COORDINATING CONSTRUCTION PROJECTS:
MODERN ORGANIZATION THEORY APPLIED TO
PROJECT MANAGEMENT

by

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ABSTRACT

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Submitted to the Department of Civil Engineering in December 1976 in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

This thesis discusses coordination as an alternative to management-by-exception for construction project management. The increasing size and complexity of construction projects present Project Managers with such an enormous number of "exceptions" that the detection of those exceptions that require urgent attention becomes more and more difficult. Corrective action is very often undertaken when it is too late to have any effect. A coordinating approach attempts to predict problems before they arise: appropriate methods to avoid them, or at least deal with them promptly and consistently when they arise, are established ahead of time.

Three theories relating to coordination of project groups are relevant to this approach. Thompson presents coordination as influenced by the interdependence of activities performed, while Lawrence and Lorsch indicate activity uncertainty as another factor affecting the interrelationships among groups. Finally, Seiler describes cooperation among groups as a function of the consistency between relative authority and prestige.

TREND applies these three theories to detect and analyze project coordination requirements. Research conducted by a Swiss pharmaceutical company and the reported results of TREND applications to different types of projects have proved the validity of TREND as a tool for analysing inter-group coordination.
A limitation of TREND, as it was presented by its author, is that it considers the organization chart as fixed. It can consequently only indicate effective coordination tools to be adopted, but not necessarily the most efficient and least costly coordination solution for the particular project situation. The design of an appropriate organization chart according to the principles of Thompson's theory, is the means to achieve coordination in an efficient manner.

The fact, then, that coordination needs often change at different stages of the project suggests that even more efficiency can be achieved by adopting a different organization chart for each stage of any project.

It should be noted that the above ideas apply to all types of projects. Because of the particular characteristics of the Construction Industry and of construction projects, however, construction projects are among those which most dramatically need the implementation of these ideas, and which best lend themselves to analysis.

Thesis Supervisor: Raymond E. Levitt
Title: Assistant Professor of Civil Engineering
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Without his help, this thesis would have probably been intelligible only to the author.
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CHAPTER ONE
INTRODUCTION

A. PURPOSE OF THIS THESIS

The main purpose of this thesis is to emphasize the importance of coordination in construction projects. A concept that will be repeated many times in the following chapters is that coordination is, above all, an alternative to management-by-exception. While management-by-exception provides for the solution of problems only when they arise and are detected by the control process, a coordination approach tends to predict problems before they arise. Appropriate methods to avoid problems - or, at least, solve them consistently and promptly when they arise - are established even before the project commences.

The Construction Industry dramatically needs this approach. The size and complexity of construction projects are in fact increasing dramatically, and management-by-exception degenerates into management-by-crisis with growing frequency. When the exceptions have been reported to the Project Manager and he has spent the necessary time to decide which ones need corrective actions and what corrective action must be undertaken, it is often too late for the corrections to be effective.

Coordination activities include not only the choice of appropriate techniques, but also - and above all - the design
of efficient project organizations to make coordination itself easier and less expensive.

We hope to demonstrate, with this thesis, that coordination is not an academic, utopian dream, but, on the contrary, a concrete idea that can be feasibly and fruitfully applied to the management of construction projects.

B. THESIS LAYOUT

The characteristics of project management organizations and the particular activities that make the work of a Project Manager so different from those of a traditional functional manager are described in Chapter 2. Planning, control and coordination activities are discussed and compared there.

Management tools are the topic of the following chapters. After a general overview of all management tools in Chapter 3, our attention is concentrated only on those relating to project coordination. Chapter 4 summarizes the main theories underlying the process of coordination, while Chapter 5 describes TREND, the first management technique based on these theories and designed to help project managers in their coordinating functions. A number of applications of TREND are also described there.

More recent coordination techniques, providing for the design of efficient organizations, are presented in Chapter 6, and a method for varying project organization charts at different stages of a project is proposed in Chapter 7.
Chapter 8, finally, examines the need for coordination in Construction and the applicability of coordination techniques to Construction Projects.
CHAPTER TWO
WHAT IS PROJECT MANAGEMENT?

A. PROJECT AND MATRIX ORGANIZATIONS

Stewart (1965) indicates four parameters -- scope, unfamiliarity, complexity and stake -- that can be used to determine whether a given undertaking is a project. A project is an undertaking that:

- is definable in terms of a single, specific end result;
- is not familiar to the existing management group;
- involves many interdependent activities combined in a unique set, and thus results in a unique mix of different skills; and
- would entail serious costs or penalties in case of failure.

In the last two decades the number and the scale of construction projects have been increasing dramatically. The forces which have promoted this tremendous growth are summarized by Lynch and Harwell (1976):

- economies of scale, made possible by technological development;
- the "great game of national catch-up" in underdeveloped countries with exploitable resources;
- growing scarcities of economic, conveniently located natural resources, forcing construction of
large plants in remote locations; and
- environmental regulations, discouraging small
efforts and further increasing the cost and
complexity of projects.

More money is invested in single projects, more people
with a wider range of specializations are employed, and more
service functions are required than on traditional projects.
Many companies have realized that, in order to carry out
"projects", as defined above, their styles of management have
to be reviewed and modified. More flexibility and adaptabil-
ity to changes and better horizontal and diagonal relation-
ships than those offered by the traditional functional
organizations are necessary. The relatively new form of
management called Project Management seems to be the right
answer to these requirements.

There is not only one type of project management organiza-
tion, but many types characterized by increasing degrees of
differentiation from the functional approach to management.
In all of them, a selected individual, the Project Manager
(P.M.), is given full responsibility for all aspects of the
task, but the amount of authority he has over the resources
needed for the task accomplishment (especially the personnel)
is not always the same. Luthans (1973) distinguishes
individual, staff, intermix and aggregate project structures,
depending on whether the Project Manager has no one, a
restricted staff, selected primary functional heads or all the
project personnel reporting directly to him.

Other authors prefer to use the term "project organization" only for those structures in which all of the resources needed for the accomplishment of a specified objective are set up as a self-contained unit headed by the Project Manager ("aggregate" project structures according to Luthans). The term "matrix organization", instead, is adopted for all other forms of project management organizations.

As Youker (1976) indicates, functional and project organizations (Figures 1 and 2) are uni-dimensional structures in a multi-dimensional world: the former is, in fact, organized around technical inputs such as engineering and marketing, and the latter around outputs such as a new dam or a new product. A matrix organization (Figure 3), instead, is a multi-dimensional structure: it aims at maximizing the strengths and minimizing the weaknesses of both the functional and the project organizations, by combining the standard vertical hierarchical structure with a superimposed lateral or horizontal interaction of a project manager (or coordinator). The different forms of matrix organizations constitute a continuum, ranging from forms very close to functional organizations to forms very close to project organizations (Figure 4): a "weak" matrix (near functional) has only a part-time coordinator, while the matrix get "stronger" as we move to a full-time coordinator, and then to a full-time project manager and finally to a project office.
FIGURE 1 - FUNCTIONAL ORGANIZATION

FIGURE 2 - PROJECTIZED ORGANIZATION
FIGURE 3 - MATRIX ORGANIZATION

FIGURE 4 - ORGANIZATIONAL CONTINUUM
Which type of organization -- functional, project or matrix -- is the most effective? Of course, there is no universal answer to this question. Managers must examine the particular situation facing their company to decide which road to follow. The main factor they should consider in this analysis is the nature of their company's activities. The characteristics -- scope, unfamiliarity, complexity and stake -- indicated above as differentiating projects from all other undertakings must be taken into account. Whether a project management organization is to be adopted and, if it is, which type of structure -- project or matrix -- is most appropriate depends upon the degree to which the four conditions hold. There are two industries -- Construction and Aerospace -- in which all four conditions hold for almost all undertakings, and it is in these industries that the most radically "non-functional" organizations ("aggregate" project structures according to Luthans' terminology) are most often adopted.

B. ACTIVITIES OF A PROJECT MANAGER

It is easy to understand from what we have said until now about projects that the work of a Project Manager is completely different from that of a traditional functional department manager. There are special kinds of problems that a Project Manager must handle, whatever type of project management structure is under his responsibility. To indicate these
problems in a more explicit form than done above, we can refer to the short list Bennigson (1971) has made of them:

- Projects are conducted only once, usually involve considerable uncertainty about resource requirements, and consequently pose substantial planning and control challenges.

- Obtaining commitment of people to do project work can be difficult, especially if the project represents only a small part of the work done by an individual.

- Projects often engage individuals and groups in cooperative activity when they have not previously worked together, thus presenting organizational and interpersonal problems of coordination.

In other words, a Project Manager has well-defined time, cost and quality commitments for a task which is not fully familiar to him; the resources he can rely upon to meet these commitments are uncertain; the people cooperating with him are not likely to have ever worked together before; and they may, in addition, be engaged in the project on a part-time basis only.

A Project Manager performs three types of activities to handle these special problems:

1) planning activities,

2) control activities, and

3) coordination activities.
The first step of any project is to establish an objective: in Construction, the objective is usually getting a facility built. A general plan to reach this objective is then drawn up, taking into account both the existing constraint and the necessary capacities. Besides listing technical specifications, the plan indicates the date by which the project must be completed, the total cost that must not be overrun, and the minimum quality standards that have to be achieved.

The Project Manager may or may not participate in this first phase. All of the subsequent planning phases, however, have him as the principal actor: he examines the project’s technology and environment, breaks it up into a certain number of discrete tasks, studies their interdependencies, schedules their execution times, allocates resources (personnel, equipment, etc.) to them, estimates their costs, makes time-cost trade-offs and assigns responsibilities for activity execution. The degree of participation in these functions of those who will actually perform the different project activities depends upon how much the Project Manager is oriented toward decentralized decision-making. In any case, it is up to him to tie all the decisions together in a single project plan in the form of a schedule and a budget.

The planned schedule and budget have important functions in the control cycle. Control in Project Management is generally carried out with a "management by exception"
approach: only deviations from what had been planned are identified, and only on deviations of a certain magnitude does the Project Manager concentrate his attention. He investigates their causes and then proceeds to undertake the necessary steps for their correction.

"Management by exception" must not degenerate into "management by crisis": there must still be some reason to take action by the time a problem has been detected and the corrective action has been decided upon. Degeneration into management-by-crisis is particularly likely and dangerous for those projects in which many critical activities are involved, and activity delays cause considerable cost increases. In Construction, many projects fall within this category and the way the control process is organized and carried out is thus of critical importance.

An improvement over the planning and control processes that we have just described can be realized by a Project Manager through his coordination activities. "Coordination" is, above all, an alternative to management by exception: it consists of a global, and often preventive, approach to project-related problems. Coordination negates the dangerous principle that management must intervene only when anomalous situations arise and are detected by the control process. This principle is dangerous because, as previously noted, it involves the risk of not leaving sufficient time for sound
corrective actions, and further it does not insure a consistency of action during the life of a project.

Through his coordination activities, instead, the Project Manager tries to anticipate future problems, and, when possible, avoid them; he also devotes himself to devising a series of tactics for rapidly and consistently tackling unanticipated problems when they arise. A good part of Project Manager coordination activities is devoted to the human resources of the project. Project personnel are generally people with different specializations and backgrounds, unaccustomed to working together and often also engaged in other activities unrelated to the project. Conflicts are likely to occur. Handling them through coordination activities means: inducing people to give their full commitment to the project, speaking and understanding the "languages" of all involved, improving communication, anticipating possible conflicts and finding means of avoiding them and solving unanticipated conflicts through clearly defined procedures when they arise. Psychology and organizational behavior become basic sciences for this aspect of the Project Manager's work.

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After describing the characteristics of project management organizations, the particular activities of a Project Manager have been discussed in this chapter. Planning,
control and coordination activities have been defined and analyzed.

An overview of tools and techniques supporting a Project Manager in all the three types of activities is presented in the next chapter, while, from Chapter 4 on, our attention is concentrated only on those relating to project personnel coordination.
CHAPTER THREE

AN OVERVIEW OF CURRENTLY USED PROJECT MANAGEMENT TECHNIQUES

A. INTRODUCTION

We will define a "management technique" as a procedure, involving well-defined consecutive steps, that a manager can follow in solving a problem or carrying out an activity of a specific type. It saves him the time and effort of devising a unique problem-solving methodology on his own. Furthermore, after some experience in applications to similar cases, it decreases the risk of methodological mistakes.

A Project Manager has many management techniques available to support him in his work. Most of them are for planning and control applications, while only very few are for coordination. This reflects the attitude of the majority of project management theorists and practitioners, who concentrate their attention on planning and control functions and tend to consider coordination as secondary, if not irrelevant. This chapter will provide a brief overview of currently used techniques in all three areas.

B. PLANNING TECHNIQUES

Planning techniques can be divided into two separate groups depending upon which of the two main project variables, time or cost, they refer to. The core of the first group is represented by the network scheduling techniques: as
Melvin (1975) indicates, their first appearance in the late '50's constitutes a milestone in the development of the project management science. A network is a descriptive model of the time structure of a project. The first step in its preparation consists of a thorough analysis of the project, and its breakdown into a number of distinct time-consuming activities. An estimate of the duration of each activity is then made, keeping account of the work quantities and resources that the activity will require. This estimate is deterministic in CPM, while it is probabilistic in PERT, in which not only one but three durations -- most likely, optimistic and pessimistic -- are considered.

As PERT is less commonly used in Construction than CPM, we shall not refer to it explicitly in the following paragraphs. We want to note, however, that the only difference between the two methods is that for PERT, activity durations are expressed probabilistically rather than deterministically. Most of what we shall say for CPM is therefore also valid for PERT.

Once durations have been determined, the physical and time interrelationships among activities are analyzed and represented in a diagram which constitutes the project network. In the most common form of network, each activity is represented by an arrow: the connecting nodes at the beginning and ending points correspond to "events". All
activities whose corresponding arrows end with a single event must be completed before any activity, whose arrow begins with that event, may be started. A "path" is defined as a sequence of activities starting in the "Job Start" node and ending in the "Job Completion" node.

When activity sequential relationships and durations have been determined, the scheduling process begins. Given a date for the job start and a target date for its completion, the earliest and latest dates on which activities can start and finish are determined. The visualization of the project logic provided by the network makes this computation relatively easy. The difference between early and late starts of an activity, equal to the difference between its early and late finishes, is called "float" and indicates the amount of time by which the actual completion date of the activity can exceed its earliest expected completion date without causing any delay for the whole project, if all other activities on the same path(s) are started as early as possible. The activities with least float are defined as "critical"; if their float is equal to zero, no flexibility is possible in their scheduling.

When CPM is applied in the basic form we have just described, only time and sequential constraints are taken into account, while resource requirements and availabilities are completely disregarded. Many "resource allocation" techniques have been developed to extend the capability of
the basic CPM model. Most of the new developments that have occurred in recent years in the general area of network methods have taken place in this field.

Davis (1974) distinguishes three categories of resource allocation techniques:
- Time/Cost trade-off procedures
- Resource leveling techniques
- Constrained-resource scheduling techniques.

Time/Cost trade-off procedures are directed at determining the least-cost schedule duration. The performance of some or all project activities can be accelerated at the expense of higher activity direct costs. This permits earlier completion of the project and consequently reduces the amount of the job indirect or penalty costs. An "optimal", minimum-cost project duration exists for which the increase in activity direct costs is exactly equal to the corresponding decrease in indirect costs. The time/cost trade-off procedures aim at determining this optimal duration. They do this by setting a time/cost curve for each activity, by choosing the activities most appropriate to be "crashed" first, and by constantly monitoring the total project cost.

An important point to note about time/cost procedures is that they usually do not consider resource limitations explicitly; none of these procedures can automatically produce a minimum-cost schedule that satisfies stated limitations on the availability of resources such as cost, manpower or
equipment. The problem of handling these limitations is, instead, tackled by the two other types of resource allocation techniques that we have noted above.

Resource leveling techniques apply to those scheduling situations in which the total level of resource demand is not of major concern because ample quantities of the required resources are available. It is, however, desirable to distribute resource usages uniformly over time and to minimize their period-by-period variations. The completion date is not postponed, but only a more uniform employment of resources is sought by moving activities with floats.

Constrained-resource scheduling techniques are, instead, for those cases in which a limited amount of resources are available; schedules are produced that do not require more than this limited amount of resources in any given period and have durations that are increased beyond the original critical path duration as little as possible. These techniques can be categorized into two major groups on the basis of their distinctly different methods of approach and utility to management. The first category includes the heuristic, or approximate, procedures which are designed to produce good resource-feasible schedules. The second category, in contrast, consists of procedures which are designed to produce the best schedule and includes approaches based on different mathematical techniques; the fact that these mathematical procedures are capable of handling far less complex problems
than the heuristic category explains why very few of them are currently used.

It is not within the scope of this chapter to discuss the individual resource allocation procedures in more detail. More detailed descriptions of these techniques may be found in Moder and Phillips (1970) and Davis (1974). We only want to add a final consideration on this subject here. The use of resource allocation procedures is made possible by the existence of network methods. A network format of project representation has, in fact, the ability to easily generate information on time-phased requirements of such project resources as manpower, equipment or money. This information is a by-product of the usual critical path method of scheduling computations. It only requires that the resource demands associated with each project activity represented in the network diagram be identified separately. Resource allocation techniques do not therefore diminish the importance of CPM; on the contrary, they enhance it by broadening its area of application.

As we have just seen, the costs involved in a project are very often considered in scheduling and resource allocation. The way they are taken into account in these processes, however, is always in terms of how they influence the variable "time". Traditionally, the actual planning of the variable "cost", producing the job budget, is instead kept completely separate from that of the variable "time". The two types of
planning are based on separate data and, sometimes, entrusted to different people.

Just as a network is a model of the time structure of a job, so a budget is a model of its cost structure. In Construction, budgets are generally organized around functional accounts such as "excavation", "formwork" and "rough carpentry". A set of appropriate functional accounts is created, and the estimated total project cost is distributed among them. In each account, costs are divided between labor, equipment, material and subcontracts.

Although traditional cost planning is in common use, it has several shortcomings. Probably the most important is its inability to forecast cash-flow requirements and to predict the impact of schedule changes. This is clearly caused by a complete lack of consideration of the time component in cost-planning. Integrated time-cost systems seem to be the good solution to this problem.

Sears (1975), who has presented one of the first systems of this type, indicates many other advantages that the creation of an interface between time and cost systems involves; among them, a more easy execution of time-cost tradeoffs, and the production of more information output with less input than if budgets and networks were prepared and used independently.
The radical improvements that integrated systems can realize in both planning and control suggest that, in the next few years, many of the important developments in management techniques will be in this direction.

C. CONTROL TECHNIQUES

The job schedule and budget that are produced in the planning phase become the basic elements of the control operations. As we have already indicated, control is carried out with a management-by-exception approach. At regular intervals during the job execution, actual progress and cost information is collected, and reported respectively on the "Job Progress Report" and "Cost Status Report", together with the variances from the estimated activity durations and costs to date. New duration and cost forecasts are also regularly made, with progressively more accurate estimates of the final project duration and cost. Corrective actions are undertaken on those variances that exceed a certain magnitude.

Much of a project manager's time is devoted to the information processing activity on which both control and re-planning are based, i.e., to the search for situations requiring his corrective intervention. The project manager's information processing capacity becomes a serious constraint to his work, and can only be extended if information is presented to him in an organized format. Well-structured reports allowing for easy problem recognition are of con-
siderable help to a project manager; they enable him to have sufficient time available for analyzing the anomalous situations thus detected, and for selecting an appropriate course of action (Logcher & Levitt, 1976).

D. COORDINATION TECHNIQUES

Coordination techniques are far less numerous than those for planning and control. They are also generally more recent and their validity has not therefore been proved by an equally large number of applications in project management practice. The first results they have given, however, are satisfactory and induce their promoters to believe that the right direction has been undertaken in developing them.

Coordination techniques presently available are devoted to problems of intergroup coordination. All of them involve the preparation of a project coordination plan. As a job schedule and a budget are estimates of the job time and cost structures, a coordination plan is an estimate of its future developments as far as interpersonal and inter-group activities are concerned.

In spite of this parallelism, however, a coordination plan is used in a totally different way than a schedule or a budget, reflecting the completely different approach to management that coordination provides. As we have indicated in Chapter 2, coordination is, above all, an alternative to control with management-by-exception. A coordination plan is not used,
therefore, as a basis of comparison for actual results, and hence to detect anomalous situations during the life of a project. On the contrary, it is a means of anticipating possible future problems before they arise, and of devising appropriate methods to either avoid them or tackle them promptly and effectively when they arise.

A detailed discussion of the coordination techniques currently available is presented in the following chapters.

E. THE IMPACT OF COMPUTERS ON PROJECT MANAGEMENT

An overview of Project Management techniques cannot be complete without mentioning the effects that the application of computers have had on these techniques. Melvin (1975) considers this event the second most significant event in the development of management techniques after the introduction of network methods.

Computers have vastly increased the amount of data that may be processed as well as the speed of data processing and mathematical computations. Consequently, they have made possible the introduction of simulation procedures. More schedules, for example, may be tested and compared for a single project; the effect of a possible strike or a bad weather period on the job duration may be forecasted; that of a labor wage increase on the budget cost may be determined. All the "what if" tests of this type would require enough time, if they had to be executed manually to make them unfeasible.
Another important fact to be noted is that the enormous increase in data processing speed allowed by computers tends to encourage more planning and control. Much more data can be processed at a cost-per-datum which is generally lower; more numerous and detailed reports can therefore be generated. That, of course, provides many advantages but also one big risk: a Project Manager can find himself facing too many data. When an overwhelming number of exceptions are reported to him, much of the time he could spend correcting the most critical ones is, instead, spent by him in analyzing reports and searching for relevant information among the many data he receives. The degeneration of "management-by-exception" into "management-by-crisis" therefore becomes likely.

We have mentioned above that the use of computers does not necessarily increase project management costs; on the contrary, it generally enables them to be kept lower. The introduction of a computer in a Company requires of course considerable initial costs for hardware, software, assistance from specialists and personnel training. Automatic data processing is, however, much less expensive than manual processing. Furthermore, the improvement of traditional management functions and the introduction of totally new functions allowed by the computer (if not used incorrectly or overused) provide advantages that, even though not easily translatable into money benefits, are most likely to exceed the initial costs.
An overview of Project Management techniques has been presented in this chapter. Our attention has been especially devoted to planning and control techniques. Coordination techniques will be analyzed in more detail in the following chapters.
A. INTRODUCTION

Since the development of the field of organizational behavior, a large number of articles, papers and books have been devoted to the study of conflicts between individuals and/or groups in organizations. The characteristics of conflicts have been analyzed from various points of view, and different ways of anticipating, avoiding and solving them have been indicated.

We shall refer here only to three of the many "coordination theories" currently available. Presented respectively by Thompson (1967), Lawrence and Lorsch (1967), and Seiler (1963), they seem to be those that best apply to the particular problems of a project organization. TREND, already mentioned as the first-fully developed project management coordination technique, is completely based upon these three theories; and the most interesting recent extensions of TREND apply them even more closely.

B. INTERDEPENDENCE - THOMPSON

An organization, according to Thompson, must not only meet the objectives that its managers have set for it, but must also do so with the least possible waste of resources. In other words, it is not sufficient that the organization is
effective: it must also be efficient. That requires a clear definition of boundaries delimiting responsibilities and control over resources of the participating members. At the same time, however, strict coordination of the separate units defined by these boundaries is also necessary. The fragmentation of the organization into units charged to handle different types of problems insures a specialized ad hoc approach to each aspect of a job; at the same time, the linkage of these units in a rationally coordinated structure allows an overall optimization of organizational performance, rather than many different and inconsistent sub-optimizations.

Depending on the type of interdependence existing between the activities performed by groups of the same organization, different types of coordination devices are necessary for linking the groups together in a rational structure. Thompson defines three possible classes of internal interdependences:

1) **Pooled**: no direct relationships exist between two parts, but each part renders a discrete contribution to the whole and each is supported by the whole. An example might be two teams from the same Company working on two different projects or on two completely unrelated sectors of the same project.

2) **Sequential**: the output of the activity of one part constitutes the input of the activity of the other. Group A cannot start its work until Group B has
completed its own, as in the case of a construction team that needs the completion of a structural drawing by the engineering department before it can start building the structure.

3) **Reciprocal**: there is a two-way sequential inter-relationship. The outputs of each become inputs for the others. As an example, we can think of the relationship between the Structural and the Mechanical Contractors in a job which requires the completion of a first set of structural works before the installation of part of the mechanical equipment, then other structural works, then other mechanical works, and so on.

The three corresponding tactics for achieving coordination are indicated by Thompson as:

1) **Pooled Interdependence**: Coordination by Standardization
   Routines or rules are set to make each part of the whole act consistently with the others.

2) **Sequential Interdependence**: Coordination by Plan
   Sequential and specific plans are drawn up for each particular job, clearly defining each unit's responsibilities for time, cost, and whatever other job parameters are concerned.

3) **Reciprocal Interdependence**: Coordination By Mutual Adjustment
Committees are established, intergroup lines of communication emphasized, and third-party interventions insured, to allow a continuous two-way transmission of information during the performance of a job.

Managers can apply the analysis we have just described from Thompson's theory when their organization has a well-established and fixed structure. In this case, if they use the relationships suggested by Thompson between activity interdependence and the types of coordination tactics required, managers can decide, before the start of a job, the particular initiatives that will be necessary for the achievement of the best group integration. By anticipating possible conflicts and inconsistencies among the job-executing units and taking appropriate steps to avoid them on time, managers decrease to a minimum the possibility of having to face the much heavier task of solving conflicts after they arise during the project execution. As we shall see, that is the basic idea of TREND, whose existence and validity are, in fact, largely due to the principles enunciated by Thompson.

Thompson's theory says much more to managers who have to design an organizational structure from scratch or who are allowed to modify the existing one. Looking at the list of coordination tactics reported above, we observe that there is a considerable cost increase involved in changing from
coordination by standardization to coordination by plan; and an even more considerable one in changing from coordination by plan to coordination by mutual adjustment. An efficient organization, that is by definition a resource-optimizer (and thus a cost-minimizer), will therefore try to minimize the necessity for devices of coordination-by-mutual-adjustment.

The question is no longer: "Given the interdependencies between group activities, which devices are necessary for achieving coordination?", but: "Given the interdependencies, which organizational structure can achieve coordination at minimum cost?". For what we have just said about the association of particular coordination tactics with particular activity interdependencies and about the differences in costs among the three types of tactics, the answer to this question cannot be other than an organization in which reciprocal interdependencies between groups are as few as possible. Therefore all individuals and groups who perform reciprocally interdependent activities are assigned to one single unit that by Thompson's definition is "(a) local and (b) conditionally autonomous".

The basic first-order units are shaped according to sequential or pooled interdependencies only if there are no reciprocal interdependencies remaining to be handled. Second-order groups, then, link together the basic units and handle those reciprocal interdependencies that cannot be absorbed by the first-order grouping, plus the less expensive forms of
interdependencies. The grouping procedure continues with groups of third, fourth, etc. order until all interdependencies (pooled interdependencies last) have been considered: at that point the design of a rational structure for the organization is completed.

Thompson indicates, as an example of an organization structured according to the above principles, the medium bomb wing of the U.S. Air Force Strategic Command, when operating B-50 aircrafts. The basic first-order unit of this organization was an air crew composed of ten people, whose different specializations were all necessary for operating the aircraft and its equipment: each had to adjust his actions to the actions of the others (reciprocal interdependencies), and an efficient mutual adjustment was consequently required. Sequential interdependencies existed, instead, among the activities of all air crews using the same aircraft and of the first-echelon maintenance teams: hence, the second-order groups (bomb squadrons) were composed of all air crews sharing a single aircraft and the teams charged with its routine maintenance. A third-order group, then, included all of the different bomb squadrons and a specialized-maintenance unit serving all of the squadrons. The third-order group therefore contained both pooled and sequentially interdependent groups.

The straightforward and almost automatic way in which
Thompson's ideas about how to structure an organization are applied in the bomb wing example is not typical of the majority of management situations. Too many factors are, in fact, generally uncertain and unpredictable in management practice to make managers believe in the possibility of a fully rational design of an organization. Even though the optimum cannot be reached, however, the best organizational structure allowed by the situation can be sought, and an intelligent application of Thompson's theory seems to be a good method of doing that. The most recent coordination techniques, to which we shall refer in Chapters 6 and 7, demonstrate that this theory can be fully applied (and not only partially, as in TREND), especially when organizations deal with undertakings that have the characteristics of projects, therefore requiring unique approaches, and thus making the design of a specific organization for each case sensible and feasible.

C. ACTIVITY UNCERTAINTY - LAWRENCE AND LORSCH

What seems to be lacking in Thompson's theory is the consideration of other important factors, besides the type of activity interdependence, that affect the interrelationships among groups and subsequently their coordination. Among them are activity uncertainty and group prestige, whose influences have instead been analyzed by Lawrence and Lorsch, and Seiler,
respectively. Like Thompson, Lawrence and Lorsch start from the consideration that different specialized units are needed by an organization to tackle the different parts of the environment that it faces. These units must furnish their specialized contributions to achieve a satisfactory overall level of performance for the organization; therefore they must be closely coordinated. Differentiation and integration are both necessary, although antagonistic. The task of reconciling them and getting the best results from both is not easy and grows in difficulty with the degree of differentiation among subunits. The degree of differentiation depends, in large part, on the difference in the uncertainty of the subenvironments that the various units face, and of the tasks that they perform.

Groups that face uncertain environments differ from those that face certain environments in:

- Interpersonal orientation: people in a "certain" group aim primarily at getting the job done, without much concern about maintaining positive social relationships with co-workers (task-orientation). A more marked interpersonal orientation, instead, characterizes members of less "certain" groups.

- Time orientation: short-term matters are primary concerns of "certain" groups, while "uncertain" groups are more inclined towards long-range matters.
- Reliance on formal authority: reliance is high in "certain" groups, low in "uncertain" ones.

The manager who is in charge of coordination (the Project Manager in a project organization) cannot ignore these radical differences when he plans the integration of groups with different task uncertainties. The more contrasting the group orientations are, the more time he must spend in their coordination and the more complex coordination methods he must apply.

D. PRESTIGE AND AUTHORITY - SEILER

Another factor the integrator cannot ignore is the relationship between the relative prestige of each group and its relative authority. The organization chart, the job contract documents, the size of the group and the degree of difficulty involved in the activities performed place a group in a defined position associated with a certain level of prestige. The real authority of the group however evolves from other factors, the most significant of which is the structure of the job schedule. The more dependent its activities are, in fact, on the activities of other groups, the less real authority the group has.

Conflicts are likely to arise if relative prestige and relative authority are not consistent: i.e., if group A
depends heavily on group B, but group A has higher prestige* in the organization than does group B. According to Seiler's terminology, conflicts cause a waste of part of the total amount of "active energy" that a group has available. The person that we have indicated before as coordinator or integrator has, therefore, to be also a "group energy saver". He must first determine the prestige attributed to each group in the organization, and then compare it with its real authority evolving from the job schedule. When he detects the possibility of conflicts, he may change the organization chart to achieve more consistency between group prestige and authority. As an alternative, when modifications of the organization structure are not possible, he may establish appropriate actions for either avoiding, or at least reducing the relative wastes of active energy.

In this chapter, we have described three theories dealing with group coordination. Their applications to management techniques will be examined in the following chapters.

*Prestige, as used here, is very much like responsibility. This entire theory may be equated to the classical theories which suggest that authority and responsibility should be matched.
CHAPTER FIVE
T.R.E.N.D.

A. A DESCRIPTION OF THE METHOD

TREND (Transformed Relationships Evolved from Network Data) represents the first management technique devoted exclusively to coordination and, up to now, still the only one in this field which has successfully progressed through the research and experimental stages and reached a structure usable in management practice.

This method, presented by Bennigson (1972), is based on Thompson's, Lawrence and Lorsch's, and Seiler's coordination theories, described in Chapter 4. A summary of the elements of the three theories that TREND utilizes is shown in Figure 5. The basic concept resulting from the combination of these elements is that the relationship existing between groups performing interdependent activities has different characteristics for different types of activity interdependence, group relative task uncertainty, and prestige-authority correlation: each type of interrelationship therefore requires a specific, different integrating mechanism.

The above basic concept is applied by TREND to project coordination analysis in a procedure involving two subsequent phases. In Phase 1, future interrelationships between project groups are predicted and their characteristics are determined
### THOMPSON - ACTIVITY INTERDEPENDENCE

<table>
<thead>
<tr>
<th>Interdependence Types</th>
<th>Schematic</th>
<th>Integrating Mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>POOLED</td>
<td>[Diagram]</td>
<td>Routines, Rules, Standards</td>
</tr>
<tr>
<td>SEQUENTIAL</td>
<td>[Diagram]</td>
<td>Plans, Schedules</td>
</tr>
<tr>
<td>RECIPROCAL</td>
<td>[Diagram]</td>
<td>Mutual Adjustment, Feedback</td>
</tr>
</tbody>
</table>

### LAWRENCE AND LORSCH - TASK UNCERTAINTY

<table>
<thead>
<tr>
<th>Low Uncertainty Factor</th>
<th>High Uncertainty Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>(such as manufacturing)</td>
<td>(such as basic research)</td>
</tr>
<tr>
<td>Short</td>
<td>Long</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Task</td>
<td>Task vs Interpersonal Orientation</td>
</tr>
</tbody>
</table>

#### Levels of Uncertainty of the Two Interrelated Groups

<table>
<thead>
<tr>
<th>Integrating Mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low - Low</td>
</tr>
<tr>
<td>Direct, Simple, Management, Hierarchy, Paperwork, Contact Between Representatives</td>
</tr>
<tr>
<td>Low - High</td>
</tr>
<tr>
<td>Indirect, Third Party Integrators, Separate Integrating Groups,</td>
</tr>
<tr>
<td>High - High</td>
</tr>
<tr>
<td>Direct, Complex, Committees</td>
</tr>
</tbody>
</table>

### SEILER - GROUP PRESTIGE

Cooperation among two groups

= Increasing Function (Consistency between relative prestige and relative authority)

---

FIGURE 5 - SUMMARY OF COORDINATION CONCEPTS UTILIZED BY T.R.E.N.D.
in relation to: 1) the activity interdependence type, 2) the task uncertainty and 3) the group prestige-authority correlation. In Phase II, appropriate actions are then planned for coordinating these anticipated interrelationships.

The main source of information for Phase I is a job network plan in which the group responsible for each activity, as well as the variability of activity durations, are indicated. Using the network plan, relationships between activities are translated into relationships between the groups responsible for carrying out those activities. At the same time, task uncertainties are deduced from the range of variation in the expected duration of each activity. Estimates of relative group prestige are, then, inferred from contracts, organization charts and backgrounds, while the real authority of each group is established in terms of sequential interdependencies, where the party which is dependent is considered to have low relative authority.

The whole Phase I can be computerized. Input data to a TREND computer program includes, for each activity:

1. an activity number
2. a number for the responsible project group
3. the activity number of all predecessor activities
4. three time estimates, or one time estimate and an estimate of high or low uncertainty.

The output, generally superimposed for convenience on an organizational chart to obtain a "TREND MAP", includes:
1. the number of both the high and low uncertainty tasks that each group must perform
2. the number of both the high and low uncertainty tasks each group depends on
3. the identification of all pair-wise sequential and reciprocal relationships.

Analysis of only critical path activities or of determined portions of the network are also provided as special features by the computer program. No computer support is available for Phase II, which according to what we have already said, consists of a thorough examination of the results of Phase I reported in the TREND Map, and in the subsequent preparation of a "coordination agenda". This agenda generally indicates: a) the groups whose activities will be of critical importance either during the whole project duration, or during particular periods, and which therefore requires a very close monitoring; b) the groups that will be lightly involved in the job and whose commitments are therefore likely to be difficult to obtain; and c) all the key intergroup relationships, with indications of appropriate methods for achieving their coordination.

B. TREND APPLICATIONS

TREND is a recent technique and has, therefore, not yet been applied to an extremely large number of practical cases.
A small literature, however, already exists on the results obtained with this method. An important contribution to this literature has been made by the R & D department of Sandoz, one of the largest European pharmaceutical companies, with headquarters in Basle, Switzerland.

Bennigson and Balthasar (1974), in particular, have presented a set of important data about nineteen projects of that company, which were subjected to TREND analysis. The actual outcomes of these projects were then investigated by distributing questionnaires to the people who had been directly involved in developing them. In particular, the extent of relationships with other people and groups in the same job were investigated to obtain actual data for comparison with TREND results and thus to measure the reliability of this method.

Ten out of the nineteen projects were "infrastructure projects" involving the development of analytical or management tools: their networks were written in terms of responsible individuals, and respondents answered questions as individuals. The other ten were "product projects" involving the development of new drugs in the first clinical trials. Their networks were in terms of responsible work groups, and respondents answered questions as representatives of their departments.

The research results have been more satisfying for the infrastructure projects than for the product projects. The
coincidence between the number of interrelationships detected by TREND and the actual ones, detected by questionnaires has in fact been better for the former.

For the infrastructure projects, the research has not only proved TREND's ability to identify relationships, but has demonstrated that the completeness of TREND identification is a function of the project duration and of the average number of activities per responsible group in the network plan: the shorter the project and the more detailed its network, the more complete TREND identification was obtained. These results are illustrated in the table and the diagram of Figure 6 and may be generalized for all TREND applications.

The less encouraging results from the research carried out on "product" projects do not seem to diminish the validity of TREND indicated by the infrastructure project results. They seem, in fact, to be due more to the way questionnaires were answered than to an inapplicability of TREND. First of all, individuals answered about interrelationships among groups; furthermore, respondents very often tended to indicate, among the relationships of their groups, the continuous contacts with superiors, which were of a routine-nature, rather than project-based, and which did not therefore appear in the network plans. On the other hand relationships with committees or staff positions, identified by TREND, were almost never indicated in the questionnaire replies.

The general conclusion that we can draw from this
<table>
<thead>
<tr>
<th>Project Identification</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>O</th>
<th>P</th>
<th>Q</th>
<th>R</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of activities</td>
<td>19</td>
<td>25</td>
<td>15</td>
<td>33</td>
<td>102</td>
<td>84</td>
<td>60</td>
<td>66</td>
<td>73</td>
</tr>
<tr>
<td>Total duration (weeks)</td>
<td>21</td>
<td>106</td>
<td>19</td>
<td>55</td>
<td>172</td>
<td>62</td>
<td>116</td>
<td>105</td>
<td>93</td>
</tr>
<tr>
<td>Number of units responsible</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>5</td>
<td>8</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>Activities/Unit</td>
<td>4.8</td>
<td>4.2</td>
<td>3.0</td>
<td>6.6</td>
<td>7.3</td>
<td>16.8</td>
<td>7.5</td>
<td>9.4</td>
<td>4.9</td>
</tr>
<tr>
<td>Pairwise Relationships:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total identified by respondents</td>
<td>6</td>
<td>13</td>
<td>3</td>
<td>10</td>
<td>50</td>
<td>7</td>
<td>17</td>
<td>15</td>
<td>42</td>
</tr>
<tr>
<td>% Detected by TREND total</td>
<td>83%</td>
<td>38%</td>
<td>100%</td>
<td>80%</td>
<td>46%</td>
<td>71%</td>
<td>71%</td>
<td>80%</td>
<td>47%</td>
</tr>
<tr>
<td>% Not detected by TREND</td>
<td>17%</td>
<td>62%</td>
<td>0%</td>
<td>20%</td>
<td>54%</td>
<td>29%</td>
<td>29%</td>
<td>20%</td>
<td>53%</td>
</tr>
</tbody>
</table>

SUMMARY OF RELATIONSHIPS IDENTIFIED BY TREND IN EACH INFRASTRUCTURE PROJECT

Proportion of valid cases detected by TREND for each infrastructure project as a function of the Network TREND Index.

Completeness of TREND Identification = Project Duration = Network TREND Index
Av. No. of Activities per Responsible Group in the Network

FIGURE 6 - EXPERIMENTAL RESULTS ON T.R.E.N.D. VALIDITY
research is that when it was not affected by inaccuracies in answering questionnaires, it really proved that TREND works well in achieving its goal of detecting project interrelationships through analysis of network plans. Detailed plans allow better TREND applications and short projects are more likely to be successfully investigated. This last fact can be explained considering that network plans for projects whose durations do not extend too far into the future can be prepared with less uncertainty, and can, therefore, yield more reliable information.

C. AN EXAMPLE OF TREND ANALYSIS IN CONSTRUCTION

A good example of a non-computerized TREND application is reported here from Levitt (1973). The project in this example is the construction of an extension to an existing harbor in Cape Town, South Africa.

The project involved slipforming approximately 40 caissons, each 120' x 30', in the existing drydock, floating them, towing them out into the harbor extension area, and then sinking them in place onto prepared stone beds (the number of caissons are, for simplicity, reduced to four in the example). After being placed, the caissons were sandfilled by the dredger. A bollard beam was then cast at the top of the harbor-side of each caisson, and post-tensioned. A concrete mass capping was subsequently cast over the sand and finally services were installed.
x = no. of critical activities performed
y = total no. of activities performed
U = general uncertainty level: H-High
     M-Medium
     L-Low
A --- B ; B depends on A
A ---- B ; B depends upon A
     on Critical Path
     (all relations sequential)

FIGURE 8 - TABLE BAY HARBOR PROJECT: TREND MAP
**"TABLE BAY HARBOR PROJECT": C.M.'s COORDINATION AGENDA**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>OBSERVATION</th>
<th>MANAGEMENT IMPLICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) No of Tasks</td>
<td>General - 18</td>
<td>Most important group. C.M. maintain close contact.</td>
</tr>
<tr>
<td>2) No of Tasks</td>
<td>Divers - 2</td>
<td>Divers lightly involved. Insure availability when required.</td>
</tr>
<tr>
<td>4) Critical Path</td>
<td>Tugboat - 2</td>
<td>Tugboat Operator has two high-uncertainty activities on the Critical Path. Maintain careful control here.</td>
</tr>
<tr>
<td>5) Tugboat - General</td>
<td>Heavy dependence on Critical Path</td>
<td>Key Relationship: Different prestige levels. Higher prestige group in dependent position. Possible conflict. C.M. should set up committee with representative from each group and himself.</td>
</tr>
<tr>
<td>6) Prestressing - General</td>
<td>Heavy dependence on Critical Path</td>
<td>Key Relationship: Different prestige levels and uncertainty classifications. Higher prestige in dependent position. Lower uncertainties than for (5). C.M. should coordinate directly here.</td>
</tr>
<tr>
<td>7) Tugboat - Dredging</td>
<td>Heavy dependence by higher prestige group</td>
<td>Key Relationship: Higher prestige group extremely dependent on group with high uncertainty. High probability of conflict here. C.M. should form a committee with representative from each group and himself.</td>
</tr>
<tr>
<td>8) Dredging - General</td>
<td>Heavy dependence by General</td>
<td>Same prestige levels and uncertainty classifications. No language problems. Create coordinating committee with representatives from each group.</td>
</tr>
<tr>
<td>10) Diver - Tugboat</td>
<td>Both High uncertainty</td>
<td>Tugboat Operator depends upon Divers. Same prestige level. Coordinating committee should be set up with representatives from each group.</td>
</tr>
</tbody>
</table>

**FIGURE 9 - TABLE BAY HARBOR PROJECT: COORDINATION AGENDA**
The project extended over about two years, and was in fact a joint-venture contract between the general contractor, who was also responsible for the design, and the dredging contractor. For illustrative purposes, the organizational relationships are slightly changed in the example. The sequential dependence relationships from the network, represented in Figure 7 in the "activity-on-node" form, are plotted onto an organizational chart to give the TREND Map of Figure 8. The analysis and implications are then presented in summary form in the Construction Manager's coordination agenda of Figure 9.

It is interesting to note, as a proof of TREND validity, that the relationships highlighted by the TREND-analysis as areas of possible conflict were in fact those which caused the most problems on the actual project.

D. ADVANTAGES AND DISADVANTAGES OF TREND

TREND works with data evolved from networks; a good network is therefore a necessary prerequisite for any TREND application. When the network is available, not much additional information is necessary as input to TREND. This means a low implementation cost of this coordination method and constitutes one of its main advantages.

Other advantages can be indicated to prove that TREND is not only feasible and inexpensive but also -- which is of course the most significant point -- really useful for
management practice. Among those listed by Gutzwiller (1974), its flexibility seems of particular interest: TREND can be used for projects of any kind and size, and, in addition, can be referred to different levels of aggregation in the sense that it can analyze interdependencies between departments, groups, persons, committees, etc.

Of course, the method also presents some disadvantages. First of all, the fact that its output is not particularly user-oriented limits somewhat its applicability. In order to use TREND efficiently, a Project Manager must know how to interpret its output, and must spend a considerable amount of time in elaborating it. Another disadvantage derives from the strict dependence of TREND upon the availability of a good network: no TREND-analysis is possible if a good CPM is not available.

There may be a few situations in which these disadvantages outweigh the benefits deriving from a TREND-analysis. Jobs with poorly developed networks and/or Project Managers unable to carry out the analysis of the TREND Map and the preparation of the Coordination Agenda are all examples in which we should not suggest the application of TREND.

E. POSSIBLE EXTENSIONS OF TREND

An assumption implicitly made with TREND, when applied in the form presented by Bennigson and described in this chapter, is that the project organization chart is fixed. The
only form of coordinating intervention that a Project Manager can undertake in this case is that of adopting the most effective coordination methods that the situation allows.

As we have said in Chapter 4 when we spoke of Thompson's theory and shall repeat in more detail in the next chapter, the adoption of effective coordination tools does not necessarily lead to the most efficient solution. Efficiency can be, in fact, achieved only by designing an appropriate organization structure. The organization chart must be an output of, rather than an input to, the coordination activity.

We shall indicate in the next chapter how the possibility of extending TREND in this direction has already been experimentally considered.
A. INTRODUCTION

As we have seen in Chapter 5, TREND develops the data contained in the project network, organization chart and contract documents into a form which provides the Project Manager with detailed information about the number, nature and characteristics of possible inter-group conflicts. The TREND-analysis is done before the start of the job, and sufficient time is consequently available to the Project Manager for choosing appropriate measures to either avoid conflicts or solve them promptly when they arise. Effective and consistent coordination is the important result that this analysis enables a Project Manager to achieve.

Effectiveness and consistency however are not necessarily equivalent to efficiency, and while the application of TREND in the form presented by Bennigson and described in Chapter 5 of this thesis allows the achievement of coordination in an effective manner, it does not necessarily lead to the most efficient solution. To understand the reason for this, we must recall the basic concepts of Thompson's theory (see Chapter 4). Thompson indicates different mechanisms for achieving coordination with different types of group activity interdependencies. The costs involved in their implementation
vary with the type of activity interdependence that they coordinate. Pooled interdependence is the least costly type to coordinate. Sequential interdependence involves more coordination costs than pooled, being based on specific schedules and plans rather than on standard rules. Reciprocal interdependence is the most costly to coordinate, requiring mutual adjustment between the interdependent groups. An efficient project organization is one which locates reciprocally interdependent individuals or subgroups in its primary groups.

The design of an organization of this type is not realizable by a TREND analysis, which considers the project structure as a given fixed input and can therefore only give an effective, but not necessarily efficient coordination plan. Coordination techniques involving a more close and integral application of Thompson's theory than TREND are thus necessary for achieving coordination at a lower cost and with more efficiency. The basic idea of a technique of this kind is to provide a Project Manager with the ability to design the most appropriate organizational chart, rather than merely to choose the most effective coordination tools for an already-designed organizational structure.

A project is a one-time undertaking which, by its very nature, always requires the design of a specific organizational chart to assign responsibilities and define authorities among the people and/or groups assigned to its performance.
Traditionally this design is either based on a standard model established by the Company for all its jobs; or it reproduces, at a reduced scale, the same formal authority relationships existing among the original units from which the different project groups come. The new coordination techniques contrast this approach by prescribing that specific organization design criteria be established for each new project on the basis of its characteristics. These criteria should be such as to minimize the costs and efforts of coordination.

Although agreement on the above ideas is almost unanimous, not very much has actually been realized in this direction by project management theorists and practitioners. While we have spoken of new "coordination techniques" we would have been more correct if we have referred to them as interesting current trends that will probably develop into real techniques in the following years.

Balthazar and Schubarth (1974) (from the R & D Department of the large Swiss pharmaceutical company whose applications of TREND were described in Chapter 5) indicate interesting results that they have achieved in the study of how to evaluate different organizational designs from a coordination point of view. They implicitly agree that TREND used in the form described by Bennigson is unable to go beyond an effective, but not necessarily efficient, solution to the coordination problem. They proceed to demonstrate that, if used
differently -- namely, as a simulation tool -- TREND can also be used in the design of the most efficient organizational structure.

Given a certain project and the people and groups assigned to it, a good number of different aggregations of those people and groups are possible: group A and B may, for example, both be positioned as dependent upon group C; or group A may be at the same level of authority as group C with only group B in a lower authority position directly dependent upon group C; and so on. Once all the possible alternatives are identified, each of them may be subjected to a TREND analysis. The corresponding TREND maps are then compared, and the one requiring the least costly and complicated coordination mechanism is chosen.

The same procedure can also be applied to those projects in which the organizational chart is already established. In this case, an increase in efficiency may be derived by the creation of temporary subteams, composed of people coming from different project groups. A TREND simulation, operated on different alternatives with or without subteams, allows a rational choice among them.

B. EXAMPLE OF ORGANIZATION DESIGN FOR CONSTRUCTION PROJECT

In the example of a TREND application to the South African harbor project that we have presented in Chapter 5, a different organizational chart would have probably been more
efficient than the one which was actually adopted (Figure 8).
The TREND map relative to a modified organizational chart is shown in Figure 10; its comparison with that of Figure 8 indicates that the modifications shown could have made coordination easier and less costly.

The Mechanical and Electrical Contractor, whose activities heavily depended on those of the General Contractor and who
thus had a lower real authority assigned by the schedule structure, could have been better positioned as a sub-contractor of the G.C. rather than as another prime contractor. In this way a higher prestige (and concomitant responsibility) would have been conferred to the G.C. to match his higher authority.

The Dredging, Diver, and Tugboat contractors could have been more easily coordinated if they had had the same degree of authority and more direct lines of communication. In particular, the relationship between the Dredging Contractor and the Tugboat Operator would have been improved by such a modification. The Tugboat Operator had, in fact, activities of higher uncertainty on which all Dredger Contractors' activities depended sequentially; it did not, therefore, make much sense to have the Dredging Contractor in a higher prestige position.

The fact that the modifications of Figure 10 were not made may have been caused by a number of valid reasons; for example, specific dispositions from the Harbor Authority might have imposed the condition that the Mechanical and Electrical Contractor be at the same level of authority as the General Contractor. If no constraints existed and the chart of Figure 8 was adopted with no previous examination of all the possible alternatives, however, the coordination activity of the Construction Manager should be defined as inefficient. The additional costs involved in not choosing a better alternative should be fully ascribed to his failure to use
coordination techniques adequately.

C. CONCLUSIONS

We realize that numerous constraints often exist that do not allow any flexibility in the organizational design. Furthermore, even though many changes are possible, they are sometimes not advisable as they could dissatisfy some of the project key-members and decrease their commitments towards the job. We do not therefore believe that the TREND-based simulation procedures are always possible, not that the adoption of a traditional organization based on standard practice is necessarily incorrect. It is important, however, that the adoption of a standard, fixed organizational structure does not constitute the only considered alternative. Other alternatives should be taken into account, and discarded only when proved either less efficient than the standard form, or unfeasible.

We have examined in this chapter the possibility of improving the efficiency of project coordination by an appropriate design of the project organizational chart. The benefits deriving from varying the organizational chart during the job performance in order to meet changing coordination requirements is discussed in the next chapter.
A. INTRODUCTION

We have seen in the last chapter that a considerable increase in Project Management efficiency can be achieved by designing an appropriate organization chart, rather than taking the organization chart as given. The latter approach limits coordinating activities to the adoption of effective integrating mechanisms. An efficient organization design, on the other hand, has all groups and/or individuals whose coordination would require the most costly techniques, clustered into primary units. Furthermore, an attempt is also made, when designing this efficient organization chart, to match group authority and prestige, and hence to reduce conflicts.

Although the design of an organization chart according to the above criteria provides a considerable increase in efficiency, it still has one limitation -- coordination needs usually change through the life of a project. An organization chart adopted for the entire duration of a project cannot, therefore, insure the achievement of the most efficient coordination in each phase of the project.

Variable organization charts, modified at different stages of the project to meet changing coordination needs, enable this limitation to be overcome. The groupings of
subteams are varied to reflect the changes of intergroup activity interdependencies. Furthermore, leadership positions are entrusted, at each project phase, to different groups or persons, in order to keep relative prestige and authority always consistent. The job network indicates, for each phase, which groups perform the most critical activities and thus have more real authority. In order to avoid conflicts, an equivalent degree of prestige -- and hence responsibility -- must be entrusted, for that phase, to those groups.*

Let us consider, for example, a building construction project. The different work phases of a project of this type are generally the following:

- Excavation
- Foundation Works
- Structure Erection
- Placement of Curtain Wall
- Mechanical Installations
- Finishing Trades.

In the first project phase, the most critical activities are performed by the Excavation Team. Since all other trades are sequentially dependent upon the excavation team in this phase of the project, the excavator has a high relative authority. It is important, therefore, that this team is provided with enough prestige to match its authority. The theories underlying this approach to coordination are discussed in Chapter 4.
Project Manager can do so by appointing the leader of the Excavation Team as Assistant Project Manager for the first project phase, with all other groups in lower organization chart locations. That position is then occupied by the leader of the Foundation Team (perhaps the concrete superintendent) when foundation works become more critical. The same procedure is repeated at all subsequent project phases, until one of the Finishing Trade Team leaders becomes Assistant Project Manager for the final period.

B. EXAMPLE OF VARIABLE ORGANIZATION STRUCTURE

A good example of a real application of this variable organization idea is offered by a project performed by the U.S. Army Corps of Engineers in Saudi Arabia a few years ago.

The project consisted of the construction of 24 apartment buildings (Area 1), 80 single family houses (Area 2) and a large warehouse (Area 3). The different teams involved in the project execution are indicated in Figure 11. There was a separate structure-erection team for each of the three areas; the other trades worked on all three areas.
Rather than keeping all the project groups at the same level of prestige during the entire job duration, the organization chart was modified at three different stages of the project to give more prestige to those trades that had to execute the largest number of critical activities in each stage. In each of the three areas, the Earthwork Team had a prominent position in the first phase, the Structure-Erection Team had prominence in the second phase, and the Drywall Team did in the third and final phase (Figure 12).

Excellent coordination results were obtained with this approach, as attested to by Corps personnel who worked on the project.

In this chapter we have examined the possibility of changing the project organization structure at different
FIGURE 12 - U.S. CORPS OF ENGINEERS PROJECT IN SAUDI ARABIA: BALANCED ORGANIZATION CHARTS FOR THREE SUBSEQUENT PROJECT PHASES
stages of a project. A successful application of this technique to a large residential and commercial construction project was described to demonstrate the simplicity and feasibility of using variable organizations in construction. The particular coordination demands of Construction projects will be discussed in more detail in the following chapter.
CHAPTER EIGHT

COORDINATION IN CONSTRUCTION: CONCLUSIONS

A. CHARACTERISTICS OF CONSTRUCTION

Many differences exist between Construction and Manufacturing industries. It seems appropriate to analyze these differences before attempting to examine the applicability to construction of what we have said, in previous chapters, about coordination.

The characteristics of construction whose combination makes this industry so different and unique may be summarized as follows:

Complexity of Products

Many raw materials are generally used and many different types of complicated operations are performed, requiring the employment, in most jobs, of a large number of different, specialized skills. A larger proportion of construction workers are skilled than is true in manufacturing. Furthermore, construction work is relatively more labor intensive than manufacturing work, so labor represents a larger proportion of total production costs.

Immobility of Products

Products are large, heavy, costly and immobile. That involves a number of consequences:

(1) Production is almost always carried out entirely at the job site, prefabrication in a fixed plant being the
exception rather than the rule.

(2) Workers have no fixed stations, in contrast to the "process lay-out" with workers at fixed stations along a moving line of work in progress. The teams with different skills, that we have previously indicated as necessary to perform the various specialized operations, must sequentially intervene in the production process, moving to other areas of the site where they are required as soon as they have completed their portion of work in a certain area. That involves considerable problems of coordination of the different skills, and difficulties in continuously supervising the mobile workers.

Remote Project Location

Logistic problems are associated with the remote outdoor job location:

(1) It is necessary to plan equipment and material deliveries to the job site well in advance, with knowledge that errors can cause a halt in work and consequent high increases in costs.

(2) There are difficulties of communication between line (site) managers and top management, with more responsibilities for site managers.

(3) Adverse weather conditions that have no effect on factory operations can cause a temporary halt in some construction work.

Job Shopping

There is neither mass production nor continuous flow
production in construction. Most construction undertakings are one-time custom-order projects. In a sense a construction firm introduces a new product each time it embarks on a new project. That requires an extreme flexibility in the organization to effectively cope with the unique mix of skills and resources required for each situation.

**Particular Type of Project Organization**

A typical organization for a construction project is shown in Figure 12. We shall consider the role of all the people indicated in this figure from the point of view of the General Contractor and his Project Manager.

![Diagram of construction project organization](image-url)

**Figure 13 - Organization of a Construction Project**
Owner and Architect: They can be considered together, as it is the latter that represents the former in all relationships with the General Contractor. The Architect is appointed by the Owner to develop the project design, assist him in the choice of the General Contractor and supervise the quality of the General Contractor's work. This role of the Architect is unique to construction. Emmerson (1962) comments "In no other important industry is the responsibility for design so far removed from the responsibility for production", and in no other industry -- we should add -- is the control by the client so continuous during the production process.

Subcontractors: The number of subcontractors necessary in any job fluctuates according to the direct labor forces employed by the General Contractor and is generally very high. Often, a General Contractor has only an administrative staff directly employed by him, and subcontracts all of the direct construction work.

The General Contractor has much the same relationships with his subcontractors as exists between him and the Architect. If the Architect has to insure that the General Contractor carries out construction work to acceptable standards of time, cost and quality, so the General Contractor must insure that the work of the subcontractors is appropriately performed. The responsibilities are, however, different; while the Architect does not pay any penalties for halting the job of the General Contractor when he believes it does not meet the
required standards, the General Contractor is directly responsible to the Owner and the Architect for all mistakes and delays caused by his subcontractors. The appointment of the right subcontractor therefore is a very delicate decision. We do not believe that it should be made only on the basis of the lowest bid; a trade-off between subcontractor reliability and proposed fees is more likely to maximise a general contractor's profit.

Once the subcontractor has been appointed, the contract binding him to the General Contractor is the primary tool that the General Contractor has to insure his commitment to the job and induce him to coordinate his activities with those of other subcontractors and of the General Contractor's direct labor forces. The content and the detail of the contract, therefore, have great importance for the success of the whole job.

**Direct labor force:** Construction is probably the industry with the lowest number of permanently employed workers. The need for many different specialized skills in any project means that most of the workers are required only for limited portions of a job. The fact, then, that other jobs of the same Company may be at distant locations does not permit re-employment of the same people on other projects. In each project, a Project Manager has to work not only with new subcontractors
but also with new employees of his own company; that of course makes his planning and coordinating activities more difficult.

One important fact to be noted about both subcontractors and direct labor forces is that in construction, more than in manufacturing, a well-defined level of prestige is associated with each type of skill. Really serious problems arise, in construction, when this prestige is inconsistent with the corresponding real authority.

Job Bidding

The choice of a contractor by the owner may be done in two different ways. The owner can directly negotiate a contract with a particular firm, or - and this is what occurs most of the times - he can put the job out to "open" tender. In the latter case, the contractor submitting the lowest bid is usually accepted for the job. A contractor must therefore keep his costs as low as possible if he wants to, first, get the job and then make a profit on it. As the amount that can be saved in materials and labor is limited, the overhead costs are those that tend to be reduced most drastically; minimum supervision, small project staff and few unsophisticated management techniques result as one of the most striking characteristics of this industry.

Reluctance towards Innovations

Innovations in both technology and management are always introduced in construction with much difficulty. This shying
away from everything which is new is usually explained by saying that innovations, in construction as everywhere else, generally require considerable initial costs, while, in construction more than everywhere else, short run costs must be kept low to get new jobs and make them profitable. In the author's opinion, this is not a reasonable explanation; good innovations, though initially expensive, may in fact provide considerable savings in the long range. It is indeed more a traditional management reluctance towards innovations, rather than the necessity of reducing short run expenses as much as possible, that makes construction the biggest U.S. industry with, however, the least developed technology and management.

B. NEED FOR COORDINATION IN CONSTRUCTION

The above description of the main characteristics of the construction industry clearly indicates that a Project Manager generally has more responsibility and a greater work load in construction than do managers in any other industry. A construction Project Manager does not usually have a large project staff helping him in his job, and the company staff is often too far from the production site (job location) to provide continuous and timely support. Furthermore, the small cost margin left by the necessity of keeping overhead and profits very low does not allow the Project Manager to make big mistakes or to risk job delays without compromising the
The people working in the project have many different specializations and are unlikely to have ever worked together before. A core of old-time employees around which the whole job could be organized does not generally exist, even the direct labor forces are often composed of temporary workers. The presence of many subcontractors and continuous supervision by the Architect certainly do not make the situation any easier to handle.

Coordination seems to be the "name of the game" in construction, even more than in manufacturing. Conflicts are likely to be numerous and must be anticipated as early as possible to find efficient means to avoid them, or, if they cannot be avoided, to have consistent methods established for solving them when they arise. As the size and complexity of construction projects continuously increase, the traditional management-by-exception approach, on which construction has always relied, becomes more and more inadequate, degenerating with growing frequency into management-by-crisis. It is dramatically necessary to predict problems, rather than only tackling them once they have already arisen.

C. APPLICATION OF COORDINATION TECHNIQUES TO CONSTRUCTION PROJECT MANAGEMENT

All the techniques that we have described in the
previous chapters of this thesis may be applied to construction. Construction projects are generally of a relatively short duration, and are often provided with sufficiently detailed CPM's; the two basic conditions therefore exist for a fruitful employment of TREND. Furthermore, the existence of a good network schedule frequently allows the use of TREND with little additional input and, therefore, at very small incremental cost.

The first benefit that a TREND-analysis can give is an indication of the magnitude of the coordination requirements on a given project. The number and type of interdependencies indicated by the TREND-analysis help the Project Manager to better understand what kind of project he is facing, and what kind of coordination approach and effort is, therefore, required from him.

Another significant benefit is furnished by a TREND-analysis, if it is performed prior to the selection of subcontractors. It indicates which of them is going to perform the activities which are most critical to the coordination of the project. If, for example, the analysis demonstrates that a certain subcontractor is going to perform many critical activities, upon which most of the other job activities are going to depend, particular attention should be given to choosing the most reliable sub-contractor for that phase of the work, rather than basing the selection only on the lowest bid price.
The indications about the complexity of the project, and the guidance in the selection of subcontractors, though useful to the Project Manager, are only of secondary importance when compared with the main contribution offered by coordination techniques to a construction project manager -- namely, that of allowing the project manager to design an efficient project organization. When the project organization chart is fixed, the project manager can only use TREND to analyze the predicted intergroup conflicts and to choose the most appropriate mechanisms to avoid them, or solve them promptly when they arise. More efficiency can be achieved, however, when the organization chart is an output of, rather than an input to, the analysis. Different organization charts can be examined by a sequence of TREND simulations. The one that allows the minimum number of reciprocal activity interdependencies, and best matches group authority and prestige, is then adopted.

A higher degree of sophistication and even more efficiency can be achieved by designing different organization structures for different phases of the project. As indicated in Chapter 7, this method is not a theoretical and utopian project management dream; it has already been adopted in construction practice and has proved to be very successful.

Good, usable coordination techniques do, therefore, already exist. It is now up to the construction managers to overcome their traditional reluctance towards everything that
is new, and to start thinking of coordination as the only efficient way to manage increasingly large and complex construction projects.
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