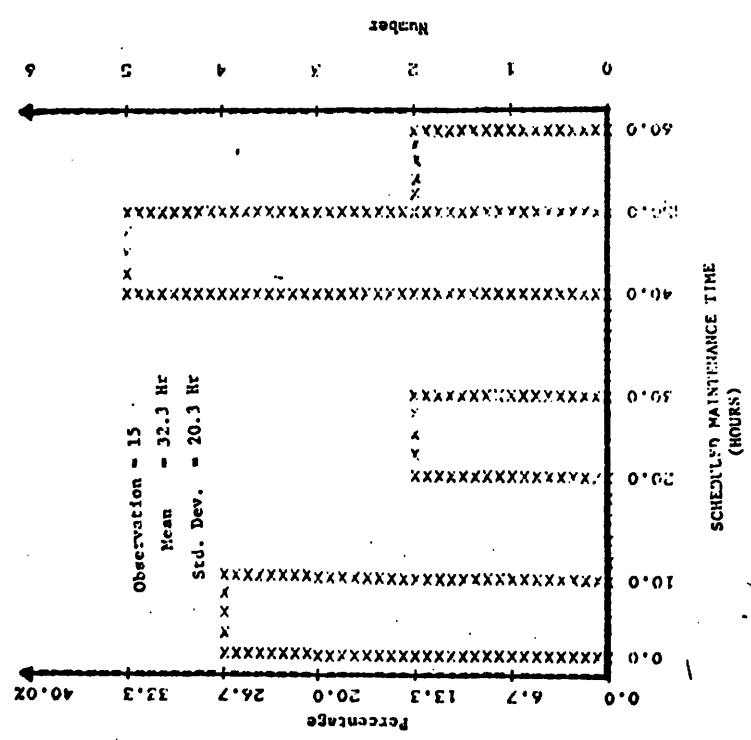
MECHANICAL DEPT.

REPT NO. 2146 FRA INSPECTIONS DUE FROM SEPTEMBER 02, 1980 TO SEPTEMBER 09, 1980

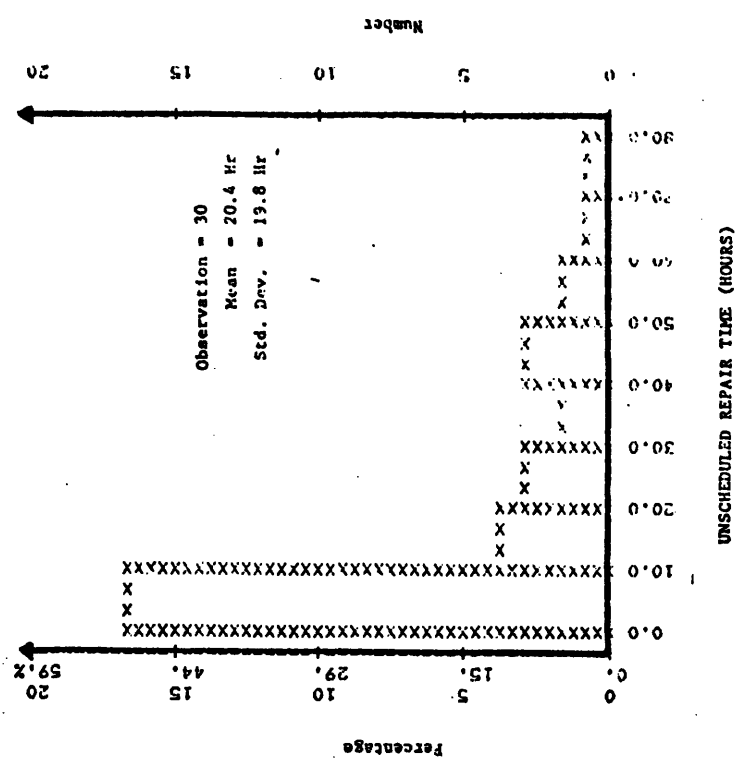
CWNER	UNIT	MAINTENANCE	CYCLE	QUARTERLY	SEMI-ANNUAL	ANNUAL	BI-ANNUAL
01	3077	09-06-80	45				
01	5053						
01	5059				09-07-80		10-23-80
01	6005	09-06-80	45	09-09-80			
01	6017	09-06-80	45	09-07-80			
01	6054	09-06-80	45	09-08-80			
01	6056	09-05-80	45	10-23-80			
01	6058			10-22-80			
01	6064	09-08-80	45				
01	6066	09-04-80	45	10-21-80	10-25-80		09-06-80
01	7706	09-02-80	45				
01	7717			09-08-80			10-19-80
01	7724	09-06-80	45	10-23-80			
01	7729						
01	7734	09-09-80	45				09-08-80
01	7739	09-07-80	45		09-12-80		
01	7740	09-06-80	45		10-24-80		
01	7741					09-08-80	
01	7850	09-05-80	45	09-06-80		09-03-80	
01	7905	09-07-80	45				
01	7906				09-03-80		10-24-80
01	7907	09-08-80	45				
01	7908	09-07-80	45	09-09-80			10-25-80
01	7913	09-02-80	45	10-19-80			
01	7953	09-03-80	45	10-20-80			
01	7961	09-05-80	45				
01	7972					09-07-80	
						09-02-80	

Exhibit 5-1-6 SCHEDULED AND UNSCHEDULED MAINTENANCE TIME

DISTRIBUTION OF SCHEDULED MAINTENANCE TIME



DISTRIBUTION OF UNSCHEDULED MAINTENANCE TIME



Unscheduled shoppings are in principle related to the amount of preventive maintenance practiced by the railroad. Therefore, for reliability reason, in addition to the mandatory inspections, a railroad must find its own desired levels of preventive maintenance [*] which will result in an affordable amount of road failures and unscheduled shoppings for the road. The size of the locomotive fleet is in large part determined by these levels, implicitly or explicitly. However, according to a mechanical officer in Railroad A, their maintenance operations were not preventive but "mandatory" oriented. An engine is shopped either at the last minute of the inspection due time, or in a failed condition. The major reason is that any preventive maintenance must be proved "productive to justify the budget; but thus far there is no such analysis or data available in the industry to suggest and defend any engine preventive maintenance policy." Because preventive maintenance is an important notion to mechanical reliability, it deserves further elaboration.

[*]: Practical preventive maintenance refers to overhauling components of the diesel engine and other key modules at regular intervals, and after 1 to 3 overhaul, for instance, the engine will be given a complete rebuilding usually at the middle of unit's economic life, 10-15 years.

5.1.2 Notes on Power Reliability and Scheduled Maintenance

Scheduled inspection and maintenance, in principle, can be categorized as a preventive maintenance practice based on system parameters monitoring [Gertsbakh, 1977]. At the end of various inspection periods, different levels of standard diagnostic procedures are applied to an engine. For instance, the scope and depth of a 90-day inspection is more thorough than a 45-day one, and so forth. In theory, in a preventive maintenance system, what the maintenance officer actually controls are the service policies of the equipments which include the inspection period, the critical level for the controlled parameters and the stopping rules regarding the use of the equipment [ibid, p.8]. An optimal preventive maintenance policy should consist of a set of optimal service policies.

In the context of locomotive maintenance, since the equipment is such a sophisticated piece of machinery and the operating environment is so complex, to our knowledge, explicit and practical quantitative guides regarding the optimal power preventive maintenance policy have not yet been developed. In a recent effort, Canadian Pacific reported the followings [1977, pp.14-16]:

On Short-Term Periodic Inspection: "The data inspection is considered to be the backbone of our preventive maintenance policy. As such, its effect should be measurable, and to this end we chose to determine whether the occurrences of unscheduled shop visits and road defects were influenced by the time elapsed since the date of inspection.

The results illustrated for unscheduled visits showed that the rate of occurrence was constant with them. While we initially concluded that the data did not appear to have any impact on subsequent unscheduled event and defects. Discussion with Dr. A. K. S. Jardine of University of Windsor. made it clear that such an outcome is to be expected. When discussing the question of

evaluation of short-term inspections, which Dr. Jardine considered to be the most difficult in the maintenance field, he stated that a complex piece of machinery, such as locomotive with many- failure modes, would be expected in sum, to exhibit constant rate of occurrences. What the inspection frequency and content does do is affect this rate and this can only be measured by experimentation. The first stage in this process is to have an accurate picture of the defects and the reasons for repair, from which those items requiring preventive maintenance can be identified and incorporated in the inspection. Not having such information we were unable to make any further analysis in this direction.

On Long-Term Replacement and Overhaul. "Gathered all available data on labour laws, material, road failures and availability for a group of SD-40's, these data were plotted with respect to time, using the previous overhaul point as base zero. When suitably smoothed, a trend towards a "bathtub" characteristic was observed indicating the three phases of running-in (the post-overhaul period), the period of least unscheduled work, and finally the period of rising costs and failures.

Concurrent experiments in extending overhaul intervals on selected units have just indicated that serious engine problems can be developed if overhauls are deferred a year beyond the prescribed value [5 years], also realizes that indefinite deferral of overhaul result in excessive failures".

In this study, within the limited time frame and accessible data, we failed either to find any sensible relationship between the locomotive's unscheduled repairs, work load and maintenance schedules. One major difficulty in studying the actual impact of preventive maintenance on engine reliability by using existing data base is that one should factor out the effect of all intermediate inspections (including running repairs performed during servicing) [*] between the scheduled inspection and the observed failure. In fact, this is a virtually intractable task except through some particular experimental efforts as suggested by Dr. Jardine cited above.

[*]: More precisely, one should also factor out the effect of the scheduled inspections prior to the preventive maintenance in study.

In summary, although we have no way to determine how much room for improvement there is left on the existing maintenance schedule , it is plausible to conclude that the current mandatory inspection schedules do have their preventive effect on power reliability; different quality of diagnosis as well as workmanship do result in different failure rate. Exhibit 5-1-7 gives a two-year monthly summary of reported road failures, in terms of failure frequency/unit. [*]

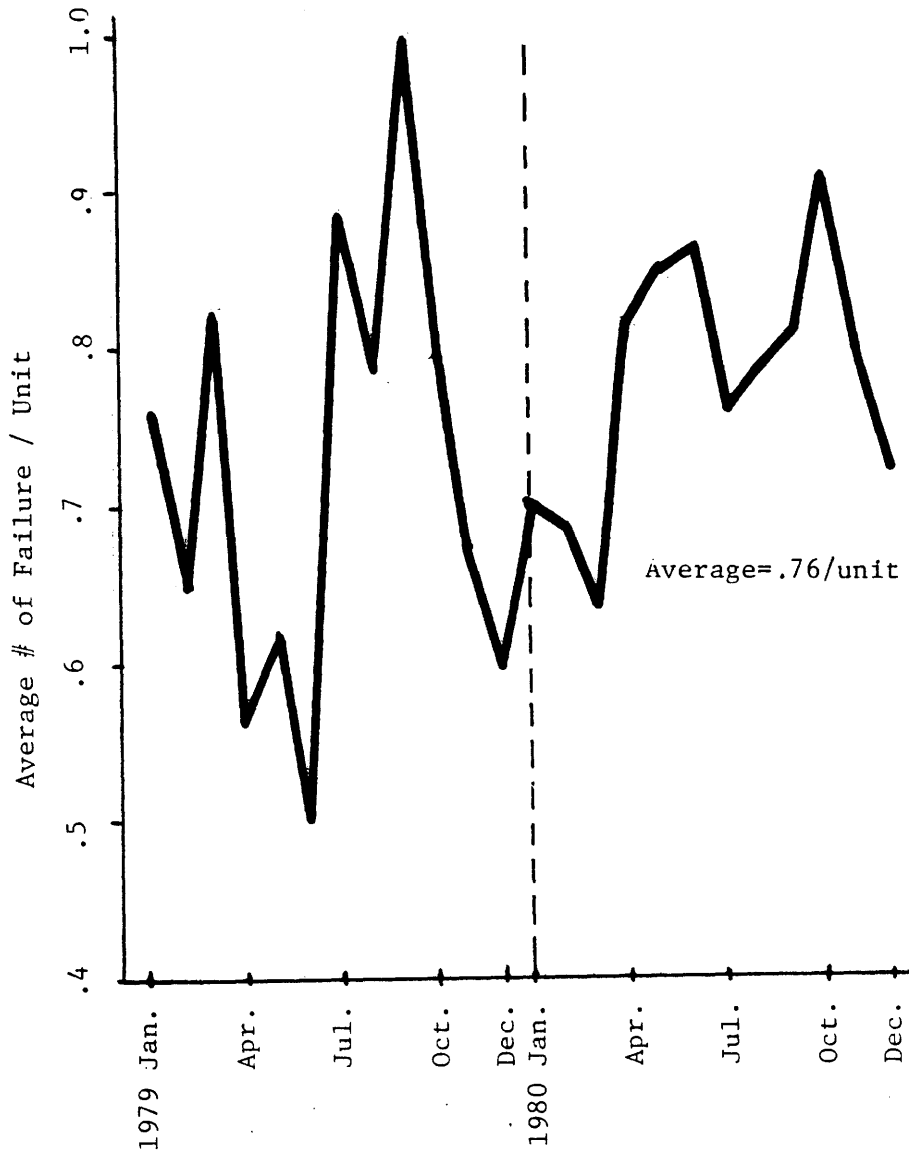
5.1.3 Vehicle Technology and the Maintenance Logistic Systems

A. Impacts of Vehicle Technology Change

To illustrate the impact of vehicle design and technology on the maintenance practices, the most dramatical examples are found during the late 1950's and early 1960's dieselization movement in the U. S. railroad industry. The following is a summary of various railroads' experiences reported in Railroad Systems and Management Association's "Railroad Motive Power Utilization, 1964, Chicago".

[*]: Road failure record is a very controversial statistic. Both the transportation and Mechanical departments maintain separate information systems for recording road failures. The transportation data is based on failures reported by engine crew and train dispatchers. The mechanical sources are normally the same except that the department judgementally determines whether an equipment failure did occur. For instance, cases commonly reported as road failures include: 1) a stall on a grade due to improper reporting of the train weight; 2) running out of water / fuel en route; 3) failures due to component breakdown or improper servicing which prevented the unit from normal function. From a mechanical viewpoint, only the last case consists of an actual equipment failure.

EXHIBIT 5-1-7 MONTHLY ROAD UNIT FAILURE PATTERN



In addition to other operating advantages, diesel units are generally perceived to be more maintainable and reliable, i.e., they require less inspection in a given period and it takes shorter time to complete the maintenance work. However, a more remarkable impact of dieselization on maintenance is resulting from diesel unit's operational characteristics. Due to the fact that the diesel engine can run much longer mileage than the steamer locomotive before any servicing is required, several significant changes have taken place since the dieselization:

- 1) Railroads centralize their power distribution authority which was previously a divisional responsibility - because diesel power can travel far beyond the divisional boundary, it is no longer operationally efficient to treat the diesel engines as divisional assets.

- 2) Railroads begin to consolidate their maintenance facilities to enjoy the scale economy. Originally, servicing equipment was required at each terminal; engine shops were distributed over the network, dieselization makes many intermediate servicing points unnecessary and decentralized maintenance operation inefficient.

- 3) More deliberate distribution effort will be required to bring an engine back to the home-shop when it is due. For a non-home-shopping system, in which an engine is not regularly assigned to a specific shop, engine shops have to take care of more unexpected work load than before.

The lessons we can learn from the above historical events are that vehicle technology will significantly affect 1) the availability and reliability of the engine, 2) the maintenance policies, and 3) eventually the maintenance logistic systems. When we put the above

observations into perspective, they in fact highlight the importance of matching the capability of maintenance systems with the transportation operating characteristics. In the followings, we shall discuss some key options concerning the maintenance logistic systems.

B. Maintenance Logistic System

General Maintenance System Structure. Since the nature of the physical process of power maintenance can generally be categorized into two classes [*], namely: operational servicing (including daily inspection and running repair) and major maintenance (including scheduled maintenance and unscheduled repair), the power maintenance system can be structured into a two-level system accordingly, as in Railroad A. In such a system there are certainly more servicing stations than repair shops. Nonetheless, there is an alternative structure which consists of three levels, i.e., in addition to the second-level major maintenance shops, there is a level of back-shops which perform the actual repair work [**]. In this case, the second-level shops only perform basically a replacement function, so as to minimize the power detention time.

[*]: Engine rebuilding certainly is another class. However, for railroads with rebuilding capacity, like Railroad A, they usually separate it from the normal maintenance function and operate the rebuilding shop primarily as a contractor that can also accept outside rebuilding projects on contract basis.

[**]: According to AAR's "Compendium of Locomotives and Cabooses Information System", 1979, Union Pacific's maintenance system is so structured.

Pools of components furnished by the back shops must be stocked by the replacement shops in this system, and all the replaced components are delivered to the back-shops to undergo repairs. It is evident that the three-level system tends to use higher material inventory cost to trade-off shorter power out-of-service time.

In addition to the levels involved, another decision of maintenance systemic structure is the degree of concentration. The location of maintenance facilities inhibits the availability of the fleet. Too few locations require longer travel time for necessary shoppings, whereas too many locations make control difficult. In Railroad A, there are more than ten (level-two) engine shops in operations. For many mechanical officers in the railroad, such a system is considered to be too decentralized and uneconomical to operate. However, they are short of capital to consolidate the facilities.

Shopping Assignment Policy and Mechanism. Assigning the maintenance responsibility of each individual unit to a specific shop tends to improve reliability [Emerson, 1975]. This is the so called home-shopping policy. In addition to the advantage of clear accountability, this policy also makes the shop work load more predictable and material inventory more controllable. However, a strict home-shopping policy may result in extra nonproductive power deadheading mileages by returning engines home for either scheduled or unscheduled maintenance, or excessive power idle hours when those engines which will be due shortly are held at their respective home terminals awaiting scheduled maintenance to save the otherwise required distribution effort. In both cases, fleet availability suffers.

In addition to the accountability of engine reliability, another important consideration is shop workload to the design of shopping policy. Due to the uncertain nature of unscheduled maintenance, strict home shopping policy may result in an imbalanced distribution of workload of shops in the system from time to time. To efficiently utilize the shop capacity and to maintain desirable availability, shopping assignment policy should be sufficiently flexible to allow some balancing of workload among shops, although this balancing should be minimized if responsibility integrity for individual units is to be sustained.

Either for the purpose of minimizing the loss of fleet availability associated with the shopping operation, or for the purpose of shop workload balancing, the coordination between the mechanical and transportation control officers is vital. Some railroads consider shop workload balancing as a priority maintenance policy; they even assign a mechanical liaison officer working together with the power dispatchers in the same office to schedule power shopping activities on a real-time basis [RSMA, 1964; AAR,1979]. However, this is not the mechanism employed by Railroad A.

Material Control. Spare parts inventory is an important element of power maintenance logistic systems. Inadequate control of power spare parts not only can cause excessive parts inventory cost, but also can prolong the out-of-service time of power. Usually two categories of items should receive particular attention, namely, high use rate items and high cost items. The stock level of the first category is preferably kept high and the second category low.

5.1.4 The Total Maintenance Task

In summary, maintenance is a rather complicated function. Although the floor level control tasks are easy to be recognized, high level tasks are not as apparent, e.g., the design and operations of the maintenance logistic systems. The development of a proper conceptual framework (which guides the identification of the control tasks at all levels) is essential to the analysis and assessment of the maintenance performance (as well as to the proper discharge of the maintenance responsibility). To do this, in this section (5.1) we investigate the nature of the control tasks and their interrelations involved at various levels of maintenance operations. Given this knowledge, we are able to synthesize the total control tasks concerning power maintenance.

A Causal Map of Maintenance Decision

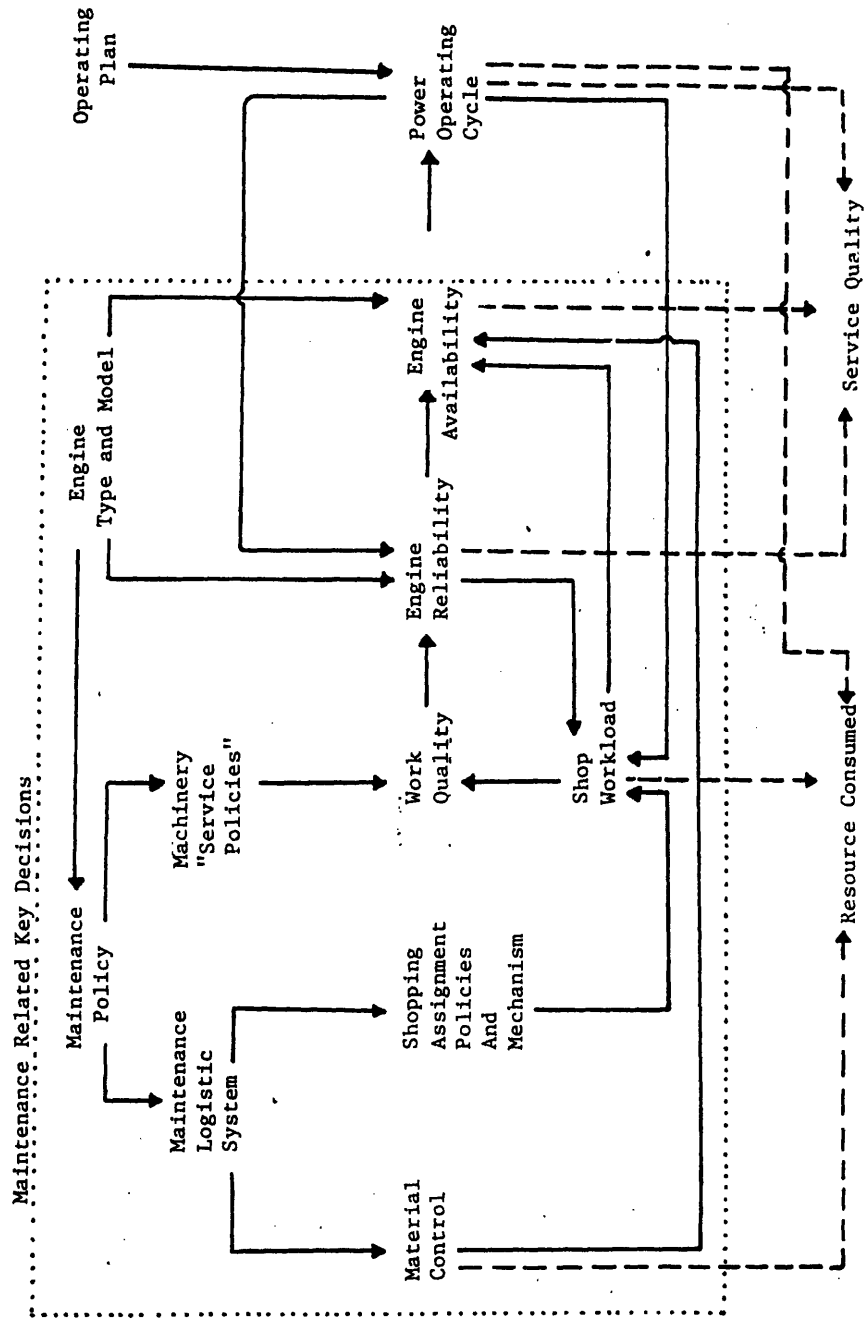
Before we synthesize the maintenance control task hierarchy, let us first summarize the causal relationships discussed thus far.

Since high engine utilization is dependent on availability, and engine availability in turn is dependent on the efficiency (time required) and effectiveness (reliability) of maintenance operations, availability and reliability constitute the core of the maintenance tasks. Centered around such a core, Exhibit 5-1-8 gives a summary of the causality regarding maintenance decisions discussed in this chapter.

Briefly, vehicle technology is essential to the selection of maintenance policies, while the maintenance policies can be categorized into two major groups: the "service policies" of the equipment which include policies on inspection intervals, critical level of controlling

Exhibit 5-1-8 CAUSALITY OF MAINTENANCE DECISIONS

(modified from Manheim, 1981)



parameters and stopping rules; the other is the choice of the logistic systems which include the choice of the maintenance systemic structure, material control policy, and shopping assignment policy and mechanism. Equipment service policies set the tune of the required maintenance standards and work quality, as well as directly determine the achievable level of power reliability. The performance of material control has a direct bearing on fleet availability and maintenance cost; while the practice of shopping assignment in conjunction with power cycling operations determine the shop workload which in turn affects maintenance quality, and eventually the engine reliability.

Control Tasks Hierarchy of Maintenance Operations

To facilitate our later analysis on task responsibility, we can translate the interrelationships shown above into a control task hierarchy in matrix form as shown in Exhibit 5-1-9.

Briefly, because maintenance function is operated within the general (meta-control structure) of power management, in the maintenance module our concern starts from the work units relating to maintenance cycle. The control tasks involved in the power maintenance cycle in general include: 1) the planning of maintenance logistic systems, facility locations, service policies and various standard operating procedures; 2) the execution of serviceable fleet standards, maintenance budget, mechanical quality standards and related transportation service quality standards; and 3) the review of fleet availability, maintenance costs, and the system's train performance relating to maintenance function. The execution phase of the above tasks can be further elaborated by breaking them down into two sets of components, i.e.,

Exhibit 5-1-9

TOTAL MAINTENANCE CONTROL TASKS

Management Cycle Power Cycle Component	Planning	Execution	Performance Review
Maintenance Cycle	<ul style="list-style-type: none"> • Maint Logistic System • Facility loc. • Service Policy • SOPs 	<p>Standards:</p> <ul style="list-style-type: none"> • Serviceable Fleet Profile • Maint. Budget • Mech. Quality • Transp. Serv. Q. 	<ul style="list-style-type: none"> - Fleet Avail - Maint Cost - Train Perform Due to Maint.
Scheduled/Unscheduled Maintenance	<ul style="list-style-type: none"> - Maint. Schedule plan - Manup Level 	<ul style="list-style-type: none"> - Shopping Assign - Shop Supervision - Material Control 	<ul style="list-style-type: none"> - Shop Cost - Unit shopping Time - Unit Reliability - Shop Expense
<u>Operating Cycle</u> Servicing	<ul style="list-style-type: none"> - Material Handip policy - Train Sch. 	<ul style="list-style-type: none"> - Quality Control - Servicing Super. - Dispatching Coordination 	<ul style="list-style-type: none"> - Servicing Count - Unit Servicing Time - Train Perf. Due to Maint.

scheduled and unscheduled maintenance, and servicing operations. In practice, they may be carried out in an interrelated way. The tasks involved include: 1) the planning of maintenance schedule, shop manning level, material handling policy, as well as the intervention in train schedules if necessary, 2) the execution of shopping assignment, shop floor supervision, material control, mechanical quality control, servicing supervision, and the train/power dispatching coordination, and 3) the review of shop count, shopping time, unit reliability, shop expenses, servicing count, servicing time and terminal train performance accountable for maintenance.

5.2 The Controlling System

5.2.1 Engaged Actors

From a power cycle control point of view, in the maintenance context, there are three major sets of control tasks: the control of the power maintenance cycle in general, the control of scheduled and unscheduled maintenance operations, and the control of the power operating cycle related to the servicing operations. The actors engaged in the above three tasks are identified in Exhibit 5-2-1, by following Railroad A's Mechanical Department structure as given in Chapter 4.

Looking more closely at the floor level management, Exhibit 5-2-2 shows the organization of a major power maintenance shop in Railroad A. Management is primarily organized on a work-shift basis and along distinct craft lines. Among the positions on the organization chart, shop coordinator deserves our particular attention; he plays a liaison role between the transportation and shop operations. In other words, in Railroad A, there is no central maintenance scheduler to coordinate the workload among major shops, but such coordination task is normally taken care during the daily 9 A. M. telephone conference which is chaired by the General Superintendent-Mechanical, or the shop coordinators and Division Master Mechanic in case of an emergency.

Engine terminals which primarily perform servicing function, have much smaller staffs (refer to Exhibit 5-1-4). The foreman in charge of the servicing operation usually reports directly to the Division Master Mechanic who in turn coordinates with other divisions and the power control center. Nevertheless, in any situation, the power control center can directly contact servicing foremen to determine power status

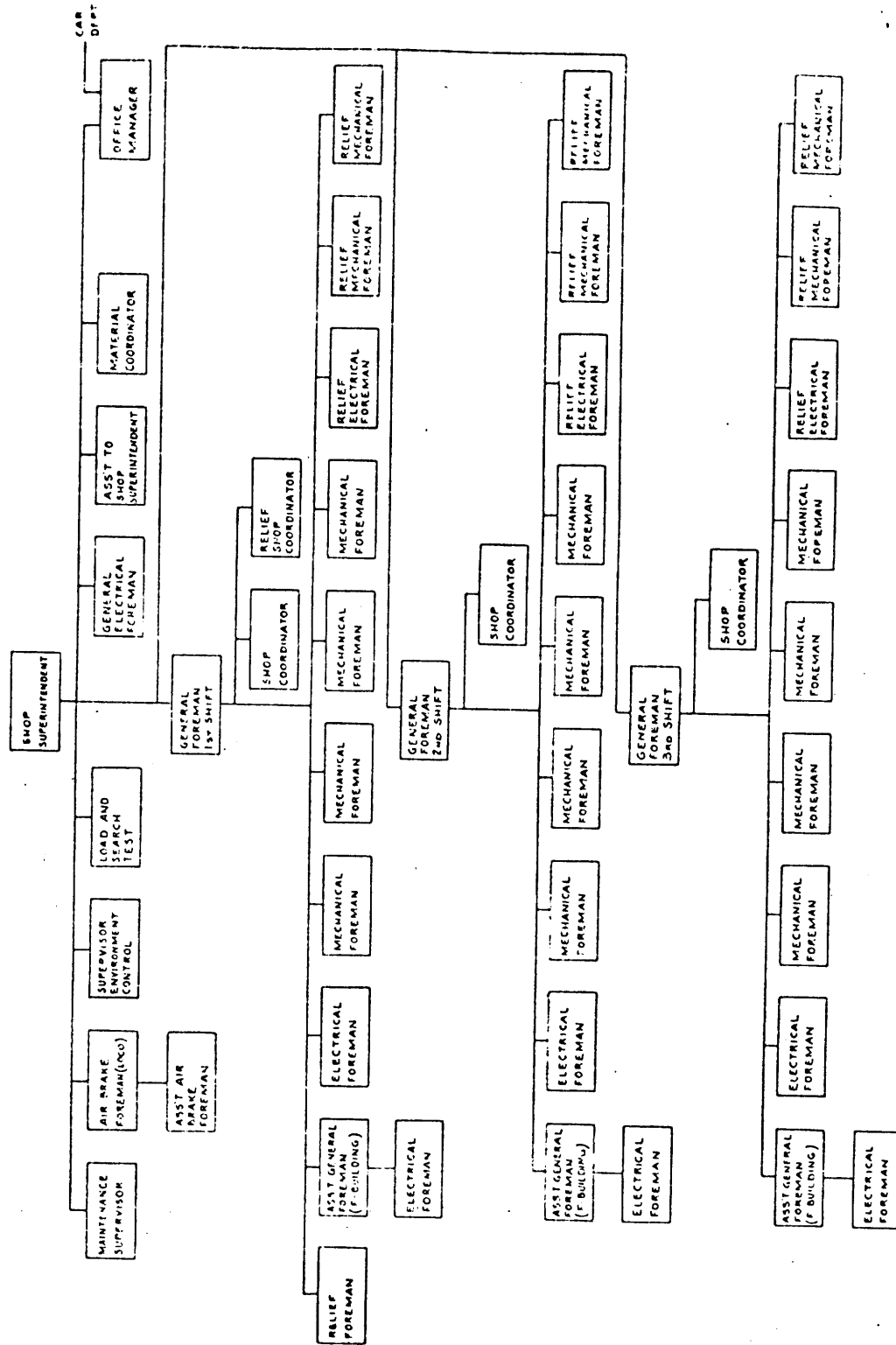
Exhibit 5-2-1

Actors Involved in Power Maintenance Management

ORGANIZATION LEVEL POWER MAINT. CYCLE COMPONENTS	GENERAL	COORDINATING SUPPORTING	OPERATING SUPERVISION
<u>MAINT. CYCLE</u> (MECH. COMPONENTS)	VPT VPM	L.R. planning Unit E.E. } unit M.E. }	Gen. Supt. Mech.
SCHEDULED MAINT. UNSCHED. MAINT. <u>OPERATING CYCLE</u> SERVICING	Gen. Supt. Mech.	Q.C. unit Material supply unit	Shop Supt. Master Mech. Repair Foreman Servicing Foreman

TYPICAL ORGANIZATION OF A MAJOR MAINTENANCE SHOP

(RAILROAD A)



or ask them to prepare power consists for outbound trains.

Given the actors engaged in the maintenance operations, in the followings we shall examine how they actually perform their roles.

5.2.2 Maintenance Control in Practice

To examine actual maintenance control practices, we concentrate on three aspects: shop level supervision (including both servicing operation, major inspection and repairs), shopping assignment and power status monitoring, and general maintenance performance control.

A. Shop Level Supervision

The supervision of shop performance is basically comprised of the control of resources (including human and material) and the control of maintenance physical process. The control of manning level and parts inventory are tasks with a relatively long time frame as compared with the control of flow level of maintenance operations. In a sense, the former two provide an operating environment for the latter. The shop Superintendent and the Master Mechanic are the persons in charge of the workforce and material supplies for their respective shop or division. By and large, these decisions are made within the frame of a monthly shop (or division) budget. The general foreman is normally the person in charge of the flow level maintenance operation.

Control of Maintenance Physical Process. Based on the interview data from Railroad A, the control of maintenance physical process may be described as follows. At the beginning of each shift, the general foreman first looks at the turnover report prepared by the preceding

shift's general foreman (sample shown in Exhibit 5-2-3) regarding what work remains. Then he will check the crewforce statement (sample shown in Exhibit 5-2-4) and the parts inventory statement prepared by the clerk in the shop superintendent (or master mechanic's) office, concerning the available man power and material. After that, he refers to the maintenance schedule as well as the train schedule and estimates, implicitly or explicitly, the incoming workload. Finally, he asks the Superintendent or Master Mechanic for special instructions, and then sketches out a working plan for his shift regarding crew assignments and job priority. Certainly, revision of the plan is necessary whenever an operating contingency occurs. Exhibit 5-2-5 gives an output rate profile of a Railroad A's major repair shop, which represents an outcome of the interactions among manning level, material supply status, work planning and execution, maintenance schedule, shopping assignment and power dispatching requirements.

Putting the above introspections into the framework of the expert's cognitive process suggested in Chapter 2, because of the repetitive nature of the work, an experienced general foreman will develop a number of rules of thumb for the sketching of his working plan. By applying such a heuristic, it usually will not take long for them to work out a plan. Indeed, the key questions are: How good is the plan? Are better plans feasible? and How could they be developed? In this regard, the design of some accountable performance indices becomes critical to the evaluation of a general foreman's performance. Moreover, these indices should be capable of not only reflecting the efficiency and effectiveness of the working plan, but also the nature of the execution

Exhibit 5-2-3 EXAMPLE OF ENGINE REPAIR-SHOP TURNOVER REPORT
 (Prepared by 11 - 7 Shift General Foreman)

7 AM

11/18/80

- 731 - Reported K.C.C.B. & K.L.O.B. - I&W
- 7778 - Finish checking oil blow - under piston foot of W. bearing - I&W
- 3036 - 90 Day inspect.
- 3046 - Finish check downer - check out 4000 - I&W
- 3077 - Gov oil line in turbine burner - finish 4000 - I&W
- 6064 - D.O.M. - reported 2/10 turbine - I&W
- 7710 - 90 day inspect. - I&W - (check for valve blow)
- 7736 - Finish turning outside - I&W
- 7993 - Clean for 4000 inspect. & remove tilt
- 8034 - take up brake springs - Check & clean for 45 day
- 8278 - March - 90 day inspect. - I&W
- 8461 - Annual inspect. & clean
- 9178 - 90 day & clips - chg. air comp
- 9252 - Turn 2 valves (one 2 turn 1/2 turn & 1/2 turn) - I&W
- 9429 - K.C.C.B. - I&W - (check 2/10)
- 9513 - Valve blow
- 742 - Oil cut stack - I&W
- 9242 - Check probe cyl. valves - clips - run to Palush (check downer)
- 8007 - Finish cleaning for 4/11 inspect.

- 103 - Finish changing #42 valves - check for fuel leaks - I&W
- 1250 - Finish 6000 & clips - make pilot modification -
- 407 - Finish L#2 coil spring - I&W

- 2522 - Coming - from Palush - getting wheel clip - check # 47M
- 6066 - " " - from 7000 downer - check S.C.R.
- 8111 - " " - check for fuel leaks & oil (per 4000)
- 8224 - " " - on 10/14 from 7M Comb - has 1/3 m.t. - R/p
- 3007-3063-3070-7723-8137-8195-8233-8257-8273 - oil samples
- 9019-8021-8195-8325 - get 7/8 oil samples

- 7547-3019 - Coming from do. fuel
- 8274 - Coming on 146 - repairs not holding properly
- 9432 - " " " - dead (reason unknown)

- 450 - March - put in checks on & connect leaks on #1 & 2 7M's
 repair brake ring & L.B. squish is out of pocket - finish
 drawing into oil - send O.I.T. to Palush

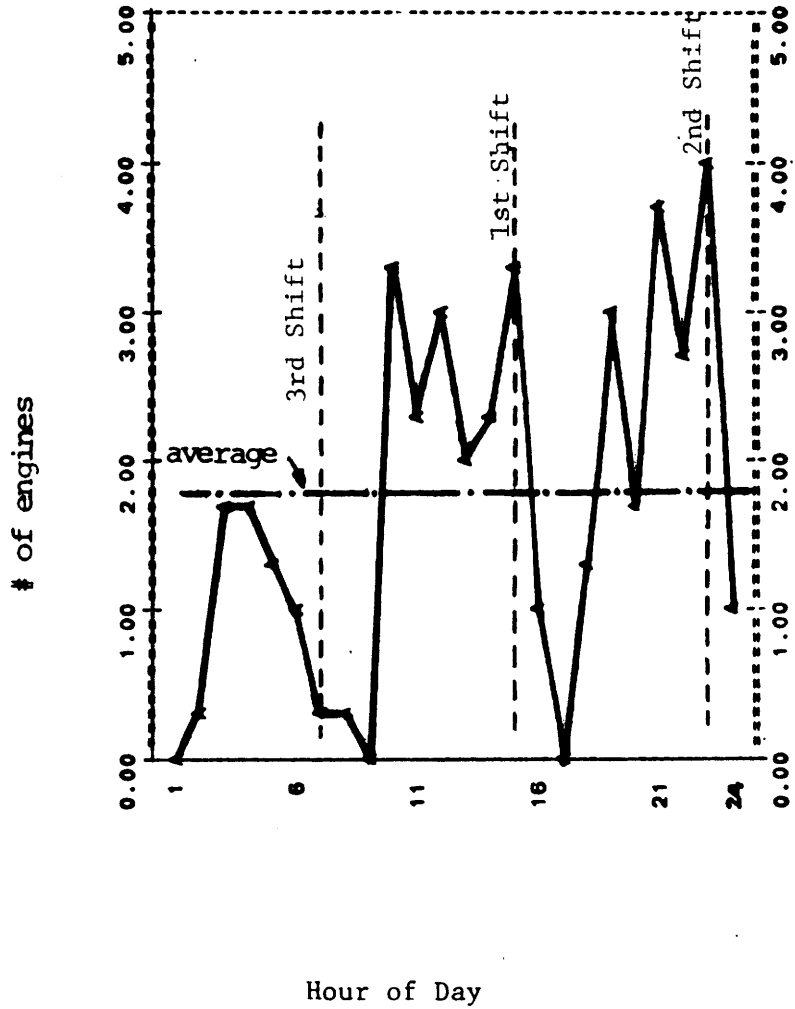
- oil sample
 647-3007-7954-8143-8144-8446-9145-9505 - I&W
- oil sample
 9511-4637 - I&W

- 8180 - Use in speed to remove fuel (within fuel) - Do not fuel

- 1214 - Check on 45 day

- 1434 - due on 18th - 1209 due on 20th
- 1431 - in small - oil coming out L. air box drain
- 104 - at "a" gauge - main air gauge 4/10
- 325 - at "a" gauge - R.K. point in burner - R#9 brake cyl. leak

Exhibit 5-2-5. Output Rate of Shop



of the plan (which includes the control of work quality). We shall return to this point later.

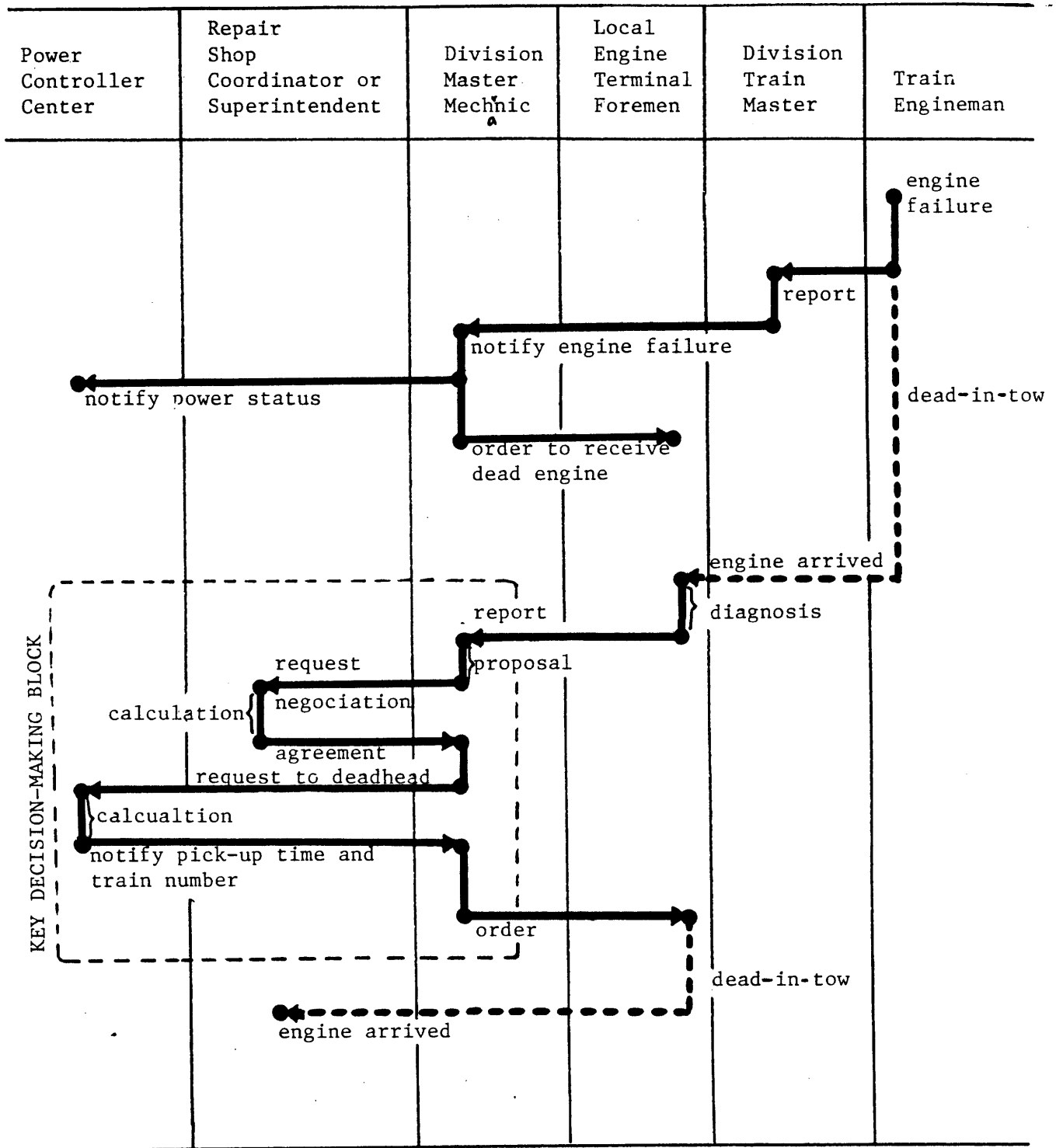
B. Shop Assignment and Power Status Monitoring

Shop Assignment. The importance of shopping assignment comes from its impact on shop workload. Usually, scheduled maintenance in a home-shopping system and servicing operations for scheduled trains' power consists do not cause trouble to shops or service stations, because they are anticipated. The real problem is the unscheduled work. In the following, a communication locus concerning the handling of engine road failure is presented which sheds light on the underlying mechanism for the assignment of unscheduled maintenance work (Exhibit 5-2-6).

When road failure occurs, the responsible Division Master Mechanic is notified through the Division Train Master. The Master Mechanic informs the power control center as well as orders the local engine terminal preparing to receive the dead engine. In many cases, the Master Mechanic also asks the train engineman about the problems through radio. In any case, the local maintenance crew will diagnose the engine after its arrival and report to the Master Mechanic about the type and amount of work to be done.

If the work can not be handled in the Master Mechanic's division for some reasons (e.g., lack of necessary part, repair equipment, crew speciality, or all facilities has been overloaded already), then he will select and contact the appropriate shop superintendent or coordinator to ask for an agreement to accept the bad-order. Given the

Exhibit 5-2-6
EMERGENCY (ENGINE ENROUTE FAILURE) SHOPPING PROCEDURE

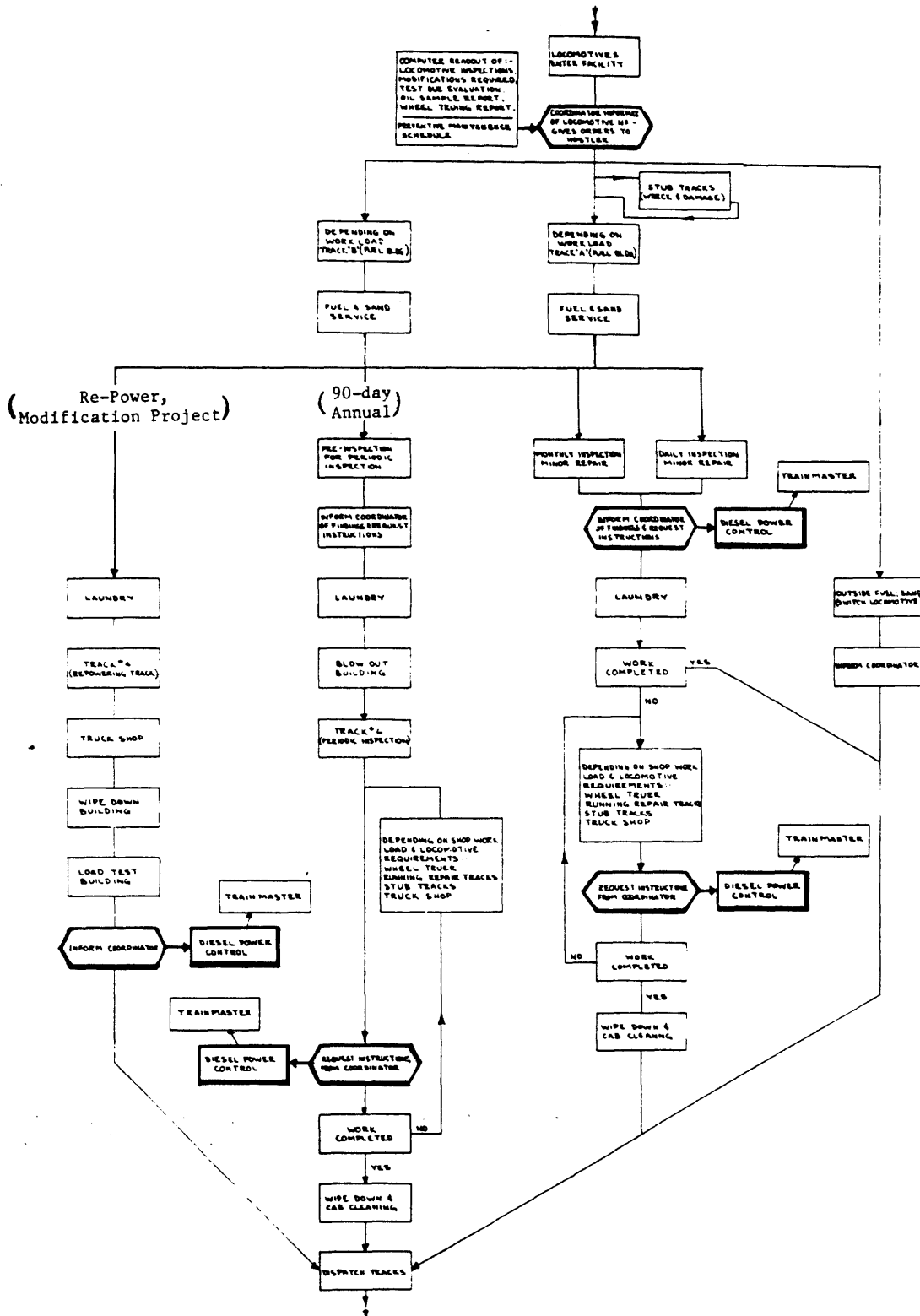


confirmation from the negotiating repair shop, the Mechanic will next request the power control center to deadhead the engine, while the center will determine the time and train number to make the delivery. Finally, the local maintenance officer will be notified to make ready for the deadheading. The key to the whole process is the choice the Master Mechanic made on the candidate repair shops, and the basis for him to negotiate afterwards.

Power Status Monitoring. Detailed information on the fleet status is essential to power dispatch operations. Efficient communication between the maintenance officers and the power control center is the premise of efficient utilization of power. The flow chart shown in Exhibit 5-2-7 illustrates the operating procedures adopted in the engine shopping process in Railroad A (this flow chart is a an elaboration of the shop movement components of power flow shown in Exhibit 5-1-2). Particular attention should be given to the role played by the shop coordinator. The tasks performed by the coordinator include: 1) assigning the engine to tracks that lead to areas which perform certain specific work, and 2) keeping power control center informed concerning the change in the engine's status (e.g., the beginning of a new process, completing an old process). For local servicing stations, such a coordination role may be taken by designated foreman or Master Mechanic himself in case the stations encounter a work balance problem.

The above observations also indicate that there are channels through which the power control office can exercise its influence on the maintenance operations. When an engine passes through a branch point of the shop's process, the shop coordinator may contact the responsible

Exhibit 5-2-7 MAINTENANCE SHOP STANDARD OPERATING PROCEDURES



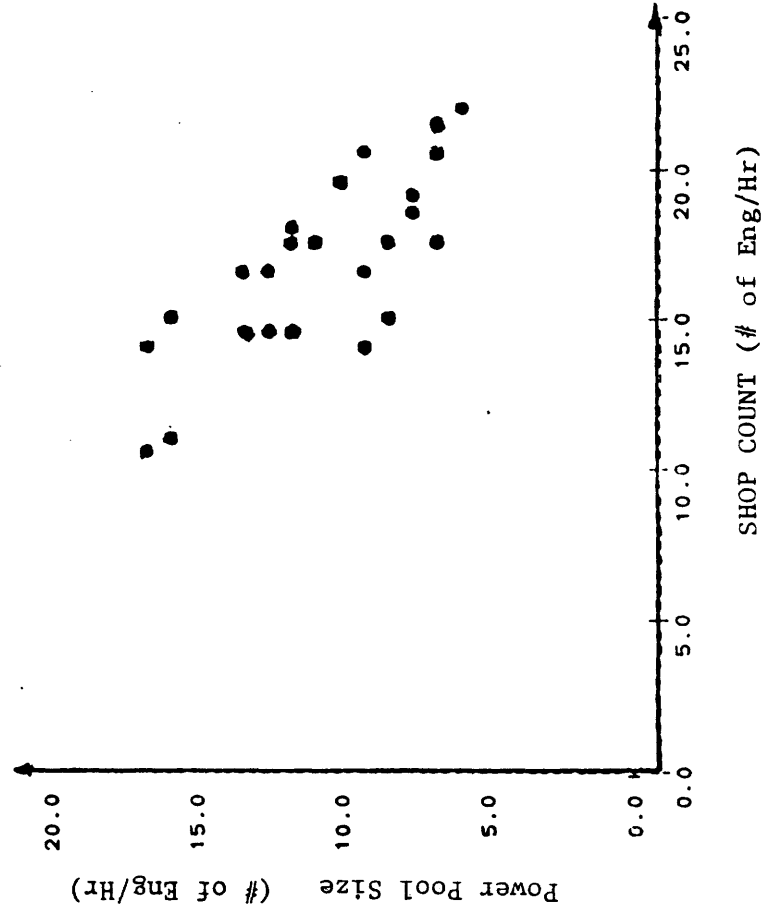
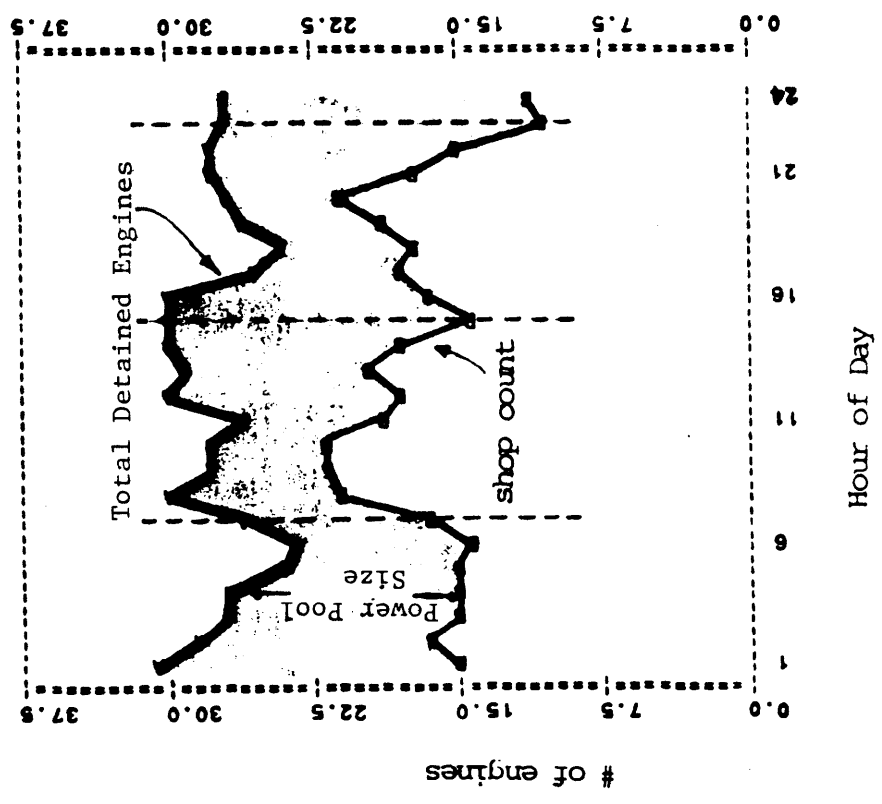
power dispatcher. In case of a power shortage, the power dispatcher can then affect the mechanical officer's subsequent decisions through the same communication channel; for instance, influencing them to alter their work plan or priority, or increase the immediate size of power pool to satisfy a pressing demand. Exhibit 5-2-8 shows the relations between the power pool size and shop count in one terminal area. The point is that the opportunity to pull more shopped units back to service usually exists, yet the key questions are: 1) Whether it is necessary, since this practice implies the remaining units may stay longer due to reallocation of (concentration of) man-power, and 2) If necessary, on what basis the power dispatcher can exercise his intervention effectively? One should remember that there is no formal authority relationships between him and the shop officers.

C. General Maintenance Performance Control

There are at least four levels of tasks involved in the control of general maintenance performance: daily telephone operating conference, periodic performance and policy review, annual budgeting and long-term systemic improvement.

Daily Telephone Conference. The daily telephone conference is an important coordination mechanism adopted by railroads (in Chapter 6, we shall discuss the transportation version of the operating conference). In Railroad A, the maintenance operating conference is held on a regional basis (there are two regions in the system) and chaired by the Regional General Superintendent-Mechanical (RGSM) who is in charge of region-wide operations and reports directly to VPM.

Exhibit 5-2-8
 IMPACT OF MAINTENANCE PERFORMANCE ON REAL-TIME ENGINE AVAILABILITY
 IN A RAILROAD TERMINAL
 (Railroad A)



The function of the conference is principally to 1) give the RGSM opportunity to review daily performance and to coordinate operations in the region (balance shop work-load, set work priority and so forth), and 2) give the Shop Superintendents and Division Master Mechanics an opportunity to get immediate feedback regarding their performance, put forth their specific requests, and receive from RGSM special operating instructions concerning the coming day's operations. Exhibit 5-2-9 and 5-2-10 show two sample reports which will be referenced during the conference. The first is a 5 A. M. shop count report, which stands for the number of engines out-of-service in a particular engine terminal. When summed up across the system, in Railroad A this measure stands for the shop-margin of the fleet for the day; therefore, shop count is in fact the operational basis for calculating the daily serviceable fleet. The second report is a summary record of locomotive en-route failures occurring in the previous day, and it will eventually reach the VPM's desk every morning. In fact, this report reflects, only in part, the fleet reliability during the last 24 hours, because a complete reliability measure should cover all the unscheduled repairs of which road failures are only a part. However, the road failure record is the only available reliability report in the railroad.

Periodic Performance and Policy Review. Daily performance is sensitive to the variability of the rail operations; therefore, for evaluation purpose, average performance through a relatively long period (e.g., a week, or a month) is usually a more appropriate measure. In the power maintenance context of Railroad A, the principal performance target applied throughout the year is a 10% rule - shop margin of the fleet

Exhibit 5-2-9

EXAMPLE OF 5 A.M. SHOP-COUNT REPORT

(Prepared by 11 P.M. - 7 A.M. General Foreman)

(Used by Division Master Mechanics in 9 A.M. Telephone Conference)

JURISDICTION: DELTA DIVISION DATE: NOVEMBER 18, 1980

AVAILABLE: 4 3014-3042-7900-8007

INFOUND: 10 647-3007-7954-8143-8444-8446-9145-9505-9511-9637

HELD: 21

LOCATION	UNIT NUMBER	DATE IN	TIME OUT	REASON FOR SHOPPING
C&IW	103	11-17	3PM	CHG #4 & 6 ASSYS
	407	11-17	11AM	COIL SPRING
GM&C	731	11-16		KLCF-KCCF
	742	11-18		OIL CUT STACK
	1250	11-13	3PM	SEMI-ANNUAL
	2278	11-17	3PM	STACK GASKET BLOWN
	3036	11-18	5PM	QUARTERLY
	3046	11-15		CHG TURBO
	3077	11-17	3PM	CHG #4-9-10 & 14 ASSYS
	6064	11-15		DCA-RPT F/O TURBO
	7710	11-18	3PM	QUARTERLY
	7736	11-13	11AM	TRN WHLS
	7993	11-17	11AM	CLEAN FOR 45 DAY
	8034	11-11	3PM	TAKE UP BRAKE STRAPS
	8270	11-18		QUARTERLY-SEARCH
	8461	11-17	11PM	ANNUAL
	9178	11-17		QUARTERLY-CHG AIR COMP
	9242	11-18	2PM	AIR LEAK
	9252	11-14	7PM	TRN WHLS
9429	11-17		KCCF	
9513	11-17	11PM	VALVE BLOW-TM CUT OUT	

EXHIBIT 5-2-16 EXAMPLE OF ROAD FAILURE REPORT

RECORD OF ACCUMULATIVE LINE OF ROAD FAILURES PERIOD ENDING 5:00 A.M. 11-17-

UNIT NO.	FAILURE LOCATION	DATE	DISPATCH POINT	RECEIVED DATE POINT	REPORTED FAILURE	REPAIR POINT	FAIL CODE	POSS	REPAIRS MADE	DOT
836		11-16		11-16	KCCP					
282		11-16		11-15	15-16-17-18-19-20					
131		11-16		11-17	KL08					
2375		11-16		11-16	18-19 grade washed					
2536		11-16		11-16	KL08					
2450		11-16		11-16	20-21/22					
2506		11-16		11-16	100-110					
2620		11-16		11-16	110-120					
2538		11-16		11-16	KL09					
222		11-16		11-16	7M 56 CWS					
2017		11-16		11-16	KL03					
2441		11-16		11-16	CRASH SITE / EMP. COMP. FOUND					
276		11-16		11-16	3/0 Bury DKS					
241		11-16		11-16	only bedding for mats					
914		11-17		11-15	OKS when put in 12-18-19					
2511		11-17		11-17	KL08					
2153		11-17		11-17	prep-work to be done					

should be no more than 10% - the primary calculation basis is the daily 5 A. M. system shop count. The actual achieved shop margin, in terms of monthly average, normally ranges from 8% to 12%. According to a senior operating officer, the designation of the 10% rule dates from the early years of dieselization of the railroad and the rule has been left unreviewed ever since. In other words, no deliberate review process concerning the policy of fleet availability existed in the road.

Exhibit 5-2-11 shows two monthly shop performance summary reports prepared by the Information System Manager of Mechanical Department regarding the average out-of-service time for each type of scheduled maintenance and the maintenance expenses. From the above performance-report, one can find that relatively few units underwent scheduled maintenance without having unscheduled repair work done, for instance, for the 45-day inspection the ratio is 38 out of 106.

Annual Budgeting and Long-Term System Improvement. Maintenance budgeting is basically a top-down process in Railroad A. The "flat" serviceable fleet policy (10% rule), the approximately constant fleet size and incrementally changed train schedules result in a comparatively stable average maintenance workload which makes annual budgeting relatively straightforward. Primarily because there is no explicit policy review concerning with appropriateness of existing maintenance practices.

5.2.3 Linkages Between the Two Systems

A. Task-Actor Matrix

EXHIBIT 5-2-11 MONTHLY SHOP PERFORMANCE REPORT

DECEMBER, 15

(ALL \$ AMOUNTS ARE IN 100 OF DOLLARS)

MAINTENANCE EXPENSES

	RUNNING REPAIR			ACCIDENT DAMAGE			HEAVY REPAIR			OTHER		
	* NO	LABOR MATERIAL TOTAL	* NO	LABOR MATERIAL TOTAL	* NO	LABOR MATERIAL TOTAL	* NO	LABOR MATERIAL TOTAL	* NO	LABOR MATERIAL TOTAL		
THIS MONTH	405	\$4217 \$4674 \$9491	20	\$1 \$0 \$1	3	\$0 \$0 \$0	7	\$0 \$0 \$0		\$0 \$0 \$0		
YEAR-TO-DATE	6072	\$57066 \$62646 \$119712	340	\$53 \$0 \$53	30	\$0 \$0 \$0	81	\$0 \$0 \$0		\$0 \$0 \$0		
THIS MONTH LAST YEAR	475	\$5355 \$5660 \$11015	26	\$1 \$0 \$1	3	\$0 \$0 \$0	10	\$0 \$0 \$0		\$0 \$0 \$0		

COST RECAP

NO	LABOR MATERIAL TOTAL
THIS MONTH	439 \$4818 \$4674 \$9492
YEAR-TO-DATE	6523 \$57119 \$62646 \$119765
THIS MONTH LAST YEAR	514 \$5356 \$5660 \$11016

SCHEDULED MAINTENANCE

	NO. OF INSPECTIONS AND AVERAGE HOURS PER INSPECTION										
	45-DAY NO. HOURS	90-DAY NO. HOURS	SEMI-ANNUAL NO. HOURS	ANNUAL NO. HOURS	BIENNIAL NO. HOURS	TOTAL INSPS.	SEARCH TESTS	SEARCH AND LOAD TESTS	LOAD TESTS	SEARCH AND LOAD TESTS	
THIS MONTH	106	17	24	79	5	122	9	158	152	12	24
EXCLUDING RUN REPAIRS	38	9	4	51	0	0	1	110	44		
YEAR-TO-DATE	1280	20	416	61	203	69	100	173	2092	271	475
THIS MONTH LAST YEAR	57	14	34	57	18	119	5	92	165	37	61

TOTAL HRS MATERIAL DELAY	AVERAGE HRS AWAITING DISPATCH
THIS MONTH	301
	43
	11

For Units Released from the Repair Shop only.

The observations and findings presented above can be summarized in terms of the relationships between the control tasks and responsible actors as shown in Exhibit 5-2-12. In fact, this Task-Actor matrix is an elaboration on the maintenance module in the general Task-Actor matrix as shown in Exhibit 4-2-7. Further detailed diagnostic assessment and change recommendations will be discussed in Chapter 7.

B. Summary

Maintenance is a key functional activity which supports as well as constrains power utilization. The knowledge on maintenance operations is essential to the assessment of overall power management performance. The relationships between maintenance and transportation operations also provide us with an opportunity to observe problems concerning the process of interdepartmental coordination. In addition, this chapter also shows how to develop work units in a specific functional area based on theoretical and practical insights into the technological system to be managed, and how to apply these insights to describe and analyze the controlling function of maintenance operations. From the methodology point of view, this chapter shows how to apply various descriptive and analytical techniques, e.g., work unit (control tasks) matrix, communication locus analysis, task-actor matrix, etc., in a specific performance area to generate and document data essential to the later phases of intervention (i.e., diagnosis, prescription and action). The insights gained in this chapter also facilitate more microscopic diagnosis through the provision of contextual information.

EXHIBIT 5-2-12 MAINTENANCE TASK-ACTOR MATRIX

Organization: Units Control Tasks	VPT	VPM	LR, Pln. IE, ME Dev.	Mech Gen. Supt.	Q.C. Mtrl. Supl.	Shop Master	Repr. Foreman	Serv. Foreman
	Maint. Logistic System Facilities Locat/Desg. EQU. SERVICE Policy Stand. Operat. Proced.	CONSU.	DEC. (MOST)	PROPOS.	EXECU.			
Annual Effective Fleet Size Guideline Maint. Annual Budget	CONSU.	DEC.	PROPOS.	EXECU.				
Mech. Reliab. Guide Tran. Serv. Level Gud.	CONSU.	DEC.	PROPOS.	EXECU.				
Prev. Maint. Schedule	NOTIF.	DEC.	PROPOS.	CONSULT/EXECU.				
Maint. Manning Level Material Handling Ping				DECISION	PROPS/EXEC.			
Engine Shopping Assign				(DECISION)	CONSU/AUTH			
Train Dispt. Coord.				(DECISION)	CONSU/AUTH			EXEC/AUTH
Shop Work Supervision Material Control Quality Control					DECISION	AUTH.		
Servicing Supervision					DECISION			AUTH
Repair Shop Count Unit Shopping Time		EXCEPT REPT RECEIV	REV.	REVIEW	DIRECT. ACCOUNT			
Servicing Count Unit Servicing Time				REVIEW	DIRECT. ACCOUNT			
Shop Expenses Unit Reliability	REV.	REV.		DIRECT ACCOUNT.				
Train Delay Acc. Mach.								
Fleet Availability Maintenance Expenses	REV.	ACCOU.						
Trans. Perf. Acc. Mech	REV.							

Chapter 6

THE STEERING CONTROL OF POWER OPERATING CYCLE

Given the knowledge of Meta-Control Structure (Chapter 4) that characterizes the general operating context within which power managers perform, as well as the nature of the supporting maintenance function (Chapter 5) that imposes the primary constraints on real-time engine availability, we are ready to discuss the control of the power operating cycle.

In the following sections on the controlled system side, we will first examine certain key determinants which directly govern the performance of the power operating cycle, and then we will translate these determinants into decision variables. Performance indices corresponding to these decisions are specified as well. The goal is to shed light on the causal relations underlying the physical process, which can be manipulated by power managers through their control decisions.

On the controlling system side, given the higher level decision premises discussed in the preceding chapters, we can narrow our focus down to real-time operating control issues. Starting from group-level activities to individual decision processes, the analysis reveals the nature of the progressive decision-making processes, the characteristics of individual decision-making processes, and the interactions between individual and team performance. Through such an analysis, the goal is to pin-point the potential areas for improvement and to indicate the nature of needed changes.

6.1 The System Being Controlled

The dynamics involved in rail power operations are complex which relate to complicated interactions among those factors such as tonnages, linehaul running time, detention time at terminal, bad orders, and maintenance and repair times. For analysis purposes, we divide the operation into two major categories: linehaul and terminal.

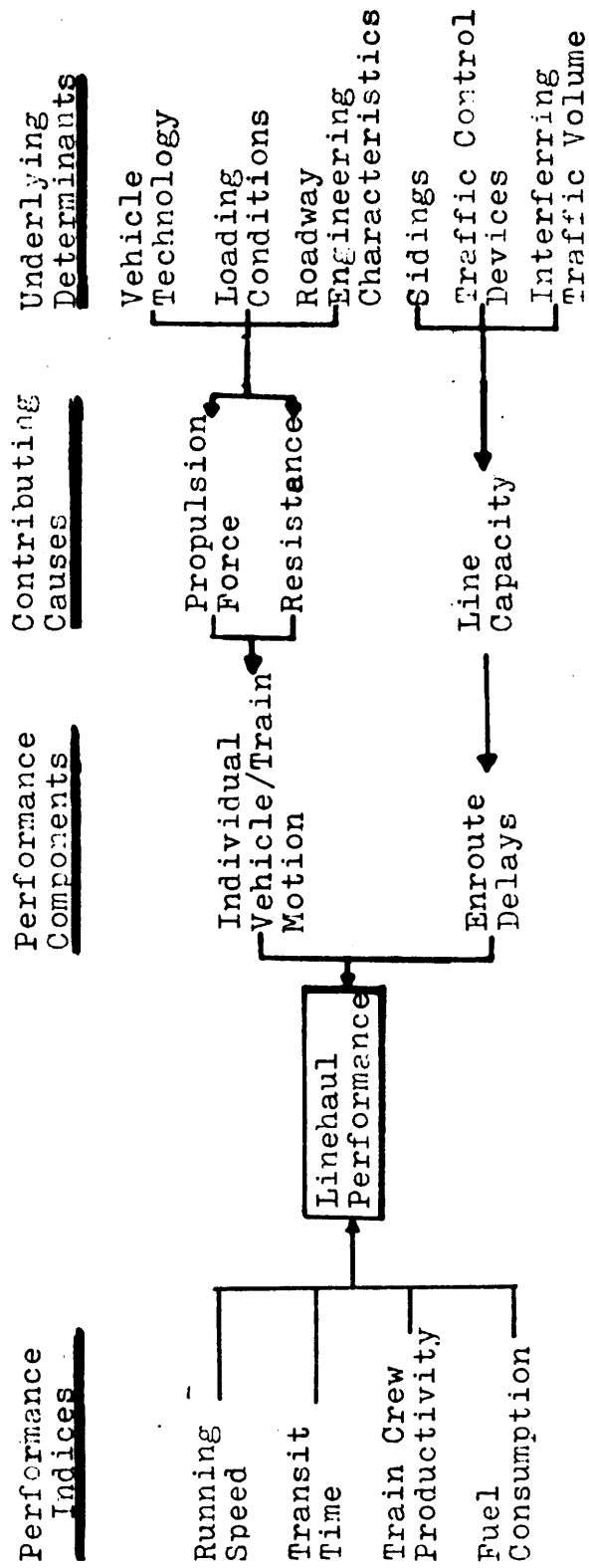
6.1.1 Linehaul Operations

Linehaul speed is, to a very large extent, governed by physical laws and is the traditional emphasis of transportation engineers. The remaining major factor concerning linehaul performance is en-route delay caused by congestion. Exhibit 6-1-1 gives a further breakdown of the cause-effect relationships.

A. Train Motion and the Demand-Tailored Power Unit

The power on railroad trains is typically closely tailored to the actual transportation requirements. For most main line trains, multiple engine units are used to form a power consist. Due to the complex interaction of locomotion forces, gradient and curvature, train motion usually cannot be predicted by simple analytic formula but by simulation [Morlok, 1976, p.169], although the fundamental rules are relatively straightforward, namely, 1) the minimum number of motor axles (lower bound)- which generates the required total tractive force and in turn can be translated into the required number of locomotive units - is determined by ruling grades and /or desired accelerations; and 2) total power (upper bound) is determined by speed or travel time of a train (as imposed by time table). However, for some line sections, the

Exhibit 6-1-1 Factoring Determinants of Linehaul Performance



loading limits of a structure, e.g., bridge, track, and road-bed, may also constrain the maximum axle weight.

In practice, to facilitate the task of assigning power to trains, railroad management usually specifies the desired speed for each train, applicable ton-per-horsepower ratio or tonnage rating for each type of locomotive, and the maximum allowable axle weight in each line segment. Exhibit 6-1-2 gives an example of such a special operating instruction - including speed restrictions, locomotive tonnage rating and engine restrictions. Here, the tonnage rating and ton-per-horsepower ratio deserve further explanation.

Tonnage Rating. The maximum tonnage that a specific locomotive can haul over a given territory at a specific minimum speed is called its tonnage rating. Detailed derivation of the tonnage rating formula can be found in the Appendix of this chapter. Since the usual speed of a train ascending a grade is between 10 and 20 mph, that is the speed at which engine produces maximum tractive force [Armstrong,1979]; the key limiting factor of an engine's tonnage rating is then the ruling grade of the territory in question. In short, tonnage rating is the discounted (according to the ruling grade) total pay load an engine can haul over a given road segment. In other words, this rating is used to specify the minimum number of engine units needed to satisfy the minimum service requirement, given the tons to be moved.

Ton-Per-Horsepower Ratio (W/P Ratio). An alternative to the tonnage rating as a power assignment guideline is a load factor, which gives the maximum allowable ton-per-horsepower (W/P) for each train on each

EXAMPLE OF SPECIAL OPERATING INSTRUCTIONS
-- SPEED LIMITS, ENGINE RESTRICTIONS,
ENGINE TONNAGE RATING (Railroad C)

SPEED RESTRICTIONS

ALL SUBDIVISIONS	MPH All Trains
Through all switches, except where another speed is prescribed:	
Dual Control switches and spring switches	20
All other switches and crossovers	10
Approaching "19" indication train order signal until rear of train has passed	30
TRAINS HANDLING ORE CARS	
On 1st, 2nd and 3rd Subdivisions	30
On Line and 4th, 5th, 6th, 7th and 8th Subdivisions	25
TRAINS HANDLING SCALE TEST CARS	
Except X-870	25
Locomotives with friction bearings when handled dead in a train	25
TRAINS HANDLING PIVOTING MACHINERY ON ITS OWN WHEELS, derricks, pile drivers, cranes, etc., except wreckers	
On 1st, 2nd and 3rd Subdivisions	25
On 4th, 5th, 6th, 7th, 8th Subdivisions and on Line	20
(Note: Locomotive cranes 258054 and DS-823—speed shown applies only when boom end is trailing. Boom Car must be behind crane. When lined up otherwise, handle only on separate instructions)	
WRECKERS	
Diesel & Steam Wreckers with boom end trailing and boom car behind.	*Freight Train Speed
*Unless slower speed required as directed by wrecker foreman. Conductor will confer with wrecker foreman to determine speed desired.	
FIRST SUBDIVISION	
MAXIMUM SPEED	40
EXCEPTIONS:	
MP 178.9— Crossing, Jct., until crossing is occupied	20
MP 205.8— —over St., 1st crossing west of depot	10
MP 205.9— —through First Subdivision turnout	10
MP 252.6— Crossing, 3.7 miles west of until crossing is occupied	20
LINE	30
EXCEPTIONS:	
MP210-MP 236.3— Between and	20
SECOND SUBDIVISION	
MAXIMUM SPEED	40
EXCEPTIONS:	
City—on Uptown Track over first curve crossing highway and two curves at bridge	5
MP294.0-297.0—Between City and	30
MP 314.5-MP 314.9 —between Line Crossing and Third Street	20
MP 330.7— trains using siding over first crossing east of depot	5
LINE	10

LOCOMOTIVE RATING IN TONS OF 2,000 POUNDS BETWEEN ENGINE AND CABOOSE

SEVENTH AND EIGHTH SUBDIVISIONS				
WESTWARD		HORSEPOWER		
From	To	1750	1500	1200
.....	3400	3000	2125
.....	3100	270	1575
.....	3800	3300	1950
.....	3000	2600	1550
.....	3500	3100	1775
.....	4000	3500	2000
.....	3500	3100	1800
.....	3300	2900	1650
.....	3800	3400	2125
.....	3300	2900	1650
.....	3900	3450	2475
.....	3100	2700	1950
.....	2100	1800	1300
.....	2600	2300	1650
.....	5700	5000	3850
.....	Ryder	3800	3300	1950
.....	New Town	3900	3400	2125
EASTWARD				
From	To			
.....	2400	2100	1525
.....	3800	3300	1950
.....	3700	3200	2300
.....	2600	2300	1600
.....	3900	3400	2450
.....	4500	4000	2950
.....	4000	3450	2450
.....	5300	4900	3125
.....	3000	2600	1575
.....	3800	3400	2125
.....	2400	2000	1500
.....	2900	2500	1900
.....	3000	2600	1850
.....	3700	3300	2350
.....	5200	4500	3175
.....	6300	5600	3500
.....	3500	3100	1775
.....	3800	3300	1950
.....	3700	3300	2350

NOTE: These ratings are for single units.

Locomotive ratings in tons of 2000 pounds for 2000, 2250, 2400, and 2500 horsepower units is 150% or the ratings for 1500 horsepower units.

ENGINE RESTRICTIONS

Fourth, Fifth, Sixth, Seventh and Eighth Subdivisions
 And the & Lines

- Do not operate four axle locomotives exceeding a total weight of 267,000 lbs.
- Do not operate six axle locomotives except Unit No. (SD-9).

Second Subdivision—Locomotives with six wheel trucks will not be operated on the middle transfer track at

Third Subdivision—At locomotives cannot be operated beyond clearance point of track 15 (loading platform track).

When pusher engines are used at the rear of trains to assist on grades, the following restrictions will apply:

- No more than two units may be used to push trains. If pusher engine consist exceeds two units, the excess units must be isolated and left idling.
- When total power of pusher engine consist exceeds 3,000 horse power, not including units idling in consist, controller must not be advanced beyond the fourth (4th) position.

section of line under a given speed requirement. The underlying principle of this approach is similar to that of tonnage rating. The major difference is the means of expression - in W/P ratio approach, the running speed is an explicit independent variable (refer to Appendix). Therefore, this ratio can be used to specify the power assignment rules for high speed service, not only the minimum speed. Exhibit 6-1-3 shows the typical relationship between W/P ratio and linehaul speed.

Practical Considerations of Power Assignment. Economy usually rules out frequent consist changes. In actual practice, it is not uncommon to compromise grade and speed requirements at ruling locations, i.e., overpower the train to maintain desired speed at ruling grades (e.g., TOFC service), or apply ruling grade-minimum power and sacrifice some speed on flat terrain to minimize power requirement.

If a power consist is made up of units with different tonnage ratings, tonnage for the consist is calculated by multiplying the number of units by the rating of the lowest rated units. If the units are not compatible, there is usually some loss of performance of the more capable units - maximum speed is limited to the unit with lowest gear ratio.

The fuel consumed by an engine can be estimated from the total work performed on that engine trip. However, when a train is "overpowered", more fuel will be consumed per gross-ton-mile than in normal situations. Exhibit 6-1-4 depicts such a relationship. (Nevertheless, within the range of the sampled data, the fuel consumption is positively related to workload and negatively related to running speed as shown in the regression equation given in Exhibit 6-1-4.)

Although data collected in this research are not sufficient to establish the relationship between an engine's workload (both in terms of time used and mileage travelled) and its maintenance need (refer to Chapter 5), according to Armstrong [1979, p.170], scheduling train speed very close to a locomotive's rating may result in high traction motor maintenance need. In other words, maintenance prefers conservative assignment.

B. Line Capacity-Related Decisions

Because of the interactions between scheduling, dispatching, and the physical characteristics of the line, line capacity can be defined in a number of ways. The physical capacity of a railroad line can be specified as a function of train length, speed, headway, distance between sidings, and the nature of the traffic control system [Little, 1982, p. 11]. According to Manheim [1979, p. 271], "although physical capacity is usually a well-defined concept, workable practical definitions of capacity must be related explicitly to the level of delay." However, on our host railroads, the line congestion problem is a minor one relative to other more pressing issues such as the control of terminal operations.

Exhibit 6-1-3
RELATIONSHIP BETWEEN TON/HP AND LINEHAUL SPEED

Data Source: Railroad A's "Fuel Consumption of Locomotive in TOFC Service"
 Nov. 1976.

Average Linehaul Distance = 480 miles.
 Average Horse-Power / Unit = 2400 HP.
 Test Locomotive Pool = 15 units [6xGP40, 5xGP10, 4xGP38].
 No. Test Runs = 14.

$$\left\{ \begin{array}{l} \text{North Bound: } \ln(\text{Speed}) = 3.13 - .35 * \ln(\text{GT/HP}) \\ \quad \quad \quad (R^2 = .67, \quad t = 32.65, \quad -3.2) \\ \text{South Bound: } \ln(\text{Speed}) = 2.84 - .39 * \ln(\text{GT/HP}) \\ \quad \quad \quad (R^2 = .75, \quad t = 21.68, \quad -3.8) \end{array} \right.$$

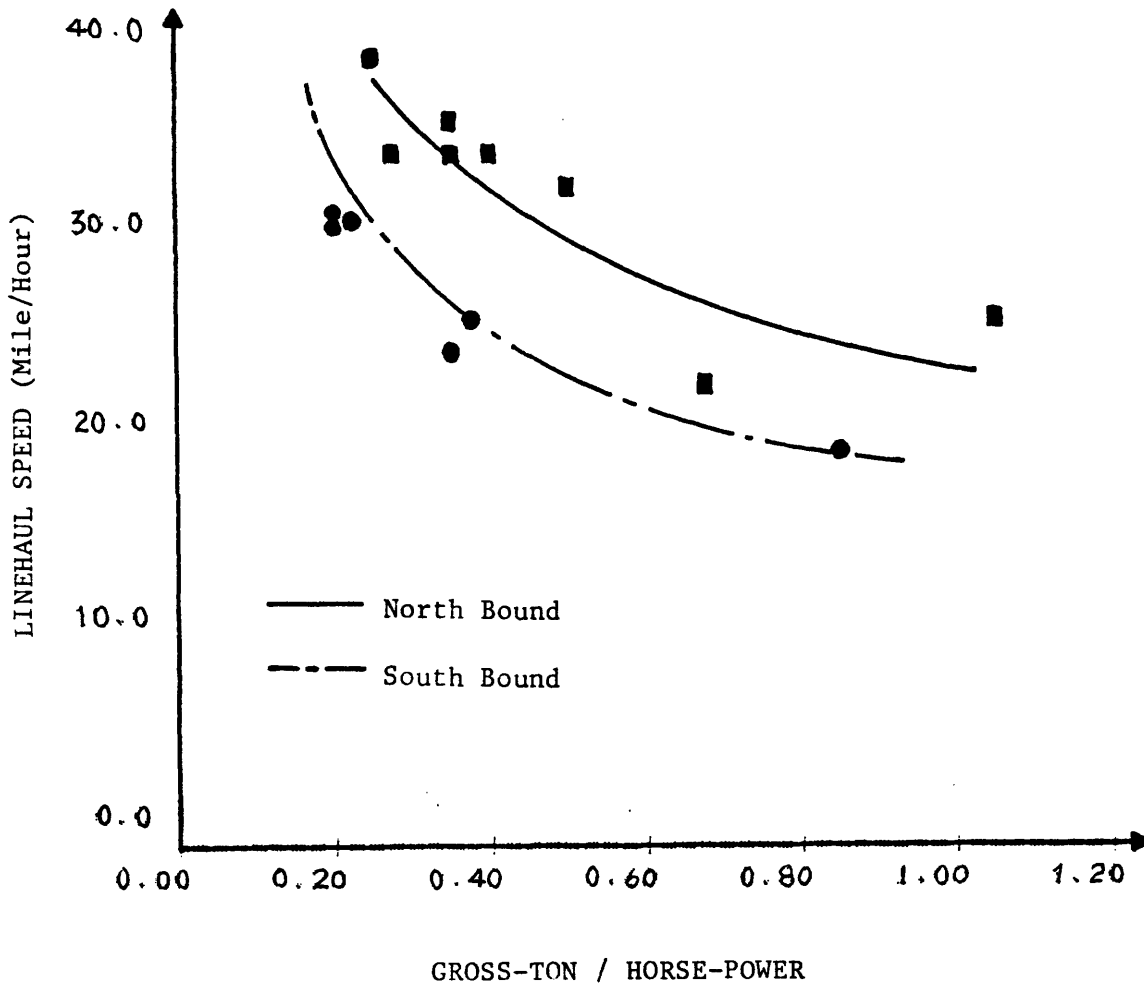


Exhibit 6-1-4 FUEL CONSUMPTION vs. ENGINE WORK LOAD AND SPEED

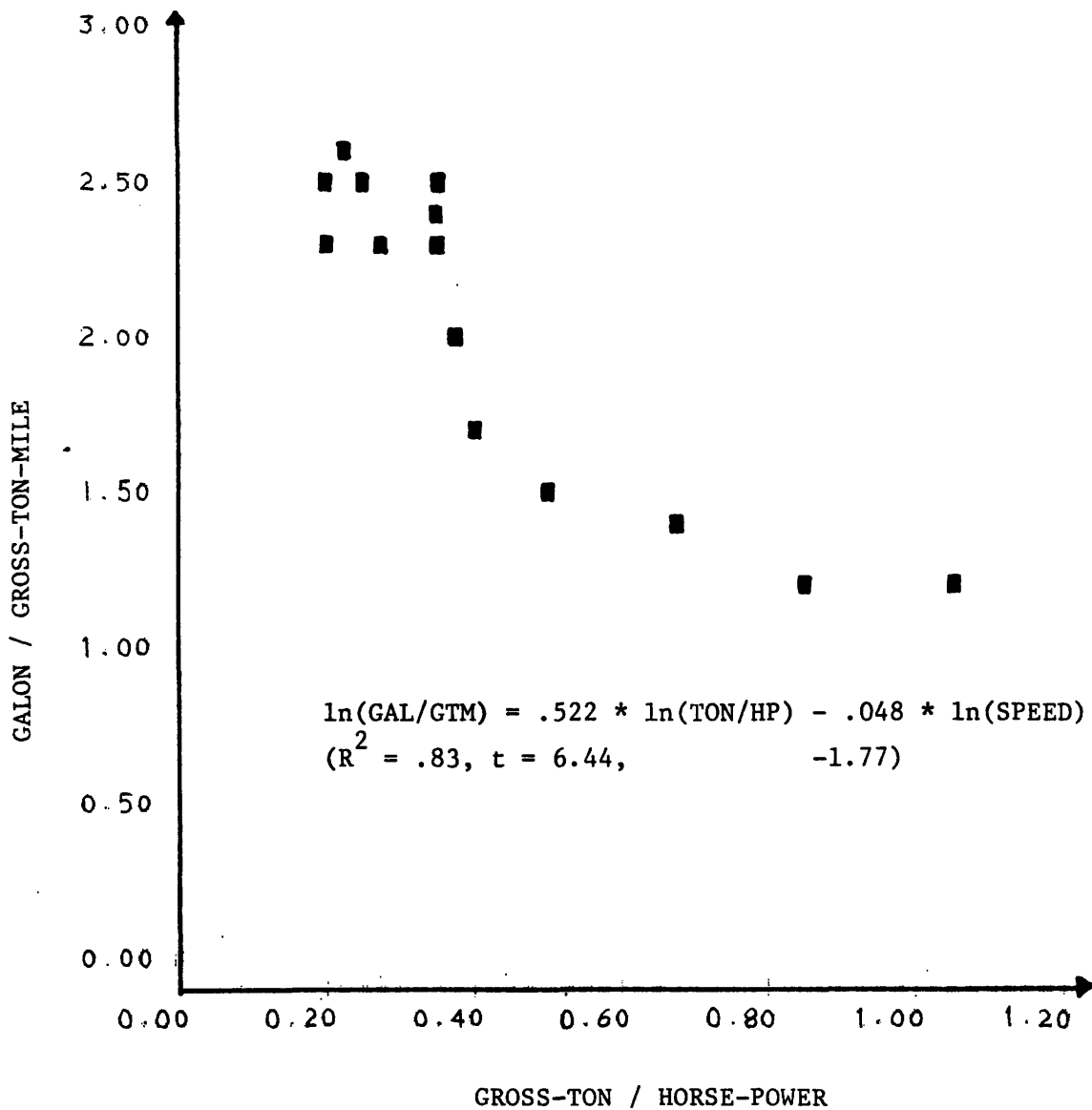
Data Source: Railroad A's " Fuel Consumption of Locomotive in TOFC Service", Nov. 1976

Average Linehaul Distance = 480 miles.

Average Horse-Power / Unit = 2,400 HP.

Test Locomotive Pool = 15 units [6XGP40, 5XGP10, 4XGP38]

Number of Test Runs = 14.



6.1.2 Terminal Operations

Recalling the interactions between the power cycle and freight car cycle mentioned in Chapter 4, the linehaul movement is the only component in which both vehicles are interlocked. In other words, the linehaul performance of one vehicle can be directly translated into that of the other. However, this is not the case in the terminal operations. Once a train arrives at a terminal, freight cars and power consist are usually decoupled; and they will then be sent into two totally different processes before being reconnected and departing from the terminal again.

Since the power process is perceived as a supporting task to car movement, in order to assess the power terminal performance, it becomes necessary to briefly examine the nature of the operations of car switching first.

A. Car Switching Processes

General Procedures. The car switching process can be generally divided into three phases - receiving, classification and assembly. From a control point of view, the essential decisions involved in each phase can be identified as follows [after "Freight Car Utilization and Railroad Reliability: Case Studies", AAR Report Number R-283, 1977, pp.302-303]:

1. Receiving Phase

- 1) track assignment of arriving train
- 2) number of crew required/available to inspect trains

3) clerical support required to finish the paper work promptly

2. Classification Phase

Planning:

- 1) classification priority of cars
- 2) assigned tracks to particular blocks
- 3) manning level and allocation of switching crew and engines

Execution: If a track is full,

- 1) should an overflow track be established?
- 2) should that track be pulled before continuing classification?
- 3) should additional cars for that block be sent to a re-hump track?

3. Trimming and Assembling Phase

- 1) crew manning and assignment
- 2) timing and block order of train assembling
- 3) in case of tonnage constraints, which traffic should be delayed?

Exhibit 6-1-5 is a schematic summary of the control decisions, their premises and consequences concerning the car switching process in a terminal area. The influence of power operations will come into play at the last step in the process.

Complicating Factors

On the surface, the freight car switching process may look very much like the stage-wise manufacturing production line. However, one distinctive feature of rail service is the variability of the throughput. To gain the necessary stability required by efficient operations, the manufacturing process can be isolated from the exposure of fluctuating demand by inventory stocks. For transportation systems, on the contrary, producing prompt service to both expected and unexpected demand is the business of the industry. Therefore, all the decisions specified in the preceding sections should take into account the variability of traffic patterns.

Exhibit 6-1-6 shows the average weekly profiles (base on four consecutive weeks' data) of arrived cars, departed cars and car inventory in a major terminal of railroad B. It is not uncommon that the actual traffic level is 20 to 30% higher or lower than the average level - an amount which may be well beyond the tolerable limit of any predetermined operating plan. From power management's point of view, the variability of terminal throughput means variability of demand for power service. It is the need to respond to the variabilities effectively that makes the real-time control of power operation challenging.

B. Train and Power Dispatching

Operational Buffer - Power Pool at the Dispatch Tracks. The mechanism railroads employ to cope with the abovementioned uncertainty is the creation of various operational buffers (e.g., resources pools) to absorb the unexpected variations, and to localize the impact of these variations. From a power management perspective, both the assembled car blocks at the forwarding yard and the lined up engines at the dispatch tracks can be conceived of as such operational buffers.

In the completion of servicing or maintenance, engines will be lined up at the dispatch tracks to constitute a pool of power that can be allocated in any desirable way to the subsequent outbound trains. In other words, it is this power pool which insulates the mechanical department's maintenance operation from the transportation department's train/power dispatching operations.

Since the train crew should be called one-and-a-half hours earlier

Exhibit 6-1-5 RAIL TERMINAL DECISIONS AND DECISION ENVIRONMENT

Key: → Causality or Decision Sequence

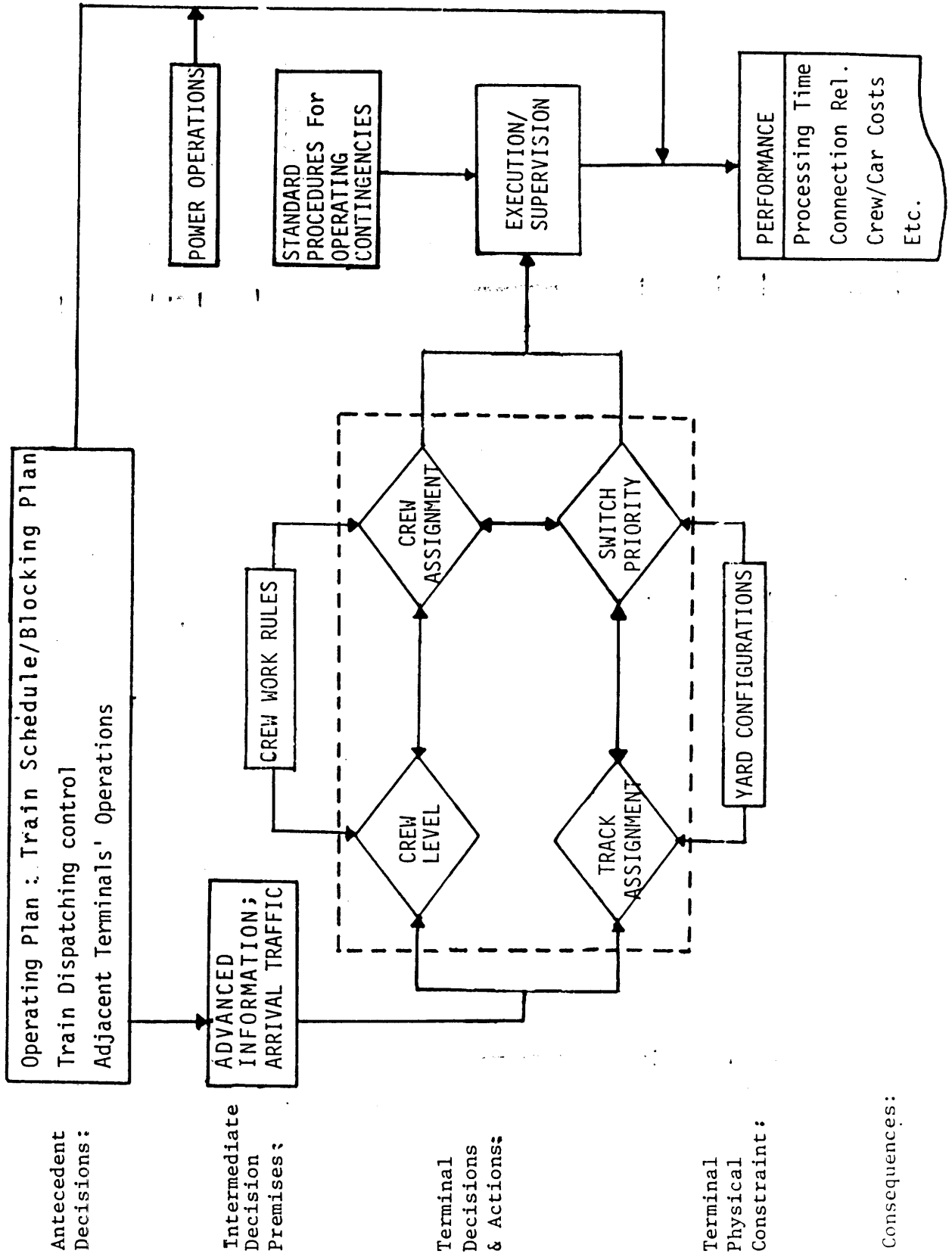
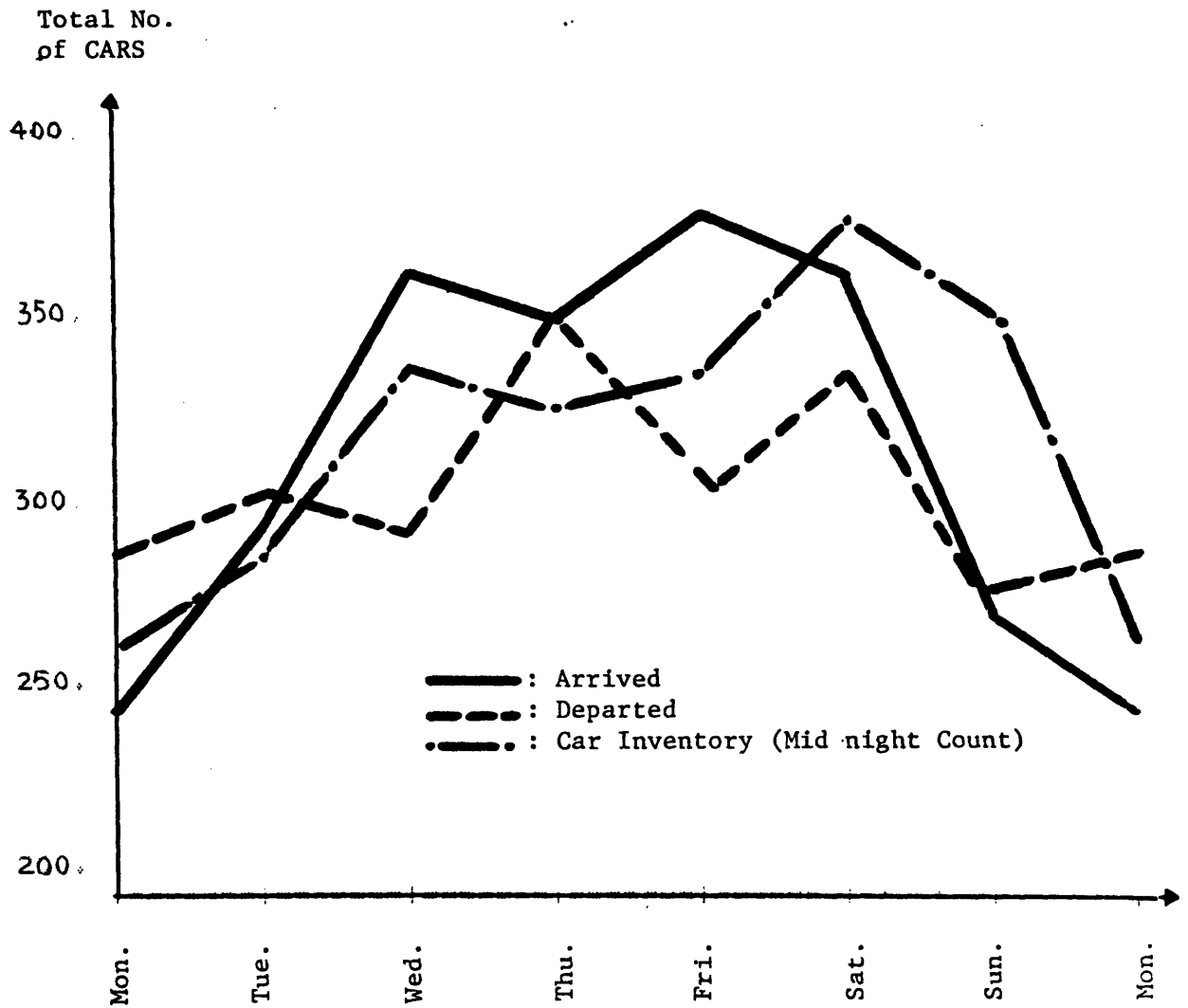


Exhibit 6-1-6 WEEKLY TRAFFIC PATTERN IN A RAIL TERMINAL



than the anticipated train departure time, and power will usually be confirmed available before the calling for crew. An approximate two-hour time-lead was observed between the profiles of the power pool and outbound power (Exhibit 6-1-7) [Mao and Martland, 1981]. This correlation in pattern may have resulted from a mutual adjustment between the practices of train and power dispatching - when power is unavailable, outbound trains must be held; and similarly, in the anticipation of a great deal of outbound trains in a terminal area, more power may be distributed to the terminal in advance, and faster power service may be found to replenish the power pool quickly.

Train Departure Performance. To dispatch a train, several necessary conditions must be satisfied, such as the availability of power and crew, and the completion of car switching and train assembling. A train would be delayed if any of these conditions were not met. Nevertheless, when all these conditions are satisfied, a train may still be delayed because of other operating contingencies.

Put into the classical production function framework of micro-economics, to satisfy a given level of demand, the above two operational buffers, i.e., car queues at forwarding yard and the power pool, are the mechanisms a railroad can use to trade-off the utilization of two essential resources - power-hours and car-hours. In other words, to serve a given amount of traffic at any particular terminal, on one extreme, a railroad can maintain a large power pool relative to the outbound volume, and result in high power idle time but low car delay time account for power. On the other extreme, a railroad can maintain a small power pool and hold the trains when power runs short - despite the

service quality implication, this is a strategy where car-hours are used to substitute for power-hours.

To test the notion of this production function empirically, one may hypothesize that the real leverage the power managers have in protecting the unexpected demand is the "surplus margin" of the power pool, i.e., the difference between the inventory level of power pool and the level of actual or expected subsequent outbound power flow. Exhibit 6-1-8 using data collected from Railroad B highlights the existence of the trade-off between train departure delay and power idle time, where power idle time is the idle time of the surplus margin in the power pool. In short, when the surplus margin goes short, the chance of train delay would become larger and the delay time would be longer.

Therefore, to effectively support train dispatching, both in terms of departure reliability and minimizing car backlog due to power shortage, the essential task of power operating cycle management is the control of the power pool at each terminal.

6.1.3 The Total Control Tasks of the Power Operating Cycle

From the above, we can conclude that the essential control task of power operating cycle is to deploy a network-wide power pool system. In principle, power distribution could be an integral part of the power tonnage rating or W/P ratio policies. In normal operating conditions, decisions following policy guidelines should not result in distribution problems; nevertheless, in emergency situations (e.g., high traffic seasons, sudden surge of traffic, significant directional unbalance), timing becomes a key factor and the power distribution requires particular effort. The general distribution strategies include: 1)

Exhibit 6-1-7

Power Pool Inventory And Outbound Flow

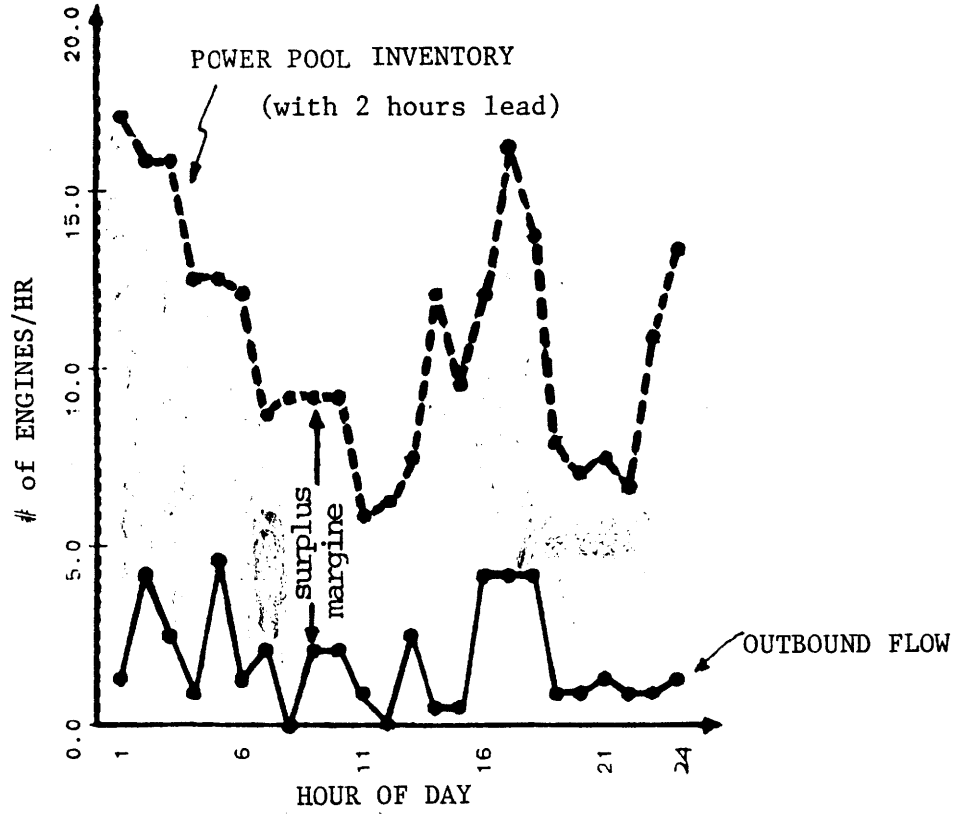
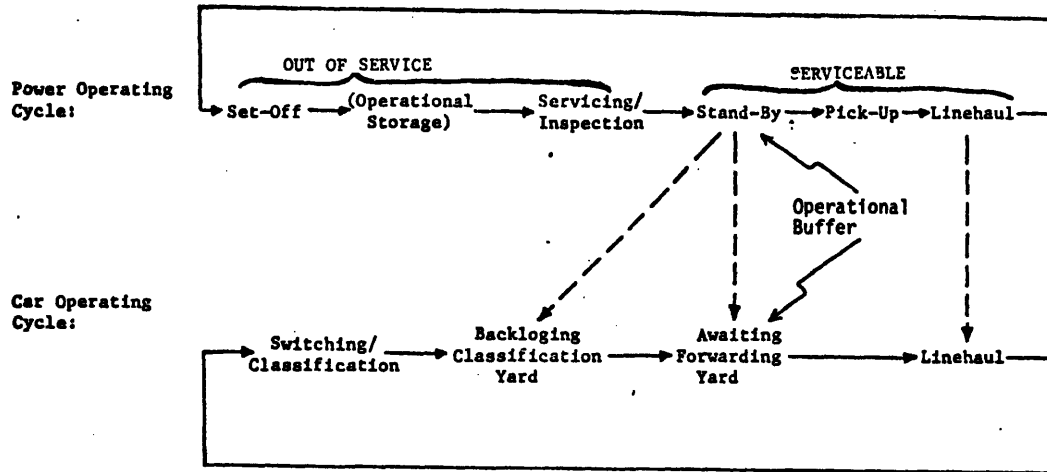
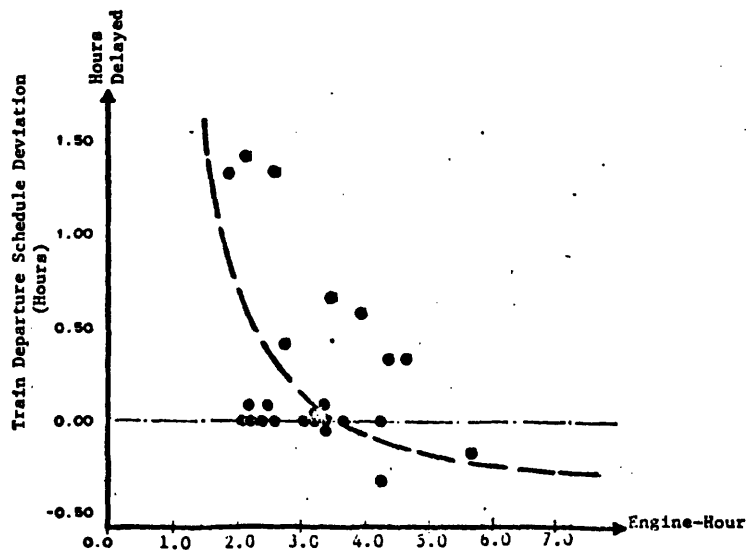


Exhibit 6-1-8 IMPACT OF ENGINE AVAILABILITY ON REAL-TIME TRAIN PERFORMANCE

(A) Interactions Between Power Cycle and Freight Car Cycle



(B) Trade-Off Between Power Idle Time and Train Departure Delay.



total engine-hours of power pool's surplus margin

overpower the train (running light train) from power surplus area to the deficit area; 2) deadhead power consist; or 3) intervene in the maintenance operations to pull back promptly more serviceable units.

To summarize, the control task concerning power operating cycle is comprised of two interrelated sub-tasks. One is the coordination of power and train dispatching so as to serve the scheduled demand and to protect the unexpected demand. However, the success of the first sub-task is very much dependent upon the effective execution of the second sub-task, i.e., the control of power inventory at each individual terminal. To accomplish these two sub-tasks effectively, both the competence of distribution planning and the efficiency of the coordination with mechanical operations (servicing and repair) are the primary factors.

6.2 The Controlling System

6.2.1 Steering Control Settings

A. Engaged Actors

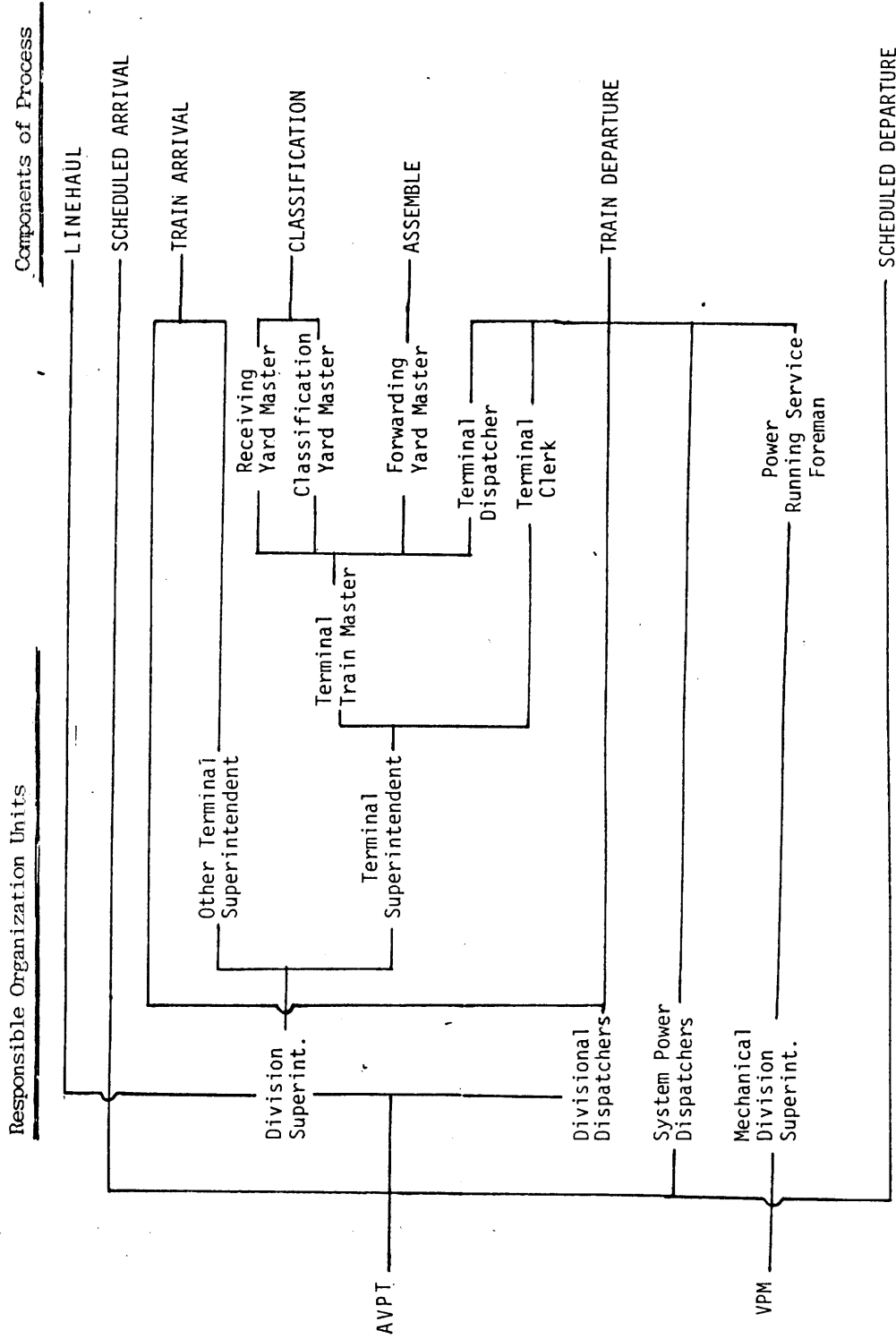
Actors engaged in real-time control of linehaul and terminal operations can be traced through the authority-responsibility lines of the physical processes. Exhibit 6-2-1 gives the organization hierarchy responsible for real-time operations. In the following, the dynamics which take place among the specified actors during the actual controlling practices will be examined.

B. Overall Controlling Mechanism - Daily Operating Conference

The daily operating conference held at the beginning of the day (8:00 A. M.) is a mechanism to coordinate various departments' daily working plans so as to ensure consistency between the control actions of different functional areas. This mechanism is also necessary to make the Document Priority System [refer to chapter 4] function effectively.

General Procedures. The conference can be divided into three consecutive sessions, i.e., pre-session, main-session and post-session. Before the main-session takes place, each participant will review the previous day's performance, inquire about the current system status from local officers, identify special operating situations to which he and his superiors should pay attention, and develop a working plan for the responsible task for the coming day. The main-session basically provides a formal channel to exchange information across departmental boundaries, and to facilitate senior management in its issuing of new

Exhibit 6-2-1 Steering Control Responsibility



general operating guidelines or specific operating orders [*]. The post-session is basically order transmission activities, i.e., transmitting the conclusions of the conference to first line management who issue the eventual operating orders.

Performance Review. Reviewing the previous day's performance is a key task of general management in preparation for the daily operating conference. In railroad A, at least three media are used to generate needed performance data, namely, through the standard operating reports, through the inquiring function of the Train Operating Information Systems, and through interpersonal communication. Shown in the Appendix of this chapter is a set of sample operating reports, Exhibits 6A-2-A thru 6A-2-F (in the original priority order), found on the desks of the AVPT and his assissting managers every morning. In principle, the contents of standard operating reports reflect the emphasis of the operations managment & performance meausres appearing on summary reports represent the most important control focus. As far as power management is concerned, in the operating summary statistics (Report B in the Appendix), the only power related performance index is Locomotive Availability (total fleet vs. available fleet). The potential deficiency of such a reporting system on power management will be discussed in Chapter 7.

[*] It certainly also provides the opportunity for the senior managers to patch-up disputes as well as nurse damaged egos among their subordinates, if any.

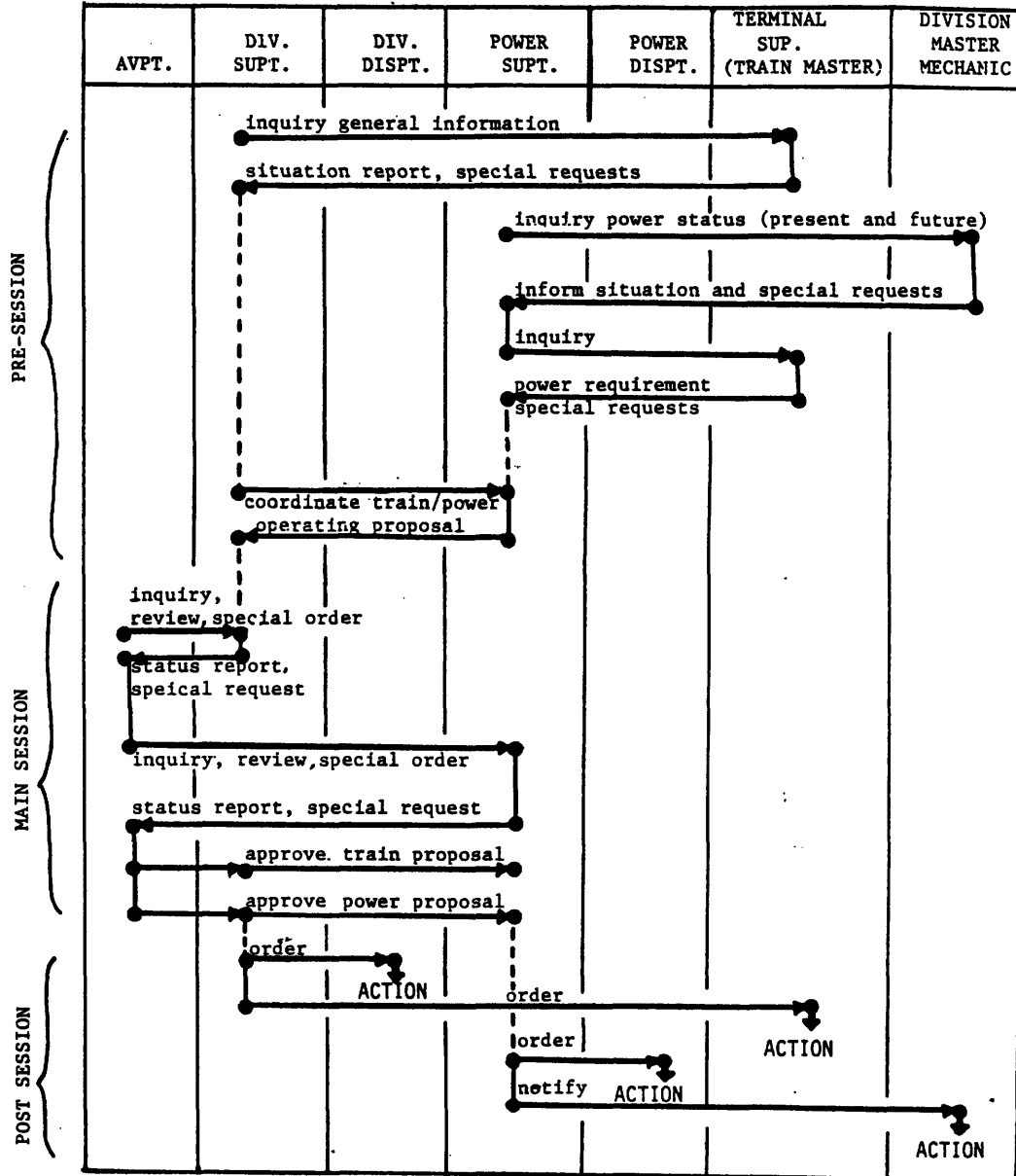
Daily Operating Conference in Practice. Exhibit 6-2-2 shows a typical scenario of dialogue sequences of the daily operating conference in chronological order. For a relatively small railroad like Railroad B, a telephone conference would be an efficient medium to accomplish the multi-functional and multi-divisional coordination. However, for larger railroad face-to-face meetings may be necessary. In Railroad A, the meeting is chaired by AVPT; Division Train Dispatchers in the Operating Control Center, the Power Superintendent, General Manager-Terminal Operations are the key participants. The typical agenda is as follows. First, each division dispatcher, in turn, briefly reviews the past 24-hour performance of his division and proposes contingency operating plans for the coming 24-hour if necessary. Then the whole group's attention focuses on the discussion of various contingency proposals. After all opinions have been expressed, the AVPT makes decisions regarding each proposal. The meeting usually takes 20 to 30 minutes.

In summary, due to the high degree of interdependence of railroading processes, decision makers in each functional and divisional area require a relatively large decision base (Information regarding goals, criteria, constraints, system states, etc.) to make coordinated decisions. The daily operating conference is a particular mechanism devised by railroads to facilitate the up-dating of each individual decision base at the beginning of each day. The locus of the interpersonal communication indicates the input and output relationships between the decision bases. More detailed discussion is provided in the later sections.

Exhibit 6-2-2

RAILROAD DAILY TELEPHONE OPERATING CONFERENCE

Chronological Dialog Scenario (Railroad C)



6.2.2 Real-Time Control of Road Power Distribution

Given the general setting concerning the control of real-time rail operations, we are ready to examine the steering-control of road power distribution.

A. The Function of the Power Control Center

Development of Daily Working Plan. The control of real-time road power distribution is the primary task of the Power Control Center. Power Dispatchers, under the supervision of Power Superintendent, give instructions to each terminal regarding the numbers of units to be coupled to trains. Since the task is well-defined, there are identifiable procedures to accomplish the task. The general procedures, according to our interview and observations, can be described as follows.

At the beginning of each shift (three shifts per day), the Center contacts each division by phone to assess the situation in various areas and routes, and to formulate tentative working plans for the shift - the morning shift may be responsible to sketch a working plan for the day. Conceptually, the working plan is a plan which indicates how to develop a sufficient power pool for each outbound train at each terminal. Then, using the previous power inventory status, train schedules, power maintenance schedule, tonnage rating guidelines, as well as the specific operating orders brought back by the Power Superintendent from morning operating conference, the Power Dispatcher calculates, explicitly or implicitly, detailed power demand and supply relations on a per-train

basis. When a chance of power shortage is identified, the original working plan must be adjusted, i.e., some redistribution or coordination effort must be incorporated into the plan. After the adjustment, the working plan is finalized and ready to be executed. However, further revision may still be necessary in case of unexpected operating contingencies. It is not unusual that approximately 60% of a power dispatchers' duty time is devoted to communication with local officers to get real-time data and to issue instructions [RSMA, 1964; AAR, 1978]. These procedures can be summarized into a problem-solving framework which comprises of a series of decisions and their corresponding premises as shown in Exhibit 6-2-3.

Decision Aid Device - Information Display Board

Although the task of power distribution is a well-defined one, the execution of this task is rather complicated and usually characterized by heavy time pressure, massive data and ever changing operating contingencies. Quality of power distribution is thus dependent upon how efficiently the power dispatcher can process information.

Since the 1960's centralization of power control (which followed dieselization) [RSMA, 1964], railroads have gradually evolved an information display device - from original pencil-and-paper to current power status magnetic board - to enhance the power dispatcher's decision-making capability.

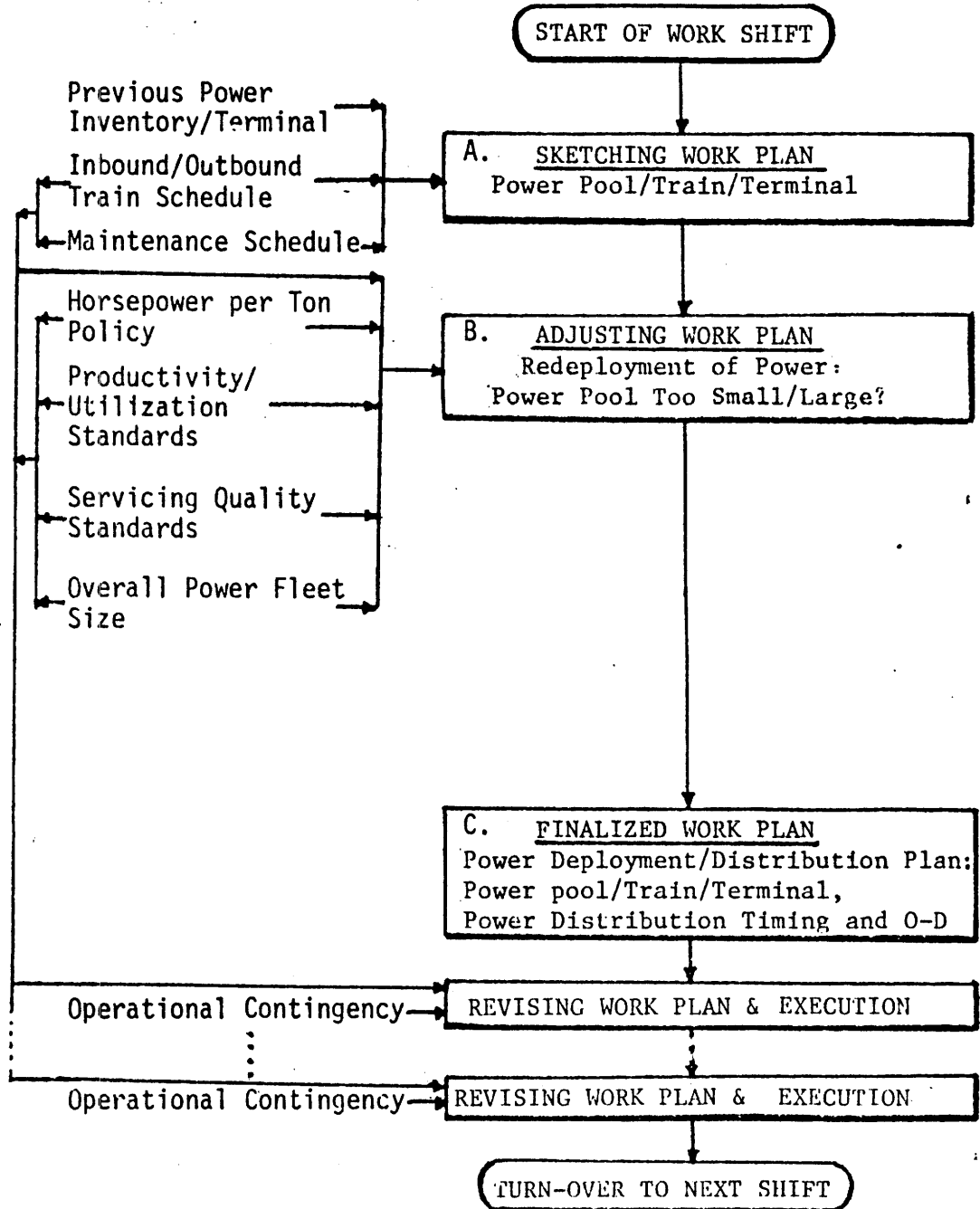
Because the inventory of power at various terminals across the system is the essential information for real-time control of power distribution, in most major railroads' power control centers (like our host railroads A and C), one can usually find a wall-wide magnetic board

Exhibit 6-2-3 POWER DISPATCHER'S PROBLEM-SOLVING FRAME

Operative Decision Premises

(Higher level constraints are not included)

GENERAL PROBLEM-SOLVING FRAMEWORK



with a schematically drawn rail network to display the power status information. Colored chips, each of which stands for a particular power unit, are placed at the appropriate location on the board. By attaching different labels to the chips and arranging or grouping the chips in some particular ways, the Power Dispatcher can show which units are being serviced, repaired, or stored, and which are available for linehaul service. In principle, the information shown on the board represents a snap-shot of the power status in a rail system at a particular point of time. In practice, for inbound and outbound units, the corresponding chips on the board are moved as events occur; but for units detained in terminals, their status is up-dated only on a per-shift basis.

B. Real-Time Control in Practice

The real-time control of power distribution involves a group of operating officers. The participants and task roles enacted in a particular power dispatching process depend very much on the context of the process. For instance, when the normal schedule is followed, the process of power dispatching is a simple routine communication task; the involved actors can also be maintained at a minimum level. However, when emergencies occur, e.g., to dispatch an extra train from a power-deficit area, an extensive search and coordination effort may be required; actors involved in the process will also be much more involved than that in routine situations. The following are two typical scenarios which characterize the above two distinctive problem contexts.

Routine Process. The dispatching of power is a part of the process of train dispatching. In this process, at least four major actors from different organizational units are directly involved: the Division Train Dispatchers at the Operating Control Center and the Power Dispatchers in the system Power Control Center, as well as the Train Masters and the service station foremen at the local terminals. In addition, there are two groups of persons playing action-taker role, namely, engine hostlers and the train crew, who actually move the engines into, around and out of the terminal.

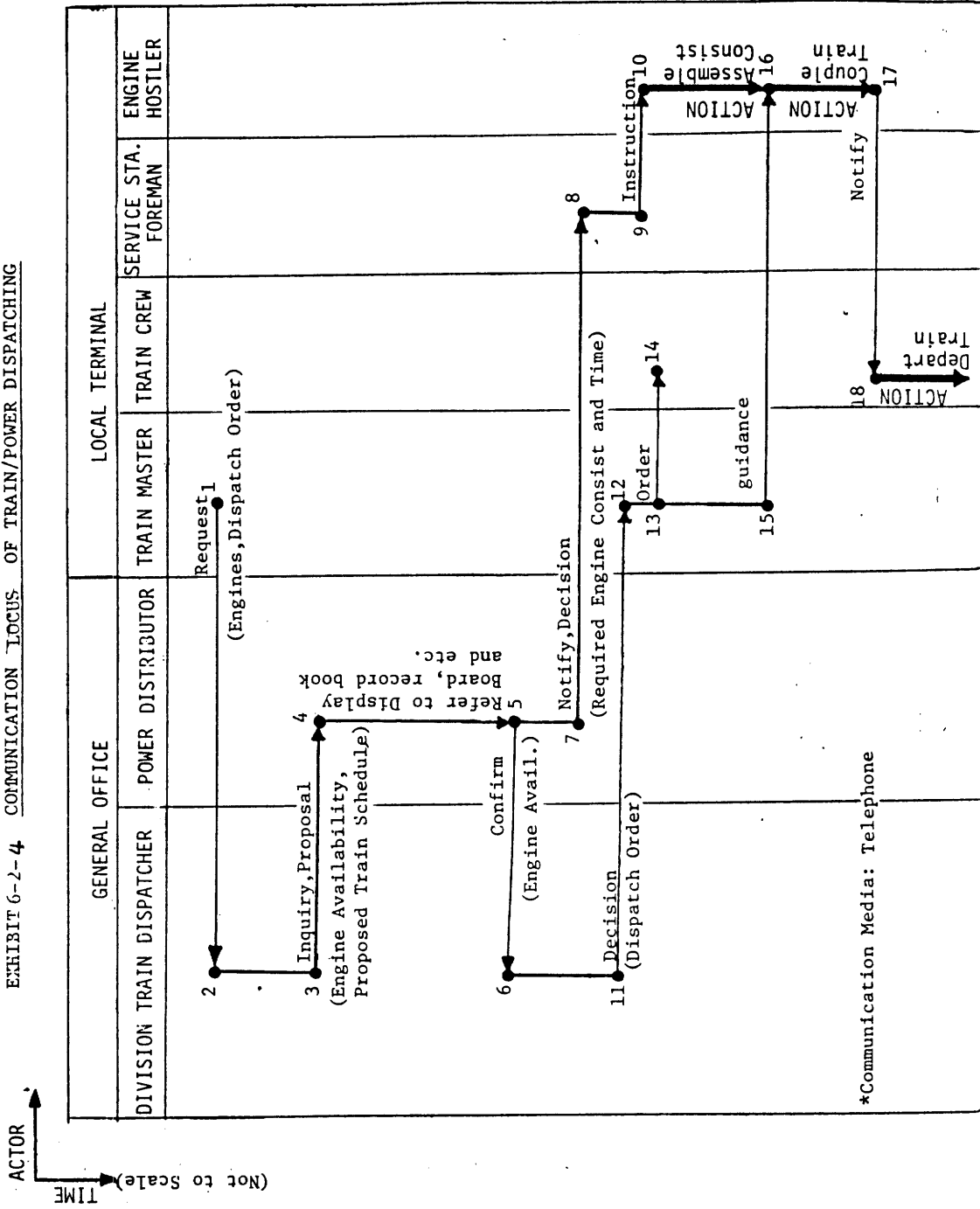
The process of dispatching a train is usually triggered by the Terminal Train Master. When a particular set of car blocks is assembled and ready for departure, he calls the Division Train Dispatcher in the

general office and asks for permission to run the train. After receiving the request from the terminal, the Division Train Dispatcher checks, among other things, with the Power Dispatcher in the central power control office to ensure the availability of power at the originating yard. The Power Dispatcher then examines the display board and check his record books or even calls the local maintenance foremen, to determine the power status and replies to the Division Train Dispatcher regarding the power situation. When the availability of power is confirmed, the Train Dispatcher can then permit the terminal to run the train.

Given the train dispatching decision, according to the operating requirements and distribution considerations, the Power Dispatcher tells the service station foreman how many units should be put on the train. Given this information, the foreman then directs the engine hostlers to pick up an appropriate number of engines from the power pool at the dispatching tracks and assemble them into the desired power consist. Meanwhile, after receiving the dispatch order from the control office, the Terminal Train Master guides the engine hostlers in coupling the power consist with the right cars and calls the train crew to depart the train.

The above process can be summarized into a communication locus diagram as shown in Exhibit 6-2-4. The response time of the Power Dispatcher in confirming a Train Dispatcher's inquiry, which corresponds to the length between node 4 and 5 in the diagram, is primarily determined by how well the Power Dispatcher outlines his work plan as

EXHIBIT 6-2-4 COMMUNICATION LOCUS OF TRAIN/POWER DISPATCHING



well as how reliable he perceives his power status information to be. If he is not confident about his information, before confirmation he has to call the local service formen to assure the power situation. However, if the train is a scheduled one, the Power Dispatcher will usually ascertain the power status before Train Dispatcher calls.

Emergency Handling Process

Due to the variability of traffic volume, railroad usually has to run extra trains[*]. Therefore, the Power dispatcher may have to handle some emergency situation once in a while. The following is such a typical scenario.

Situation:

Move extra car blocks from terminal H to terminal S, and there is no extra power available at H.

Exhibit 6-2-5A gives a partial network of the railroad.

Required Decisions:

- 1) search and choose source of extra power;
- 2) search and choose appropriate trains to carry the extra power consist to terminal H (if no appropriate train can be found, the power consist has to be deadheaded to H);
- 3) search and choose appropriate trains to move the extra traffic from H to S with the extra power .

[*]: There are at least two ways to run extra trains: 1) conditional train, i.e., the schedule is predetermined, but to run or not to run is conditional upon the size of the load; 2) ad hoc train - run the train on needed basis. The first strategy is less flexible from the service point of view, but is preferable from the operating point of view, since it is more predictable as compared with the second strategy.

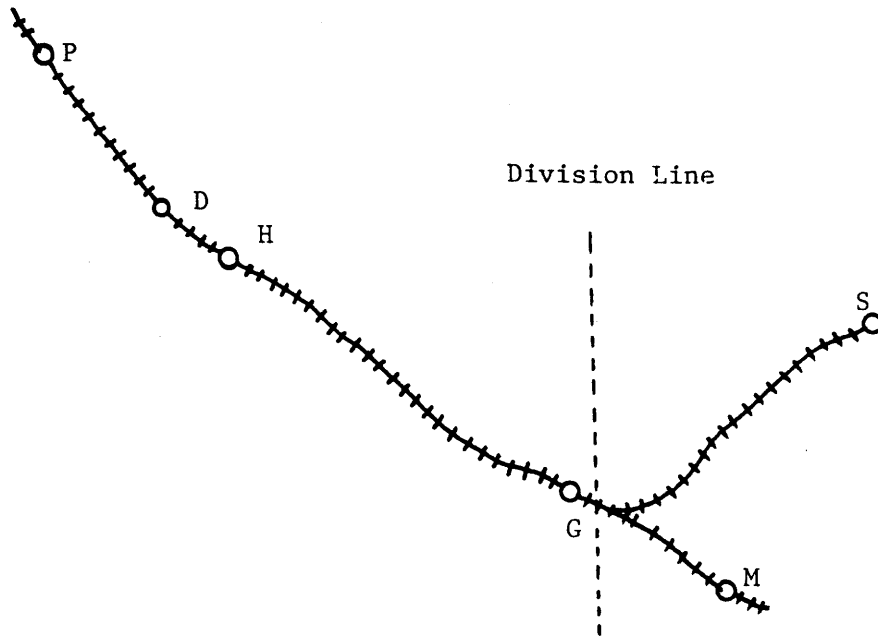
Before getting into the detailed problem-solving process triggered by the above situation, we should realize that the communication net maintained by a power dispatcher is usually quite large and complex - Exhibit 6-2-6 gives such a typical net. The decision processes are complicated by the wide-ranging possible combination of various power sources, alternative trains to pick up power and to carry the extra traffic.

Exhibit 6-2-5B shows one of the possible outcomes of the choice process: the power source is located at terminal M and some units of power will be coupled to a train (not shown in the Exhibit) heading from M to P; at the intermediate terminal D, the power will be set off and wait to be connected to train A which runs from P to M; when passing by terminal H, train A (with the extra power consist) will pick up the extra car-blocks and carry them to terminal G; at G, both the extra power and the extra car-blocks will be transferred to train B which runs from G to destination S. Exhibit 6-2-7 is the communication locus which would take place in parallel to the decision making (search-and-choice) process as well as the execution process described above.

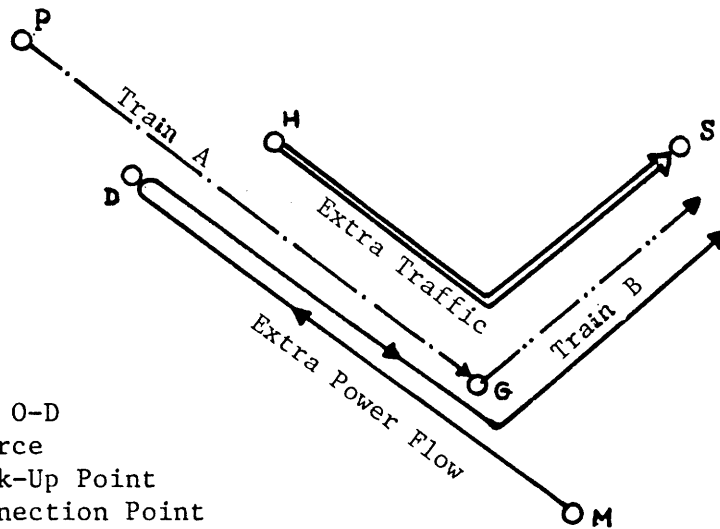
C. A Team-Support Systems' Perspective

The examination of various problem contexts (e.g., regular case vs. emergency one) provides a broader perspective concerning the managing of the control task. Exhibit 6-2-8 is a generalized view concerning the real-time control of power distribution. Power distribution is a progressive decision process. The dynamics among the actors are manifested by the exchange of information - upstream's decisions are

EXHIBIT 6-2-5 EXAMPLE OF MOVING EXTRA TRAFFIC



A. Partial Rail Network



H,S: Traffic O-D
 M: Power Source
 D: Power Pick-Up Point
 G: Train Connection Point

B. Traffic Flow and Vehicle Flow

Exhibit 6-2-6 Power Dispatcher-Centered Communication Net

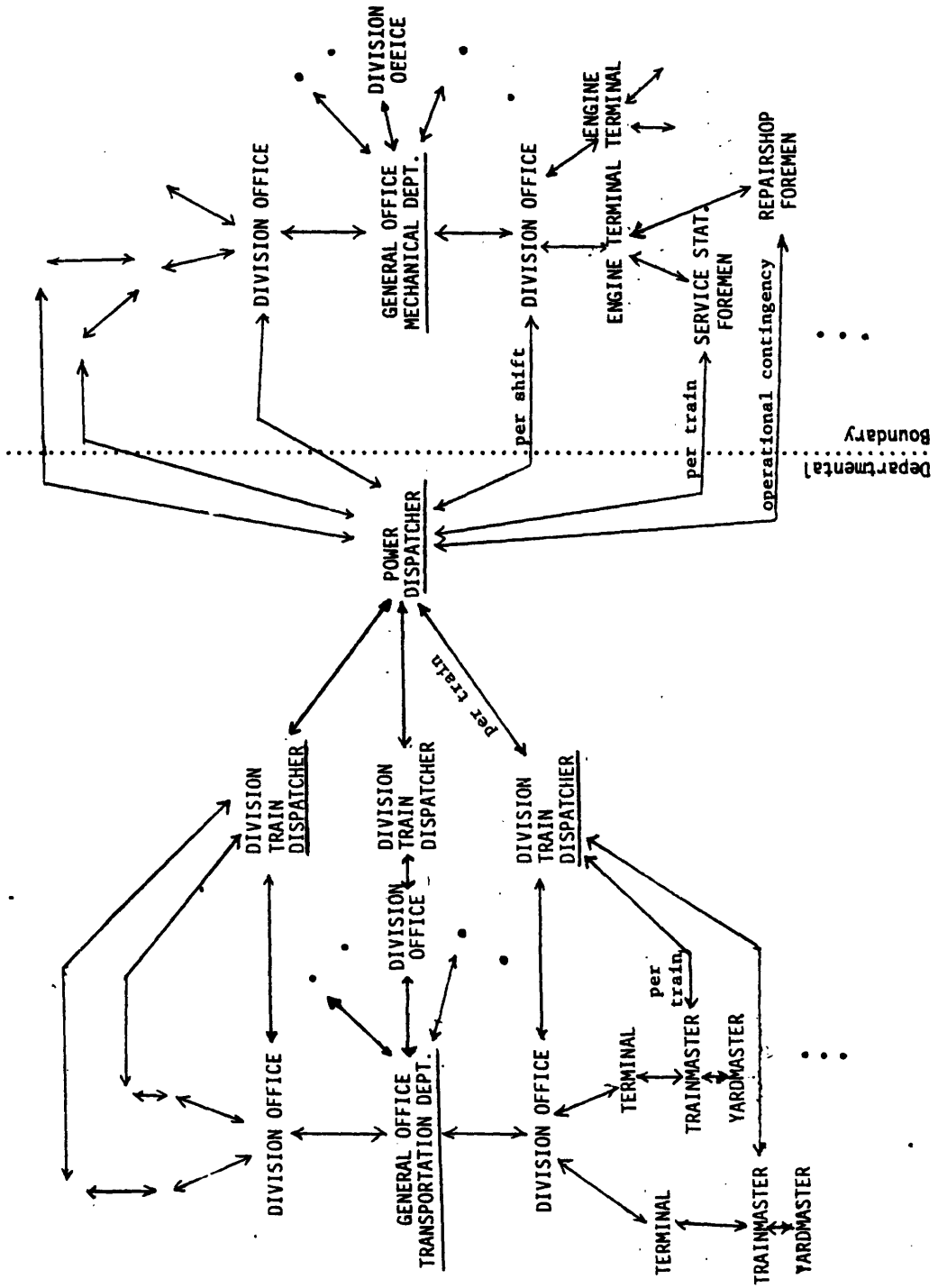


Exhibit 6-2-7 COMMUNICATION LOCUS FOR DELIVERING EXTRA TRAFFIC

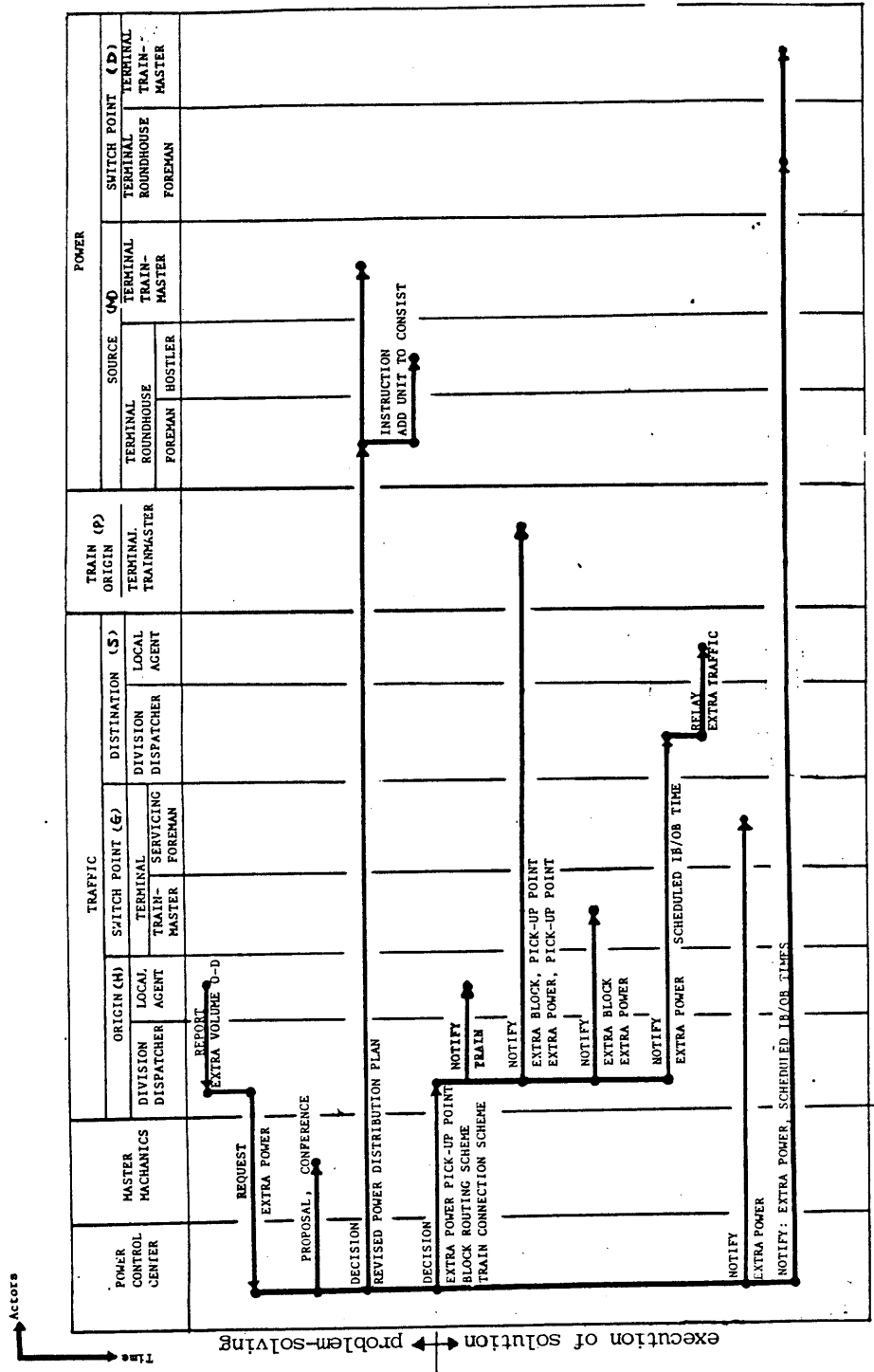
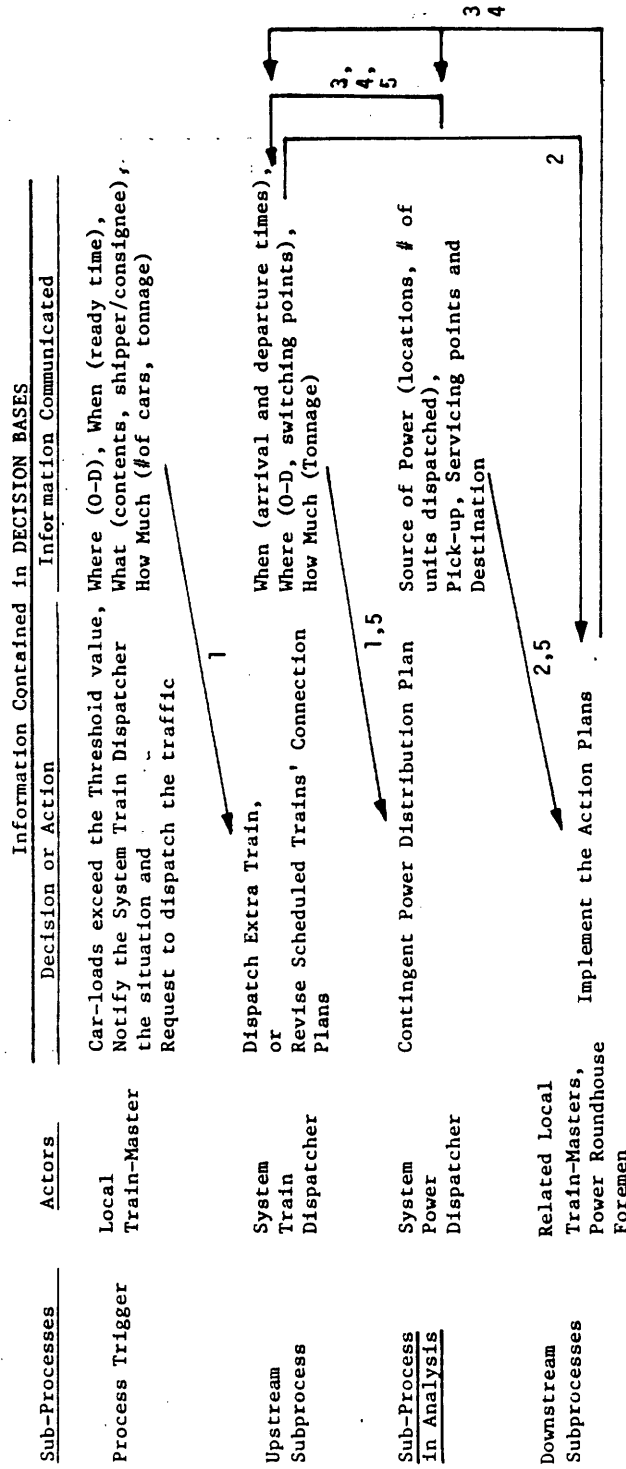


Exhibit 6-2-8 Decision Bases Involved in Power Dispatching Decision Net



- Remarks:
- 1: Decision Premises
 - 2: Action Guidelines
 - 3: Providing States/Constraints information of the system under their control to facilitate the direct decision-maker's search for alternative action plans and evaluation of the potential outcome
 - 4: Confirming proposed action plans (train schedules/power distribution plan), or notify infeasibility of the plans
 - 5: Intervening interdependent subprocesses to a) release the constraint of action space, or b) change the premises of decision

usually the downstream's decision premises or action guidelines; downstream's status usually constitutes constraints to the upstream's feasible solution space.

To amplify, the process of power dispatching [Exhibit 6-2-7] can be divided into at least four highly interrelated sets of subprocesses, namely, the process trigger, the focal subprocess, and the upstream and downstream subprocesses. Each subprocess is taken care by different organization units. Their interrelationships can be analyzed, among others, through the transaction processes of the decision bases employed by the involved actors. For instance, in normal situation, downstream actors may take the information (regarding the state of the system, the confirmation or notification of mutually concerned plans or actions) passed from the upper stream as given, update their decision base and make subsequent decision accordingly. However, in some particular case (e.g., an emergency), a downstream actor may tend to intervene in upperstream decisions, so as to release the constraints or change the premises of his action or choice space. Given the decision-net, the effectiveness (in terms of coordinability) of such an intervention, from team-support systems [Section 2.2.3] perspective, is determined by the following factors: 1) the availability and efficiency of the communication media, 2) the bases for mutual influence and 3) the skill of influence. Given the same context, a more skillful role player will perform more effectively than a nonskilled one - provided that the decision heuristics (discussed later) of the skilled actor is as good as the nonskilled one.

The study of different decision contexts also gives us insights into the nature of the decision in question, e.g., regarding the criteria to judge the appropriateness of decision rule, performance measure and so forth. Moreover, from the above analysis, we can easily recognize that, in order to have effective utilization of power, the power dispatcher's abilities to develop an appropriate work plan as well as to search out and select an efficient contingency plan under heavy time pressure play a critical role. These abilities relate to the nature of the power dispatcher's cognitive process applied in his problem-solving procedures. In the next section, we shall study this cognitive process through some introspection analysis methods [Section 3.2.2], and the goal is to identify the potential strengths and weaknesses of the process, as well as their implications to the design of decision support systems.

6.2.3 Decision Heuristics Analysis

In this study, the goal of the heuristics analysis is to describe analytically the decision behavior in the form of flow diagrams that reflect the level of expertise found in highly experienced power dispatchers. To construct the data base, the introspection approach is applied - one particular power dispatcher was asked to think about and describe on how he made his decisions involving in his day-to-day practices. The key is to specify his various problem-solving frames and to identify the intermediate stages of information-processing and decision-making.

A. General Problem-Solving Procedures

The overall problem-solving procedures employed by the sample power dispatcher can be represented by the flow diagram as shown in Exhibit 6-2-3. The fundamental idea is to develop a standing plan for each of the anticipated outbound trains in the system. In each of such plans, the available power pool is carefully checked to ensure that it is sufficient to serve the anticipated power need. Whenever the power pool is perceived as inadequate, an adjustment procedure is triggered. For instance, when a power pool is perceived as too small, the power dispatcher has to search for more power. Several strategies are in order: he may check whether there is any stored power in the concerned terminal; he may ask mechanical personnel in the same concerned terminal to speed up the servicing or repair operations so as to obtain more serviceable power from an originally unserviceable group; he may dispatch extra power from other power surplus area before the shortage

occurs; he may also intervene in the train dispatching operations by asking the train dispatcher to hold the train until sufficient power is available. On the other hand, if several consecutive power pools appeared to be too large, then he may choose to do nothing, to consider temporary storage, to notify mechanical personnel letting them have certain slack time or to distribute extra power to some potential power deficit areas. In either case, no matter which strategy the power dispatcher actually chooses, that strategy will become part of the work plan for his shift. This kind of adjustment is carried out for all the outbound trains in each terminal within his responsible region. Exhibit 6-2-9 is a diagram which summarizes the above heuristics.

From a performance control point of view, two questions are of particular importance regarding the general problem solving heuristics described above. The first is how the power dispatcher judges the adequacy of a power pool, i.e., in what situation will he consider the power pool as too small or too large? The second is when some adjustments are needed, how will he select among the remedy strategies? Both questions have vital implications on the design of the team support systems as well as the decision support systems. We will return to these in Chapter 7.

B. Algorithms for Estimating Power Pools

One sub-process which was not explained clearly in the above general framework is the detailed procedure concerning the estimation of the available power pool for each outbound train. The principle for calculating the power pool is relatively straightforward, namely, the available power pool for a given outbound train is the previous

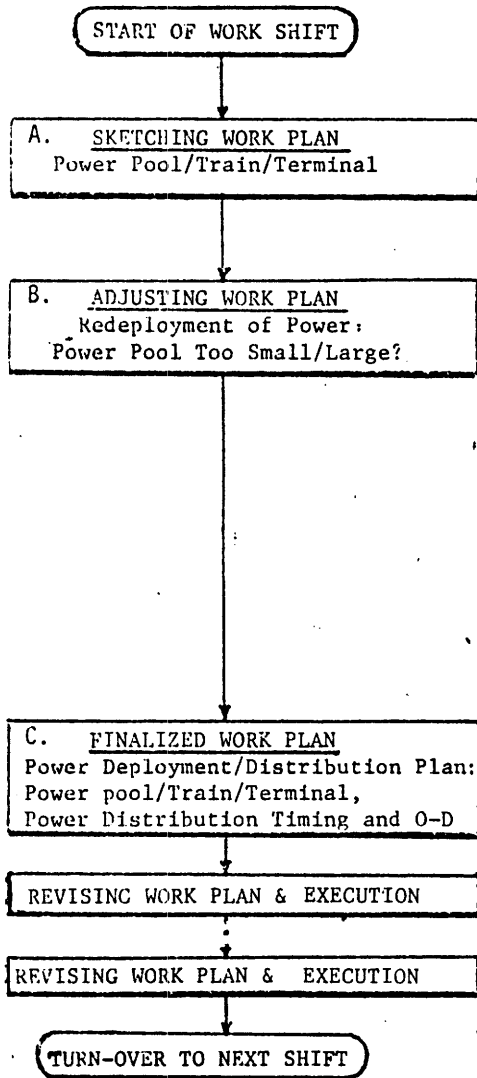
inventory of the pool power plus the inbound consist, minus those inbound units which are due in maintenance, and plus the unit back to service from previous maintenance work. In practice, since the assignment of power is not necessarily first-in-first-out, the estimation process could be very delicate. Some dispatchers, in order to save the effort of decomposing and reassembling power consist, may tend to retain the inbound consist as it is (or by adding/detaching units to/from the original consist), when such a consist may fit the need of the subsequent outbound train. This practice in fact represents a favor that a power dispatcher can do to the servicing crew; and such a favor is usually the primary basis on which a dispatcher can win the cooperation from the mechanical personnel.

Exhibit 6-2-10 shows a typical algorithm that was used by a power dispatcher in Railroad C to develop his locomotive assignment and dispatching plan in one terminal area. In actual practice, as mentioned above, a dispatcher may have some ideas, implicitly or explicitly, regarding the assignment priority of the units in each power pool - sometimes he may ask hostlers to line up the locomotives at the dispatch tracks according to his planned dispatching order, or may just line the chips up on the magnetic board for his own information. When timing becomes critical, a more detailed estimation is required to include the turnaround time of the servicing operation (which is not shown in the above flow diagram).

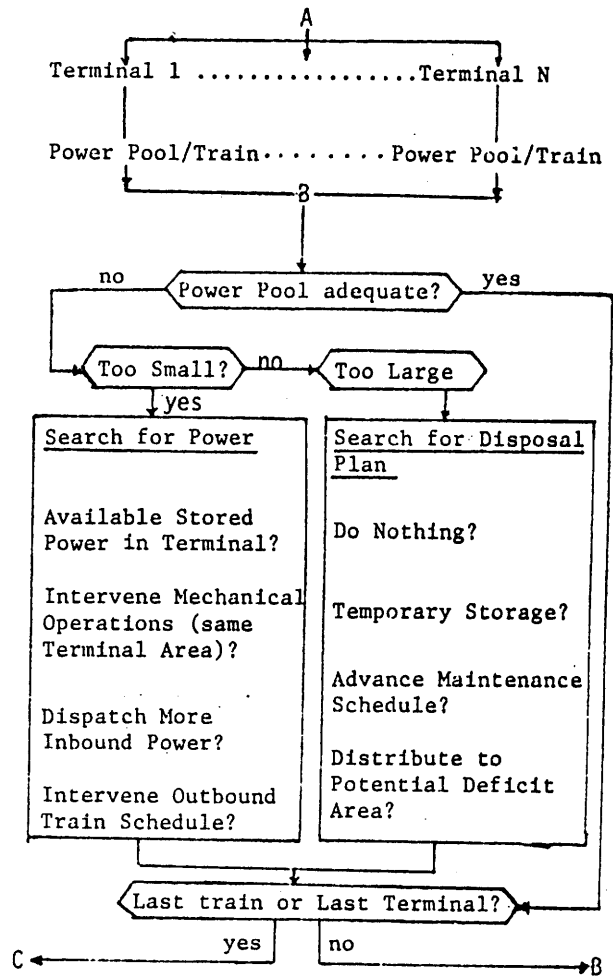
The above analysis reveals a critical issue in the capacity of human information processing. For small railroads like Railroad C, with few major terminals (or power interchange points) and some two hundred

Exhibit 6-2-9 POWER DISPATCHER'S PROBLEM-SOLVING HEURISTICS

General Problem-Solving Frame



Detailed Problem-Solving Heuristics

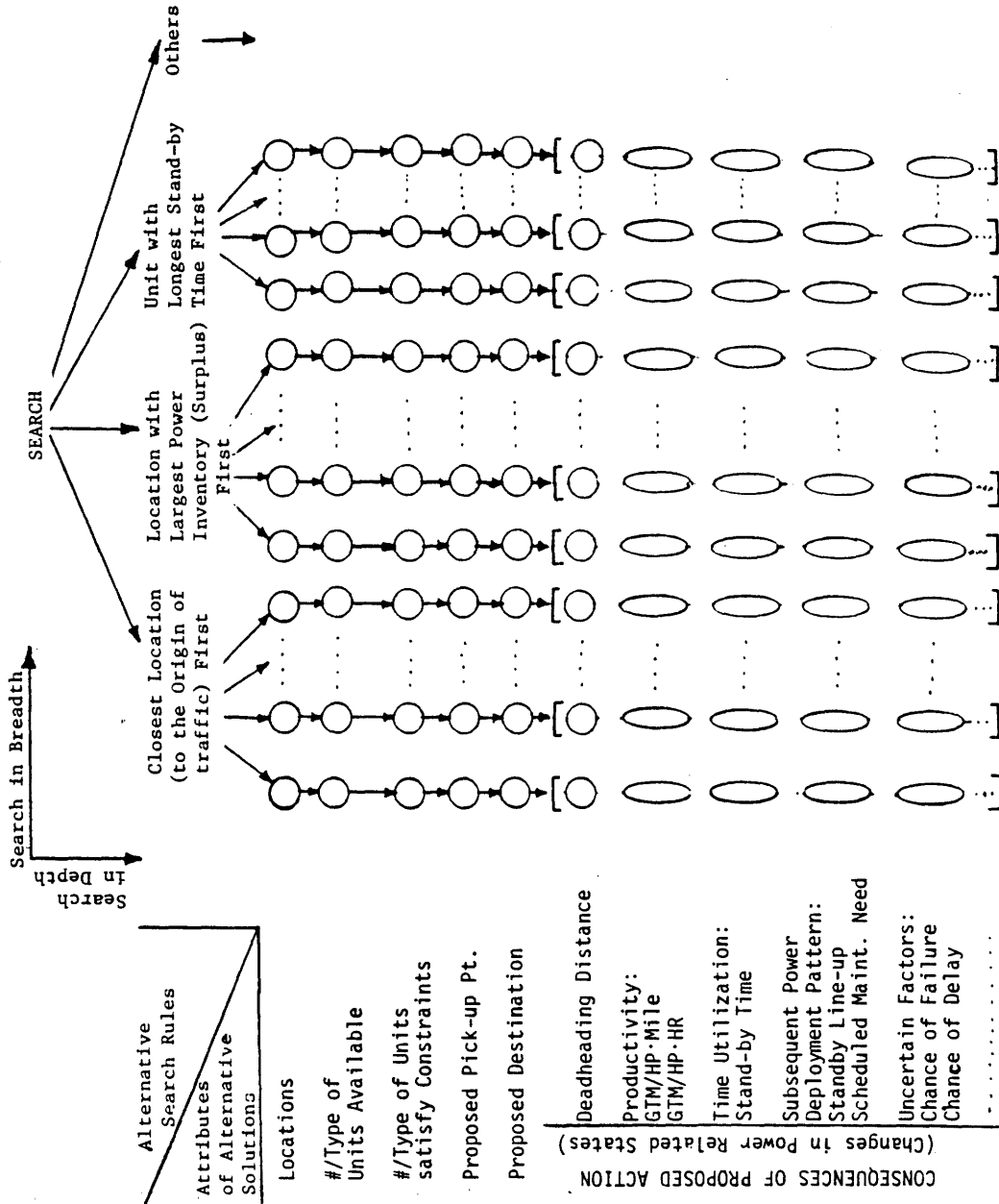


power units, the execution of the above algorithm with pencil-and-paper may be tedious but still manageable. For larger railroads with more than a thousand power units, the calculation may quickly become a mess without machine-aid - a situation of information overload. In other words, unless the responsible region of a power dispatcher can be cut down to a reasonable size, the algorithm described above has no way to be executed. Unfortunately, the situation in Railroad A is such an example. When the systematic algorithm breaks down, to play it safe the power dispatcher naturally tends to maintain large power pools at all locations all the time, if possible. We hypothesize that this is one of the major reasons to explain the low power utilization rate (38%) on Railroad A. In fact, this situation is not unique to Railroad A, according to Martland et al [1977, P.98]: the majority of Class I railroads have a locomotive utilization rate of less than 50%.

C. Search and Choice Processes

In the above two sections, the analysis was primarily concerned with the development of standing plans which deal with the anticipated demand. To uncover the underlying search-and-choice heuristics, one effective way is to ask the power dispatcher to describe his decision procedures in dealing with emergency situation (as the one presented in Exhibits 6-2-5 thru 6-2-7). Exhibit 6-2-11 is a generalized transcription of a variety of the introspections regarding the process in search of extra power to serve extra trains. The process basically can be divided into two major steps: one is the identification of candidate locations of power source and the formulation of action plans in correspondence to each candidate location; the other is the

Exhibit 6-2-11 POWER DISPATCHER'S SEARCH AND CHOICE FRAME



evaluation of the consequences (or attributes) of each alternative action plans. However, before the actual search takes place, a choice on the alternative search rule will be made, usually implicitly. In an operating environment, situations usually require immediate response based on limited information. It is unlikely that a dispatcher can generate an exhaustive choice set (under a given search rule) before he makes the final choice. Moreover, an experienced dispatcher usually has clear ideas regarding the locations where some surplus power can normally be found and which trains normally have the space to accommodate extra traffic and so forth. All this knowledge, in a sense, constitutes certain prototype solutions in his memory. Once he encounters a power shortage situation, he will zero in quickly on a small number of prototypes and let these pototypes drive further information search - aimed primarily at the elimination of invalid prototypes. Evaluation about the attributes of alternative action plans is an implicit process. Sometimes the search and the formulation of a feasible solution is already very exhaustive, yet the evaluation may be still defaulted. The first feasible solution may become the natural choice.

There are several vital and pragmatic implications which can be drawn from the above analysis. First of all, the choice of search rules often introduces significant bias. Some decisionmakers may never recognize the existence of alternative search rules. Whether a single search rule can be used to solve all cases, both effectively and efficiently, is indeed highly questionable. Therefore, how to assist the power dispatcher in exploring alternative search rules operatively,

before he commits himself to one particular rule in a practical search process, is essential to the improvement of his decision quality. Second, the application of prototypes, although minimizing information-processing efforts, can also result in significant bias or even be misleading. The essential issue here is how to efficiently formulate (generate) feasible action plans. Third, in principle, an appropriate evaluation is the basis for an appropriate choice; without sensible evaluation, no meaningful control can be exercised. Therefore, to improve the overall quality of the power distribution decision, one important element is to enhance the evaluation capability of the power dispatcher and to require him to evaluate in accordance with a desirable set of criteria.

6.3. Summary

This chapter's focus is on the management of power operating cycle. The analysis of the technological system is primarily along two lines, namely, the linehaul operations and the terminal operations. The key determinants and process components of both operations are examined. The control task concerning power operating cycle is comprised of two interrelated sub-tasks. One is the coordination of power and train dispatching so as to serve the scheduled demand and to protect the unexpected demand. However, the success of the above task depends upon the effective control of power inventory at each individual terminal. To accomplish these two tasks successfully, both the competence of the distribution planning and the effectiveness of the coordination with mechanical operations (servicing and repair) are the primary factors.

On the organization system side, we start from the analytical description of the steering control settings, including the engaged actors, the mechanism of daily operating conference. Then we examine the real-time control of road power distribution through the analysis of power control center's function, as well as real-time control practices (both the routine and emergency procedures are documented). The above team-based control processes are then put into a team-support system's perspective, to highlight the processes of coordination and role influence.

The final section of this chapter is devoted to the analysis of the decision heuristics of power dispatcher, because he is the ultimate individual responsible for the real-time performance of power dispatching. The analysis starts from the identification of his general problem-solving procedures, then the detailed computational algorithms as well as the search and choice heuristics.

In this chapter, we further show how to apply the communication locus analysis technique to describe more detailed processes carried out by decision-net. We also show how to analyze individual person's decision-making process. The insights gained from the above analyses are essential to the further diagnosis of both the task team and the individual decision-maker's performance (see Chapter 7).

APPENDIX OF CHAPTER 6

1) Vehicle Motion Dynamics

Balancing Speed condition (zero acceleration condition): a condition in which the net tractive force produced by the power consist is exactly equal to train's total resistance force. i.e.,

$$\begin{aligned} \text{Total Tractive Force} &= \text{Total Resistance Force} \\ &= \text{total car resistance} + \\ &\quad \text{total power consist resistance} \end{aligned}$$

1-1) Davis Formulas → empirical formulas calculating various vehicles' rolling resistance forces:

$$\text{rolling resistance/ vehicle} = aT + bN + cTV + dAV^{**2}$$

where: T = vehicle weight;
V = speed;
N = number of axles per wheel truck;
A = cross section area
a,b,c,d = coefficients

[remark: W. J. Davis, Jr., 1926, " Train Resistance Formulae", GET-3, November, General Electric Company, Railway Engineering Dept.]

1-2) Grade Resistance, G:

$$G = 20 \text{ (lbs)} * \text{grade}$$

where grade: 2.5% = 0.025

1-3) Total Car Resistance

Car Rolling Resistance: When running speed is within 10-20 mile range, the train resistance curves from the Davis formulas are clustered together and can be approximatly taken as a straight line, i.e.,

$$\begin{aligned} \text{rolling resistance per car} \\ &= 122 \text{ (lbs/car)} + 2.2 \text{ car weight (lbs/car)} \end{aligned}$$

$$\begin{aligned} \text{Total Car Resistance} \\ &= \text{rolling resistance} + \text{grade resistance} \\ &= \text{car rolling resistance} * \text{train length} + G * \text{total car weight} \\ &= 122 * \text{train length} + (G + 2.2) * \text{total car weight} \end{aligned}$$

where: train length = number of cars in train
total car weight = train weight excludes locomotive

1-4) Total Tractive Force

$$\text{Total Tractive Force} = \frac{308 * P}{V}$$

where: P = total nominal horsepower of locomotive;
V = speed (mph);
308 = conversion factor from HP to tractive force)

1-5) Net Tractive Force

Net tractive force = "drawbar pull" = DBP
= total tractive force - total locomotive resistance

(where the total locomotive resistance can be obtained from Davis formulas.)

2) Practical Operating Guidelines:

2-1) Tonnage Rating

$$\frac{\text{DBP}}{G+2.2} = \frac{122}{G+2.2} * \text{train length} + \text{total car weight}$$

↓ ↓
TONNAGE CAR
RATING FACTOR

Tonage Rating \geq (Car Factor + Car Weight) * Train Length

(In the above formula, the left hand side should not be less than the right hand side.)

2-2) Ton per Horsepower Ratio (W/P Ratio):

$$\text{W/P Ratio} = \frac{308}{K * V} \text{ ton/hp}$$

where: K = 20 * grade + 122 / (car weight) + 2.2 + m
m = ratio of [locomotive resistance / train weight]
train weight = total car weight + locomotive weight
V = speed in mph

Exhibit 6A-2-A EXAMPLE OF MORNING EXCEPTION EVENTS REPORT
 (Prepared by General Superintendent of Transportation)
 DATE July 7, 1957

Messrs. HTH KRS WLS HCL JFM JID JGG TDF WGB JLL JFR J EJR CMG
 HTH WLS WIA PRJ JID JGG TDF WGB JLL JFR J EJR CMG

SYNOPSIS OF SYSTEM

ENGINE SHORTAGE: None
 ADVERSE WEATHER: None
 Y&T HEEDING ATTENTION: None
 DERAILMENTS BLOCKING MAIN TRACKS: None

DERAILMENTS AND UNUSUAL OCCURRENCES

1130a.m. July 6, ... derailed and or overturned 5 cars of corn blocking Southward main track and switching lead. No personal injuries. Cause of derailment, switch point strap bolt broken and the head of bolt lodged between East switch point and steel rail causing tension to throw switch under cut of cars. Cars transloaded and clear of main track 945p.m. July 6.

240a.m. July 6, ... ITS No. 102 derailed and or overturned the 11th. through the 18th. cars ahead of caboose. No personal injuries. No dangerous commodities. Cause of derailment, slack action rear 17 cars in train account engineer using independent brake. ... Cars clear and main track open 245p.m. July 6.

235p.m. July 5, M.P. ... Dist. ... derailed and or overturned the 77th. through the 82nd. head cars which struck the 12th. through the 16th. North cars standing in East pass blocking main track, East pass and West pass. No personal injuries. No dangerous commodities. Cause of derailment, buckled track. Cars rerailed and main track open 5p.m. July 5. West Pass open 850a.m. July 5. Trains able to pass through west pass

11a.m. July 5, Grace Load, ... switcher showing 27 cars through crossover. into Grace Chem. Co. derailed 2 empty box blocking both main tracks. No personal injuries. Cause of derailment not reported. ... Northward track open 445p.m. and Southward track open 520p.m. July 5.

1040a.m. July 5, Yard, Il. Extra 635 South reported the remains of ... Degrees, 27, laying across drawbars between the 42nd and 43rd. head cars. Yard job 16 noticed the body while passing; the coal train and notified crew on Extra 635 South. Special Agent and ... Police and Fire Dept. notified and investigating.

Engineer in ... train 381-03 reported flat spots on diesel 235 leaving ... Station. On arrival ... wheel R-1 found to have 2 3/4" flat spots, wheel L-1 1 1/2" flat spots, wheels R and L 3 2" flat spots. Diesel returned to Chicago deadhead, speed restriction 40 M.P.

830p.m. July 3, ... Yard, ... JFM leaving yard derailed 5 cars in crossover North end of ... Yard blocking both main tracks. No personal injuries. Included in derailed cars 2 L.P. gas and 2 ammonia nitrate. No leakage reported. Cause of derailment, broken switch point. Cars rerailed 8a.m. July 4. Crossover is out of service.

No. 59 left ...
 2 diesels, 12 cars to ... 10 to ...
 diesel 721 dead from ...
 03" Homewood, passengers
 05" block 3-20, 20 red
 06" ... Dist. engine overspeed set too l
 07" ... work on diesel 721
 04" ... passengers
 02" ... passengers
 16" ... Dist. slow
 10" ... Dist. lost on run, 1 diesel de
 12" ... Dist. slow
 27" ... clean cars
 03" block 313-1 dark
 08" ... Dist. lost on run, 1 diesel dead
 06" ... Dist. slow
 08" ... Dist. slow
 07" ... Dist. 1 diesel dead
 05" ... work on diesel 721, unable to repair.

No. 58 left ... 51" late;
 2 diesels, 13 cars to ... 15 to ...
 10" ... Dist. slow
 04" ... Durand and Winona, passengers
 04" ... water cars
 04" ... Dist. slow
 04" ... Dist. slow
 02" ... red signal
 10" ... pick up 2 cars
 33" ... clean cars

bap

Date: Monday July 7, 1980

Loading	Yesterday	Month To Date	Budget Accum.	Forecast Accum.	Same Month Last Year *	Year To Date	Last Year To Date
Originated	197	10439				503986	509603
Received	1246	7259				270711	299141
Total	1443	17698	17656	15650	22830	774697	808744
Coal Loading	0	860				96238	97686
Hotbox % Good	7	84-75.0				3552-68.2	2308-61.9

Hotbox Detectors out of service at 12:01 AM 6

* Adjusted - Same Weekdays last year

	MECHANICAL FAILURES				LOCOMOTIVES AVAILABLE				LINE OF ROAD DERAILMENTS			
	Psgr.	Month To Date	Frt.	Month To Date	Fleet Available	1979	1980	Today	Month To Date	No. Derailments	Today	Month To Date
Car Failure	5	11	2	13		1062	1052	0	4		0	4
Trains Delayed	2	7	2	13		934	933	0	16		0	16
Loco. Failures	1	3	12	72		CABOOSES AVAILABLE		0	0		0	0
Trains Delayed					Fleet Available	N/A	N/A	Weekend Accum.				

TRAINS	NUMBER ON - TIME	PERCENT ON - TIME	PERCENT MONTH TO DATE	ON - TIME LAST MONTH	SYMBOL FRT. TRAINS	NUMBER ON - TIME	PERCENT ON - TIME	PERCENT MONTH TO DATE	PERCENT ON - TIME LAST MONTH	SPECIAL TRAIN OPERATIONS AND / OR COMMENTS	
										A.	B.
Dep 14	10	71.4	57.1	79.5	55	37	67.2	57.3	50.0		
Arr 14	6	42.9	46.4	53.6	54	31	57.4	45.0	44.8		
LATE PASSENGER & TOFC TRAINS ENROUTE										SPECIAL TRAIN OPERATIONS AND / OR COMMENTS	
# 58	Dp	Chanda		5:41A						A.	Account Railbox
59	By	Chanda		5:28A						B.	Mixed Cubical Capacities
50	By			4:15A						C.	61 foot
51	By			7/1							
CE-2	By	Ch		4:40A							
				18/27							

**Exhibit 6A-2-C EXAMPLE OF OPERATING CONTROL CENTER'S TURNOVER REPORT
(Prepared by General Superintendent of Transportation)**

July 7, 1951

I GC2 should list GC1 11:15, about 5am with 74/55 incl 4/22 W. L. Co., one crew to protect L&N this afternoon, 35 cars reported from UP at 10am, Coal train reported midnight Tuesday, nothing on hand here or Mt. Pulaski and no grain loading, GC1 left 11:00am, 13/71 incl 2/4; Ft. Dodge, UPI left Waterloo 15am with 33/23, GC2 listed Waterloo 5am with 28/21, 90's crew at Ft. Dodge to protect UP2, crews OK at Wallace, GC1 listed Mt. Pulaski 11:30pm with 20/47, crews at 11:45pm for 75 and UPI

Mt. Pulaski APL left 12:35am with 46/23, GC1 left 2:30am with 46/25, CBP listed 4:30am with 128 cars, 28 cars for GC2, 117 empty hoppers placed to Horton for load today, 105 reg hoppers on main line S. North, 112 reg hoppers on main line N. North, 3rd track ramp working and 1st track ramp unrolled

Clarksburg Less loading stone today and no loading grain train, GC1 left 2:00am with 46/24, GC2 left 3:15am with 40 Memphis, 16 Yankee cars on hand, yard in good shape, tight on North crews

Elkins 3 cars for GC2, no other cars lined up to move

Chgo 4/11 F. Jones and 11/28 Memphis for CM7, 6/15 McCracks for CN3 acct CNS too heavy, 0/1 Pady, 5/11 Cert incl 4/4 shorts, 3/2 Nth cars incl 1/0, 2/0 Maty and 30/13 Hi-bry's on hand

Chgo 2 rested crews with 0/1 and 1/1 enroute, got L&N and Cockrell grain train co

ES&L 60 Chgos will go to Duquoin on local this am, GC2 be listed 11am with about 100 Chgos, leaves 40 Chgos on hand, rest of yard tight, one rested crew with APL enroute, GC1 listed 2:45am with 64 cars

Chgo CR6 listed 5am with 66/16 incl 9/0 S. L. Co., 30/2 F. Jones and 27/13 Columbus all connections made, North local listed 2:45am with 122 cars incl 35 cars on Weldon rail train for Leffington, 50 cars for GC2 which include 1/17, 16 Memphis, crews OK for the North

Elkins RCA205 listed 6:05am, P8C listed on crews rest at 6:40am, no other crews in t

Chgo To GC2: PBC's crew to cover CBP later today
To Elkins: one crew getting rest with L&N and Cockrell grain trains may run today

Chgo Ran SCR506 at 12:15am, GC1 coming Nth to protect one of the grain trains yard in good shape

Chgo MC4 listed 2:30am, with 11/51, GC2 listed 3:15am with 46/27, GC1 listed 3:15am MC4 listed 4:15am
CNS listed 5:05am, then MM1 will be next

Chgo RCA306 listed 2:30am, with 11/51, GC2, GC1 & GC3 to run later today only 2 rested crews with CNS enroute, might want to consolidate GM6 & MM4 on JMS

Chgo MNS CN3 listed 3:30am with 88/63, GC3 ran early, GC2 will be next to run

Chgo GM6 listed 1:30am, GC1 listed 4:30am, next to run will be RCA106, crews OK

Chgo Two crews getting rest for L&N and P. 107, GC2 should have 14, GC1, 10, 4, 10 L&N and 6 Chgo, GC3 due to release about noon

Chgo LZ 238-6 on Hammond Dist out of service from 5am until noon

Chgo Confined grain train at Mt. Pulaski will not run until after section men unload some more rock today

Chgo MM1 listed L&N 11:15 2:30am, 22/11, MC4 listed Central City 1:55am, 34/22
MM2 listed Central City 3:30am, 28/48, MC2 listed Pady 5am
ran the down men yesterday to protect L&N trains from Pady which was loaded Fri and River Dist which is loading today

13/50

EXAMPLE OF TRAIN DELAY SUMMARY STATISTICS

ORPT. 2		TRAIN DELAY TYPE DAILY RECAP										07/07/81						
FREIGHT TRAINS FOR 1555 07-05 THRU 0510 07-07		DELA		CLT		5FS		540		4529		MID		YTD				
DELAY CATEGORY	DESCRIPTION	CODE	TODAY	MID	YTD	TODAY	MID	YTD	TODAY	MID	YTD	TODAY	MID	YTD	TODAY	MID	YTD	
CREW LIST	CREW LIST TIME		105	5FS	540	4529	182	1420	1550	44562	182	1420	1550	44562	-00	19	38	1270
CREW LIST	★ TOTAL		4	55	31	4	55	31	4	55	31	4	55	31	12	173	8	174
ENGINEERING	H B DETECTOR OUT	EDD	7	116	191	7	116	191	7	116	191	7	116	191	207	131	2431	2431
ENGINEERING	M OF W WORK 4R	EM	1	30	52	1	30	52	1	30	52	1	30	52	62	83	2008	2008
ENGINEERING	UNLAWFUL CROSS	ES	18	168	1432	18	168	1432	18	168	1432	18	168	1432	117	160	5196	5196
ENGINEERING	UNLAWFUL CROSS	EZ	20	178	2300	20	178	2300	20	178	2300	20	178	2300	657	160	5196	5196
ENGINEERING	★ TOTAL		61	660	748	61	660	748	61	660	748	61	660	748	2531	375	509	10766
MECHANICAL	BAD ORDER CAROUSE	MBC	0	4	9	0	4	9	0	4	9	0	4	9	0	3	4	65
MECHANICAL	BRK	MC	5	58	1084	5	58	1084	5	58	1084	5	58	1084	253	35	887	887
MECHANICAL	BRKLS STICKING	MGB	2	24	37	2	24	37	2	24	37	2	24	37	12	13	336	336
MECHANICAL	UNLAWFUL CROSS	MCL	0	16	4	0	16	4	0	16	4	0	16	4	15	1	133	133
MECHANICAL	UNLAWFUL CROSS	MCH	0	3	201	0	3	201	0	3	201	0	3	201	0	2	114	114
MECHANICAL	UNLAWFUL CROSS	MCK	0	10	15	0	10	15	0	10	15	0	10	15	4	8	194	194
MECHANICAL	UNLAWFUL CROSS	MCI	0	7	0	0	7	0	0	7	0	0	7	0	1	1	192	192
MECHANICAL	UNLAWFUL CROSS	MCT	0	10	8	0	10	8	0	10	8	0	10	8	7	3	224	224
MECHANICAL	UNLAWFUL CROSS	MDS	2	10	316	2	10	316	2	10	316	2	10	316	12	19	224	224
MECHANICAL	UNLAWFUL CROSS	MT	54	54	949	54	54	949	54	54	949	54	54	949	12	19	224	224
MECHANICAL	UNLAWFUL CROSS	MI	3	17	21	3	17	21	3	17	21	3	17	21	30	30	910	910
MECHANICAL	UNLAWFUL CROSS	MJD	3	17	21	3	17	21	3	17	21	3	17	21	30	30	910	910
MECHANICAL	UNLAWFUL CROSS	MJS	46	46	938	46	46	938	46	46	938	46	46	938	40	41	1200	1200
MECHANICAL	★ TOTAL		28	282	329	28	282	329	28	282	329	28	282	329	1119	138	164	5021
OPERATING	WAITING FOR CREWS	DLA	17	114	55	17	114	55	17	114	55	17	114	55	43	55	9369	9369
OPERATING	WAITING FOR CREWS	DLB	1	1	0	1	1	0	1	1	0	1	1	0	0	1	221	221
OPERATING	WAITING FOR CREWS	DLC	1	1	100	1	1	100	1	1	100	1	1	100	0	0	1	101
OPERATING	WAITING FOR CREWS	DLD	11	54	912	11	54	912	11	54	912	11	54	912	20	12	511	511
OPERATING	WAITING FOR CREWS	DLF	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	1
OPERATING	WAITING FOR CREWS	DLG	2	23	1847	2	23	1847	2	23	1847	2	23	1847	51	8	419	419
OPERATING	WAITING FOR CREWS	DLE	0	51	40	0	51	40	0	51	40	0	51	40	50	0	1821	1821
OPERATING	WAITING FOR CREWS	DLF	0	0	3	0	0	3	0	0	3	0	0	3	0	0	0	0
OPERATING	WAITING FOR CREWS	DLG	0	6	156	0	6	156	0	6	156	0	6	156	0	0	0	0
OPERATING	WAITING FOR CREWS	DLE	5	53	1516	5	53	1516	5	53	1516	5	53	1516	27	42	1149	1149
OPERATING	WAITING FOR CREWS	DLE	0	17	59	0	17	59	0	17	59	0	17	59	24	21	1083	1083
OPERATING	WAITING FOR CREWS	DLE	13	133	144	13	133	144	13	133	144	13	133	144	174	254	7801	7801
OPERATING	WAITING FOR CREWS	DLE	0	5	175	0	5	175	0	5	175	0	5	175	0	0	0	0
OPERATING	WAITING FOR CREWS	DLE	8	51	35	8	51	35	8	51	35	8	51	35	66	55	2032	2032
OPERATING	WAITING FOR CREWS	DLE	41	335	313	41	335	313	41	335	313	41	335	313	400	400	16320	16320
OPERATING	WAITING FOR CREWS	DLE	13	123	22	13	123	22	13	123	22	13	123	22	15	15	979	979
OPERATING	WAITING FOR CREWS	DLE	17	102	82	17	102	82	17	102	82	17	102	82	222	139	5293	5293
OPERATING	LOADING PASS-BAG	OP	0	0	7	0	0	7	0	0	7	0	0	7	0	0	0	2
OPERATING	LOADING PASS-BAG	OP	0	0	303	0	0	303	0	0	303	0	0	303	0	0	0	131
OPERATING	LOADING PASS-BAG	OP	0	0	28	0	0	28	0	0	28	0	0	28	0	0	0	0
OPERATING	LOADING PASS-BAG	OP	64	413	350	64	413	350	64	413	350	64	413	350	603	50	16730	16730
OPERATING	LOADING PASS-BAG	OP	10	120	59	10	120	59	10	120	59	10	120	59	132	251	6401	6401
OPERATING	LOADING PASS-BAG	OP	13	58	62	13	58	62	13	58	62	13	58	62	153	270	1203	1203
OPERATING	LOADING PASS-BAG	OP	5	37	18	5	37	18	5	37	18	5	37	18	2	2	277	277
OPERATING	LOADING PASS-BAG	OP	2	5	4	2	5	4	2	5	4	2	5	4	2	5	6	139
OPERATING	LOADING PASS-BAG	OP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
OPERATING	LOADING PASS-BAG	OP	0	22	14	0	22	14	0	22	14	0	22	14	57	27	1645	1645
OPERATING	LOADING PASS-BAG	OP	5	46	57	5	46	57	5	46	57	5	46	57	60	60	2462	2462
OPERATING	★ TOTAL		375	3107	3365	375	3107	3365	375	3107	3365	375	3107	3365	24744	2318	2436	6672
POWER	PHASOR ENGINE	PP	12	122	102	12	122	102	12	122	102	12	122	102	270	74	2271	2271
POWER	PHASOR ENGINE	PP	0	37	51	0	37	51	0	37	51	0	37	51	0	0	0	0
POWER	PHASOR ENGINE	PP	0	12	10	0	12	10	0	12	10	0	12	10	0	0	0	0
POWER	★ TOTAL		16	212	269	16	212	269	16	212	269	16	212	269	740	144	236	912
TRAIN INFO	TRAIN CONSIST	TCS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRAIN INFO	★ TOTAL		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Exhibit 6A-2-E
 EXAMPLE OF DAILY TRAIN PERFORMANCE DETAIL REPORT
 -- BY TRAIN SYMBOLS

DAILY TRAIN PERFORMANCE DETAIL																		
DESIGNATED FREIGHT, PASSENGER, & UNIT TRAINS 1555 07-05 THRU 0510 07-07																		
TRAIN	W	LDS	MTY	HP	TONS	HP/TON	EV	STATION	TIME	RUN	VARIATION	SCHEDULE	TIME	CODE	CAUSE	DELAY	EXPLANATION	
AS4606	3	22	27	5550	2840	1.954	AR	VICKRS	0725	25.55	A	25.55	A	40	SO, PU, CLASSIFY		MNRO S/D 3-4 P/U 10-21	
		22	61	9600	4640	2.069	DP		1055	1.30	L	24.25	A	45	SO, PU, CLASSIFY		PRY YARD PICKUP	
		15	69	9600	3700	2.595	AR		1245	1.40	A	25.05	A		CLT CREW LIST TIME		PRY YARD P U ENGS 2267 5436	
		15	69	9600	3700	2.595	DP		1405	1.10	A	26.15	A	140	SO, PU, CLASSIFY		CL 1000	
		15	69	9600	3700	2.595	AR		1604	-0.1	A	26.16	A	10	SO, PU, CLASSIFY		S/D 16-33 P/U 9-41 AT JACKSON	
		15	69	9600	3700	2.595	DP		1605	.29	A	26.45	A	10	SO, PU, CLASSIFY		S/D 0-22 AT NEWTON	
		15	69	9600	3700	2.595	AR		1740	-0.4	L	26.41	A	50	UM MEETING & PASSING		MEET XBR107M SWY906 AT MFFMAN	
		15	69	9600	3700	2.595	DP		1805	-0.4	A	26.45	A					
AUG206	2	8	5	4500	901	4.994	DP	I I G	2010	-0.0		-0.0		10	CLT CREW LIST TIME		2000	
		8	5	4500	0	0.000	BY		2217	.22	L	-22	L	10	OT LATE MAKE UP, SET		PLDT	
		1	29	4500	1010	4.455	DP		0015	.18	L	-40	L	65	OLA DELAY ACC AMTRAK		AND 304 BYAT NHRMA	
		1	29	4500	1010	4.455	TR		0055	.50	A	-10	A	20	US SU, PU, CLASSIFY		MILLSDALE	
										.20	A	.30	A				SOURLET	
FFC804																		
P02106	2	10	0	6000	0	0.000	DP		1114	-14	L	-14	L	14	CLT CREW LIST TIME		2000	
		0	0	0	0	0.000	BY		1207	.05	L	-19	L	15	LATE MAKE UP, SET		CHGO TC & FC 1030	
		0	0	0	0	0.000	BY		1227	.00	L	-19	L	6	SLW ORDERS		CHGO AND PSGRS	
		2	10	0	6000	0	0.000	AR	1337	-15	L	-34	L	6	UM MEETING & PASSING		PORTIAC MD 22	
		10	0	6000	0	0.000	DP		1540	.00	L	-34	L	7	ES SIGNAL MALF		TERMINA TO NORMAL CROSSING	
		0	0	0	0	0.000	BY		1421	1.29	A	-27	A		CLT CREW LIST TIME		CLT SVC 4 LOCATIONS	
		0	0	0	0	0.000	BY		1542	1.21	L	-27	L				ILLR FC 1320	
		0	0	0	0	0.000	BY		1557	-0.1	L	-27	L	5	EDD H B DEFECTOR		OUT SHIPMAN	
		2	10	0	6000	0	0.000	TR	1625	-16	A	-10	L	5	EDD H B DEFECTOR		OUT SHIPMAN	
P02206	2	11	0	6000	0	0.000	DP	J I	0530	-45	L	-45	L	35	CLT CREW LIST TIME		STL TC & FC 0815	
														10	GMC LATE CONNECTIONS		STL AND SERVICE TRAIN	
															OS	SO, PU, CLASSIFY		STLOUIS, P/U 1 CAR

EXAMPLE OF TRAIN PERFORMANCE DETAIL REPORT
 --- DIVISIONAL SUMMARY

OPRI0679

DIVISION

MORNING REPORT THRU 0615 ON 07/04/80

--- LATEST EVENT ON DIVISION ---		--- DIVISION ENTRIES ---				
TRAIN	EV STAIN TIME	DATE SCH VAR	P LDS MTS	GN DIVN	LS/GN DELAYS	
101003	TR	0734	07/03	00.04LT	0 4 0 00.14LT	00.10G 00.05
101004	TR	1805	07/03	00.03LT	0 4 0 00.00	00.03L 00.00
101005	TR	0810	07/03	00.05LT	0 3 0 00.05LT	00.00 00.00
101006	TR	1900	07/03	00.23LT	0 3 0 00.00	00.23L 00.32
101007	BY	1234	07/03	00.46LT	2 11 0 00.25LT	00.21L 00.45
101008	TR	1627	07/03	02.27LT	2 9 0 02.41LT	00.14G 00.00
101009	TR	1318	07/03	02.33LT	2 13 0 02.33LT	00.00 00.00
101010	DP	1630	07/03	00.10LT	2 11 0 00.10LT	00.00 00.48
101011	TR	1015	07/03	00.05LT	1 4 0 00.16LT	00.11G 00.05
101012	BY	0907	07/03	00.04LT	1 6 0 00.00	00.04L 00.04
101013	BY	1846	07/03	00.38LT	1 6 0 00.10LT	00.28L 00.28
101014	TR	2140	07/03	00.25LT	1 5 0 00.31LT	00.06G 00.10
101015	TR	1022	07/03	00.07LT	1 2 0 00.07LT	00.00 00.00
101016	DP	1806	07/03	00.21LT	1 2 0 00.21LT	00.00 00.24
101017	TR	0846	07/03	00.14AH	1 2 0 00.14AH	00.00 00.00
101018	DP	1858	07/03	00.48LT	1 4 0 00.48LT	00.00 00.59
101019	DP	0840	07/03	00.00	1 5 0 00.00	00.00 00.00
101020	TR	2133	07/03	00.02AH	1 5 0 00.02AH	00.00 00.00
101021	DP	1745	07/03	01.15LT	3 62 28 01.15LT	00.00 01.25

Chapter 7

ASSESSMENT OF POWER MANAGEMENT PROBLEMS AND DEVELOPMENT OF SOLUTIONS

The specific goal of organization diagnosis, from a dual-system point of view, is to: 1) understand the characteristics of both the system being controlled and the controlling system; 2) improve the controlling system through the enhancement of the control linkages between the dual systems, and appropriate allocation of the controlling capacity to tasks to be controlled. The material presented in Chapters 4 through 6 accomplishes the first goal, namely to develop an understanding of the complex characteristics involved in power management activities. In this chapter, we focus on the development of improvement plans for the controlling system, with particular emphasis on: 1) the effectiveness of the general task management structure; 2) the coordinability of multi-functional activities; and 3) the efficiency of the individual decision-making process concerning the control of power dispatching.

To integrate the individual organization units in the controlling system and to articulate the controlling and the controlled systems, information is an essential linking element, thereby, in this chapter we also provide an analysis of the existing management information systems, focusing particularly on their current and potential capability. Then corresponding to each of the three specific foci identified in the preceding paragraph, three interrelated improvement proposals are presented: the refinement of the power dispatcher's decision-support

systems, the development of multi-functional team-support systems, and the reconstruction of the general meta-control structure. The key theme here is to demonstrate the validity and practicability of the theories and methodologies suggested in Chapter 2 and 3 as well as to illustrate how to apply the descriptive and analytical data documented in the previous three chapters (4 through 6) to undergo organization diagnosis, assess system performance, and to develop change plans.

7.1 Assessment of the Power Management Problems

7.1.1 Problems with the Meta Control Structure

In Chapter 4, we argued that the system being controlled can be characterized by a control-task hierarchy. Corresponding to this hierarchy of control tasks, we identified a multi-level meta control structure - represented by the general task-actor matrix shown in Exhibit 7-1-1 (originally shown as Exhibit 4-2-7) - which integrates various individual units in the organization to perform the controlling function, and articulates both the formal and informal aspects of organizational structure and processes.

Given this document, we are able to assess the potential dysfunction of the controlling system in question by comparing the descriptive structure and processes with certain normative arguments. In the following diagnosis, our basic focus is on Railroad A, hereafter referred as the host railroad.

A. Inadequacy of Planning Support

Due to the characteristics of rail technology, maintaining the daily operation of the system in the face of its complexity and uncertainty requires a great deal of managerial energy. As a result, in the host railroad predominant management attention is given to the operating control process. In the context of power management, the operating control responsibilities are primarily well defined and usually can be traced as high as the AVP level. The planning responsibilities regarding power operations, on the other hand, are not so explicit. For instance, in the host railrad, no one can really tell

Exhibit 7-1-1 TASK-RESPONSIBILITY RELATIONSHIPS OF POWER MANAGEMENT IN RAILROAD A

ORGANIZATIONAL UNITS WORK UNITS	GENERAL MANAGEMENT	SVPO	VPT	VPM	TRANSP. DEPT.	MECH. DEPT.	TRANSP. DIVISION SUPT.	MECH. REGIONAL GENERAL SUPT.	TRAIN DISPATCHER	POWER DISPATCHER	TERMINAL SUPT.	LOCAL ENGINE TERMINAL	ENGINE SHOP
SYSTEM-WIDE PR ?	Dec ?	? Prop - Sup	Exec										
SYSTEM-WIDE PA (FLEET SIZING AND COMPOSITION) ?		Deci ?	? Sup		Prop ?								
SERVICE CYCLE (STORAGE, OFF-LINE) ?				Dec ?		Prop ?		Exec					
MAINTENANCE CYCLE (SCHEDULE)				Prop ?			Sup.		Exec.				
OPERATING CYCLE (TRAIN SCHEDULE)		Appr. Delg. Notif			Prop				Exec.				
TRAIN DISPATCHING									Delig. consult.		Exec.		
POWER DISTRIBUTION									consult	Decision	consult		
TERMINAL POWER POOL									Consult	Decision	exec	exec	
POWER MAINTENANCE												Delig. exec.	Delig. exec.
SHOP PERFORMANCE													Accoun.
POWER IDLE/TERMINAL ?								Sup. Review					Accoun.
TRAIN PERFORM./ TERMINAL DUE TO POWER										Accoun			Accoun
SERVICEABLE FLEET				Rev.	Review	Rev.		Acc		Accoun			Accoun
POWER PRODUCTIVITY ?													
POWER SERVICE QUALITY		Ps.	Acc										

what their fleet-sizing process is. This is a situation not unique to the host railroad. In a study of several other large railroads' power utilization, Emerson [1975] observed the same phenomenon.

Operating Cycle and Service Cycle Planning

According to the General Manager-Terminal Operations (who plays two roles - monitoring performance and proposing adjustment in operating plans and standards if needed), the changes in power utilization pattern will take place principally after the changes of train schedules. More specifically, before the proposed train schedule change is finalized, the Superintendent of Power Distribution will be consulted concerning the feasibility of the intended change from power viewpoint; and after the change is actually launched forth, the Power Dispatcher is presumed to adjust the power cycling pattern accordingly.

The key point is that the above process is primarily power-operating-cycle-oriented. The Power Superintendent may decide to store some units subsequent to the revision of train schedule. Nevertheless, this practice is not emphasized by management - more specifically, the Power Superintendent may not have an incentive to cut back oversized fleet even if the opportunity exists.

Maintenance Cycle Planning

The Mechanical Department's planning in maintenance schedule, as described previously, is largely by "default". From our observation, the major reason is that the generally perceived (but implicit) responsibility of the Mechanical Department to the Senior Vice-President-Operations in the host railroad is to sustain a less-than

10% shop margin at all time, and as long as the shop margin remains in that boundary, SVPO tends to leave the Mechanical Department alone; therefore, the mechanical officers are not motivated to deliberately improve the maintenance schedule. As a result, regardless of the cyclical fluctuation of traffic level, an engine will be shopped for only one of two reasons: either when mandatory inspection is due or for road failure.

Fleet Ownership Planning

From the nature of the system being controlled and the characteristics of the decision to be made, we may prescribe how railroads should size their road power fleet by drawing inferences from the aggregate power service impact model presented in Chapter 4. The following function should be included in the calculation of a systematic fleet ownership decision:

- 1) the amount of traffic projected in terms of GTMs by direction over each major route during peak months,
- 2) the desired service levels during the peak periods expressed in GTM per available horsepower-day in the most demanding direction of each route,
- 3) the planned shopping margin of the system road fleet during peaks,
- 4) the expected net balance of horsepower with foreign railroads during the peak periods, and
- 5) the change in utilization expected during the projected peaks expressed as a percentage of previous time utilization ratio.

In reality, the decision on fleet ownership is the most unstructured one. During the annual budgeting process, one implicit

criterion employed is to maintain a relatively constant fleet size (refer to the previous year's one as the basic standard). More specifically, the heuristic is normally to equate the number of new purchases to the expected number of retirements. Moreover, the decisions on power retirement program are not usually made, until the number of overaged units exceeds a certain "have-to-deal-with" limit.

In summary, due to the lack of formal procedures, deliberate planning activities are not performed in the host railroad's current power management environment. Incremental adaptation of the operating cycle is usually less than sufficient to optimize power utilization. Most importantly, in the absence of the explicit planning processes, accountability for various levels' performance become vague and implicit. This drawback, in fact, significantly limits the efficiency and effectiveness of the control function of the system.

B. Absence of Effective Control Cycles

Due to the need to coordinate a set of highly dependent operations, rail management is largely characterized by intensive means-control activities which are embodied by a sophisticated hierarchical steering-control mechanism(e.g.,in part, the operating document priority system). In the specific context of power management, as described in Chapters 4 through 6, the execution of daily operations is closely monitored in minute-detail through both verbal channels and computerized on-line information systems. However, the means-control oriented supervision of real-time operations is only one facet of the control function. Equally important is the end-control oriented assessments of performance and the allocation of accountability, as well as the detection of the need for replanning. Due to the sensitivity of real-time performance to the operating variability, it normally requires a longer time horizon to practice the end-control. Thus, the nature of end-control is primarily a high level control function, and in effect, it concludes the managerial cycle that begins with planning.

The major drawback of the current power performance review system of the host railroad can be summarized into three categories: 1) the specifications of performance indices, 2) the accountability for performance, and 3) the replanning mechanism.

Performance Measures. As we will see later in this chapter, the data bases of the existing computerized information systems of the host railroad are capable of generating a wide variety of performance indices. Therefore, the key problem regarding performance review is not

lack of data but the handicapped information filtering process which prevents management from getting decision-relevant information. For instance, as mentioned in Chapter 6, regardless of the availability of the extensive power performance data, there is only one measure - serviceable fleet size - which appears on the operating summary statistics (one of the two reports that most likely receives the senior management's attention each morning). Of course, we are not suggesting that more measures are better[*], but challenging the appropriateness of the measure to meaningfully represent the performance of power operations. Another example is the qualitative index - engine shortage - shown on the exception events report [see Appendix of Chapter 6]. The problem here is that it is a crippled measure. During the years with growing traffic or during the peak seasons, engine shortage is certainly an important signal to be received by the senior management. However, when the traffic is declining or in the off-peak seasons, engine shortage is no longer an issue. During these periods, the real issue turns to engine underutilization instead of shortage. According to the host railroad's SVPO, he realized that their power fleet had excessive idle time incidentally through a fuel saving campaign as mentioned in Chapter 5. This story reveals two problems: 1) the formal reporting system, including daily and periodical summaries, failed to signal symptoms which merit senior management's attention - either the signals may not be produced at all in the system or too weak to be received by the senior management;

[*] To higher level management, few carefully designed indices are more valuable and useful than a large number of unselected measures, because the latter may cause the problem of information overload [Section 2.3.3; Ackoff, 1967].

2) management failed to integrate certain effective performance review mechanism as the complement to the formal reporting system and performance review session during the daily operating conference. This complementary mechanism can include standardized off-line analysis, special reports on specific performance areas and so forth. The common premise to solve the above two problems is the need for a set of appropriate indices which balancely cover the major performance areas and are capable of gauging the potential symptoms.

Accountability Assignment. There are two issues involved in this category. The first is the failure to explicitly assign the accountability of performance of the real-time routine operations. The decision processes of power real-time operations are well-structured, thus in principle the assignment of performance to the responsible individual should be relatively straightforward. However, in reality, the host railroad's control over the real-time power operations, in a sense, is largely effort-oriented rather than result-oriented. For instance, referring to the progressive decision process depicted by the communication locus given in Exhibit 6-2-4, the consequences of the decisions are not measured by the railroad in the first place (the arc between nodes 4 and 5 is not adequately evaluated); second, without an identifiable decision process regarding the higher level power cycling, there is no ground to explicitly assign the performance accountability. Although the immediate train performance associated with power dispatching is measured, this single measure is less than sufficient to reflect the contribution a power dispatcher is presumed to make. Other equally important measures, such as the time utilization of the fleet,

and the productivity of each horsepower hour are not routinely reported in Railroad A, let alone the assignment of their accountability.

The second issue is that, due to the vague planning procedures, it is difficult to assign accountability of high level power cycles.

Replanning. Effective replanning relies vitally on the explicit accountability assignment concerning the system performance, because only with well-known performance responsibility, can the feedback information on system outcomes be appropriately received by the accountable officers and properly used to direct their future planning. Without clear performance accountability (let alone the incentives system [*]), the host railroad, in effect, not only fails to conduct adequate performance review, but also misses the opportunities to adjust its power management through replanning.

C. The Need for an Explicit Meta-Control Structure

Meta-control, in a sense, refers to the learning capability of an organization. In response to changing operational premises, the meta-control mechanism utilizes the feedback signals from both the internal and external sources, adapts the performance standards, the operating plans as well as the controlling procedures and structure. Most importantly, the meta-control is based on lower levels' control mechanism; it can function properly only if the lower levels' controlling function performs well.

[*] In principle, a completely effective adaptive system further demands certain incentive components which motivate the engaged managers to behave as desired in response to the feedback information.

From the preceding discussion, it is evident that the host railroad is handicapped in its meta-control function by the malfunction of the lower level control practices[*]. One of the most fundamental causes of system malfunction is that the railroad fails to explicate their meta-control structure, to direct planning and control activities concerning power management and without such a conceptual framework, it is difficult for management to effectively inquire, digest and utilize the available information as well as the knowledge for diagnosing and adjusting the function of the controlling system. For instance, as remarked by the General Manager-Terminal Operations concerning the utilization of the massive information produced by their computerized information systems: "We don't know how to use it yet," - despite the fact that the information systems have been adopted and evolved for at least a decade in their railroad.

The value in making the meta-control structure explicit is more than technically enhancing management in information transaction. Most importantly, a clearly spelled-out meta control structure reveals the whole spectrum of options at management's disposal. In a discussion with the host railroad's SVPO, after we mentioned that there was room for improvement in certain current maintenance practices, he commented: "I have never thought about that before!"

In conclusion, the lessons learned from the diagnosis of the general management of power operation are clear. Planning, execution and review are the integral parts of a complete controlling cycle. Without

[*] We may say that the meta-control system in the host railroad does exist but in a rudimentary and implicit way.

identifiable decision-making procedures for planning, it is difficult to allocate performance accountability. Without explicit accountability, performance feedback can hardly be received properly and utilized effectively to direct replanning. Moreover, effort-oriented steering control is less than sufficient to accomplish the control demanded in the system. Without clear result-oriented goals, there is no ground for developing operational indices and standards as the basis for performance evaluation. Without deliberately designed performance indices, adequate controlling-relevant information can hardly be generated; as a result, the system becomes handicapped by the malfunction of the controlling mechanism.

In the context of power management, various symptoms in line with the above pathological causes have been found in the host railroad. To overcome the deficiency of the controlling mechanism regarding the management of the general task, the key is to develop an explicit Meta Control Structure and use this Structure to guide the various planning, execution and performance review activities and to diagnose as well as to adjust the function of the controlling system. We shall amplify this later.

7.1.2 The Impact of Inadequate Multi-Functional Coordinability on the Maintenance Function

The maintenance function is an essential module in the overall power management task. The drawbacks concerning the general management structure of the host railroad identified in the previous section are commonly shared by the maintenance function. For instance, effort-oriented control consumes the mechanical officers' energy; maintenance planning is an implicit process (one may note that the planning responsibilities shown in Exhibit 5-2-12 are not specific), and consequently the higher level accountabilities (such as fleet reliability) are difficult to assign to specific individual (except to the VPM); a number of fundamental performance indices are either problematic or not measured at all; feedback either does not exist or is not effectively used to guide future planning in many primary performance areas; and as a whole, the adaptation function of the maintenance system does not perform well. In this section, we shall investigate more closely and specifically the above symptoms in the maintenance area. In addition to the above relatively macro-level issues, problems concerning the more detailed operating coordinability between the maintenance function and the general transportation function will also be examined.

A. Planning and Control of Mechanical Service Policies

The power mechanical service policies, as defined in Chapter 5, refer to: 1) the inspection period, 2) the critical level for the controlled parameters which reflect the conditions of an engine's major

components, and 3) the stopping rules regarding the use of engines. Among these policies, the controlled parameters' tolerable range and the stopping rules are largely determined by the engine's inherent mechanical properties. To these two policies, the planning issue is related to the choice of engine type and model and/or the need for engine modification, both of which are primarily one-shot decisions, while the control issue is concerned with the implementation of policies which is essentially an on-going task and crucial to the fleet reliability. As to the policy of inspection period, i.e., the maintenance schedule, however, both the planning and control issues are recurrent in nature. On the planning side, in principle, the inspection interval and the inspection level of each unit is at management's disposal as long as the decision is not conflicting with the federal mandatory framework. For instance, mechanical officers can schedule the power fleet's higher level inspection - biennial, annual, semi-annual etc, (which usually take longer shop time) - to off-peak months, so as to reduce the shop margin of the fleet and leave more shop capacity for taking care of unscheduled operations during the peaks. On the control side (execution and review), the fundamental task is related to the actual shopping assignment and the balance of shop work-loads. Given the above notion, we have found that there are a number of shortcomings in the current conduct in the host railroad regarding the planning and control of service policies which are discussed below.

Serviceable Fleet Is Not Geared to the Traffic Level

In current practice, the creating of maintenance schedule is primarily the product of a straightforward "bookkeeping" process

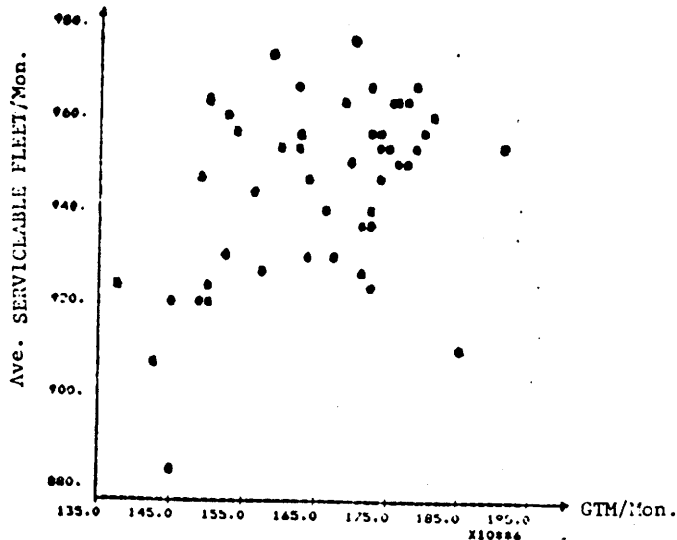
conducted by the Manager of the Information Systems in the mechanical department. There is no explicit decision involved in such a process, nor the consideration of transportation requirement. Exhibit 7-1-2 shows the relationships among traffic level, serviceable power fleet, W/P ratio, and power time utilization. Because the serviceable fleet is not coordinated with the traffic level, to accommodate high traffic level, an average unit must both work harder and turnaround faster. The major problem concerning the above practice is that, because the operations during the peak months are normally the real challenge to rail management, strategically speaking, to perform their task efficiently, management should take every opportunity to maximize its controllability over the situation. In the maintenance context, unscheduled maintenance is the major uncontrollable element in the system. To minimize the adverse effect of this uncontrollable factor on both the system shopload and the fleet serviceability, during the peaks it is preferable to: 1) reduce the need for unscheduled maintenance by reducing the engine's work-load, and 2) reserve more shop capacity to take care of the unscheduled repairs so as to shorten their shop time. A key to achieving above two goals is to make a deliberate effort to reschedule certain peak periods' preventive maintenance work to off-peaks.

Ideally, a well managed power fleet should exhibit behaviors as shown in Exhibit 7-1-3. More specifically, the serviceable fleet size is properly geared to the demand level; despite the traffic level, the work load (in terms of W/P ratio) is relatively constant - closely follows the desired W/P policies; the turnaround time is also relatively

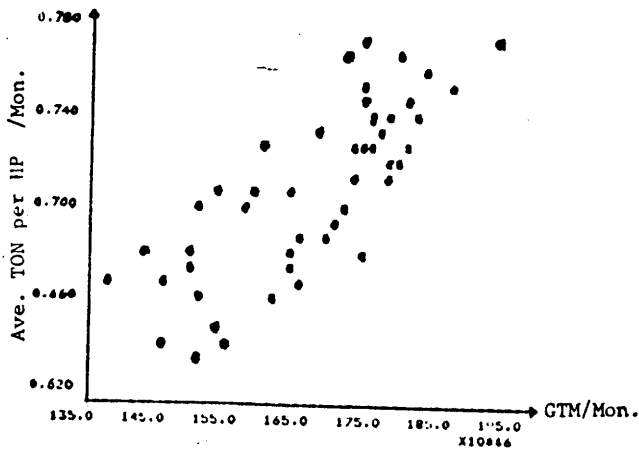
Exhibit 7-1-2

THE INTERPLAY AMONG TRAFFIC VOLUME, SERVICEABLE POWER FLEET,
TON/HP RATIO, AND POWER TIME UTILIZATION

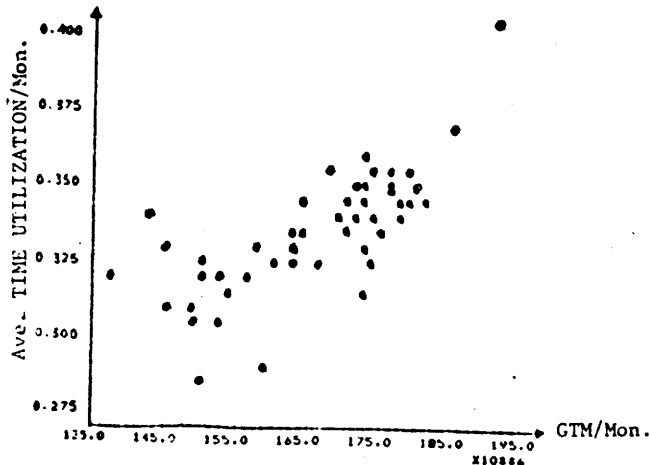
(A) No regularity can be concluded between the Traffic Level (GTM) and the Serviceable Power Fleet.



(B) In response to higher Traffic Level, an average engine must work harder --- larger TON/HP Ratio; and/or



(C) In response to higher Traffic Level, an average engine must turnaround faster --- higher Time Utilization Ratio.



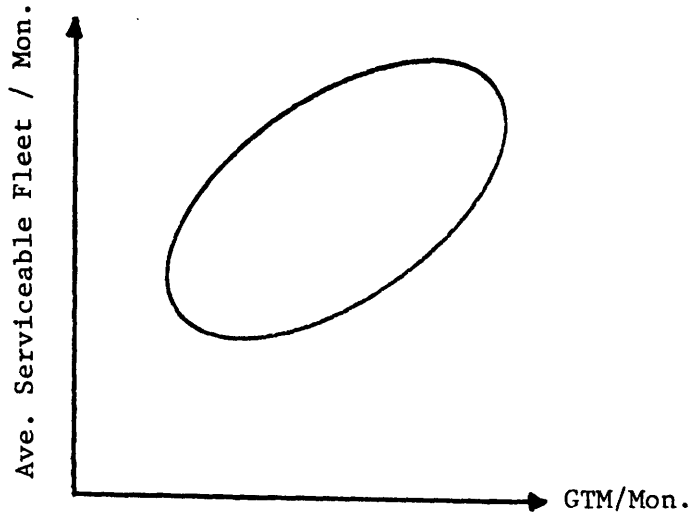
constant despite traffic level. By this token, a stable stand-by time pattern can be upheld and in turn a more reliable train service can be maintained throughout the year. Of course, the notions of constant workload and stable turnaround time do not preclude the need to search for a more efficient power utilization patterns (while providing the same service quality). However, such an effort should be directed to upgrading the average utilization pattern but not the peak utilization - technically speaking, the goal to change power utilization pattern is to shift upward both the W/P ratio and time utilization lines shown in Exhibit 7-1-3 as a whole, but not to change their slopes.

However, we cannot totally blame the Mechanical Department for the current inefficient conduct. Without the necessary antecedent transportation planning process, no delicate maintenance planning effort can possibly be motivated and properly guided. It is then conceivable for the mechanical officers to strictly follow the well-known mandatory frame as their maintenance schedule. By this token, they can avoid any responsibility for "rocking the boat" and can stabilize both expectations of the shop operators regarding their workload and the transportation officers concerning the maintenance requirements - the latter expectation is particularly important in the absence of a formal coordination mechanism for the planning of a serviceable fleet.

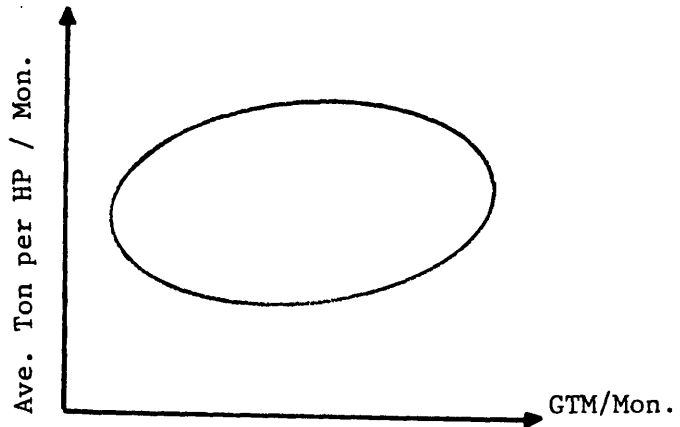
To improve the current situation, two steps must be taken: the first starts from the development of a formal transportation planning process and subsequently a maintenance sub-process to direct the planning of the serviceable fleet; the second is the reorganization of the existing planning function in the Mechanical Department by designating

A HYPOTHETICAL INTERPLAY AMONG TRAFFIC VOLUME, SERVICEABLE FLEET,
TON/HP RATIO, AND POWER TIME UTILIZATION

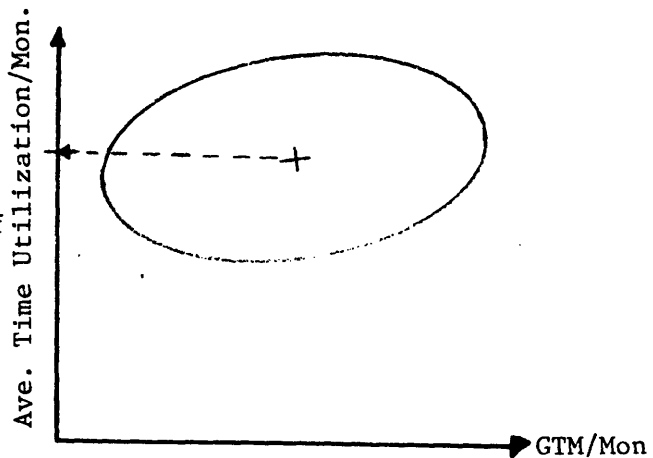
(A) More responsive adjust-
ment of Serviceable
Power Fleet to the
Traffic Volume.



(B) Relative constant power
workload (TON/HP),
regardless of Traffic
Volume.



(C) Higher but relatively
constant Power Time
Utilization, regardless of
Traffic Volume.



certain units specifically to deal with the scheduling of preventive maintenance and developing certain procedures for the planning of the serviceable fleet.

The Hidden Cost of Fleet Unreliability

Referring to Exhibit 5-1-7, from 1979 through 1980, (due to road failures), each unit in the host railroad exhibited unscheduled visits to the shop 0.76 times every month, while the scheduled visit is conducted every 45 days, or equivalently, 0.66 times every month. The consequences of the high fleet unreliability are devastating.

Reliability and Power Assignment. First of all, it causes the collapse of transportation personnel's confidence on power reliability. For instance, a Division Superintendent remarked: "As soon as a train leaves our terminal, we start to worry about a road failure." In response to our question regarding their low W/P ratio (which is approximately 0.7 from 1977 through 1980), the General Manager-Terminal Operations commented: "A stall on the road because of engine failure is too expensive to afford; therefore, we usually 'overpower' the train to prevent the stall from occurring." As a result, the host railroad had to use part of its road fleet unproductively as "insurance" power; and despite a train's length, the minimum standard power assignment was a two-unit consist. The direct impact of such conduct is reduced productivity of power. In Railroad C, one serviceable horsepower-day produces 170 gross-ton-mile, while in Railroad A, the same horsepower-day only produces approximately 100 gross-ton-mile, there are a number of factors which can cause the above difference, e.g., train speed and power time-utilization; nevertheless, the W/P ratio was a key factor. In Railroad C from 1977 to 1980, it was approximately 0.9,

while in Railroad A, it was about 0.7.

Reliability and Shop Operations. Fleet unreliability not only causes a high frequency of shopping but also long shopping time, and both affect the shop operations significantly. Exhibit 7-1-4 shows published locomotive shop productivity standards. Comparing these standards with the actual performance represented in Exhibit 5-1-6, we can conclude that the actual average scheduled maintenance time (20.3 clock hours) was much longer than the documented standards for two reasons: one is because approximately 60% of scheduled shoppings were 45-day (standard: 6 manhours) and 30% are 90-day (standard: 18 manhours) inspections during the surveying period, the average scheduled shopping time was supposedly to be much shorter than 20 hours; and the other is that normally more than one craftman were assigned to work on a unit, therefore, if there were no delay for whatever reason then, in terms of clock time, the scheduled shopping time should be much less than the man-hour standards. According to a Shop General Foreman, the shop performance we observed was not atypical, and the main reason which causes the undue maintenance time was the large amount of unscheduled maintenance - from time to time, he felt he needed more workforce and larger material stocks.

Reliability and Operating Control Effort. Referring to Exhibit 5-2-6, the process for handling engine failure is relatively complicated. For a 1000-unit fleet with 0.76 road failure rate per-unit each month, there are approximately 25 road failures every day. This was indeed a remarkable extra burden on the Power Control Center, Division Master

Exhibit 7-1-4

LOCOMOTIVE SHOP PRODUCTIVITY STANDARDS

<u>ACTIVITY</u>	<u>STANDARD (MAN-HOURS)</u>	<u>ACTIVITY</u>	<u>STANDARD (MAN-HOURS)</u>
Loco. Handled	1	<u>ELECTRICAL (Continued)</u>	
<u>INSPECTIONS</u>		Auxiliary Generator	
45 Day	6	Change brushes	1
90 Day	18	Repair leads	1
Semi	20	Clean	1
Annual	30	Change	24
61-annual	60	Traction Motor	
<u>MECHANICAL</u>		Change brushes	1
Coupler	3	Change brush holders	2
Coupler & draft gear	10	Repair leads	3
Check for fuel leaks	2	Clean	2
Check for water leaks	2	Change	12
Check for oxidized lube oil	2	Repair cooling fan	1
Check for blow-by	3	Change cooling fan	4
Check for wear metals	4	Repair T.M. blower motor	1
Oil change (engines)	2	Change T.M. blower motor	4
Change fuel filters	1	Misc. Motors (Fuel pump, turbo pump, heater, inertial filter, axle alternator, exciter, starting motor)	1
Change fuel bumper line (S)	1	Service or repair	1
Change injector (EMD)	1	Change	
Change cylinder head	6	Batteries	
Change power assy.	10	Service	1
Change lower main bearings	14	Change-1	1
Change upper & lower mains	24	Change-8	4
Change governor	5	Power Circuit (Reverser, power contactor, relay, contactor, interlock, resistor)	
Change eng. blower	14	Repair cabling or wiring	4
Change turbo	48	Change component	4
Change aftercooler	2	Control Circuit (Relay, contactor, rectifier, diodes, capacitors, resistors, rheostats, potentiometers, interlocks, control stand, switches, grounds)	
Change exhaust stack gaskets (set)	18		
Change lube oil filters	2		
Change lube oil cooler	14		
Change water pump	3		
Change radiator (1 bank)	8		
Change cab heater core	2		
Change air compressor	20		
Change oil pump	4		
Change inertial filter (1 side)	8		
Change engine air filters	4		
Change truck (1)	7		
Change wheel & axle	15		
Change gear case	4		
<u>ELECTRICAL</u>			
Main Generator - Traction Alternator			
Change brushes	3		
Change fuses & diodes	3		
Change brush holder	2		
Repair cabling	3		
Clean	4		
Change	100		
Resurface commutator	16		

Mechanic and Shop Coordinator. Coordination is usually costly in terms of time consumed by all the engaged actors. Moreover, because a decision-maker's attention is a limited resource [Simon, 1973], the more the attention of a power dispatcher, for instance, is oriented to the handling of emergency, the less for the decision making with respect to normal operations. In effect, the decision quality regarding the normal operations could be jeopardized significantly.

In summary, the symptoms concerning the unreliability of the road fleet and its devastating effects on many areas are evident. The key sources of troubles are the unsuccessful planning and implementation of service policies and the lack of control over maintenance quality. However, there is no straightforward solution. For instance, we should keep in mind that the notion of accountability can hardly be applied to the individual labor level, because unions prohibit the management from assigning the responsibility of equipment performance to any specific worker. The best the management can do is to take an entire shop in whole as a responsibility unit, adopt the home shopping principle strictly and incorporate some formal incentive mechanism (and possibly associated with certain MBO procedures) with a refined performance review system.

B. Shop Performance Control

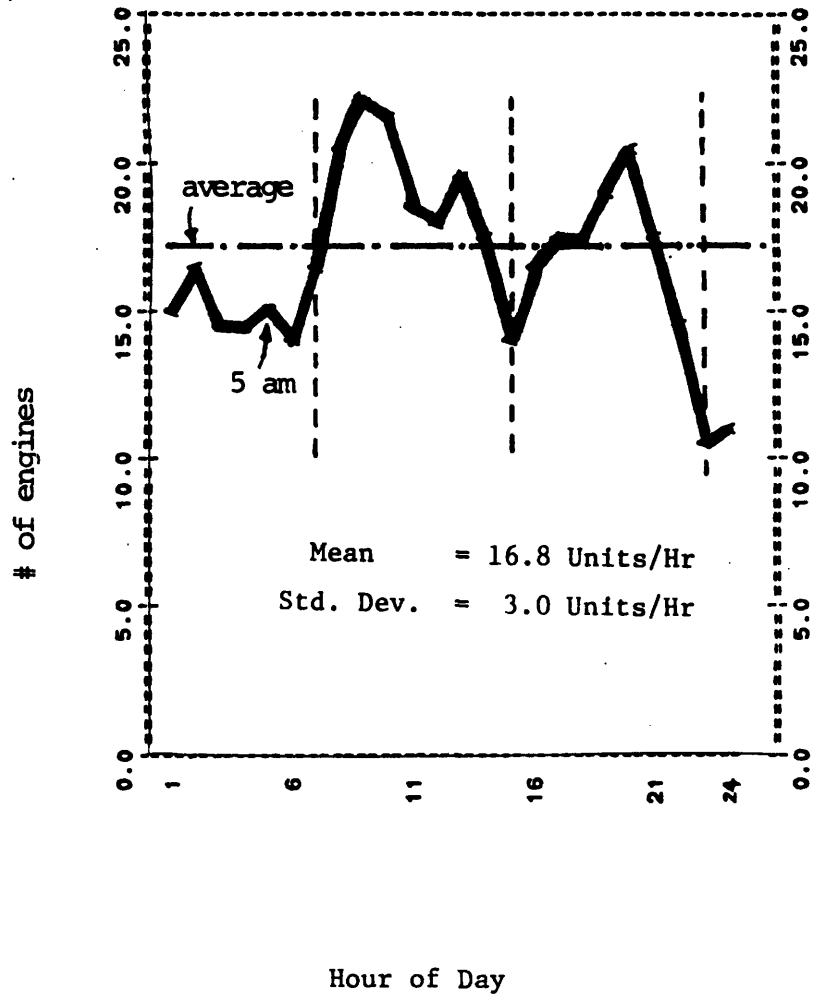
Shop margin, as described in Chapter 5, is the single index emphasized by the host railroad for the evaluation of shop performance. In principle, any single-measure control system can easily result in unbalanced performance. Unfortunately, the host railroad's maintenance performance is exactly such a case. For instance, the remarkable fleet

unreliability is one of the direct consequences of the biased control mechanism. Despite the counterproductive side-effects, the shop-margin measurement procedure per se is also problematic.

The current shop margin is defined as the sum of the 5 a.m. shop count over the entire system. However, Exhibit 7-1-5 gives a daily shop-count profile of a major repair shop in the system [Mao and Martland, 1982], which clearly indicated that the 5 a.m. count is below the mean and among the lowest points of the profile. In other words, because the only performance measure is calculated merely on one specific moment of time, it is conceivable that the shop operator could intentionally make the performance at that moment look good. This would make the current measure calculated from the 5 a.m. shop count an underestimate of the true shop margin and an overestimate of shop performance. Because shop performance information is an important item on the agenda of the morning maintenance conference which is usually held at 9 a.m., to obtain a shop count measure, the turnover report between the third and the first work shift is a convenient source which is practically prepared around 5 a.m.; therefore, the 5 a.m. shop count becomes institutionalized as a fleet shop margin measure for the system. However, given the modern computerized on-line information processing capacity, the preparation of multi-point shop counts is no longer a difficult job. Therefore, to avoid the pitfall of the current counting procedure, a per-shift or per-hour based counting system should be more desirable and able to produce more accurate shop performance indices.

Moreover, to improve the situation caused by the current single-index control system, a set of deliberate indices, which must

Exhibit 7-1-5 Shop Count Profile



include reliability measures and service quality measures (such as train delay account for mechanical operations, etc.), should be introduced to refine the existing system. Such a refinement of the existing performance evaluation system is aimed not only at providing more accurate information on shop performance, but also to guide the shop operations adequately toward more balanced performance.

C. Maintenance-Transportation Coordination Problems

Due to the high degree of mutual-dependence, rail power management is characterized by the interwoven decision nets involved in various tasks. In the real-time operating control context, the dynamic aspect of the decision net, particularly the timing and the sequence of contact of the involved actors, becomes critical to the eventual outcome of the process. The actors activated in those processes are very much contingent upon the nature of the situation and choice of the antecedent actors. For instance, referring to Exhibit 5-2-6, let us consider the following alternative scenario: if the Division Master Mechanic in question was rejected by all the shops he had been negotiating with, or anticipated the difficulty at the outset of finding an available repair shop, a most likely solution he may choose, then, would be a report to the General Superintendent-Mechanical. As a result, one more actor was activated, the decision chain became longer; and more importantly, the key decision-maker of the process was now shifted from the Division Master-Mechanic to the General Superintendent-Mechanical. The problems of our real concern are: 1) Why and When a particular decision net is evoked? 2) What makes it function?

Evocation of A Decision-Net

According to the theories suggested in Chapter 2, there are at least two ways to explain why a particular decision-net is evoked. First, a decision-maker may act on his own if he perceives his routinely received information sufficient to make the decision; otherwise, he has

to search actively for the needed information, and in effect a decision-specific communication net is thus evoked. The individuals involved in the net must stand for information-points which are relevant to the decision. The above notion explains partially when a decision-net will be evoked and why a specific net will be selected.

The second is following the notion of controllability derived from March and Simon's observation regarding the search sequence of the "problem-solving program" [1958, pp.179-180]. If a decision problem is perceived by a decision-maker as a problem that can be solved effectively by mobilizing resources under his control, then presumably he will act on his own to solve the problem. For example, if the Division Master Mechanic was sure that his division can take good care of the failed engine, then the bottom half of the communication locus shown in Exhibit 5-2-6 would certainly be defaulted. However, if the desired solution of the problem is considered already beyond his control, then the decision-maker has to intervene in other operations. For instance, he may pass the problem to someone who is presumed capable of solving it, e.g., the case represented by Exhibit 5-2-6. In many other situations, he may also intervene in either downstream or upstream operations, e.g., if for whatever reason an engine is unable to be released to serve a train in time, the responsible Master Mechanic can ask the Division Train Master to either hold the train, underpower the train, or leave certain car blocks behind. When all of the above methods have not worked and the problem still cannot be successfully solved, the decision-maker may seek to influence the higher level indirect decision-maker to alter the decision premises, i.e., decision

criteria or task goal. However, in case of the breakdown of the control function, decision maker may simply abandon the decision criteria or goal by following his own rule. An unfortunate example in this regard can be found in the host railroad: because the shop productivity standards, as shown in Exhibit 7-1-5, were considered hard to follow, many foremen never even knew such standards existed. In summary, the notion of controllability not only explains the reason when a decision-net is evoked, but also explains more specifically the way in which the net is evoked.

Basis of Mutual Influence and Intervention

The power control center is operated around-the-clock in three shifts, and there is observational evidence that some power dispatchers can get along with mechanical personnel much better than others; and more importantly these dispatchers are usually considered performing better than the latter ones. In theoretical term, the former have more competent role skill than the latter. Among other influence strategies mentioned in Chapter 2, in the context of power management, the sensitivity toward the mechanical person's work-load is critical. The favor that a power dispatch can offer to the servicing personnel by saving their effort in decoupling a power consist is just one typical example.

To assess the coordinability of a decision net, it is necessary to examine the basis for mutual influence and intervention. Due to the professional specialty and the nature of the task, the Mechanical Department is a distinct social group from the Transportation Department. According to a mechanical officer, in many cases the

situation is: "If we do well, it is our duty; if anything runs into trouble, we are the first to blame." In such an operating environment, morale becomes a critical issue, and recognition and appreciation of their contribution are eagerly sought by the maintenance personnel.

In addition to the above perception problem, an inherent conflict exists between the power dispatcher and the maintenance officers, in term of their respective daily operating concern. For the power dispatcher, the major driving force of his on-going decision effort is to satisfy the power need derived from train operations. The maintenance operators however, could care less about how the power demand is satisfied; for them, the priority is how to perform their maintenance job smoothly and easily. Two points can be made then, 1) between the above two parties, the power dispatcher has more influence and is in a better position to offer favors which may be appreciated by his counterpart; and 2) the most effective approach for winning the cooperation of the counterpart is to take their decision concern into account.

D. Team-Support - A Summary

The issue of coordinability concerning the maintenance-transportation interface activities can be examined along various dimensions and levels. Based on the data collected from the host railroad, we summarize our diagnosis as follows.

Real-time decisions are usually pressing problems. The routine procedures which are a part of the existing organization design can usually bring together the information and the efforts from various

relevant actors and work out a solution. As we illustrated above, the evocation of the decision net is very much dependent on the key decision-maker's perception of the sufficiency of information as well as the controllability of the problem. Therefore, two questions are in order: What is the likelihood that the decision-maker will make a premature decision because 1) of his miscalculation regarding the information requirement? or 2) of the barriers to communication either making him reluctant to request further information or causing him to consume too much time in obtaining the information thus making the process inefficient?

The first problem is essentially related to the nature of the performance control system, as well as the competence of the decision maker. As we stated earlier, no manager will seriously take into account those factors which are not included in the formal or informal performance control system, no matter how important in principle the factors are supposed to be. On the one hand, this problem restresses the importance of refining the performance control system. On the other hand, as illustrated in Chapter 6, an individual's decision heuristic vitally determines human information processing characteristics; a biased heuristic could constantly mislead the judgement on the information requirement. The solution to this problem is through training and/or the provision of certain delicate decision-support systems (DSS). More detailed examination of the problems related to the individual decision heuristics is provided in the next section.

As to the problem concerning the multi-departmental communication barriers, it is a challenge to the design of an organization

coordination mechanism. Given the stereotype perceptions between the mechanical and transportation officers, the need for effective coordination between these two parties is urgent. To improve coordinability, the railroad should develop certain mechanism for productively utilizing the potentially conflicting interests of these two parties (by identifying those practices which will benefit both sides as well as the organization as a whole), devising mutual intervention channels, as well as providing a balanced basis of influence to facilitate the exchange of favors for each other. A more detailed discussion on the design of such a mechanism, referred to as team-support systems, will be discussed in Part 3 of this chapter.

7.1.3 Problems Within the Steering Control of Power Dispatching

In the preceding section we assess the performance of a multi-functional decision net. In this section, we examine in detail the individual decision process concerning power dispatching.

The power dispatcher is the first line manager in charge of the control and coordination of the power operating cycle which is interdependent upon two sets of tasks. First, all the higher level power cycle's control decisions constitute the decision premises of power dispatcher - either as goals, criteria or constraints of his decision. The train dispatching and maintenance execution are the second set of tasks closely related to the control of power operating cycle, which demand coordination through real-time control effort. Intensive information transmission will take place among the actors involved in the above three operations so as to update their respective decision bases continuously to support their decisions. Given this concept, we shall probe in detail the following issues: 1) How are the far-reaching policy decisions (e.g., service guidelines, if any) actually implemented by the first line power dispatcher, i.e., to what extent, and how the high level policies become a built-in part of the power dispatcher's decision heuristics? 2) How do the decision heuristics of the power dispatcher as well as the information utilized by him influence ultimate power performance?

The approach to the above two problems is to examine 1) the nature

of the formal communication channels which routinely furnish information to the decision base of power dispatcher, as well as the decision triggers which is the mechanism (as an implicit or explicit result of the organization design) that conditions the timing of the power dispatcher's decision; 2) the forces which motivate the dispatcher to request more intensive or extensive information with an aim of making better quality decisions and the availability of such inquiry media. Through such an investigations, we intend to identify the problems presented in the current practices as well as the opportunities for improving the decisions of the power dispatcher.

A. The Decision Base of the Power Dispatcher

Routine Information Receiving Channels and Decision Triggers. Referring to Exhibit 6-2-3, the power dispatcher needs to receive routinely a variety of information which includes train schedules, maintenance schedules, horsepower per ton policies, productivity/utilization standards, service quality standards, power fleet size, home shop list (if any), and power status. Using the data from the host railroad, we can identify the sources for each item of information as shown in Exhibit 7-1-6. One can see that several performance related guidelines are not formally furnished by the system. In fact, the above finding is not surprising, it is merely additional evidence of the lack of a clearly defined performance control system in the host railroad. The major drawback of such an incomplete decision base is that it may respond to effort-oriented pressing issues well, but is insensitive to performance-oriented planning issues.

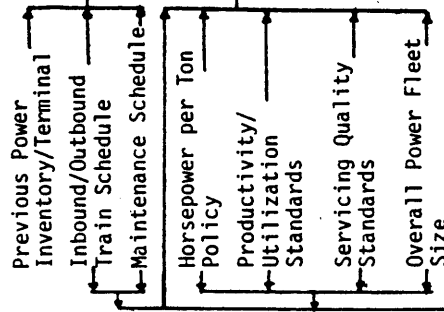
To support the above argument, refer to the general problem solving heuristics summarized from the observation of the power dispatcher given in Exhibit 7-1-7 (a merger of Exhibits 6-2-3 and 6-2-9). Without an explicit time utilization standard, when there is an anticipated power surplus in a certain terminal, "most likely we would choose to do nothing, if there was no obvious shortage anticipated elsewhere" as remarked by a Railroad C's dispatcher. Any deliberate effort to redistribute surplus power is not rewarded by the system, so there is no incentive for the power dispatcher to utilize the surplus. A more subtle reason could be that whether the power pool as an excessive surplus is a judgement based on some estimation of demand; given the high variability of rail operations, the redistribution of surplus power may likely result in a power shortage if the demand level is underestimated. Taking such a disincentive into account, it is unlikely that the power dispatcher will do anything about the oversized power pool. In other words, in terms of the flow chart given in Exhibit 7-1-7, all elements related to the identification and utilization of surplus power will be constantly defaulted. From the railroad's point of view, such a practice: 1) makes the fleet utilization suffer, 2) also loses the opportunity to obtain prompt feedback from the power dispatcher concerning the overage of the fleet particularly during the low seasons, and 3) consequently loses the opportunity to strategically adjust the active power fleet size. As a result, according to one mechanical officer, "The surplus power sometimes may be kicked back and forth across the division lines, when there is not enough room at the dispatch tracks in either division."

Exhibit 7-1-6 ROUTINELY RECEIVED INFORMATION FOR POWER DISPATCHER

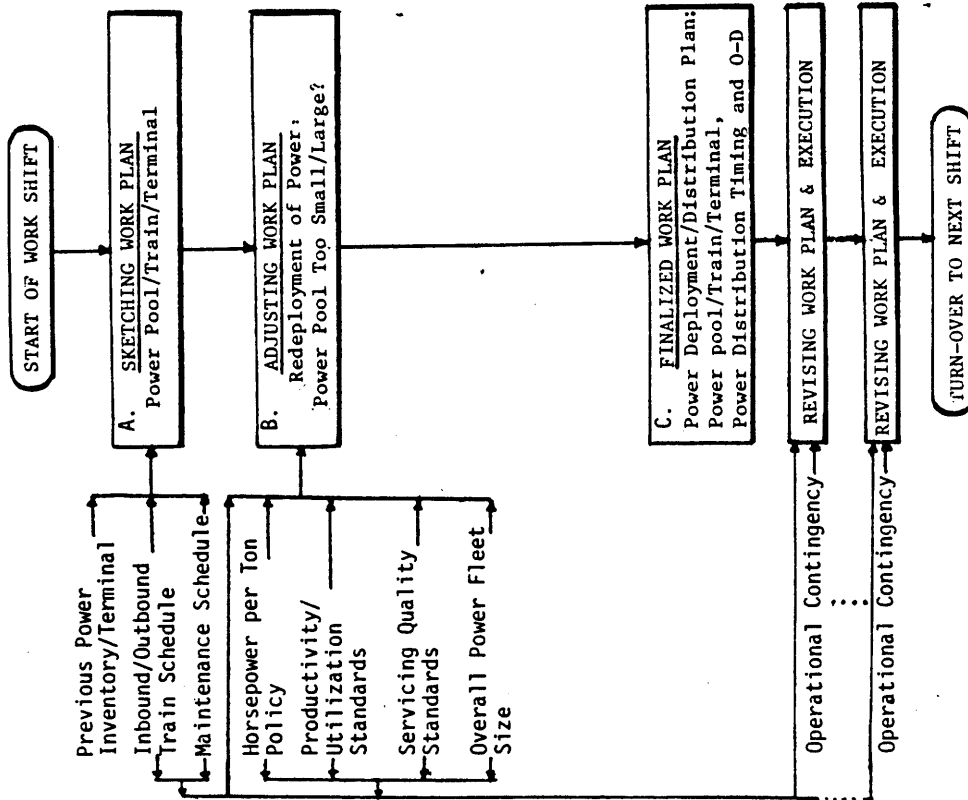
INFORMATION ITEM	SOURCE
TRAIN SCHEDULE	PUBLISHED TIME TABLE; TRAIN ORDER (THROUGH DAILY OPERATING MEETING)
MAINTENANCE SCHEDULE	WEEKLY COMPUTER READOUT
HORSEPOWER PER TON POLICY	(NO FORMAL DOCUMENT)
PRODUCTIVITY/UTILIZATION STANDARDS	(NO FORMAL DOCUMENT)
SERVICE QUALITY STANDARDS	("TRAIN DELAY CAUSED BY POWER" MEASURED, NO FORMAL STANDARDS ESTABLISHED)
POWER FLEET SIZE HOME SHOP LIST	} POWER ROSTER
POWER STATUS	SHIFT TURN-OVER REPORT (POWER CONTROL CENTER) ON-LINE MONITORING CHANNELS

Exhibit 7-1-7 POWER DISPATCHER'S GENERAL DECISION HEURISTICS

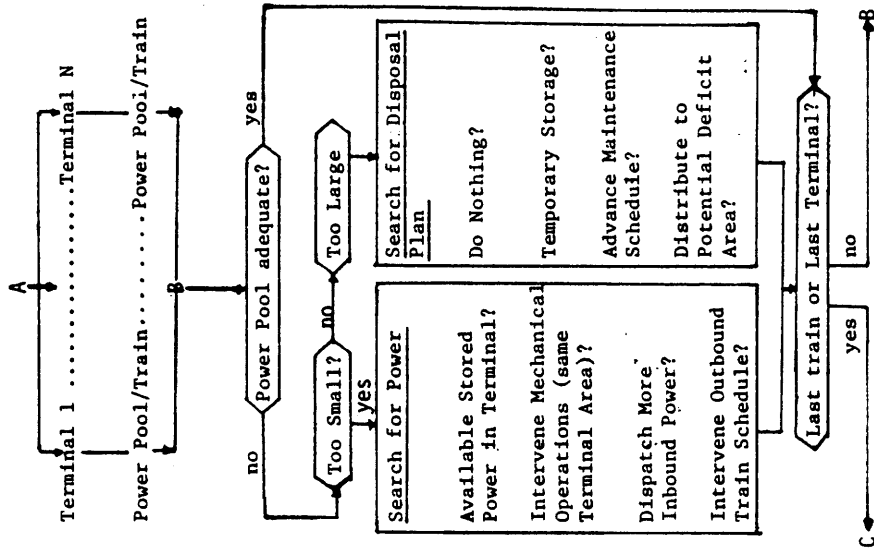
Operative Decision Premises
(Higher level constraints are not included)



General Problem-Solving Framework



Detailed Problem-Solving Heuristics



Motivation and Media for Active Inquiry

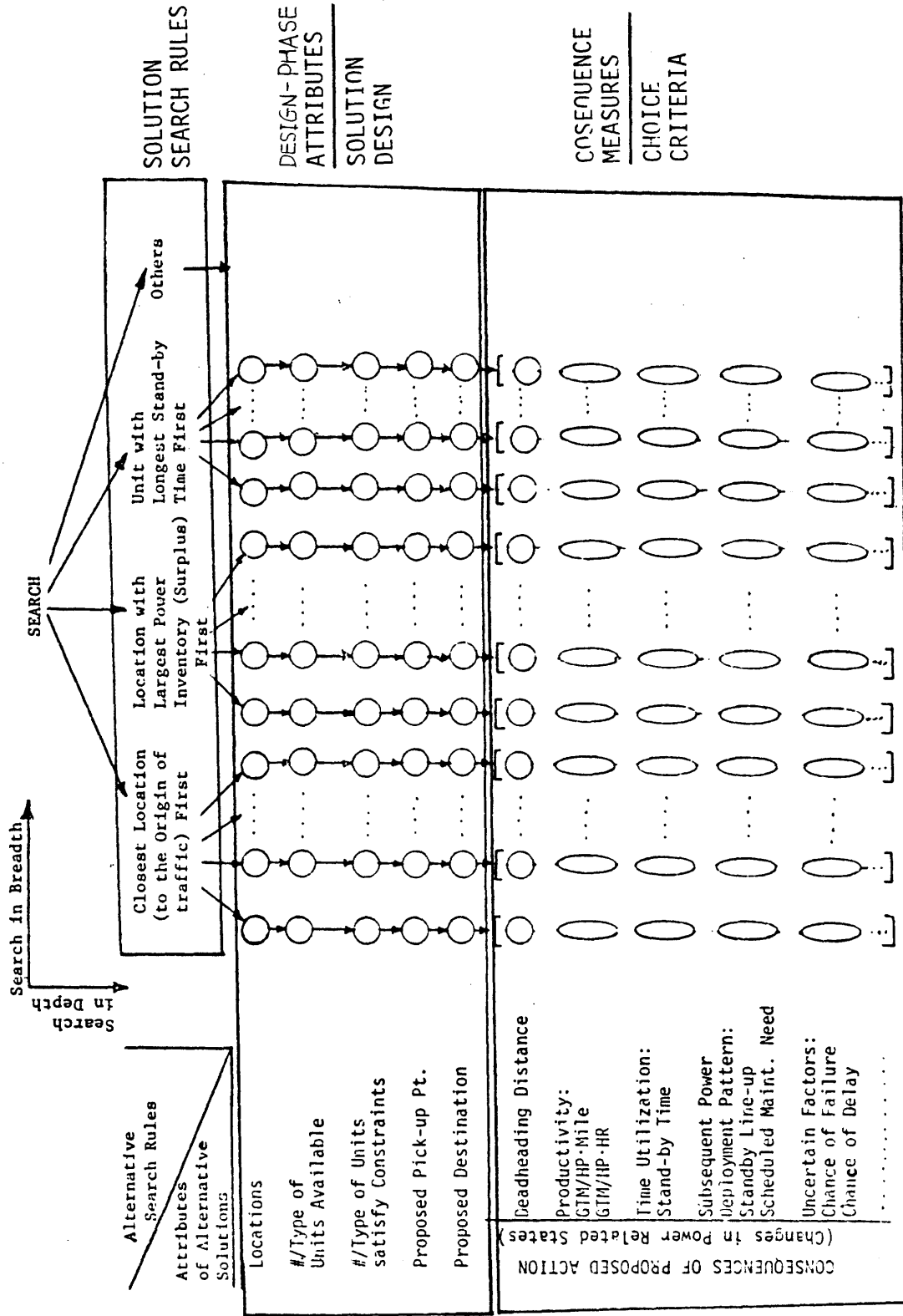
The preceding assessment emphasizes the coverage of the decision heuristics on different categories of the problem. In addition, we should also be concerned with the quality of the decision in a given problem category. To examine this problem, we can systematically probe the search process for extra power as a response either to the need to serve an extra train (as the example given in Chapter 6), or to the need to replenish an undersized power pool identified during the development of the daily working plan.

Search Rule. The choice of search rule is usually implicit and habitual; nevertheless, it determines the subsequent solution space as well as the characteristics of the potential solution. Without any particular control emphasis, a tendency which follows from the discussion with two power dispatchers is to search for extra power primarily through a location-oriented rule, i.e., start from the location which is closest to the deficit terminal. Certainly, in practice, the dispatcher may only consider large terminals and exclude small ones from his choice set. As mentioned in Chapter 6, the final choice is usually the first feasible solution the dispatcher can find. The dilemma here is that such a choice is likely to be a prematured one, while a delicate solution is usually too time-consuming to develop. Because the search for a better solution is a heavy information burden for the dispatcher, and the marginal gain in decision quality may not seem to compensate the loss of timing for decision as well as the cost associated with the extensive search effort, in current practice, it is

conceivable that the timing wins the priority. However, the question to consider is: Is there any possible way to improve the satisficing level of the solution, without reducing the timeliness of the decision through certain deliberately designed information processing aides? Before reaching our conclusion, we shall further examine other critical problems concerning the search process in question.

Evaluation of Solution Attributes. Referring to Exhibit 7-1-8, two sets of attributes to a solution need to be considered in the decision: one is design-phase attributes, the other is the perceived consequences. The former set of attributes is determined largely by the design of the solution. The example of searching for extra power given in Chapter 6 illustrates that many delicate choices may be involved in the solution design phase, e.g., the selection of the host trains, the power pick-up point, the traffic switch point, etc. Therefore, the contents of the design-phase attributes could vary from solution to solution, e.g., a plan could be with or without a traffic switch point. The power dispatcher has to sketch out this set of attributes explicitly. Although some stereotype solutions may be adopted, intensive on-line inquiry as shown in Exhibit 6-2-7 is usually necessary to verify the feasibility of the stereotypes. Moreover, the coordinability also comes into play in this phase of the decision process, and it could significantly affect the quality of the eventual decision. For instance, in a highly coordinated system, a power dispatcher may be able to obtain from the shop in some nearby engine terminal the required units which are not shown as serviceable on the current status board; while in a less coordinated system, a dispatcher may only be able to

Exhibit 7-1-8 DESIGN AND EVALUATION OF POWER DISPATCHING SOLUTIONS



choose surplus units from the existing power pools which could be far away from the deficit terminal.

In short, the quality of the design of a solution is determined by at least two factors: the stereotypes adopted, and the effort of an active inquiry. In many cases, because the design phase is too time- and effort-consuming, the dispatcher simply chooses the first feasible solution and defaults on the subsequent evaluation of the consequences.

Nevertheless, the real issue of concern is not the relationships - e.g., sequential or simultaneous - between design and evaluation practices, but the underlying criteria implied by the choice. Making these criteria explicit enables us to assess the potential bias of the choice. An in-depth analysis of the choice criteria employed by the power dispatchers implicitly or explicitly exposes two issues. First, some dispatchers normally ignore certain criteria which are potentially important to power performance. For instance, one dispatcher emphasized that his priority duty is to maintain a situation in which no train is delayed by power and that he could care less about the power productivity or time utilization. The second issue is related to the calculation capability. In normal conditions, according to his experience, a dispatcher is usually able to predict quite confidently the patterns of power deployment on the network resulting from different dispatching decisions, and to choose the most desirable one accordingly. However, for many non-routine situations, one dispatcher with a rather strong system-sense expressed his uneasiness concerning the relationship of his immediate choice to the subsequent power deployment pattern - he

wondered from time to time, whether his choice was the most desirable one when taking the next few dispatching tasks into account. The thing preventing him from solving the above puzzle was that such a verification usually required an extensive search and comparison of a large number of alternatives. Given the time-pressure and the limited information-processing aid devices - pencil-and-paper and the power status board - it is normally impractical for the power dispatcher to have a try at it.

In Chapter 6, we argued that, due to the lack of appropriate decision-aid devices to support the massive information processing requirement, systematic algorithm is difficult to apply, in the development of daily overall working plans by a power dispatcher who is in charge of a large geographical area involving the movement of several hundred power units. The resulting power performance, in term of time-utilization, is normally low because of high power idle time. The above discussion further indicates that the problem of information overload can also discourage power dispatchers from searching for higher quality decisions because of the difficulty of practicing more sophisticated search-and-choice rules.

B. A Prevailing Myth about the Locomotive Assignment Scheduling

Searching for a better solution to improve power utilization is an old issue faced by rail operations management. Because in theory, the dispatching of power is normally perceived as a routine mechanistic task, rail systems analysts have long intended to develop optimization models to generate locomotive assignment schedules of which the performance, in term of certain specific criteria, is presumed to be better than that of the conventional power dispatchers' intuitive heuristics [*]. However, despite the issue concerning single versus multiple criteria, as well as the problems resulting from the massive computer memory space required by the application of algorithms involved in those optimization models to an ordinary size rail network in practice, one of the most critical difficulties regarding the attempts to use the predetermined optimal power cycling plans in the day-to-day operations is, as reported by a major U. S. railroad after their serious but unsuccessful experiment: "...various factors such as late trains and peak load conditions prevent rigid adherence to the operating plans" [McGauhey, et al, 1975, p. 1-075]. When the cycles broke down, the control center personnel have to reassign power units by following their own heuristics.

Unfortunately, the occasions in which the optimization model fails to function (e.g., the above mentioned late trains and peak loads) are exactly the time when a power dispatcher needs some external

[*] A brief review of articles in this area is given in Mao, et al 1980.

decision-aids the most. The key reason which caused the above experiment [ibid] a failure was that the model builders failed to recognize the applicability of the analytical technique to the context of the problem and failed to undertake a deliberate diagnosis of the real problems before they developed the solution. More specifically, they overlooked the fact that power daily operations are performed in the general frame of the operating document priority system [Chapter 4] which allows the railroad to promptly adjust the plans to the unpredictable operating contingencies. Therefore, without a rigidly followed train schedule and predetermined car scheduling plans, it is impossible to implement any predetermined power cycling plan produced by prescriptive optimization models. Furthermore, in the real-time operating environment, we have shown that the power dispatcher can care less about the optimal power cycle plan in discharging his responsibility. The real issue is how to enhance his decision capability to cope with the operating contingencies.

C. The Need for Decision-Support Systems

The following conclusions can be made concerning the decision behavior of a power dispatcher.

1) Due to the lack of productivity goals, in the host railroad, the power dispatcher's attention is normally focused on pressing and effort-oriented problems - servicing trains and avoiding the responsibility for train delays. Deliberate planning aimed at higher power productivity is not rewarded by the system, and in effect no dispatcher is really concerned about the long power idle time and low achieved W/P ratio. In other words, the dispatcher's decision

heuristics are unbalanced; under the existing organization performance review mechanism, it is difficult to motivate the dispatcher to actively search for better quality decisions which are able to balance both goals of service quality and productivity.

2) Time pressure and massive volumes of information characterize the decision context of the power dispatcher. Information-overload is a critical problem for the power dispatcher. In addition to the existing status display board, certain decision-aid devices, which are able to expand the dispatcher's information-processing capacity, such as computer-based DSS, are essential to the improving the performance of power dispatching task. Those devices should be capable of minimizing premature decisions, advancing the "satisficing level", and facilitating more extensive inquiry into decision-relevant information.

3) Power dispatching, in the rail freight context, is primarily a continual decision process which demands timely input of up-dated information concerning the upstream and downstream processes. The blue-print type predetermined power cycling plan produced by conventional optimization models is normally impractical in the real-time power dispatching process. In other words, the legitimacy of the conventional optimization models must be examined with great care when it is applied to the real-time power dispatching problem. Due to the multi-criteria nature of the problem (and many of those criteria are usually unquantifiable, e.g., implication on coordinability), in principle, a descriptive model - which only presents the nature of the attributes of alternative solutions, and leave the choice to the dispatcher - should be more appropriate to be adopted in the

decision-aid systems for the power dispatcher.

4) To benefit the on-line dispatching decision, the design of computer-based decision support systems must be geared to the nature of the actual heuristic applied by the power dispatchers, as well as tailored to fit the input/output patterns of information flows. However, the merit of decision-support systems is not limited to supporting an existing decision behavior; it can also be designed to offset the potential biases of the current decision heuristics by integrating certain normative elements into the systems which are able to improve and reinforce the decision rationality. More detailed discussion on this issue is given in the next section.

7.1.4. Information Systems of Power Management: Problems and Potentials

According to the dual-system paradigm, information is viewed as essential linkages between the controlled and the controlling systems, as well as among the units in the controlling system, therefore, to improve the three levels performance - organization, team and individual - it is important to assess the strengths and weaknesses of the existing operating-information systems including both the on-line inquiry capacity and the off-line analysis potential.

A. Problems of the Current Systems

The backbone of the operating information systems in the Transportation Department of the host railroad is an on-line

computerized train reporting system capable of providing fairly detailed data on the movements of trains through all terminals in the road. Complementing to the main system is a terminal management information system to take care of the detailed car transactions within each terminal area. In the Mechanical Department, an on-line power maintenance information system has been used since 1969, which provides information concerning each unit's inspection due date and its maintenance history (such as failure record, work being done, etc.) for management at all levels, and accessible by the field officers through a dedicated telex system.

As concluded in the previous section, due to the lack of a clearly specified planning and control framework, the design of these information systems was driven by the available data rather than by the understanding of the decisions to be made. More specifically, those systems in effect are designed to record the transactions for the clerks rather than to extract decision information for the managers. As a result, the volume of data available is expanded but few managers can actually benefit from it because of the already existed information-overload situation. A typical example is the readouts of daily train performance details, both by train symbols and by divisions, as shown in the Appendix of Chapter 6. Each of these reports is usually some 50 pages; and no one in the system is ever able to read them, let alone to use them. Although some summary reports are produced in conjunction with the detailed reports, the essential question is: What are the criteria or guidelines used in producing those summaries? The major problems in this aspect are at least twofold: 1) the summary

indices are usually unbalanced, for instance, the train delay summary (Exhibit 6A-2-D), is the only index that extracted from the train performance details; and 2) most of the aggregated data are too general for any management use, for instance, the summary statistics shown in Exhibit 6A-2-B. As a result, to accomplish their work, managers are normally driven to favor verbal channels, such as telephone inquiry and face-to-face meeting, and to neglect documented sources of information. In many situations, they are likely to be forced to take action superficially based on inadequate and abstract information. A rather astonishing example in this regard is that the SVPO of the host railroad used to believe that they had a problem of power shortage; however, according to our analysis, we found the fact was just the opposite - in their system, the power was normally waiting for the train, rather than the train waiting for the power [Mao and Martland, 1981].

B. Potential Capability of the Existing Systems

From the notion of information-overload, we argue that managers normally suffer from cognitive limitations that restrict the amount of information they can consider in complex decision procedures. Given the potential power of information technology, what the existing computerized information systems have missed is clearly the opportunity to enhance the capacity of human information-processing systems so as to pursue more rational and sophisticated organizational decision-making processes.

To refine the existing systems, we should first investigate what the contents of the systems are and what can potentially be produced. Exhibit 7-1-9 is a summary of the elementary relevant power-operations

source data which are principally available either in the Transportation Department's train reporting systems, or the Mechanical Department's maintenance information systems. The available data bases are rich enough to produce indices concerning all primary components of the power cycle - Exhibit 7-1-10 gives such example. Exhibit 7-1-11 further lists the power performance measure which is able to be generated from the existing systems. It is clear that the existing computerized information systems are capable of supporting a power performance control systems which embodies the concept of power cycle. The key problem left is how management should use these data bases efficiently and effectively in power operations? We shall amplify this issue in the next section.

Exhibit 7-1-9

POWER STATUS VARIABLE SOURCE DATA

● OPERATING CYCLE †

A. Time Based Data - Source: Train Reporting System

- 1) Time Arriving Terminal - Scheduled and Actual
(associated data: train type, number of car loads, O-D mileage, gross-tons)
- 2) [Time Arriving Servicing Area (Time Beginning Servicing)]*
- 3) [Time Finishing Servicing (Time Entering Dispatching Tracks)]*
- 4) Time Called (Time Calling Crew or Time Leaving Dispatching Tracks)
- 5) Time Depart Terminal - Scheduled and Actual

*: not included in the Train Reporting System but available in servicing foreman's working diary

B. Event Based Data - Source: Power Maintenance Information System

- 1) [Fuel Issued or Consumed]
- 2) Other Service Done : [Water, Sand], Oil
- 3) Running Repair Work Done (date, type of work done in code number)

†: Power cycle status(per unit information) could include:

General Information - Engine ID, Class, Current location, maintenance history;
Specific Information - Position in The Consist, Direction (Head Facing).

[]: Data Unavailable or Not Sure Its Availability.

● MAINTENANCE CYCLE

A. Time Based Data (Source: Maintenance Information System)

- 1) Time Arrive Maintenance Shop
(Associated with information of units' due date of scheduled inspection or project)
- 2) [Time Expect to Leave the Shop]
- 3) Time Leave Maintenance Shop (Return to service)

B. Event Based Data

- 1) Tests Done (Oil Sample Taken and Test Results, Oil Change Date)
- 2) Repair Work Done (Engine, Car Body, Trucks, Parts)
- 3) Enroute Malfunction and Location
- 4) [Defects or Critical Symptoms Detected (During Daily Inspection or Scheduled Maintenance)]
- 5) Shopping Reasons (Project, Preventive Maintenance, or Remedial Maintenance)
- 6) Special Status (e.g., awaiting Material)

C. Shop Status

- 1) Material Inventory and Consumed
- 2) [Man-Hour Available / Craft]
- 3) Man-Hour Consumed / craft / unit
- 4) Operating Expense

● SERVICE CYCLE (Source: Train Reporting System, Power Dispatcher's Notes Book)

Time Based Data

- 1) Time Taken Off-line (time leased or stored)
- 2) Time Return to Service

Remark:[] indicates information may not available currently in the formal information system. It normally requires prediction which is not usually done explicitly at shop floor level. However, these pieces of information can be acquired through oral communication.

EXHIBIT 7-1-10 DETENTION COMPONENTS OF POWER CYCLE
AND THEIR TIME MEASUREMENTS

COMPONENTS OF POWER CYCLE
IN TERMS OF TIME

REQUIRED DATA

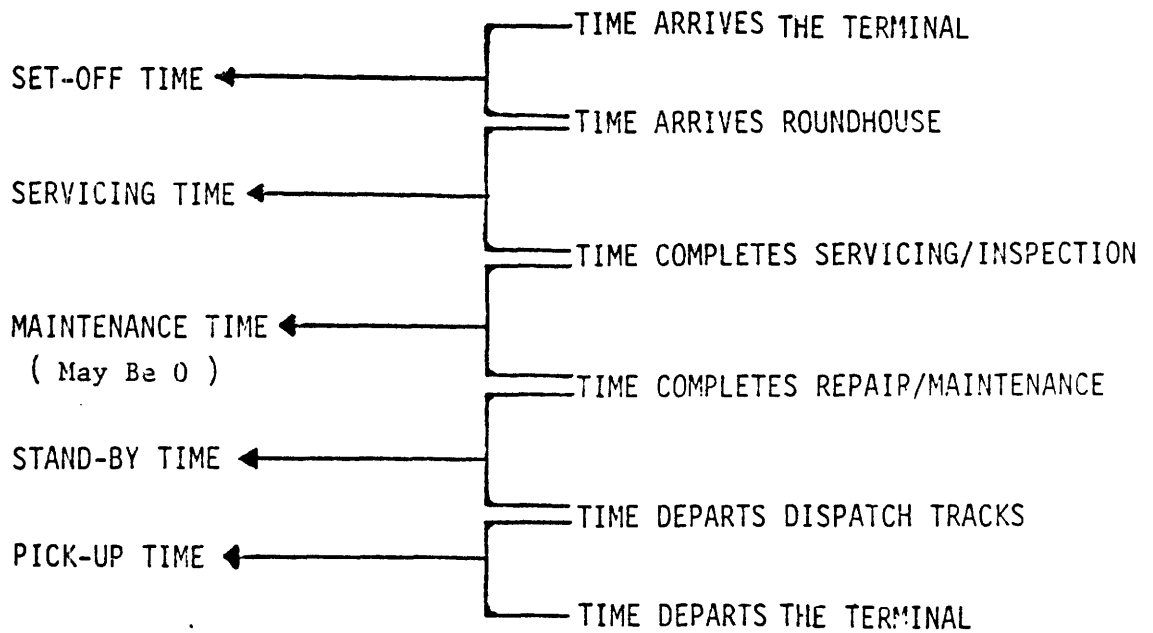


Exhibit 7-1-11 INVENTORY OF POWER PERFORMANCE MEASURES

A. Efficiency Measures --- Power Cycle Based

(1)scope	(2)time interval	(3)measurement	(4)measured events
network-wide		units	off line (storage/lease)
terminal-wise	day	horsepower	out-of-service (maintenance)
fleet type or class	month	unit-hour	available (with servicing)
individual unit		HP-HR	serviceable (w/o servicing)
		% of fleet	utilized (line or yard operation)
		% of time per unit	stand-by (serviceable not used)

*the actual measure used could be any combinations of the elements in the about table---following sequence (1)-(2)-(3)-(4).

B. Service quality

numerator	denominator
train terminal delay amount power	
traffic left behind	
train enroute delay account power [*2]	UNIT HOUR
enroute under power	HP MILE
enroute failure stop	
enroute failure under power	
car cycle time	
yard time	
total transit time	
crew dead-heading [*2]	

*1 could be ratio measure or straight numerator terminal case no. denominator except the unit idle time is used.

*2 no terminal-wide measure

C. Productivity Measures --- Power Cycle Based

numerator	denominator
unit-miles	available HP-HR (or -day)
HP-miles	utilized unit-HR (OR -DAY)
gtn	TOTAL EXPENSE
ntm	
nrtm	

D. Expense

numerator	denominator
fuel cost	unit HR
maintenance labor cost	HP mile
maintenance material cost	
train crew cost	

E. Potentially Capable Off-line Analysis

- o network-wide / district-wise geographical distribution of power:
 - o distribution pattern of power requirement
 - o distribution pattern of power overage/shortage

- o MTRF
- o MTFITF (from inspection to failure)
- o serviceable days/shopping time

7.2. Three Approaches to Improve the Controlling System

7.2.0 An Organization Information-Processing Perspective

Problematic symptoms are merely stimuli that usually direct attention but do not necessarily cause action, therefore to formulate a coherent set of change plans, the nature of the problems must be stated in a way that arouses ideas about the needed corrective actions. The diagnostic assessments given in the above sections - which not only identifies the symptoms of problems concerning the host railroad's power management, but also explains how they have arisen - greatly facilitate the development of change plans.

Due to the complex dynamics involved in the organizational process, effective intervention usually demands multi-dimensional strategies that are capable of creating the desired momentum to bring about an organizational change [Section 3.0; Huse, 1980]. However, in this study, we do not intend to develop comprehensive change plans; instead we choose one particular intervention dimension, namely, the organization information-processing perspective, to demonstrate how to derive the change plans based on the diagnostic results. More specifically, to put the change planning into perspective, our goal is to formulate a set of plans capable of bridging the gaps between the information-processing capacity of the controlling system and the information-processing requirements derived from the nature of the system being controlled.

Based on the concept of problem-conversion, in Chapter 2 we argued that there is a qualitative difference along the vertical dimension of the organization hierarchy in terms of the nature of decisions to be

made. Following this argument, we further infer that no single decision-oriented information system can satisfy the needs of management at all levels. Taking these notions as the premises, in this section we are going to demonstrate how to use the existing formal computerized information systems (train reporting systems and maintenance information systems) as a general data base [Nolan, 1971] to construct three distinctive information-processing systems to bridge the gaps between the information-processing requirements and the existing information-processing capacity in three particular domains of power management: individual decision aid, team process support, and overall meta-control structure. As mentioned at the outset of this chapter, we shall not consider any specific detailed design problems, but will outline the key design considerations.

7.2.1 Power Dispatcher's Decision-Support Systems

As diagnosed in Section 7.1, the problems concerning the power dispatcher's decision are: 1) the potentially unbalanced solution search rules resulting from biased stereotype solutions; 2) the premature choice due to lack of explicit planning and evaluation within allowable decision time frame; and 3) the lack of performance-oriented search and choice activities due to a weak linkage between the organization policies and the choice criteria of the dispatcher's decision heuristics.

To solve the above problems, the basic task is to use the power of computer technology to enhance human information-processing capacity. To do so we should first clarify the respective roles played by human and computer in the decision process of power dispatching.

The Role of the Computer

Power dispatching is a real-time decision, and to support such a decision, not only the availability but also the age of information become critical. According to the General Manager-Terminal Operations, the information in the train reporting systems is less than one hour old; as to the maintenance information system, the information is normally updated on a daily basis as described by the Manager of Information of the Mechanical Department.

In order to support real-time power dispatching, neither of the existing systems can satisfy the requirement for current information. In other words, either 1) the current field data-entry procedures should be revised to meet the dispatching decision needs; or 2) some kind of "man-machine system" should be adopted, e.g, the formal computerized system only finishes the primary information to the decision base of the power dispatcher, and the dispatcher updates it as needed through real-time communication channels.

The major problems associated with the first approach are the amount of capital investment required on the hardware (local data-entry terminals) and the data transmission network, the amount of training necessary for the local personnel to familiarize themselves with the system, the amount of monitoring required to check field respondent's data entries as well as their willingness to complete the needed entries. All these are not easy problems.

The second alternative is in fact very close to the current practice, the key difference being that a dedicated or shared processor is required to handle the operations of a decision support package which

assists the power dispatcher to accomplish the following functions: 1) generate the daily working plan, 2) adjust and finalize the working plan, and 3) generate contingency plans as needed. More specifically, such a program should at least include the following modules (model bases, see Section 2.2.3):

1) a power pool development routine represented by the flow diagram shown in Exhibit 6-2-10, which can estimate the power pool for each outbound train at each terminal for a particular work shift; any pool which is too small or too large as compared with certain standard should be automatically flagged to indicate the need for adjustment,

2) an interactive search routine which can display design-phase attributes as well as the key consequences of available alternatives generated from a variety of search rules (Exhibit 6-2-11 provides such an image). This routine will be used for the adjustment of the daily working plan to indicate the need for power redistribution and for the generation of contingency plans to serve unexpected traffic. The most important design guideline in this regard is to build in some normative elements so as to balance the potentially biased search rules as well as the normally overlooked choice criteria.

In short, taking the advantage of well-structured nature of the power dispatching decision, the potential of the computer information-processing capacity can be well exploited through a deliberate modeling effort to translate the power dispatcher's decision heuristics into computer programs to enhance his decision-making capacity. Moreover, the design of decision-support systems can effectively embody the desired ends into the available means and offset

the potential decision biases.

The Human Role

Given a computerized decision-support environment like the one described above, the power dispatcher primarily plays two roles: 1) making the choice in each search process, and 2) furnishing updated information into the system. To facilitate the conduct of the second task - furnishing updated information - one additional module (a data base with dialog interface) should be included in the decision-support systems, namely, an inquiry routine capable of displaying the relevant data as well as their age. Then it is at the dispatcher's disposal regarding whether a particular data should be updated.

It is important to note that the power status data in such an inquiry routine is nothing but a computerized version of the magnetic display board. Therefore, the adoption of a computerized display system causes minimum change in the dispatcher's general operating procedure, i.e., instead of removing the chips on the magnetic board or updating the record on his notes book, the dispatcher keys in an entry into the computer. However, the advantage to have computerized decision-support systems (in which the display program is a part) is vital. Most importantly it allows the dispatcher to be released from the burden of information overload and enables him to spend more time and energy in planning and coordination activities with longer time horizon and larger geographical space that could seldom be concerned in the past. Moreover, because well designed DSS can explicitly display the predicted consequences of alternative actions as well as indicate trade-offs among alternatives to an extent which can never be done by the ordinary human

mind in the same time frame, more innovative plans can be explored and new insights could obtain. The above effects collectively will lead to the improvement of the power dispatcher's decision quality.

Performance Review

The installation of the DSS with the above described features should significantly improve the capacity as well as the quality of the power dispatcher's decision. Nevertheless, to completely support the power dispatching function, one more element must be integrated into the systems, that is a feedback component which allows the dispatcher and his supervisor, the General Superintendent-Locomotive Distribution, to review the performance of the power operating cycle.

As illustrated in the preceding section, the existing information systems are capable of generating a fairly comprehensive array of performance indices including both measures of power productivity and service quality (Exhibit 7-1-11). Therefore, to build a feedback function into the proposed decision-support systems is to design an inquiry module associated with the historical performance data base which enables the dispatcher to trace the actual consequences of his decision, and possibly to make self-correction through learning process. As to the Power General Superintendent, he concerns with the average power performance over a period but not the decision by decision performance, thus he should have the access to certain inquiry packages able to generate periodical performance measures and ideally also able to do some analyses, e.g., the trade-offs of productivity and service quality implied by different dispatching patterns. Based on this knowledge, he can give solid guidance to the power dispatchers and

better control over their performance.

To conclude, we should recognize that no matter how deliberately the decision-support systems are designed for the power dispatcher, there is a limit that the systems can do about the control of power performance, because what the Power Dispatching Center can control is only a subset of the factors which determine the overall performance of power operations. To really put power performance under control, the power dispatchers have to intervene in other mutually dependent operations (to coordinate the "uncontrollables") or to change the general operating premises (to change goals, criteria and operating plans). These are the issues discussed in detail in the following subsections.

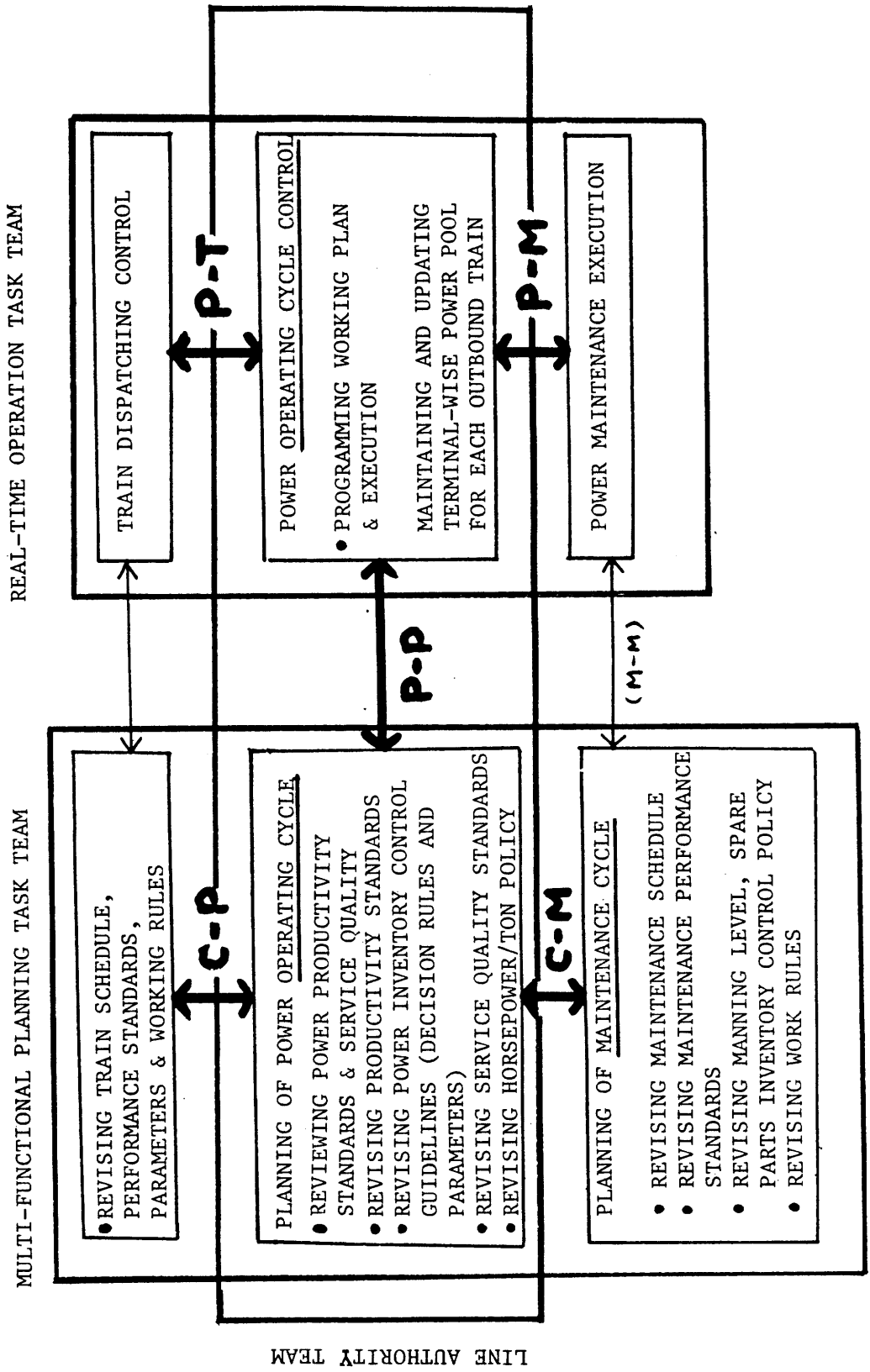
7.2.2 Multi-Functional Team-Support Systems

Power operations are multi-functional activities. Centered around the task of real-time power dispatching, there are at least three interwoven decision-nets surrounding three task teams [Exhibit 7-2-1]. The first has already been discussed, i.e., the line-authority team consisting of power dispatchers and the Power General Superintendent (the P-P link in Exhibit 7-2-1). The second may be called a real-time operations task team which comprises the power control center, the train dispatching center and field mechanical officers (the P-M, P-T links). The third is the team that is in charge of the coordination of multi-functional planning, which includes officers holding line or staff positions from the Transportation, Mechanical and Marketing Departments (the C-M, C-P links). We should note that the first two teams are easily identifiable in the existing organization of the host railroad, while the third team is a novel one to take care of the currently poor planning function. The purpose of this subsection is to illustrate how to design proper mechanisms to enhance the coordinability of each task team. We call these mechanisms the team-support systems [Section 2.2.2].

To facilitate our discussion, by using the Task-Actor Matrix technique, a diagram can be constructed which indicates the ideal control and coordination structure for each of the above tasks as well as the desired interrelationships among the actors (Exhibit 7-2-2). The loops shown in the diagram correspond to the heavy arrows shown in Exhibit 7-2-1. Their implications are amplified below.

Line-Authority Team

Exhibit 7-2-1 THREE TASK-TEAMS INVOLVED IN POWER MANAGEMENT

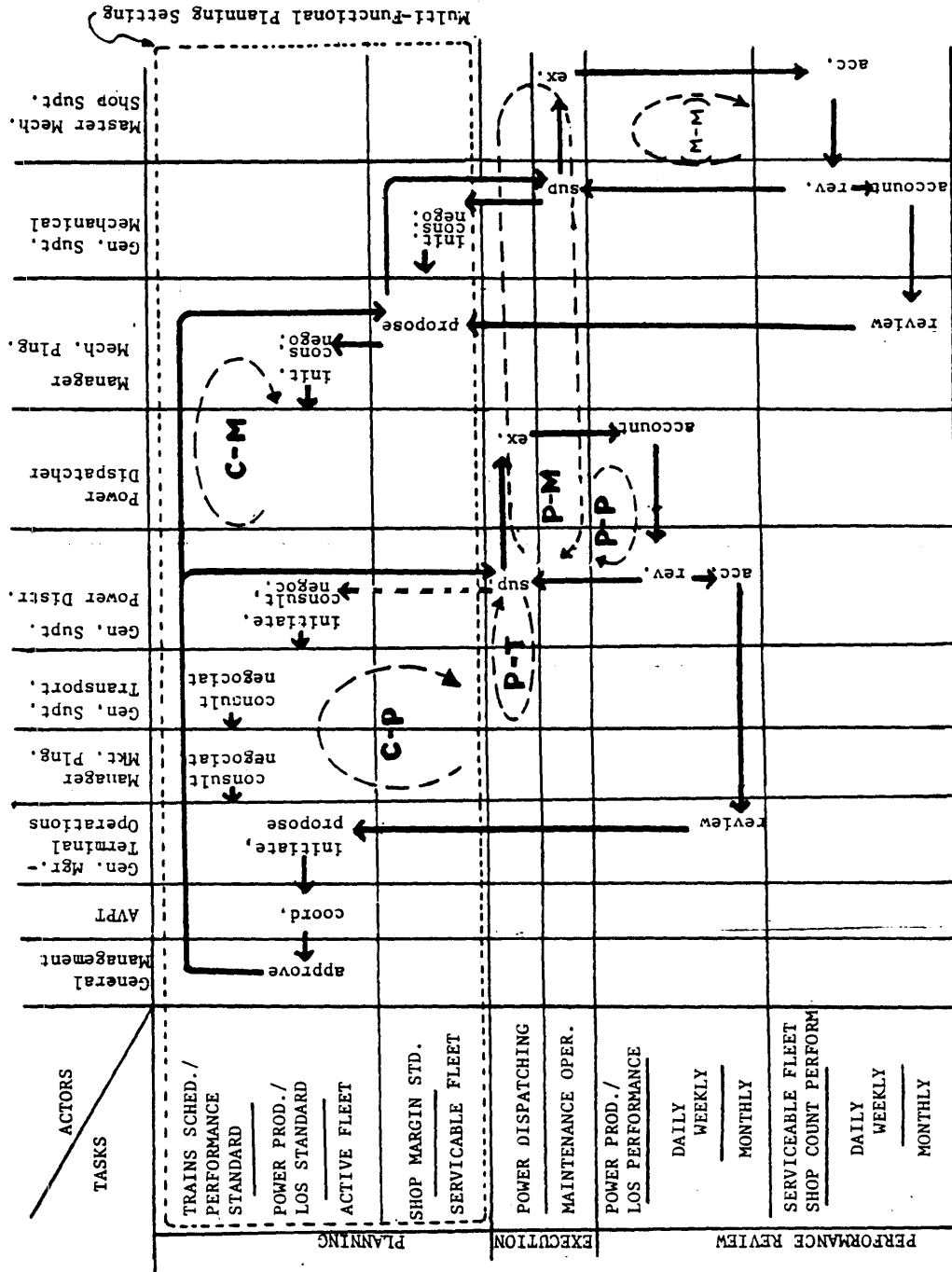


The ideal control procedure for this team is indicated by the P-P loop in Exhibit 7-2-2. The essential media to support this team's activities are the power dispatcher's decision-support systems and the performance inquiry analysis package (i.e., his DSS) used by the Power Superintendent. In this team, the dispatchers are accountable for the short-term power performance; they use the DSS to assist them to effectively and efficiently choose the dispatching patterns which satisfy the criteria imposed by their supervisors. Since the power superintendent is responsible for long-term performance, he uses his inquiry/analysis package to control the dispatchers' performance. It is important to note that one critical role for the superintendent is to identify when the structure or the built-in parameters of the dispatchers' DSS should be revised. This means that, in time of change, certain decision rules (such as power assignment rule, weights for different consequence measures) should be revised to maintain a desirable level of performance. In case the required modification is beyond Power Superintendent's allowable discretion range, then he should flag the need for change of higher level decision as indicated by the vertical dot line shown in the Exhibit 7-2-2. By and large, the process involved for this team is relatively straightforward.

There is a mechanical counterpart line-authority team and its process is shown by loop M-M. Since the issues concerning the design of an individual DSS, the team support media, as well as the functioning procedures are, in principle, the same as those involved in the power group, we shall not discuss them in detail here.

Real-Time Operations Team

Exhibit 7-2-2 THE FUNCTIONING OF POWER MANAGEMENT TASK-TEAMS



Two processes are involved in this team's activity: one is the power group to train dispatchers (as indicated by the P-T loop in Exhibit 7-2-2), the other is the power group to mechanical officers (the P-M loop). In the following discussion, we take the second process as an example.

In the earlier part of this study, we mentioned that the power dispatcher may make deals, implicitly or explicitly, with the servicing foreman in order to acquire the needed serviceable power. In this regard, the critical factor for success is basically communicational, i.e., channels for easy and friendly communication should be available. However, the real leverage of this team's activity does not solely lie in the above microscopic interaction. A more significant power performance improvement which can be achieved in the real-time operation is through the deliberate coordination between the two groups to reschedule the engine shopping time during the week, as reported by one mechanical officer of a railroad:

"We will particularly aim early in the week; which is our light period, to get as many units in as possible. We will have a large force to accommodate the greater number of units. As we reach our peak usage period toward the end of the week, our changing needs are taken up by the difference in number of relief people. We will handle 10-15% more when the through demand is down, and our own capabilities are geared up to accordingly." [RSMA, p.82]

By following the above practice, both goals of transportation (high power availability to serve surge demand) and mechanical (even shop workload) can be attained. To effectively implement this strategy in the host railroad, the Power General Superintendent and the Mechanical General Superintendent should work closely. Certain computerized systems (DSS) can be designed for the mechanical GS which is capable to

display the existing shop conditions across the system and predict workload under various rescheduling plans. As to the power GS's DSS, in addition to the inquiry/analysis package (used for performance evaluation) mentioned before, one more module should be designed and integrated to enable him to predict at least the weekly power demand pattern. Given these two respective DSSs, two general superintendents can then talk, in solid terms, on how to shop engines most efficiently.

Multi-Functional Planning Team

Real-time operations are performed within a framework determined by higher level planning decisions which define their ends (goals, standards, criteria) and their means (plans, policies, schedules). Following the principle of the operating document priority system, although the discretion range of real-time operations is relatively large, the allowable adjustments still have their limits. How to devise a mechanism to identify: 1) when such limits have been reached and 2) how to design a procedure to trigger and accomplish the needed replanning accordingly, are the two issues vital to the viability of rail operations. In the power management context, due to the highly multi-functional nature of the operations, a large group of rail officers from various departments should be involved in taking care of these two issues.

Triggers for Replanning. The railroad should explicitly define a set of performance indices (such as those suggested in Exhibit 7-1-11) which reflect the rationality of the system. Second, the standards for these performance measures should be reasonably assigned (available tools to

establish these standards will be discussed later). Third, the performance accountability and reviewing responsibility should be allocated to specific personnel such as shown in Exhibit 7-2-2.

Given the above conditions, taking the power active-fleet sizing as an example, there are at least four ways to trigger the replanning process: two are through the planning staff and the other two are through the operating officers as shown in Exhibit 7-2-2. The advantages of having a set of multiple process triggers are as follows: because the operating officers are responsible for accomplishment the standards, in case the performance is below the standard, they are expected to initiate replanning, either to lower the standard or to revise the operating plan so as to bring the situation back into control. The planning officers are responsible for pursuing higher level performance; if opportunities for better performance are identified through the review process, they are expected to initiate replanning, either to develop a better plan or to set higher performance standards. Therefore, to devise the replanning triggers in both line and staff units, a balance between the reactive and proactive forces, which drive the replanning activities, can be achieved. Moreover, from departmental perspective, due to the conflicting interests concerning power performance (e.g, mechanical personnel prefer to having a larger shop-margin standard, while transportation personnel normally prefer higher fleet availability), some balance can also be attained - in terms of the emphasis of the plans - due to the functioning of the replanning triggers in both departments.

Media of Replanning. In multi-functional operations such as the power

management, the causality of the underlying physical processes is very complex. To facilitate coordination and to provide a solid base for communication, certain models which are able to produce objective projections concerning the consequences of alternative actions are necessary. A good example in this regard is the case of the MIT Service/Planning Model (SPM) [McCarren and Martland, 1980]. The design philosophy of that model is based on a theory that the legitimate process for formulating a rail operating plan (including blocking strategy and train schedules) should be a collective decision process participated by all the concerned departments (Transportation, Marketing, Labor, and Mechanical) and by both line and staff personnel. The model is used to generate certain quantitative indices concerning the consequences of different proposals to facilitate further discussion and refinement of plans. In fact, any model with the above nature can serve as an ideal medium for multi-functional planning.

Therefore, it is desirable to develop a power operations planning model by following the same design principle as applied to the MIT-SPM. The model should have sufficient detail to address all the major issues, and have the prediction capability to generate reasonable performance indices. Given such a model, the railroad should then institutionalize a multi-functional planning process with the participants (as minimum) and their roles as indicated in Exhibit 7-2-2. The alternative proposals formulated through such a process serve as input to the power operations planning model, and the output from the model are used to guide further refinements of the proposals until some non-inferior plans are crystalized. Those plans are then recommended to senior management

for final choice and approval. In such a planning process, the AVPT should act as a coordinator and the General Manager-Terminal Operations as the technical supporter to operate the model.

Within the above planning framework, maintenance planning is a sub-process which can operate separately but interactively to provide either input (shop margin constraint) to or receive output (shop margin standard) from the main process, depending on how we initiate the process. Because the active fleet size is, in principle, geared to the traffic level, following this planning process, the serviceable fleet can also be geared to the general transportation requirements.

To illustrate, let us assume the railroad adopts a two-mode operating strategy - one is for peak seasons, the other is for non-peaks - and the planning issues are: 1) When to shift from one mode to another, and 2) Which part of the operating plans should be revised and how. As discussed earlier in this study, facing the coming of the lower season, the mechanical officers may propose to raise the shop margin level, i.e., to shrink the serviceable fleet, to enable them to have a longer time to perform heavy repairs or to give their crew time for vacations, while the exact timing for change and the change extent are determined by the collective decision process proposed above.

In conclusion, following Cyert and March's argument [1963, p.119], different units in an organization usually can work together to deal with the pressing issue well but not with longer-run strategies. To overcome this drawback, a creditable model, which is capable of addressing the multi-functional issues and creating certain desired feedback-react environment, could be an effective facilitator for the

communication and coordination of the multi-functional planning. Of course to make such a model a really sensible tool to the organization, some institutional arrangements discussed earlier in this section must be carried out. Only by doing so can the higher level planning and the day-in-day-out operations be integrated as a whole, and a more responsive operations management pattern be presumed.

7.2.3 The General Meta-Control Structure

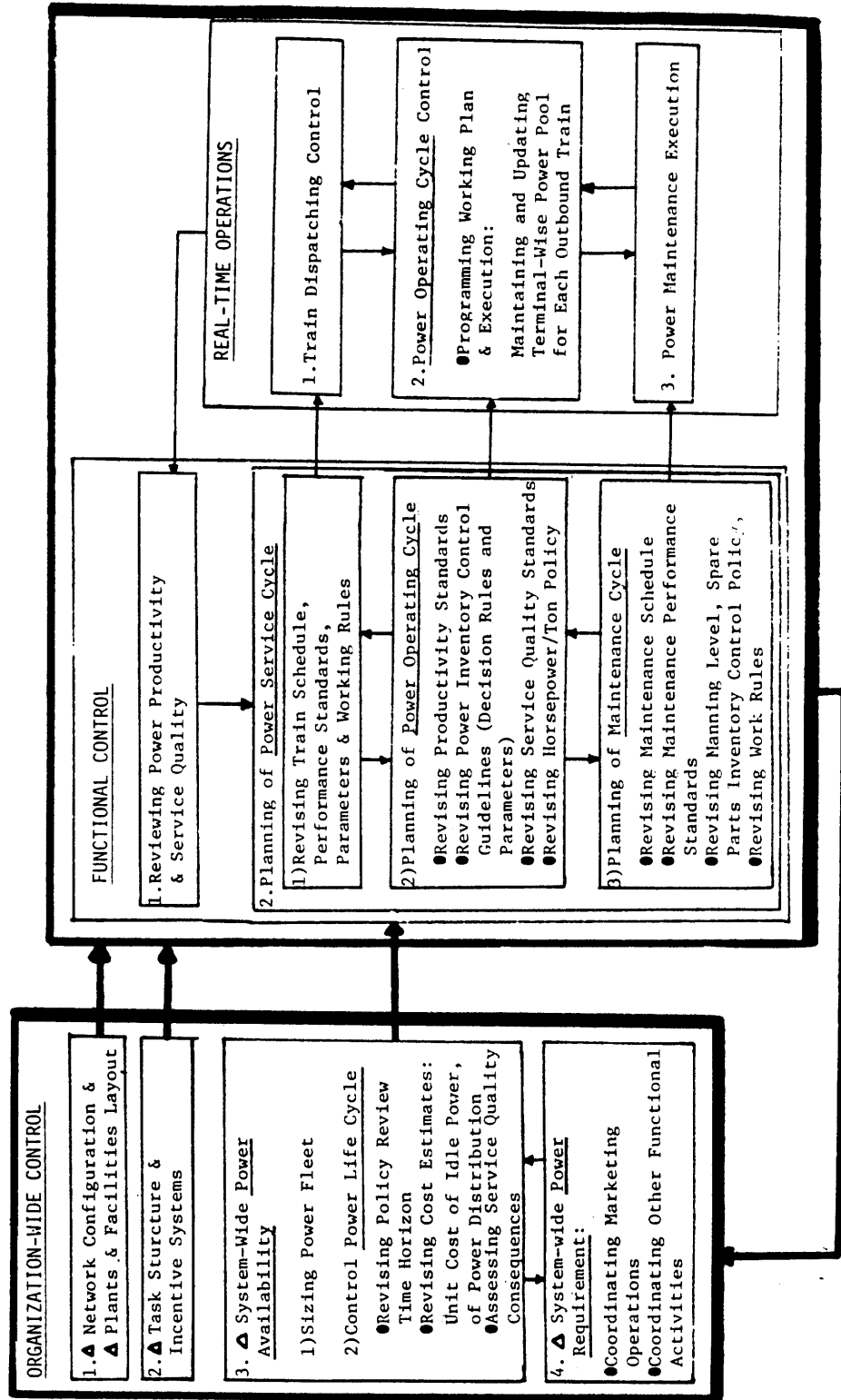
Developing An Explicit Meta-Control Framework

Alfred Chandler used to say [1962, p.19]:

The failure to develop a new internal structure, like the failure to respond to new external opportunities and needs, was a consequences of overconcentration on operational activities by the executives responsible for the destiny of their enterprise, or from their inability, because of past training and education and present position, to develop an entrepreneurial outlook.

To avoid the above pitfall, we suggest the controlling mechanisms outlined in the previous two sections should function within an organization-wide meta-control framework which takes care of the organizational strategic planning. By imposing a meta-control block over the functional and steering control tasks (the later two have been discussed in the previous section (7.2.2), Exhibit 7-2-3 depicts in part the image of such a framework (only the part relevant to the power management is shown). In short, at this (meta-control) level, the infrastructure, the task controlling structure and incentive system, fleet ownership, operating economic and financial goals, as well as the market and service orientation, should all be treated as variables - they are subject to change in the organizational strategic planning process. In other words, the Exhibit represents a conceptual framework which the senior managers have to bear in mind for appropriately discharging their power management responsibility. Hereafter, the discussion is based on a premise which assumes the existence of a general strategic planning process, and our focus is then on how to design the power component within such a process and how to make it function.

Exhibit 7-2-3 POWER MANAGEMENT STRUCTURE - META-CONTROL AND LOWER LEVEL CONTROL



Meta-Control in Action

The highest organization unit responsible for power operations management is the office of Senior Vice-President-Operations. This unit may concentrate its attention principally on two areas. One is the shifting demand resulting from changes in marketing or financial strategies, the other is the analysis of the internal capacity and the derivation of the managerial emphasis for the next operating period. Let us take the latter area as an example to elaborate on the desired functioning pattern.

The SVPO alone cannot handle the above function. He must be supported by certain staff which serves as a think-tank. The major task of this staff unit is to do certain off-line analysis [Section 2.1.2], which distills intelligence from the massive information generated from the operating information systems for the SVPO. In this sense, the documents generated by the existing formal reporting system shown in the Appendix of Chapter 6 are far too superficial and difficult to be used by the SVPO. What the SVPO needs in his decision-base is not some straightforward summary or aggregation from the on-line operating information systems, but a set of off-line analysis results which provide insights into the strengths and weaknesses of both the current operating strategies and managerial practices. Therefore, the staff unit should strive for a clear conceptualization regarding the functioning of the total power operations management system, as well as to seek operational approaches to uncover problems and opportunities implied by current practices.

Following the above line of thought, we argue that the analysis contained in Chapter 4 of this study represents the first step - which attempts to clarify the nature of the underlying power operating process as well as the characteristics of the managerial tasks that the staff unit in question should accomplish. Moreover, the Service Impact Model illustrated in that chapter also stands for a typical analysis required at this level. That model not only enables the SVPO to put a set of complicated policies into perspective, but also allows him to asking further questions. For instance: Is 40% time utilization the upper limit the system can achieve? What are other railroads' performance concerning this measure? What is the cost implication of this performance level? Is there any organization change needed to improve this area's performance? Is it worth doing?

In short, the kind of analyses that should be conducted at the SVPO level cannot be well-defined. However, a clear overall conceptual framework such as the one shown in Exhibit 7-2-3 should be a necessary premise. Given such a framework, some analyses concerning certain fundamental performance indices, such as power productivity, unit power operating cost, etc. could be standardized (they should be presented in terms of general trend and compared with the competing carriers' performance), while many other analyses may have to be carried out as special projects. The key is that all these endeavors be driven from a motivation to actively search for a higher level of performance. To create such an atmosphere is the critical challenge faced by the SVPO; however, the achievement of fruitful results is dependent on the qualification of the staff unit and its competence in selecting the

right tools to analyze the problems handed down from the SVPO, or to ask the right self-motivated questions and to crystallize practical recommendations.

Summary

In response to the symptoms and the underlying causes diagnosed in the power management arena of the host railroad, we have chosen the refinement of the organization's information-processing systems (IPS) for demonstration purposes, as the intervention dimension for formulating the needed change plans. However, as evidenced by the preceding discussion, our definition of IPS is rather broad - the necessary elements concerning the structure and process of the organization are also covered. Section 7.2.1 through 7.2.3 were dedicated, respectively, to the description of three different sets of information-processing systems which cover 1) the system to support well-structured individual operating decision, 2) the systems to support group decisions with various scales and different time-horizons, and 3) the system to support organization-wide unstructured strategic decisions.

We will also illustrate the interdependence between various information processing systems. Basically, the proper functioning of the higher level systems are relied on the proper functioning of the lower level systems—higher level systems are primarily embodied in the lower level system. On the other hand, higher level systems provide contexts within which the lower level systems perform.

To amplify on the above statement, considering the relationship between the mechanisms of meta-control and functional control, without

an explicitly assigned task responsibility and performance accountability, the functional level controlling mechanism (planning-execution-performance review cycle) can hardly perform and the decision authorities have no way of being delegated from above. In effect, senior management will be trapped into monitoring the on-line operations and as a result having little energy to take care of more important strategic issues which is the situation the host system is facing.

However, given a multi-level information-processing systems proposed by this study, senior management to resume its meta-control role and through the following two channels to control the functional level activities: one is the power of approval or veto of the functional plans, the other is its inherent capacity to restructure the lower levels' structure and precedures. In other words, the meta-control level holds another trigger of functional level's replanning; this trigger is not only able to initiate a change in the operating plan and performance standards, but also changes the framework of planning as well as the roles of involved actors.

In our proposed Power Meta-Control Structure, the SVPO is the person who provides the ultimate buffer function between a shifting marketing demand and power operations. There are two intelligence networks he should develop: one is outward linkages to the Financial and Marketing Department as well as the external markets, the other is inward-oriented linkages to the key internal performance areas (the required nature for the latter network has been discussed to some details in Section 7.2.3). The key message which the SVPO seeks from

both networks is the signal indicating a demand for change. However, after receiving such a signal, in addition to the need for developing a plan which can satisfy the required change, the eventual challenge the SVPO has to face is how to implement the proposed plan so as to achieve the benefit of the change (e.g., improved operating effectiveness), but meanwhile to minimize the potential turbulence resulting from the change which is usually devastating to operating efficiency, at least at the beginning of the change process.

Chapter 8

CONCLUSIONS AND RECOMMENDATIONS

This study is devoted to the development of a coherent theory which fits the nature of transportation operations management. A dual-system control paradigm is postulated. According to this paradigm, a transportation operations management system is conceived of as a control system which consists of two complementary parts: 1) the controlling sub-system - the organizational aspect of the system which possesses the controlling capacity, and 2) the sub-system being controlled - the technological aspect of the system which defines the tasks to be controlled and their interrelationships. The performance of the total system is then determined by how well the controlling capacity is matched with the characteristics of the underlying controlled tasks.

The key theme of this study is the development of theories and operational methodologies which collectively enable us to 1) understand and describe the nature of both the controlling and the controlled systems in the context of transportation operations management, 2) diagnose and analyze the strengths and weaknesses, and problems of the total system, and 3) identify desired directions of change and develop alternative change plans for improving the performance of the total transportation operations management systems.

To test the theories and the methodologies developed in this study, the management of the operations of railroad motive power - locomotives (yard switchers are not included in the study) - is adopted as an empirical case. The data are collected from three major U. S.

railroads.

8.1 Conclusions

8.1.1 Theories and Methodologies

A. The System Being Controlled

Theory. The key theme in analyzing the system being controlled is to conceptualize the physical transportation process and to identify of the tasks to be controlled. The analytical framework for the controlled system is developed from the notion of resource cycle which consists of a set of distinct status or time phases - interrelated by the natural order of transportation operations - of a particular resource used in the delivery of transportation service.

The resource cycle framework highlights the cyclic nature of transportation work flows and the systemic mutual-dependence among various core operations and operational buffers. Such a framework not only provides the analysis with perspective, but also with effective heuristics in deriving the hierarchy of control tasks along a particular resource dimension as well as the control issues concerning other interacting resources' cycles. The linkages between the controlled and the controlling systems are established through the identification of the controlled system's work units which are assignable (in terms of task authority or accountability) to organization units (individual or group of individuals) in the controlling system.

Methodologies. The notions of resource cycle and control task are operationalized through the following procedures: 1) translate work flow

into cycles of key resources, 2) break down the resource cycle into components, 3) identify the hierarchical and horizontal mutual-dependence among the components of the resource cycle, and 4) construct the control task hierarchy through the identification of the managerial tasks involved in the planning, execution and performance review for each component of the resource cycle.

B. The Controlling System

Theory. The controlling system in this study is analyzed from three different perspectives. The first views the system as a whole, i.e., an organization is conceived of as a three-level problem-conversion mechanism. The bottom level controls the physical process, operates in a well-buffered closed system and pursues production efficiency; the top level responds to the external environment, determines the systemic structure, and seeks organizational effectiveness; the middle level mediates between the two extremes, provides the necessary buffers for the lower level operations as well as the needed flexibility for higher level adaptation. In a properly functioning organization, there should be at least three major types of control cycles - steering control, functional control and meta-control. Any failure of the above control cycles indicates malfunction of the controlling system.

The second perspective emphasizes the organizational decision-making processes. In the transportation operating context, decision-making is usually a team process. The actors involved in the process constitute a decision net of which the configurations are determined by the mutual-dependence of the underlying control tasks. In

such a decision environment, because the individual decision-maker must acquire information from and transmit his decision to other decision-makers, communication and coordination are essential to the quality of the interrelated decisions as well as to the behavior of the controlling system. A well-functioning task team must be supported by proper communication media and an adequate basis of mutual-influence.

The third perspective concerns with individual decision-making behavior. The notion of human information-processing systems (HIPS) is applied. Two issues of particular interest are 1) the problems resulting from limited human cognitive capacity, e.g., information-overload and bounded rationality, and 2) potential biases of individual decision heuristics. The design of an external-aid system must thus aim at enhancing the HIPS with the power of information-processing technology, i.e., 1) expanding the individual's cognitive capacity and breaking through his rationality bound, as well as 2) detecting and offsetting the potential biases of the individual's decision heuristics.

Methodologies. Operational procedures and techniques are developed in this study to support the diagnosis of the controlling performance from each of the above three perspectives. The techniques suggested for examining the general linkages between the dual systems lead to the construction of a task-actor matrix which displays the relationships between the control tasks and the authority / accountability of the organization units. Inadequate linkages are explicated through such an analysis.

The diagnosis of team-based decision behavior is conducted through the analyses of communication locus and the decision bases of individual

actors involved in the process. These analyses allow us to examine the adequacy of the support for the process of coordination, the availability of a mutual influence basis and the effects of means- / ends-control.

Decision heuristics are the focus in the diagnosis of individual decision behavior. Protocol analysis and introspection analysis are two alternative techniques. The key theme is to specify the requirements of external aid systems capable of improving individual decision quality.

C. Summary

The research is conducted within an organization intervention framework in which substantive theories guide the information search, furnish a coherent construct for organizing the diagnostic data, identifying strengths and weaknesses, as well as for developing improvement plans; while the methodologies provide operational strategies and specific techniques for collecting and documenting the diagnostic data. To achieve the aim of improving the performance of the total system, there are at least three interrelated approaches: 1) refining the general task management structure, 2) devising or improving multi-functional team support systems, and 3) installing or improving individual decision support systems.

8.1.2 The Power Management Case Study

Chapters 4 through 7 of this study are concerning with the application of the dual-system theories, and the diagnosis and analysis methodologies to the context of rail motive power operations management. The analysis is conducted progressively from macro-level issues to micro-level issues. The findings are concluded as follows.

A. Acquisition of Diagnostic Information

To obtain a general picture of the nature of the overall task, in Chapter 4, on the controlled system side, the resource cycle concept is applied to the development of the power cycle hierarchy. The control task hierarchy of power management is identified through the construction of a power cycle vs. management cycle matrix. On the controlling system side, relevant organization units are identified through the analysis of the organizational chart, job description and formal reporting systems. A task-actor matrix is documented to show the relationships between the organization units and control tasks. The interplay between the freight car flow and power flow is presented to demonstrate the potential of augmenting the power cycle framework to address non-power issues.

Chapter 5 is devoted to the diagnosis of the power maintenance function and its coordination with the transportation function. The causality between the maintenance module and the general power operations is examined. Communication locus analysis is conducted to investigate the settings and the processes of coordination between the maintenance and transportation operations.

In Chapter 6, the context of steering control of power dispatching is the focus. Determinants of linehaul operations and terminal operations are examined through the development of the causal diagram and decision flow diagram. Communication locus analysis is conducted to examine the nature of the daily operating conference, and the power dispatching processes (including both the routine procedures and the emergency handling procedures). The decision basis for each key actor engaged in the power dispatching decision-net is explicated. Introspection analysis is conducted to document the power dispatcher's decision heuristics.

B. Problems with Power Operations Management on the Host Railroad

From the above descriptive and analytical data, various symptoms are identified in the current practices of power operations management on the host railroad system. They are summarized as follows.

1) Inadequacy of Planning Support and Absence of Effective Control Cycles

From the general task management structure represented by the task-actor matrix, a number of problematic symptoms were found in the planning- and review-phase's control tasks. In summary, a) effort-oriented control rather than result-oriented control consumed the management's energy, b) planning was an implicit process and consequently higher level accountabilities (such as fleet sizing and control of productivity) were not properly assigned to specific individuals, c) a number of fundamental performance indices were either problematic or not reported at all, d) feedback on performance either did not exist or was not effectively used to guide further planning in

many performance areas, and e) as a whole, the meta-control (adaptation) function of the power operations management systems did not perform adequately.

2) Impact of Malfunction of Meta-Control Structure on Maintenance Performance

Maintenance is a modular task of the general power management. The maintenance management structure exhibited the common symptoms of the general task management structure. In effect, mechanical officers were not adequately motivated by the current settings to maximize their controllability over unscheduled maintenance, which produced adverse effects on both the work-load of the maintenance systems and fleet serviceability.

3) Unbalanced Power Dispatching Decision Heuristics

Because deliberate planning aimed at higher power productivity was not rewarded by the systems, the power dispatcher was normally not concerned about the long power idle time and the low achieved ton/HP ratio.

4) Information-overloaded Power Dispatcher

Time pressure and a massive volume of data characterize the decision context of the power dispatcher. Rational deployment algorithms were difficult to apply to a moderate sized power fleet and rail network. Information-overload was a critical problem for the power dispatcher.

C. Proposed Improvement Approaches

To improve the performance of the total system, a variety of

intervention dimensions are available. This study proposes three interrelated approaches for refining the controlling function of the system.

1) Installing Individual Decision-Aid Systems

It is necessary to install a computer-aid decision support systems which are geared to the actual decision heuristics applied by the power dispatcher as well as tailored to fit the input / output pattern of the information flows. The design criteria for such a system is that it should be capable of overcoming the information-overload problem, minimizing premature decisions, advancing the "satisficing" level and facilitating more extensive inquiry into decision relevant information. Normative elements should be integrated into the system as needed so as to offset the potential biases of the current heuristics and improve the decision quality.

2) Devising Team Support Systems

To support a wide variety of the decision-making processes in the rail operating context, various team support systems are required. Three different interrelated teams are discussed in this study: line-authority team, real-time operations team, and multi-functional planning team. The first two deal with the on-line control of physical processes, while the third deals with the interdepartmental planning and replanning issues with longer time horizon. The key to designing such systems is to integrate the mutually-dependent individual decisions into coherent decision teams, such that a) coordination within each team can be achieved through well-developed communication channels and the

provision of mutual influence bases, b) the buffering effect between teams can be realized through planning, and c) adaptation can be accomplished through replanning.

3) Refining the General Meta-Control Structure

The meta-control structure provides the general context for power management. To effectively develop and implement the various team support systems as well as the individual decision support systems, the railroad must define a set of balanced performance indices and allocate performance accountability as well as review responsibility (which may lead to replanning) to specific organization units, i.e., the missing links between the control tasks and organization units indicated by the task-actor matrix of meta-control structure must be established. In addition, at the general system level, there is a need for integrating an externally-oriented intelligence system, together with the above internally-oriented controlling mechanism, to properly perform the meta-control function.

D. Summary

The many symptoms diagnosed in this study are not unique to the host railroad, as evidenced by many other reports cited in this study. Theory-guided diagnosis enables us to put these symptoms into perspective and to derive a coherent set of improvement plans. The improvement approaches proposed in this study, to a large extent, should have generic applicability to other U. S. railroads.

8.2 Recommendations for Further Studies

8.2.1 On the Theories and Methodologies

Theories. The dual-system control paradigm is a relatively flexible analysis framework to accommodate a variety of theories which are relevant to transportation operations management. The many theoretical constructs developed and synthesized in this study are only first-cut results toward an ultimate theory of transportation operations management. Elaboration and refinement on each module of theories concerning both the controlling system and the system being controlled are suggested.

Methodologies. The inventory of the techniques included in this study is less than exhaustive. To advance the utility of the theories, the development of operational methodologies is critical to the transportation operations management. Further synthesis and refinement of the descriptive and prescriptive methodologies from various disciplines are recommended.

8.2.2 On the Empirical Applications

Power Management on the Host Railroad. The empirical case presented in this study is a result of a relatively primitive diagnosis and prescription. Only the outlines and the design principles for the improvement of power performance are developed. Further study on the detailed design issues concerning the three improvement approaches is necessary to the host railroad.

Power Management on Other Railroad. The power management-specific

diagnosis procedures developed in Chapters 4 thru 7 are equally applicable to other railroad. Given the pilot experience on the host railroad, further application of the theories and methodologies to other railroads' power management issues could be more structured.

Application to other Resource Classes and Transportation Modes. The theories and methodologies proposed in this study are in principle applicable to the general context of transportation operations management. The application of the theory and methodology to other resources classes (besides the motive power) and other transportation modes (besides railroad) are recommended so as to further test and refine the analysis paradigm.

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CURRICULUM VITAE OF AUTHOR

Nationality: Republic of China

Birth Date: October 4, 1948

Place: Chekiang, Mainland China

Education: 1967-1971, B. A., Civil Engineering,
National Cheng-Kung University,
Tainan, Taiwan, Republic of China.

1974-1975, M. E., Systems Engineering,
Asian Institute of Technology,
Bangkok, Thailand.

License: Professional Civil Engineer

Experience: 1971-1973, Army engineer officer.

1973-1974, Highway designer, China Engineering
Consultant, Inc.

1976-1977, Transportation systems planner,
Transportation Planning Board,
Ministry of Communication, R.O.C.

Also, Part-time Operations Research lecturer,
Fonchia University, Taichung, Taiwan, R.O.C.

1977-1978, Section Chief, Transportation Planning Board,
Ministry of Communication, R.O.C.

Also, Part-time Traffic Engineering lecturer,
National Police Officer's Academy.

1978-1982, Research Assistant, Rail Group,
Transportation Study Center,
Massachusetts Institute of Technology.

Researches and Publications:

"An Introduction to Systematic Design Methodology", June
and July, 1974, China Science Monthly, Taipei.

"A Mechanism for Coordinating Sea Ports Systems", Dec.
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"On the Theories and Applications of Goal Programming",
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"Planning of the Feeder Road Systems for the Sun Yet-Shin
Freeway", January, 1977, Transportation Planning Board,
M.O.C., R.O.C.

Co-author, "The Impacts of the Six Major Transportation
Projects on Tourism Development on Taiwan", Oct. 1977,
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"An Appraisal on the Taiwan Highway Network Systems",
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Co-author, "The Relationships Between Power Availability
and Freight Car Utilization", SROE, Vol. 30, CTS, MIT.

Co-author, "The Service Impact of Rail Power Utilization",
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Co-author, "Utilization of Railroad Motive Power - Train
Delay Impacts and Organizational Considerations", The
Logistics and Transportation Review, V. 17-3.

Co-author, "Improving the Utilization of Railroad Power
Units", The Logistics and Transportation Review, forthcoming.

Many other essays discussing social and cultural issues
have been published on newspapers and periodicals in R.O.C.

Professional Memberships:

China Engineers Society
China Road Federations
Chinese Management Associations
Computer Society of the Republic of China
American Management Associations
Sigma Xi Society