A DECISION SUPPORT SYSTEM
FOR RAILROAD FREIGHT OPERATIONS MANAGEMENT

by

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ABSTRACT

Considerable effort has been spent in applying computers to the strategic management of railroad freight operations. To date, little of this has proved useful, and many railroads continue to rely too exclusively on human judgment. This study seeks the causes behind the failures in order to suggest more effective approaches.

The decisions involved in operations management are reviewed, and the two primary approaches to applying computer aids, optimization and simulation, are examined. The former incorrectly tries to replace human judgment, while the latter, by itself, cannot adequately support needed judgment.

Work by a number of people in applying Decision Support Systems to managerial tasks in other industries suggests an alternative approach, one which focuses on the decision process itself and emphasizes the importance of user involvement in an evolutionary design and implementation process.

A newly instituted interdepartmental operations planning process on the Boston & Maine, currently supported only by data systems and a network simulation model, is examined to determine appropriate areas for additional computer-based support. The creation of alternative operating strategies, now a manual process, is the area of greatest need. A series of tools and techniques, and an overall implementation plan are suggested to support the design phase, and proposals are made to support the design phase as well.

Finally, a number of conclusions are drawn concerning strategies for inducing changes in managerial procedures and for introducing new computer tools to support operations management. These conclusions seriously question many current practices.

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Title: Research Associate

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CHAPTER 1

INTRODUCTION AND BACKGROUND ON OPERATIONS MANAGEMENT

1.1 Overview of the Thesis.

The effective management of freight operations is vital to the health of the railroads as well as the welfare of the public they serve. Operating decisions, both day-to-day or "tactical" and longer-run or "strategic," have a direct impact upon expenses, equipment utilization, and service levels, which, in turn affect market demand, revenues, and the operating ratio.

Computers can be useful in both strategic and tactical management of operations. However, the chief contribution of computers has been, so far, the provision of useful information to those responsibile for the day-to-day operating decisions.* Unfortunately, the two levels of decisionmaking are so different that it is virtually impossible for the computer systems designed to support tactical decisionmaking to be effectively applied to strategic management. Furthermore, the use of computer technology to support the strategic managment of operations is still experimental and sporadic, in spite of the many efforts to develop optimization techniques and simulation models.

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* This is not to say that tactical decisions are supported well. Many of the general assertions and caveats contained herein apply equally as well to efforts to support tactical decisions. The focus here, however, will be upon the strategic management process.

There are several factors contributing to the general failure of computer-based support of operations management at the strategic level. A lack of technical sophistication or accuracy is only one of these. Most problems stem from approaches which ignore the actual process of making decisions and the organizational context.

Too many approaches view the management of operations as solving an engineering problem, while ignoring the political aspects of the process. For some, computer support means automation in the sense of decision replacement. This ignores the central role played by human judgment in most phases of the decision process.

On the other hand, many approaches appropriately support one of the several phases, but do little for the others. Simulation, for example, enables a thorough evaluation of alternatives, but provides little guidance for the design of alternatives and for the actual choice of an alternative.

There has been too little interaction between the system designers and the would-be users. Many have fallen victim to the "Have technique, will travel" syndrome[1] and the temptation to concentrate on the creation of computer systems and algorithms, rather than the decisions to be supported.

An alternative approach, labeled "Decision Support Systems," has evolved through the work and experiences of a number of people applying computer support to managerial decisions in other fields. This approach centers upon the decision process and the decision itself, recognizing that there are fundamental differences between managerial tasks and those highly structured functions where computers achieved their initial successes.[2]

The thesis of this study is that Decision Support Systems can provide appropriate computer based support to strategic operations management. In spite of previous difficulties, the computer-aided design and evaluation of operating/service plans to support strategic decisionmaking remains a desirable goal. The automation of tedious analysis to support managerial judgment is quite technically feasible, as demonstrated by a number of simulation models, but such an effort will be successful only if sufficient attention is given to all aspects of the decision process itself.

The approach will be described, and its application to the support of operations management will be shown to yield a computer system significantly different from any existing tool, one that looks very much like a Computer Aided Design system. Such a system will utilize many existing techniques and will be well within the technical state-of-the-art.

1.2 The Importance of Effective Operations Management.

The effective management of operations is vital to the health of the railroads. Resources must be allocated efficiently. The railroads must deliver competitive levels of service while holding their costs down. Yet the management of operations has, time and again, been found wanting. Task Force VI of the Freight Car Utilization Program, for example, concluded that

> The railroads generally do not know the quality of dock-to-dock service they provide to most of their customers. . . .
>
> Most railroads are not organized in such a manner that service reliability and car utilization are given enough importance in the decision-making process. . . .
>
> Car costs . . . assume little importance when performance is evaluated. . . .
>
> Railroad[s] generally do not have a clearly specified policy relating to shipment movement. Service standards exist for the movement of only a limited amount of selected loaded traffic and for even fewer empties.[3]

Effective management is also vital to the public which must rely upon railroads to provide energy-efficient, economical, and reliable service. However, there has been great dissatisfaction among shippers.[4] Excessive transit times, poor reliability, and unavailability of equipment effectively raise the cost of shipments by rail, requiring more capital to be tied up in goods in transit and extra safety stocks. Some shippers must turn to other modes, even though their transportation costs are higher.

The changing economic environment of today's railroads requires frequent and timely revisions to the operating strategy. Changes in the traffic patterns, both seasonal and long-term, opportunities in new markets, crises in old markets, and problems brought on by regulatory changes all require managerial response. Changes in relative costs arising from new labor agreements, increased fuel cost, car hire costs, and car opportunity costs (particularly in times of shortage) can alter the tradeoffs and possibly require basic changes in the railroad's operations.

An effective capability to manage operations may be of great value in certain strategic decisions. Problems in strategic planning tend to be diverse, perverse, and usually non-recurring. Systematic analysis is often of limited value due to uncertainty in what factors are relevant, how the factors relate to the decision, the unreliability and unavailability of data, and the high cost of acquiring reliable information. Nevertheless, when the decision contemplated will necessitate significant revisions in operations, an understanding of the network behavior of the railroad can be of immense help.

Such situations include investments, mergers, abandonments, and new labor agreements. In making investment decisions, for example, a prudent manager would like to know how the railroad will use a new classification yard before committing scarce resources to the project.* As another example, negotiating a smaller train crew size can sufficiently alter the economics of railroading to require radical changes in operations. These changes, in turn, will affect the predicted impacts upon workers as well as the corporate balance sheet.[5]

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* Between 1966 and 1969, the Southern Pacific invested $400,000 in a network simulation computer model to answer precisely this question in regard to the proposed West Colton yard.[6]

1.3 A Normative Model of Operations Management.

In order to make the management of operations tractable, a good practice is to take a hierarchical approach, creating a relatively static operating strategy, the "operating/service plan," as a guideline for running the railroad and deviating from the plan as required by the daily variations in traffic, breakdowns, and so on. This division of "strategic" operating decisions from "tactical" decisions has the additional advantage of making the consequences of the deviations much more predictable than if everything were ad hoc.

The recommendations of Task Force VI of the Freight Car Utilization Program (Phase I)[7] contained a normative framework for operations management in which an ongoing formalized interdepartmental strategic planning process is supported by measurements of service and other data from a number of information systems, and tactical decisions are supported by their own computer systems.

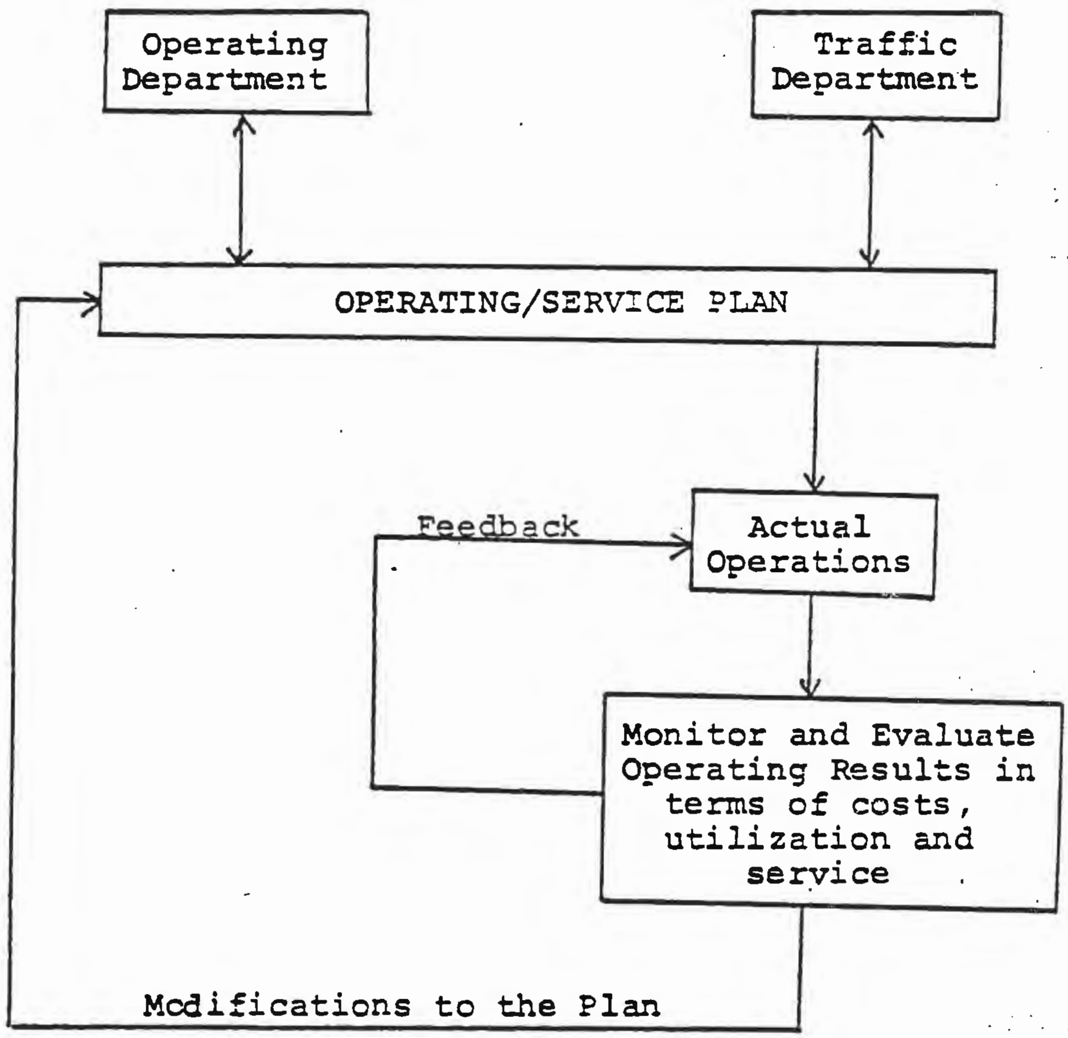
Problems, changing conditions, and human fallibility require an ongoing process able to effectively integrate feedback from the results of service measurement.

The process must be interdepartmental to coordinate projects (e.g., changes in operations and purchase of new equipment) and to achieve a proper balance between service needs and the need to control costs.

There should be an adequately staffed group responsible for the management of service. Ideally, service should be

FIGURE 1.1

DEVELOPMENT AND EVALUATION OF
AN OPERATING/SERVICE PLAN



Source: [8]

measured as the shippers see it, from dock to dock. The operating/service plan should reside within the data system in order to provide standards for the measurement of actual performance.

Data systems should be adequate to support the needs of operations management, not just to provide accounting and traffic data. One should be able to find out not only that a car got from its origin to its destination, but what happened along the way, where it was delayed, the reason for the delay, and the costs involved.

Tactical decisions must adequately reflect the impacts on car utilization and service reliability as well as out-of-pocket costs. Appropriate data systems are needed to aid day-to-day decisionmaking. The ability to exchange data with connecting railroads is a high priority.

This normative model describes the inputs and the outputs, and it points up the need for good information. However, it treats the decisionmaking process itself as essentially a "black box." The next chapter will describe several approaches to the creation and modification of the operating/service plan. The rest of this chapter will discuss the operating/service plan itself and some of the difficulties it poses.

1.4 The Operating/Service Plan.

The product of this process is the key element in operations management, the operating/service plan. An operating/service plan is a set of instructions and standards specifying the methods for handling every car tendered to the railroad and providing for the availability of resources to carry out this task. Elements included in the former are:

- o Blocking strategies
- o Train routing and block to train assignments
- o Train schedules or scheduling guidelines
- o Empty car distribution policy
- o Yard performance standards
- o Nonscheduled local pickup and delivery standards
- o Origin to destination trip time standards

The latter include:

- o Motive power and caboose assignments
- o Assignments of yard, local, and road crews
- o Provision for support personnel

Strategic management requires control over yard operations and local pick-up and delivery as well as line operations. The blocking strategy, train routing and makeup, train schedules, and the empty car movement guidelines specify the operations at the network level. At the local level, yard activities and pick up and delivery operations are quite variable and are not so easily controlled. Performance at the local level is critical to the overall levels of service as well as to the costs incurred, but many railroads attempt to control overall performance primarily at the network level and have no effective means to control the quality of the local operations.

The management of yard and local operations should be decentralized, but the quality of the operations can be controlled centrally by the use of performance standards or by a performance sensitive budget[9] (e.g., but including car hire costs in the local budget and establishing a volume-variable labor budget).

Operating/service plans can be less elaborate, being informal and decentralized. Some may be much more elaborate, including priorities for certain traffic or trains (e.g., priorities for running trains in the event of a power shortage) and contingency plans for traffic fluctuations or emergencies (e.g., instructions for alternative train schedules).

In any event the plan should be complete, providing a plan for the movement of every car, loaded or empty. It must, in fact, be feasible (an attribute not applying to many plans). The plan must achieve a proper balance among investments in plant and equipment, operating costs, and the needs for speed and service reliability. Since traffic volumes can vary significantly over time, the plan must be flexible, that is, changes in traffic should neither inordinately increase costs nor hurt the level of service.

1.5 The Difficulty of Creating Operating/Service Plans.

As can be surmised, the creation of an effective operating/service plan can be very difficult, even with the best information systems available. An operating/service plan involves six major and interrelated decisions which are the primary determinants of system service levels and cost.

The first is the definition of the blocking strategy. One must specify which blocks are to be made where, what their destinations are, and what traffic is to be included in them. Implicit within the blocking strategy are the uses to which all yards will be devoted (e.g., one may be a major reclassification point, while another may be served by a traveling switcher), the yard volumes, and, to a great extent, the requirements for crews and other resources. In some cases, the blocking strategy is taken as a given.

The second is the routing of trains and the assignment of blocks to trains. One block may be carried to its destination by one train, while another may travel on several different trains, being "block-switched" from one to another at intermediate points. There are restrictions on the assignment of blocks to a train. In picking up and setting off blocks, for example, one may wish to minimize the number of cuts at each yard. One may also wish to minimize the number of stops the train makes along the way, since each stop increases the delay and variability of the trip time. Other goals are the assignment of blocks to minimize the requirements for additional power on certain segments and the equalization of volumes across trains to facilitate the cycling of power sets from train to train.

The third is the creation of train schedules. Train schedules and workloads are severely constrained by labor work rules agreements (e.g., crew districts, the dual bases of pay, and crew size), safety regulations (e.g., hours of service and rest requirements), and power availability. If trains are poorly scheduled, line congestion can increase line haul delay and arrival time variability, and congestion at a yard will hurt connection reliability.

Together, the second and third decisions will determine road crew requirements. The number of trains, their routing, and their workload are the primary determinants, but a poor schedule may drive up the requirements by leaving some crews underutilized.

Implicit within train routing, makeup, and scheduling is the fourth major decision, power distribution policy. The key to good power distribution is to eliminate long lay-overs and to reduce peaks in demand.

The fifth is the determination of yard performance levels and the provision for the necessary staff and resources. These can be determined from past history, or if the past performance is unsatisfactory, improved service levels can be mandated by standards. Of course, improvements in performance and changes in the work loads will require changes in assignments for personnel and local power.

The sixth is the empty car distribution policy. One may hold empties at the local yards or send them, according to owner and car type, to regional distribution centers or the owning line. The empty distribution policy will determine, at least in part, the traffic the network must carry. The operating plan will determine the relative costs of sending cars from one location to another. Since the costs of moving cars are important in formulating a distribution policy for empties, these elements of the operating plan should not be considered in isolation.

The combination of these six decisions has a decided impact upon yard operations, the utilization of power, crews, and other resources, and the resulting levels of service and costs. These decisions cannot be made separately. Each decision strongly affects the others, and all are interlinked with the other elements of the operating/service plan.

For example, the assignment of blocks to trains and the train schedules affect the delay and reliability of the train to train connections and the volumes carried on each train as well. It is desirable to assign the blocks to trains and set departure times to minimize the waiting time in the yards. However, this conflicts with the need to equalize train volumes and to adjust the schedules in order to reduce motive power distribution problems.

Additionally, the scheduling of outbound and inbound blocks at each yard can have profound effects on yard operations. Concentration of arrivals and departures causes congestion, delay, and the inefficient use of resources.

As another example, once blocks are assigned to trains, it may be discovered that the yard blocking should be redefined. There are restrictions on the number of blocks which can be "block switched" as well as the number of blocks which can be made at each yard. If it becomes necessary to reclassify a block at a hump yard, then the advantage of creating that block at a preceding yard will disappear.

1.6 Implications for Computer Support.

The management of freight operations should be done in conjunction with market planning, and both require a detailed understanding of the interactions among the many variables under management control. Virtually any change in the operation of a rail network will have effects which propagate throughout the system. An improvement in one area may create deleterious and unforeseen side effects in other areas.

Of all the tasks in the strategic management of operations, the evaluation of alternative operating plans is the best understood. Evaluation is a highly structured task; definite procedures can be developed so that analysis does not have to proceed *de novo* every time. Given enough information about the characteristics of the railroad and its market environment, one can, in principle, analyze any plan and predict its likely effects on costs, service levels, and other performance measures. This is possible because we understand and can model the major interactions among the elements of an operating plan, the physical structure of the railroad, and the market demands placed upon it. For this reason, most efforts to use computers in the strategic management of operations focus on the evaluation of operating plans; these are the simulation models, discussed in the next chapter.

However, the process of creating a good operating plan is not so well understood. There are a few rules of thumb, but no algorithms for producing an optimal plan. Human judgment, based on experience, dominates, but there is some structure to the process, making the use of some sort of computer-based aid possible.

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CHAPTER 2

THREE APPROACHES TO MANAGING OPERATIONS

2.1 Introduction.

There are three archetypical approaches to strategic operating decisions:

- o Use simple analysis as a guide, but regard management of operations as essentially an art.
- o Create a simplified model of the railroad, decompose the model into subsystems, and use the methods of Operations Research/Mathematical Programming to find an "optimal solution" for one or more of the six major decisions involved in creating an operating plan.
- o Create a less simplified model, and simulate the railroad on a computer.

These pure archetypes are rarely found in reality, but they characterize most of the actual approaches used.* This chapter will examine the strengths and weaknesses of all three approaches.

2.2 Regard it as an Art

There are many who regard operations management as an art in which analytical techniques can be only of very limited

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* The Canadian National CANAT system is a notable exception and will be discussed later.

value. Alfred E. Perlman,[1] for one, in the midst of the true believers gathered at the Fourth International Conference on Railroad Cybernetics, was an atheist who "vigorously questioned the cost-effectiveness of cybernetics, automation and the use of models, which he said, were no better than good, common sense."*

There is some merit to this view. Railroads obviously functioned for over a hundred years relying on human judgment unaided by computers. The complexity of the interactions among the many decisions renders simple analytical approaches inadequate and rigorous analyses intractable.

The management of a railroad system is somewhat analogous to playing chess: The moves and the rules of chess are simple enough to be learned in an hour, but, to date, no computer program has proved capable of surpassing the best human players.

2.2.1 A Lack of Information. The artistic, intuitive approach may be required, in fact, by the general paucity of management information. Most railroad data systems are insufficient to provide information relevant to strategic decisions, even though they have been relatively successful in supporting the day-to-day decisions. Task Force VI of the

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*Perlman was probably not impressed by Allman's early simulation model, which was calibrated on the New York Central while he was president. Also the quotation is from 1974, and Perlman was fresh from a disastrous experience with a computerized car location system at the Western Pacific.

FCUP found that, in general, railroads did not even have accurate measurements of the quality of service provided to most of their customers.[2] The Task Force also concluded that

> Operating Department personnel are often unaware of the data that could be made available to them from the railroad computerized data system. Equally important is the fact that these personnel are often not sure what they want from the data system, since access to such large amounts of data was not feasible prior to the advent of modern management information systems. Because the data system is not generally fully utilized, there is less incentive for personnel in the field to assure that data input is complete and accurate.[3]

2.2.2 Sloughing off Information. On the other hand, the artistic approach actually requires that much useful information be discarded. Although relevant information can be identified, there is great uncertainty over how it should be used in decisionmaking. Further, the human mind is incapable of integrating the vast amount of information which is determined to be relevant. The managers must decide which information is the most useful and ignore the rest.

2.2.3 Incrementalism. Many railroads have adopted the Lindblom model of disjointed marginal incrementalism or "muddling through." If important information is unavailable or not enough is known about the interactions among the many policy variables to accurately predict the consequences of radically different alternatives,

> [a] wise policy-maker consequently expects that his [sic] policies will achieve only part of what he hopes and at the same time will produce unanticipated consequences he would have preferred to avoid. If he proceeds through a succession of incremental changes, he avoids serious lasting mistakes in several ways.

> In the first place, past sequences of policy steps have given him knowledge about the probable consequences of further similar steps. Second, he need not attempt big jumps toward his goal that would require predictions beyond his or anyone else's knowledge, because he never expects his policy to be a final resolution of a problem. His decision is only one step, one that if successful can quickly be followed by another. Third, he is in effect able to test his previous predictions as he moves on to each further step. Lastly, he often can remedy a past error fairly quickly--more quickly than if policy proceeded through more distinct steps widely spaced in time.[4]

This strategy uses fairly simple models to develop alternatives which are tested on the railroad itself, a fairly expensive means of evaluation. There is also the difficulty of distinguishing muddling through from incompetent muddling. (Martland[5] has suggested that in most cases there is a strong resemblance between incremental changes in operating strategy and Brownian motion.)

There are more fundamental criticisms resulting from the nature of railroading and its economic environment. Incrementalism cannot respond adequately to major changes in the environment. Economies of scale and indivisibilities mean that small changes in traffic or costs, for example, may necessitate major revisions in operations. The restriction of alternatives to marginal changes in the status quo is however, inherently conservative and inadequate.

For example, several months into the Boston & Maine Case Study,[6] it became apparent that the Operations Department was more interested in making marginal adjustments to certain trains than in considering more fundamental alternatives.

This temptation was resisted by the other participants. The interdepartmental planning group, with the help of MIT, extensively analyzed four major operating alternatives, and, in 1979, the B&M joined the Freight Car Clearinghouse and implemented a new operating plan which simultaneously eliminated several yards, created through blocks for overhead traffic, increased train frequency for east-west traffic, added two new train routes, and made several other changes. The simultaneous implementation of these changes would not even been considered before the case study.

A railroad could conceivably move incrementally toward such a radical alternative. However, the initial steps would probably make the situation worse, causing such a goal to be abandoned.

Incrementalism cannot respond quickly enough to a rapidly changing environment. Since feedback is required before each change in operations, an effective operating policy will always lag behind a dynamic environment.

An appropriate response for times past may not be a good guide for the future. Last year's traffic patterns will not be repeated. The present cost structure is different from that of the past. External factors, such as fuel shortages or strikes, will present singular market opportunities. An unwilling shipper may be converted by the railroad's responsiveness, but if service deteriorates under an increased workload the opportunity will be lost. On the other hand, if the incremental changes maintain the level of service, one may find that the cost has been higher than necessary. Incrementalism may be able to respond quickly, or it may provide inexpensive service, but probably not both.

2.2.4 Conclusions. This approach properly gives a crucial role to human judgment. It does not attempt to quantify the unquantifiable or to gather nonexistent data. It is efficient in terms of effort per decision; in fact, many decisions can be avoided completely if the problems are below a certain threshold of importance.

However, the artistic approach is ineffective. It does not take advantage of valuable information which can be supplied by detailed analyses. The resulting decisions can be far from adequate.

2.3 The Operations Research/Mathematical Programming Approach.

There is obviously much structure to the management of railroad operations. Operations Research takes advantage of this by creating a mathematical model of the structured part which can be analyzed in order to find an "optimal" solution. This method has the great advantage of being able to evaluate a large number of alternatives and has been effective in solving large problems with well defined structures, such as refinery scheduling.

2.3.1 Optimization Models. An optimization model consists of two parts, the formulation of the problem and the techniques to solve it. The problem statement must specify an "objective function," that is, a quantity to be maximized or minimized (profit, cost, total transit time, etc.) as a function of the resources under a manager's control. This requires that the objectives of the firm be specified in advance. The second part of the problem statement is a series of mathematical equations describing the relations among all the elements of the system and the constraints imposed, such as maximum number of blocks which can be formed at each yard or the minimum block size.

The solution techniques may be standard general purpose algorithms, which are embodied in a number of commercial computer software packages, or they may be developed specially to solve the problem. Often the latter are heuristic search techniques which, though not guaranteed to find the "optimum," will generally find a "good" solution.

Even after the non-quantifiable aspects have been ignored, railroad operations are still too complex for the optimization techniques to handle. The problem is therefore decomposed into pieces which can be more readily modeled. For example, the problem of empty car distribution is easily split off, and many people have attacked it with optimization techniques.[7] Others[8] have split off the problem of creating a blocking and routing strategy, with some success.

2.3.2 <u>The University of Maryland Blocking Model</u>. As an example, the University of Maryland blocking model[9] is worthy of note, since it may be the most ambitious effort to have been actually tested. The model is formulated as a cost minimization problem:

Minimize:

$$Z = (\text{Line Haul Cost}) + (\text{Yard Cost}) + (\text{Yard Delay Cost})$$

where

$$\text{Line Haul Cost} = \sum (\text{Block}_i \text{ Unit Cost})(\text{Block}_i \text{ Volume})$$

$$\text{Yard Cost} = \sum (\text{Yard}_j \text{ Proc. Unit Cost})(\text{Yard}_j \text{ Volume})$$

$$\text{Yard Delay Cost} = \sum F(\text{Link}_k, \text{Link}_k \text{ Volume})$$

The delay function, F, attempts to approximate the train makeup effects on yard time. It assumes that for any yard the number of departures along each rail link is an integral function of the volume leaving the yard in that direction.

In addition to Kirchoff's laws applied to the flows into and out of the yards, the model accomodates several constraints:

- Yard volume constraints.
- Maximum and minimum block size constraints.
- Maximum number of blocks which can be made at each yard.
- Assumption that no destination can be assigned to more than one block.

The model was tested on the Norfolk & Western, and the equations were solved using a standard mathematical programming software system. The results indicated two or three marginal changes to the existing blocking plan. After review by the railroad these changes were made.[10] The solution was quite difficult and required much manual intervention by the analysts in the form of suggested changes to the blocking stragety.[11]

Like all optimization models, the University of Maryland model simplifies parts of reality and ignores others. These may be either minor or serious problems, depending upon one's point of view. Since the model does not assign blocks to trains, route trains, or schedule trains, it cannot consider costs which depend upon these decisions, e.g., the fixed costs of running trains (mostly crew costs), line haul costs which very with the number of pickups and setoffs, yard delays which vary as a function of available connect time, and so on. Also it cannot recognize the delays due to block switching (or, alternatively, the cost savings resulting from preblocking).

It does not take the fixed costs of yard operations into account, but assumes that all yards will be used regardless of volume. Except under extreme circumstances it will not indicate that a yard should be closed. Although it will allow yard volume constraints, it does not consider the yard congestion costs which mount as these limits are reached.

2.3.3 Conclusions. Optimization models are powerful tools capable of evaluating a large number of alternatives. Conceptually, the cost is that one must settle for an optimal solution to an abstract problem, which may or may not be a good solution to the real problem. It may, in fact, be infeasible in the real world.

One must be prepared to live with some rather heroic assumptions. For example, linear cost functions, linear yard time functions, and uniform arrival distributions abound. In reality costs are nonlinear, yard time is nonlinear and dependent upon a variety of factors, and cars arrive in bunches in a peaked random distribution. It is precisely the fact that the assumptions do not hold which gives managers headaches and makes operations planning a management task.

There is also the need to specify, at the outset, the objective function. Like virtually all real management problems, rail operations management involves a number of conflicting criteria. Optimization implies a consensual utility function involving multiple criteria, which, at best, is very difficult to define.

Mathematical Programming has probably been oversold. Optimization models may be elegant to their creators, but they are bewildering to those asked to rely on them. There is some evidence questioning even its alleged successes.* Neverthe-

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* Refinery scheduling is a classic case of the application of mathematical programming. Little,[12] however, related the following anecdote which casts doubt on its real world efficacy:

> The OR Group of a major oil company recently did a survey on the use of mathematical programming in production scheduling at their refineries. Refinery scheduling was a pioneer application of mathematical programming and has been an active research area for 10-15 years. At one refinery the dialog between the interviewer and the plant OR analyst went somewhat as follows:
>
> Interviewer: "Do you make regular mathematical programming runs for scheduling the refinery?"
>
> Analyst: "Oh yes."
>
> Interviewer: "Do you implement the results?"
>
> Analyst: "Oh no!"
>
> Interviewer: "Well, that seems odd. If you don't implement the results, perhaps you should stop making the runs."
>
> Analyst: "No. No. We wouldn't want to do that!"
>
> Interviewer: "Why not?"
>
> Analyst: "Well, what happens is something like this: I make several computer runs and take them to the plant

less the techniques may be valuable in creating a number of different alternatives which can be improved by human judgment. They also may be used, if tightly controlled, to fill in the obvious details of an incompletely specified operating plan, saving no small amount of human effort.

2.4 Simulation.

Since the application of optimization techniques requires an untenable simplification of the real world, it is not surprising that most model builders have focused on simulation. Simulation can represent a truer picture of reality than that found in optimization models. Even so, simulation embodies a great number of assumptions which limit any given model to only certain policy areas.

There are presently basically two types of railroad network simulation models: Those which simulate events in chronological order and those which do not. The first class contains all except the MIT Service Planning Model (SPM). These may be either deterministic or Monte Carlo models, and many follow the yard activities and the movements of individual

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manager. He is responsible for this whole multimillion dollar plumber's paradise.

"The plant manager looks at the runs, thinks about them for a while and then sends me back to make a few more with conditions changed in various ways. I do this and take them in. He looks at them and probably sends me back to make more runs. And so forth."

Interviewer: "How long does this keep up?"

Analyst: "I would say it continues until, finally, the plant manager screws up enough courage to make a decision."

cars on trains in great detail. The second class, of course, contains the SPM, which uses analytic techniques to estimate and combine the probabilities of various events taking place.

Railroad simulation models have been in existence since 1966 and have been used, with varying degrees of success, to aid both strategic and tactical decisionmaking. In spite of the optimistic tone of the early reports, simulation has had a rough time on the railroads, producing more papers and theses than successful applications (by an order of magnitude). Folk[13] and Baker[14] have reviewed most of the early network simulation models, some of which had already been shelved. Two of the more famous of these, the Allman and AAR models will be described below along with three newer efforts, the MoPac CARS/YARDS model, the GTW/SRI Dynamic Movement Predictor, and the MIT Service Planning Model. Of these, only the MIT model has been recently used in the development of an actual operating/service plan. The Norfolk & Western, however, did use the AAR model recently in strategic operations management, to evaluate the general strategy of running shorter trains. The AAR may have a more active role in operations planning in the future.

2.4.1 <u>The Allman Model and Its Progeny</u>. In 1966 Allman[15] created the first network simulation model, which he tested on the New York Central, simulating 20 yards and 85 trains. The Frisco[16] picked it up, modified it, expanded it, but finally abandoned it in 1969, spending $400,000 in the process. In the meantime, the Canadian National[17] obtained the Allman-Frisco model and expanded it to include 500 nodes and 200 trains, but likewise abandoned it.

2.4.2 The AAR Model. The Association of American Railroads Network Simulation System,[18] developed in 1970 by the Midwest Research Institute, was to have been a general purpose model suitable for use by a number of railroads.

> Furthermore, the AAR model was to use the experience with existing models as a basis for developing advanced techniques to minimize computer costs; to have capability of representing components at different levels of detail; and to maximize user convenience.[19]

These goals were not realized, however.* The model was, in fact, difficult to use, requiring great effort to assemble the needed data base, and the initial version was rather costly in terms of computer time. Its first successful application did not come until 1974 when the model was used in Phase I of the St. Louis Terminal Study.[20]

Both the Southern Pacific and the Norfolk & Western have extensively modified the model to add flexibility, ease the data input problems, and produce more useful reports. In 1975 through 1976, the N&W used the model to help plan operations

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* The AAR model was first tested on the Chessie System. To simulate a part of the system, 30 yards and 36 trains, required seven calendar months and the help of several graduate students to prepare a 6000 card input deck. The project was abandoned after the students graduated.

The Illinois Central, after similar travail in assembling the input, simulated the Iowa Division, but gave up upon discovering that the entire network of 84 nodes and 112 trains would exceed the memory of their 360/65 (512K). Similarly, the Canadian Pacific gave up after spending one and a half years describing its network.

after the acquisition of the New Castle line.[21] The model fell into disuse until it was revived in the summer of 1979 for an early 1980 study of the feasibility of running shorter trains. Its principal user, Dr. William Romig, expects to use it again in the near future and reported that after a number of modifications, the cost per run is down to about $100.[22]

2.4.3 <u>The MoPac CARS/YARDS Model</u>. The Missouri Pacific's CARS/YARDS model,[23] possibly the most recent effort, was the subject of a glowing report at the 1979 Annual Meeting of the AAR Data Systems Division. However, MoPac management remains unconvinced of its utility, and the model remains dormant.[24]

The model apparently simulates actual operations well, giving detailed scenarios of yard and train activities, which closely parallel reports generated by the online Transportation Control System. There are, however, no reports detailing trip times or service reliability.

2.4.4 <u>The GTW/SRI Dynamic Movement Predictor</u>. The Dynamic Movement Predictor (DMP),[25] developed for the Grand Trunk Western by SRI International, is significant in that it is the first attempt to utilize network simulation specifically for tactical operations planning. Linked to a real-time, on-line data base, it is used at the beginning of each shift to provide a forecast of future events and to evaluate the effects of temporary modifications to the operating plan , e.g., canceling a train. It is a somewhat more sophisticated approach to tactical operating decisions than provided by the MoPac Freight Car Scheduling (FCS) system.[26] The DMP was briefly tested in 1977. It was not used operationally until 1979 when it was reinstalled to model a 158 mile stretch of the GT Flint Subdivision, with plans to eventually extend it to the entire system.

Although its builders alleged its usefulness in investment and strategic operating decisions, this is questionable. It is a deterministic model and therefore is incapable of estimating origin to destination transit time reliability. In fact, its current incarnation makes no predictions of transit time at all. The yard modeling is seriously deficient. Although it will not overload a train, it uses a yard cut-off time (as does the MoPac FCS system) to determine whether ot not a connection can be made. Therefore a small change in scheduling can result in an absurdly large change in performance.* It also makes no distinction between sorted and unsorted cars arriving at the yard and therefore cannot be used to evaluate preblocking strategies.

2.4.5 <u>The MIT Service Planning Model</u>. The MIT Service Planning Model (SPM) was created in 1978, primarily by McCarren and Stiles.[27] It was used that year by the Boston and Maine[28] to help evaluate four major operating alternatives and to create service standards for the plan finally selected.

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* Thus the DMP lacks the important attribute of robustness (see Little's list of desirable qualities in section 3.4.1).

It is still being used for that purpose by B&M, and MIT is now applying it to the Santa Fe to study long-range investment alternatives as well as operating strategies.

The SPM differs from the other simulation models in that it does not simulate events. Neither does it delve into the internal workings of yards or the mechanisms of line haul delays. It simply uses train schedules and yard performance parameters, which are estimated by analysts, to estimate the probabilities that connections will be made.

The simple yard submodel makes use of PMAKE functions (Probability of Making a connection),[29] which are conditional probability functions. That is, PMAKE is the conditional probability of making a connection to a certain outbound train given that all previous trains have been missed. (A more detailed explanation may be found in Appendix A.)

Using these probabilities and the train schedules, the SPM calculates the expected distributions of origin to destination trip times and the average block voluems, train volumes, and so on.

This approach has much merit, even though there are limitations (e.g., the railroad must, to some degree, use train schedules, and there are many phenomena which are ignored) and this particular implementation has some problems (e.g., it simulates a typical <u>day</u> rather than a typical <u>week</u>, and memory requirements get out of hand for large networks). There are a number of advantages:

First, and most surprising, the results are more accurate than many other network models.*

Second, there are less empirical data to collect, and it is easier to select parameters; it is not necessary to know <u>why</u> a yard behaves the way it does, only that it <u>does</u>.

Finally, it is computationally simple. Even though the programming was done in FORTRAN by novices, computer cost on a DEC VAX (a top-of-the-line minicomputer) is typically $25 to simulate a 30 yard network with 30 trains.

2.4.6 <u>Conclusions</u>. Simulation is probably the most widely used computer-based technique for supporting managerial decisionmaking in both government and industry. While optimization tends to concentrate on powerful techniques and abstract models, which managers generally find unrealistic and recondite, simulation is usually easier to follow. The great advantage of simulation is its ability to replicate the manager's environment on his or her own terms and to help evaluate a relatively small number of alternative actions to a great depth of detail.

The disadvantages are that someone has to collect information for a data base (which may be rather detailed) and create the alternatives as well as interpret the simulation results.

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* This may be attributed to a certain amount of humility on the part of the model builders in that they did not pretend to know more than they really did.

As mentioned previously, some modeling efforts have foundered upon the data base. The creation of alternatives is still a largely manual process. Simulation can evaluate an operating plan, but evaluation alone can give only limited guidance for improvement. Finally, poor performance measures and report formats have been a great problem. The SP and the N&W, for example, worked hard modifying the AAR model to produce the information they needed in the format they wanted. Usability of the output may be, in fact, the major problem with the MoPac model.

The state-of-the-art has progressed considerably. Advances in computer technology have mitigated the computer memory constraints and the excessive computational costs which plagued early models. The technology of rail network simulation is now understood well enough, even though some models have performed poorly. There now exist a number of technically competent models to choose from, and the weak points of one are often the strong points of another.

2.5 Summary

There are three basic approaches to decisionmaking in railroad operations management: To regard it as an art, to use optimization models, and to use simulation models.

To regard management as an art recognizes the limits of analysis and the importance of human judgment, but this approach is ineffective. It is too ready to discard the imperfect but valuable information which can be supplied by the detailed analysis of operations.

The optimization approach recognizes the structured aspects of operations and takes advantage of the speed of computers in generating and analyzing alternatives. However, optimization models tend to be unwieldy and inflexible, requiring that reality be simplified and judgmental factors be either ignored or replaced by simple mathematical formulae.

The third approach, simulation, builds upon the first by replacing experimentation with the actual railroad by experimentation with a computer model of the railroad. It recognizes the inadequacies of the first and the futility of the second, but it fails to take full advantage of computer power to assist human judgement in the creation of alternatives.

In the past, both computer-based approaches have tended to focus on the creation of artifacts, i.e., mathematical models and computer programs, rather than the decision process to be supported. Although these projects have produced a number of valuable ideas, none of these reviewed are themselves particularly appropriate for the management of operations. Optimization attempts to replace human judgment, but simulation needs to go further to support it.

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CHAPTER 3

THE DECISION SUPPORT SYSTEM APPROACH

> DSS offer an opportunity that is both trivial and immense--immense in that they can embed the computer in decisionmaking activities where they provide large payoffs and trivial in that they represent no major advance in technique.[1]

The accumulation of problems and failures in providing computer support to managers is not unique to railroads. It has, happily, prompted a redirection of effort, falling under the rubric, "Decision Support Systems." The term itself is used in several ways (sometimes ambiguously, but usually apparent from the context), meaning a computer-based management tool, the decision system within which the tool is embedded, a field of endeavor, or, perhaps most importantly, a new approach.

3.1 A Crisis in Management Science.

Spurred by McNamara and RAND, systems analysis became the dominant normative model for decisionmaking for several years. Its alleged successes in the Department of Defense prompted numerous efforts to analyze social problems as well, and President Johnson, in 1965, directed that PPBS (Planning-Programming-Budgeting-System, a systems analysis technique) be adopted by all federal agencies.

If the early sixties was the "Golden Age" of systems analysis and management science, then the late sixties became the "winter of our discontent." The apotheosis of systems analysis was marred by many dissidents, some working within the profession itself. In the same year that Johnson enshrined PPBS, Heany,[2] questioned whether management science practitioners were, in fact, addressing relevant management issues. Others (Hoos[3] and Sapolsky,[4] for example) questioned whether the grand successes were, in fact, successes at all.

The demoralization became apparent in the 1971 meeting of the Institute for Management Science (TIMS)[5] where six true believers discussed the sorry state of their profession. The blame was laid to a monomaniacal obsession with technique, or applied mathematics, which resulted in "a trained incapacity to think."

A recent survey of managers in six corporations by Alloway et al.[6] indicated a great mismatching of computers to managerial tasks. The survey asked managers to identify their three most important tasks, what type of computer support they received for these tasks, and what type would be most appropriate. (Table 3.1) A simple taxonomy of four types was used--monitoring, exception reporting, inquiry, and analysis systems. One third of the managers' most important tasks were not supported at all, and only one fifth were supported by an appropriate system.

3.2 Decision Support Systems.

As an outgrowth of this turmoil, DSS represents a "back to the basics" movement, that is, a radical approach. The first priority becomes the analysis and understanding of the

TABLE 3.1

RESULTS OF THE ALLOWAY USER NEEDS SURVEY

Installed System Types for Important Tasks

	none	monitor	exception	inquiry	analysis	total
number	79	120	9	12	9	229 [sic]
percent	35%	52%	4%	5%	4%	
number of appropriate type	0	30	1	8	7	46
percent	0	25%	14%	66%	78%	20%

Definition of System Types:

monitor — the system monitors daily detail activity producing standard reports on a fixed schedule (daily, weekly, or monthly).

exception — the system processes daily detail activity but produces exception reports where the definition of exception conditions is fixed.

inquiry — the system provides a data base with flexible inquiry capability enabling managers to design and change their own monitoring and exception reports.

analysis — the system provides powerful data analysis capabilities (modeling, simulation, optimization, or statistical routines) and the appropriate data base to support managerial decisionmaking.

Source: [7]

decision process rather than the development of normative mathematical theory or sophisticated computer programs. One must recognize that the systems designed to aid managers in relatively complex and nonprogrammed tasks must be qualitatively different from those used to automate clerical functions and information processing.

3.2.1 Goals. DSS has three general goals[8] which set it apart from traditional applications of computer technology:

First, to assist managers with semi-structured tasks, that is, decisions in which there is enough structure for computers and analytical tools to be of use, but where managerial judgment is still essential.

Second, to support rather than replace managerial judgment. To provide a supportive tool controlled by the decisionmakers, which does not attempt to automate the decision process, prescribe objectives, or impose solutions.

Third, to improve the effectiveness of decisionmaking by extending the range and capability of the decision process, rather than to improve the efficiency.

3.2.2 Mechanisms. The value of computers in automating clerical tasks and in collecting and disseminating information is well known. Judicious use of computer-based support can aid railroads through several other mechanisms as well. The following list* may suggest goals which should be consciously

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* This list is not unique. See, for example, Alter.[9]

sought in applying computer support to the management of operations.

1. Facilitating Interdepartment Communication. Interdepartmental planning is the *sine qua non* of rational decisionmaking. The introduction of computer tools cannot force it, but a DSS can facilitate the group process by providing information and analyses which serve to focus the group's efforts, and by helping the participants explore the logical consequences of their ideas and insights.

The use of computers requires that the assumptions and date of the various people be made explicit, on the table for all to see, criticize, and negotiate. This can be very beneficial, but there is a danger here. In a very real sense, data is power and may not be given up easily. Also, the artists in the organization may be either unwilling or unable to yield the secrets of their art. (This is not to deprecate their competence; in many professions the better practitioners are less able to articulate their methods.) Implementation should not force to overcome these problems. Rather, they should be considered, at least initially, to be real limits to the applicability of computer technology.

The ability of computers to generate mountains of paper can be put to good use, printing well-designed reports, summaries of data, and descriptions of the alternatives being considered. The reports and analyses can also be useful in communicating and defending the decisions themselves to others within the organization.[10]

2. Change in Orientation of Managers. By making inter-realtions between the various departments explicit, for example, one can expect a move from a narrow departmental cost minimization strategy to a general awareness of the importance of the cost-performance tradeoffs.

By providing a structure which can incorporate a variety of phenomena, managers may find themselves considering important factors which were previously ignored either because their importance was not recognized or because their evaluation was too costly in terms of dollars or managerial time.

3. Development of Objectives. An important flaw of the OR/MS "rational actor" model of the decisionmaker is the assumption that objectives can be articulated prior to analysis. One important use of a DSS is to discover appropriate objectives through analysis.

One often finds prescriptive models of decisionmaking which look something like the following:

1. Definition of objectives.
2. Formulation of measures of effectiveness.
3. Generation of alternatives.
4. Evaluation of alternatives.
5. Selection of plan for action.

Sometimes this is expressed as a flowchart, with clean lines proceeding from one box to the next. The mathematical programming approach to decisionmaking proceeds in exactly this manner.

However, real management decisions, though involving these activities, do not and cannot proceed through the steps in sequential order. March, a repentent member of the OR/MS priesthood, has suggested that it is

> perfectly obvious that a description that assumes that goals come first and action comes later is frequently radically wrong. Human choice behavior is at least as much a process for discovering goals as acting on them.[11]

At the outset of analysis, one may not know what one's objectives should be,* and one will certainly not know what the appropriate tradeoffs among objectives are. (In balancing costs against service in a certain market, for example, the value of time should be dependent upon the profitability of the traffic and the elasticity of demand with respect to transit time.) Additionally, in an interdepartmental planning process, considerable disagreement over objectives must be expected.

Any approach which requires a prior agreement on objectives must be considered anathema. Simulation, however, can be an effective means for learning about the operation of the railroad and for clarifying appropriate objectives. This requires that effort be invested in making simulation easier to use. Analysis of alternatives using simulation has the additional advantage of avoiding the need to agree on objectives by structuring the decision process so that only agreement on actions and expected results is necessary.

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* The maximization of long-run profits may be considered an objective, but it is rather worthless since it gives only the vaguest guidance for action, e.g., buy low & sell high!

4. Timely response. The elimination of bottlenecks will give greater continuity to the process. By shortening the time it takes to reach a decision, it will be possible to respond effectively to seasonal and shorter term fluctuations in traffic with more specific solutions. When problems arise, it will take less time to implement a good solution, reducing the length of time the problems remain.

5. Exploration of more alternatives. By reducing the cost of analyzing an alternative, it will be possible to consider more of them, increasing the expected benefits of the best alternative. Similarly, techniques borrowed from optimization models and other heuristic methods can be used, within limites, to generate more alternatives.

6. Greater depth and accuracy in evaluation. By providing a structure to relate various phenomena, a computer-based model can take more variables and options into account than is possible with informal models and back-of-the-envelope calculations. The advantages of the computer in performing lengthy calculations are obvious.

7. Incorporation of Judgments into Analysis. There is no reason why subjective estimates cannot be treated like any other data. Little[12] has suggested the concept of a "decision calculus" to formalize the process. The MIT Service Planning Model does, in fact, utilize subjective estimates of important parameters.

3.3 Decision Support Systems as an Approach.

Creating a DSS is more than plugging in a computer system. The basic purpose is to enhance the effectiveness of decisions. This may very well alter the nature of the managerial tasks themselves, as well as require basic changes in the decision process and the organizational structure.

Design must focus on the decision process itself, and implementation must be recognized as a process of social change.

3.3.1 Focus on the Decision.

Probably the primary characteristic of the DSS approach is its decision-centeredness. This is in contrast with the machine- or data-centeredness of other approaches.

Analysis begins with a description of the current process. What are the key decisions? Who is involved? What are these people like? What are the procedures? What data, models, and heuristics are used? What is the organizational structure? Who has the power? Who will gain and who stands to lose in a change? The politcal questions are actually very important. Many fine efforts have failed as a result of ignoring the intra-organizational political struggles.

The process should be analyzed from several points of view in order to diagnose the situation and prescribe normative models of decisionmaking. At the same time one must develop the strategies for implementation, coalition building, and so on. Keen and Scott Morton[13] have suggested five useful points of view. None of these are adequate by themselves, but together they can cover most of the important issues in diagnosing the process.

1. The economic, rational concept: this is the classical normative theory of decisionmaking, in which decisionmakers are all-knowing and able to evaluate all alternatives. They are dissatisfied with any solution but the best.

2. The satisficing, process-oriented view: this considers decisionmakers to be intendedly rational although cognitive limits lead to a bounded rationality; thus the goal of any decisionmaker is to get a good enough answer, not the best possible one. This point of view stresses the process of decisionmaking and not just its outputs; it emphasizes the relatively limited analysis and search most managers will make and their reliance on heuristics.

3. The organizational procedures view: this focuses on the interrelations among components of the organization. It highlights organizational structure, mechanisms for communication and coordination, and the standard operating procedures by which decisionmaking is systematized and often simplified.

4. The political view: this regards the participants in the decision process as actors with parts to play. They have strong individual preferences and vested interests and form coalitions of organizational subgroups. Decisions are frequently dominated by bargaining and conflict, with the result that only small deviations from the status quo are normally possible. Major innovations are (quite reasonably) resisted by those whose position, interests, or simply job satisfaction will be affected.

5. The individual differences approach: this view argues that an individual's personality and style strongly determine his or her choices and behavior. Personal "rationality" is subjective and behavior is very much determined by the manner in which an individual processes information. [14]

The development of normative models is the next key step. The rational actor concept of decisionmaking, although unsupported by empirical evidence, can define the logic of choice.

It can help show the direction that change should take, but not the destination. A number of normative models and designs should be developed, drawing from the user-managers themselves, their own managers (who may in fact have initiated the effort), theory and research, consultants, academics, and so on.

The use of normative models has several side benefits, as identified by Keen and Scott Morton:[15]

1. It helps clarify the choices and risks involved and ensures commitment and realistic expectations.

2. It allows the multiple theoretical, political, and organizational viewpoints to be explicitly compared in that each of them implies a design choice.

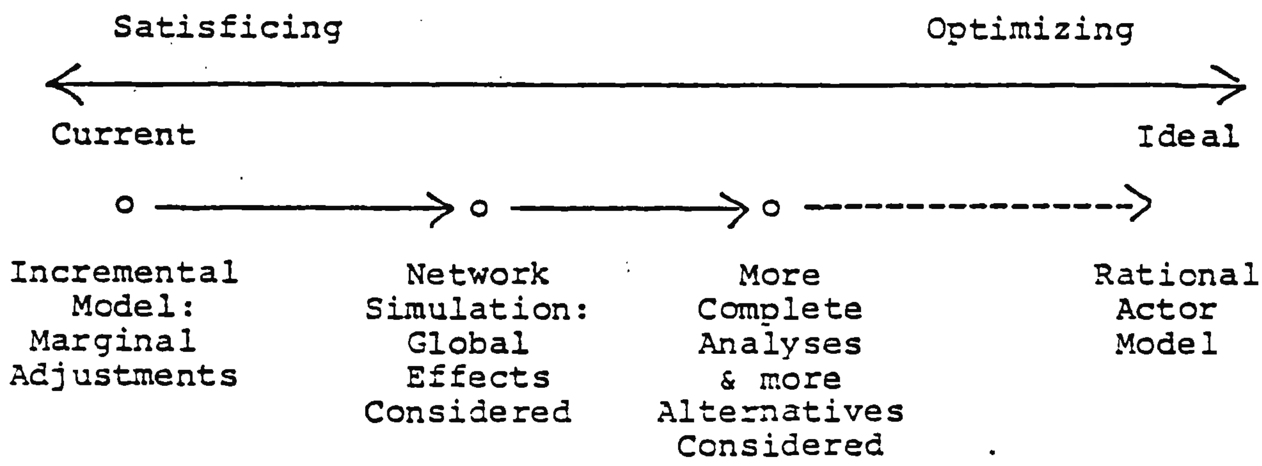
3. It encourages the use of research and theory, even when these cannot be directly implemented.

Given the normative models of rational decisionmaking, design must answer the questions: How do we move toward the goal? How far can we move? and What size steps should we take?

The railroad operations planning problem will illustrate this point. (see Figure 3.1) In many railroads today, there exist no formal operating plans that are reflected in reality. Decisionmaking is decentralized and consists of marginal changes to operating policy in response to problems or market opportunities. Operating the railroad appears to be an unstructured task requiring considerable judgment and a few informal heuristics gained from experience. In a highly dynamic environment this is clearly inadequate.

FIGURE 3.1

EVOLUTIONARY DEVELOPMENT OF A DSS



At the other extreme lies the impossible dream of making completely rational, informed decisions which maximize the objectives of the railroad. There is no theory which would allow this, even in principle and for a limited number of concrete objectives, since the interactions and the tradeoffs among the objectives are, in many cases, incompletely understood. However, this rational actor model is useful as a goal, a kind of measuring stick.

How far a railroad can move toward the goal depends very much upon its own organizational characteristics as well as the current knowledge of how rail networks behave and the applicable analytical tools and techniques. The introduction of computer support must change the management process itself and the organization as well. The greater the degree of change, the greater the risk will be. It may often be better to take several small steps than one big step.

3.3.2 The Process of Change. It is relatively easy to design and build computer systems. Changing organizational structures and attitudes is much more difficult. Clerical replacement systems are introduced to support the status quo, to enable an organization to function in basically the same way in the face of increasing pressure to change. DSS, on the other hand, are often introduced in order to produce change. Ginzberg, among others, has maintained that

> a system designed to support and improve managerial decision-making must, almost by definition, be built around a "model" of the manager's role; this role is to be different from the one in use prior to the development of that system. If such a system is to be used successfully, a change in the manager's view of his [sic] task must take place.[16]

This change will not often be easy, but will involve significant shifts in roles, procedures, power, and even the definition of the task itself.

There are two simple models which may be helpful here. The first is the Lewin-Schein model,[17] which views change as a three stage process:

1. Unfreezing: Altering the forces acting on the organization so that the homeostatic balance is disturbed enough to motivate and prepare for change. This is accomplished either by increasing the pressures to change or removing the barriers and forces resisting change.

2. Moving: Introducing new technology and procedures, learning new attitudes and techniques, altering organizational structures.

3. Refreezing: Completing the change, integrating the new system into the organization, removing pressures to slip back to the old way of doing things.

Implementation really includes all three stages, even though the narrow technical view sees it as comprising only the second. "Resistance to change" and "counter-implementation" reflect a lack of unfreezing and may be very reasonable responses. Neglecting this political process may have disastrous consequences. King,[18] in reporting the unsuccessful attempt to "sell" the Missouri Pacific's CARS/YARDS model to management, cited the fact that MoPac is "a successful railroad," that is, MoPac was still frozen.* On the other hand, one of the keys to success in the Boston & Maine case study was the lengthy period (nearly a year) spent in unfreezing the organization before the Service Planning Model was introduced.

The second model is that of Leavitt,[19] which views an organization as comprized of four interconnected elements:

1. The task(s) of the organization.
2. The technology used to perform the task.
3. The people in the organization.
4. The organizational structure.

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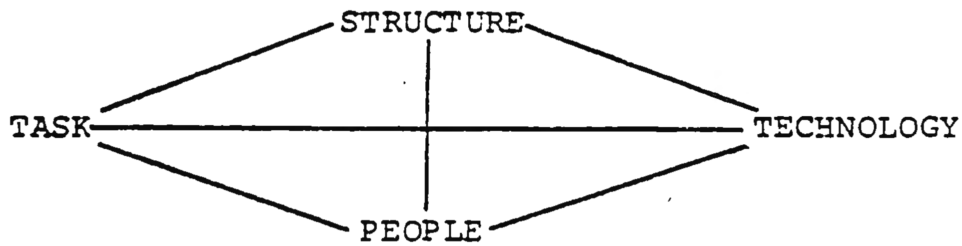
* Failure to unfreeze is a risk factor. However, causality is difficult to establish. Other possible factors in the nonacceptance of the model are bad model, bad sales effort, better alternatives available to management.

Figure 3.2 Leavitt's Diamond.



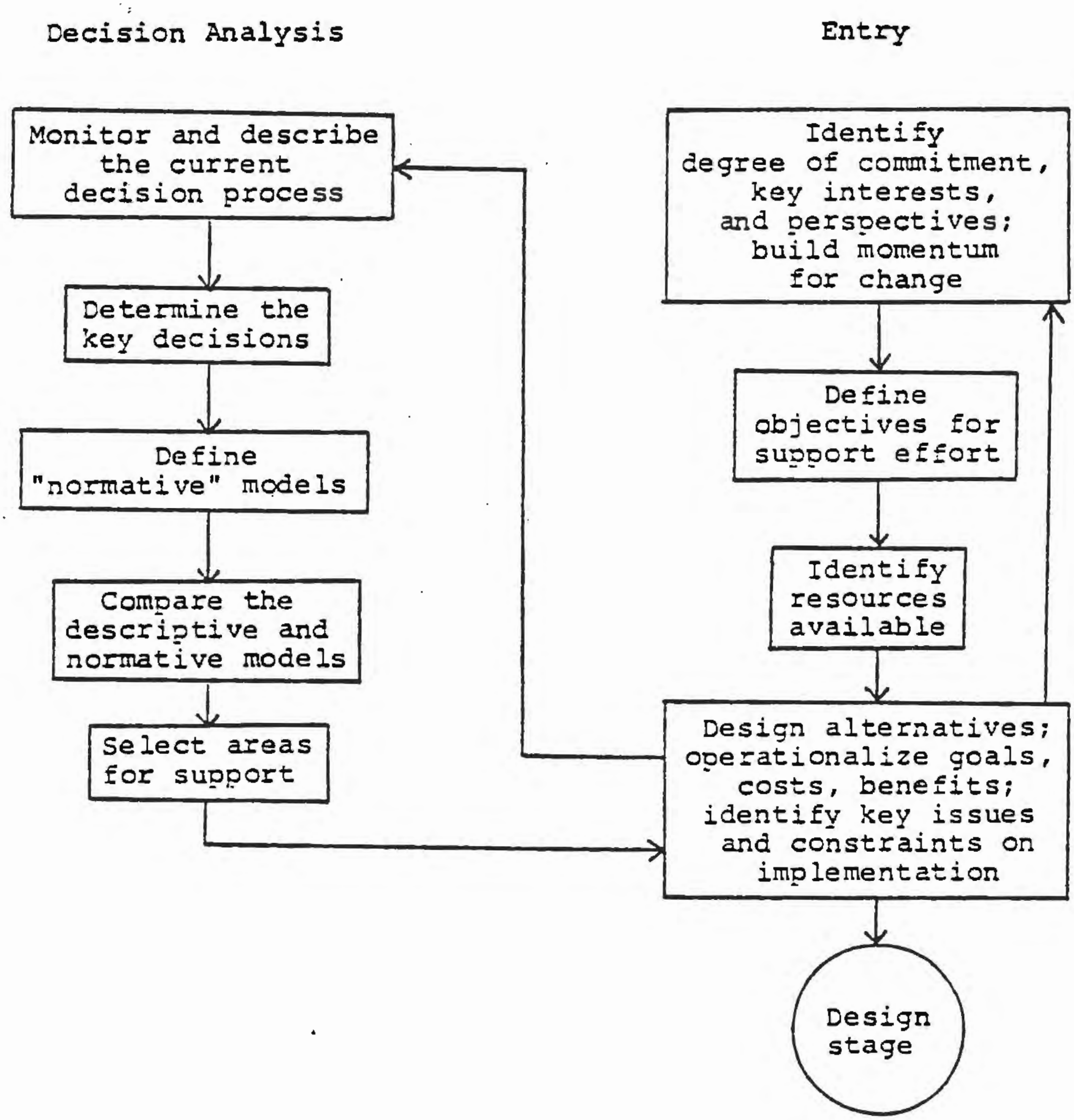
For an organization to function well, the four components must be mutually complementary and in balance. The organization is basically homeostatic; a change in one of the components will place the organization in disequilibrium, and the other elements will fight to restore the balance or will change themselves in accomodation.

These models suggest some strategies: Inducing stress on the organization, creating a "felt need," identifying an immediate, visible problem to work on, taking advantage of the fluidity brought about by a reorganization, responding quickly with tools when a user-manager is ready to innovate, and so on.

Shaking up the system, putting together coalitions, building up momentum for change, gathering resources, and so on are all important aspects of the process of "entry." As shown in Figure 3.3, entry should proceed in parallel with the analysis of the decision process. Each cycle should be repeated at least once, and one will likely find that the two processes are actually inseparable.

FIGURE 3.3

THE PREDESIGN CYCLE



Source: [20]

Keen and Scott Morton have synthesized a checklist for successful entry from a number of empirical studies. This is given in Table 3.2.

3.3.3 Implementation. Implementing a system to support managerial judgment is very different from creating an accounting system in which the relations of all the data and the tasks to be performed are neatly defined.* Design and implementation are closely related and must, to a great extent, proceed concurrently, following a strategy of evolution (Figure 3.4). This is not to say that there is no need for a plan or that one should take an ad hoc approach.

Designing a DSS is very much like exploring an unknown continent. The explorer begins with a map, a plan of action. It is crude and may be wrong on important points, but it is necessary to guide exploration. As the continent is explored,

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* In fact, the DSS gurus warn that the creation of Decision Support Systems should not be entrusted to the corporate EDP group at all. Alloway,[22] for example, explained that an EDP group that has become institutionalized[23] can do a great job of building transaction processing systems; its organization, procedures, and even its language are set up to do this task. A manager may ask for a DSS, but the DSS will look like a transaction processing system. Keen and Scott Morton[24] found that "none of the DSS with which we are familiar have been built within the main EDP department. In fact, in several of the systems, the organization's EDP group was seen as the 'enemy.'" Alter,[25] in his study of 56 such systems, found that none were developed within the main EDP group. This may be an important factor in the failure of a number of the simulation models listed earlier. Missouri Pacific's CARS/YARDS model, for example, one of the more recent efforts, falls into this category. It has apparently met its technical expectations and has performed well in tests, but the Information and Control Systems Department, which initiated and developed it, has gotten an apathetic response from the potential users.[26]

TABLE 3.2

ISSUES TO BE RESOLVED IN THE ENTRY PHASE

1. A felt need.

   a. The implementor must make sure that the problem to be worked on is visible and seen as relevant.

   b. The implementor must make sure that the client has a motive and commitment for action.

2. Definition of goals in operational terms.

   a. What are the criteria for "success"?

   b. What are the priorities and trade-offs?

   c. What "key indicators" can be used to measure progress and accomplishment?

3. A contract for change.. This involves a "deal" between designer and client that establishes:

   a. "Trust"--personal, professional, or political.

   b. Mutual understanding.

   c. Mutual respect for each other's style, investment, and needs.

   d. Realistic, mutual expectations.

4. Diagnosis and resolution of resistance to change. This involves:

   a. Including users as well as the client in implementation. (Designers often ignore the secondary users, groups who are indirectly affected by the system, such as the people responsible for collecting certain input data.)

   b. Recognizing that resistance is a signal needing response, not a pathology to be eliminated by fiat, power, or endplays.

5. Initial allocation of resources and responsibilities. This involves:

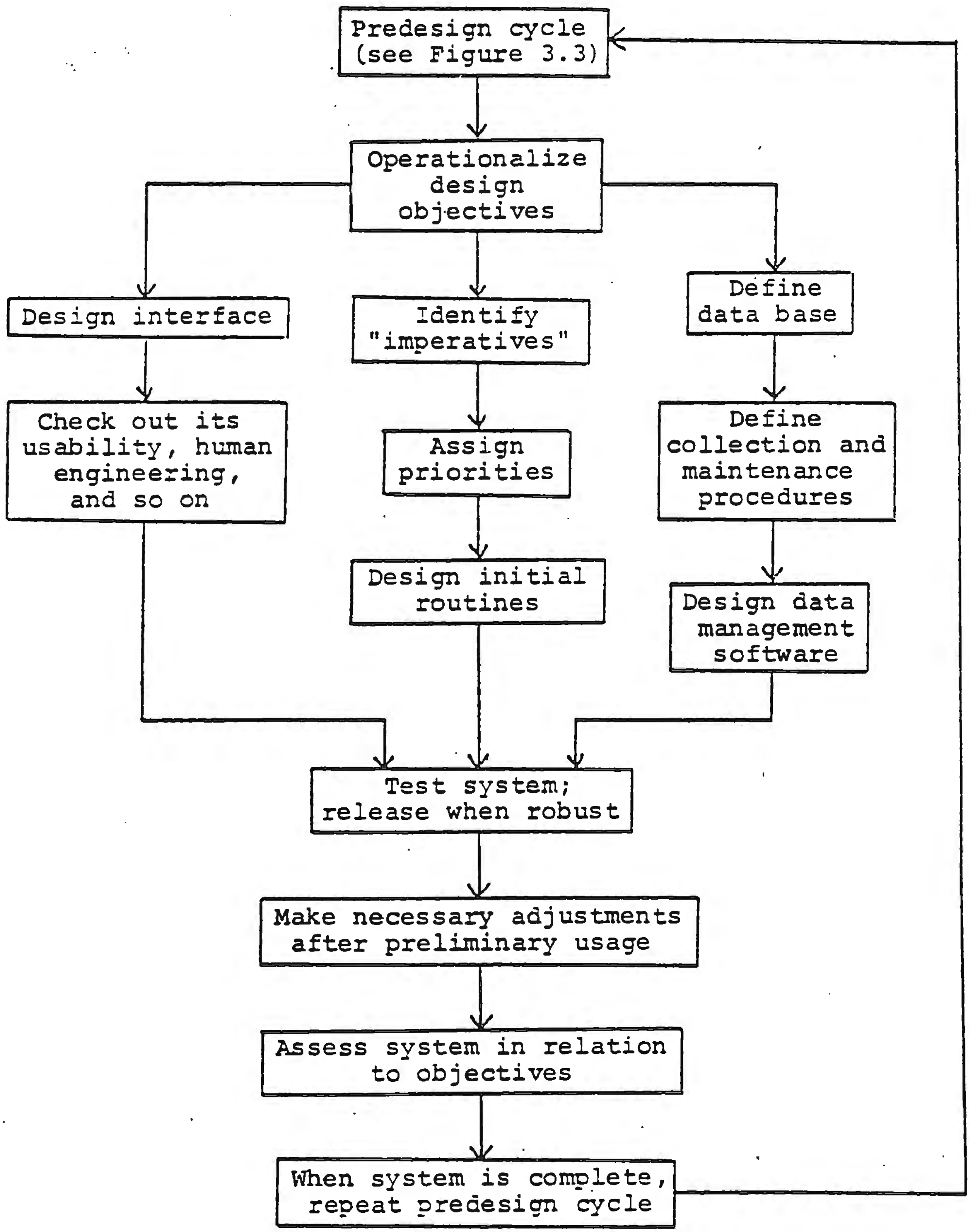
   a. Meaningful user involvement.

   b. The development of a team.

Source: [21]

FIGURE 3.4

THE DESIGN CYCLE



Source: [27]

the map is successively redrawn, becoming more accurate with each iteration until the mission is completed.

Similarly, the DSS implementor begins the design stage by working with the user-managers to draw a crude map of where they want to go and the route they want to take. They should develop a good idea of what the new decision process will look like, what tools and techniques will be appropriate to support it, and what organizational and procedural changes will be necessary.

Implementation is a process of evolution. It proceeds by throwing together a quick-and-dirty program, showing it to the users, getting feedback, evaluating the system, modifying the design, and iterating. In the initial stages of development, the user interface will be rather rough, and the users may have little idea of how to utilize their newly acquired capabilities. This will certainly be true if great changes are required in the decision process. Therefore, a person or persons who can act as an integrating agent, or "chauffer," will be of immense help. Bennett suggested four primary roles of an integrating agent:

1. As an exegetist who explains the system and interprets the concepts and objectives underlying its design. He or she can help the user get started on the DSS, beginning with simple functions and approaches.

2. As a confidant who provides support, helps overcome misconceptions, and encourages the user to view the system as a tool under personal control rather than as a threat.

3. As a crusader who can demonstrate the power and value of the DSS. A new system often involves substantial costs in terms of time, effort, and learning. Once the novelty of the system wears off, the user is aware of these immediate costs, while the benefits are less clear and more distant. The integrating agent can poin to these benefits and maintain the momentum of the project.

4. As a teacher who can be far more effective than manuals or seminars, particularly with nontechnical professionals, in tailoring the training to the individual. She or he also can help structure problems to exploit the system's capabilities.[28]

3.3.4 Evaluation. An effective evaluation process is a key to controlling the evolution of a DSS. Evaluation is made difficult, however, by the relatively unstructured nature of the tasks to be supported. Thus there are no clear criteria for assessing performance. In contrast with other computer applications, which use automation to reduce costs, economic efficiency cannot be used to evaluate DSS. In fact, the costs of making decisions will likely increase. Means are required to measure changes related to the effectiveness of decisions. Keen and Scott Morton[29] suggested a "smorgasbord" of eight evaluation methods:

- Decision outputs.
- Changes in the decision process.
- Changes in managers' concepts of the decision situation.
- Procedural changes.
- Classical cost/benefit analysis.
- Service measures.
- Managers' assessment of the system's value.
- Anecdotal evidence.

3.4 Decision Support Systems as Tools.

Even though DSS properly includes the organization and the decision processes in which it is embedded, the most visible and concrete part is the computer system itself, the artifact. Even though the success or failure of a system is determined more by its connections with this larger context than by its intrinsic characteristics, there are a number of important attributes which are lacking, to one degree or another, in all current attempts to support railroad strategic operating decisions. These deficiencies, by themselves, tend to keep otherwise promising approaches in the experimental stage. For example, Scott Morton,[30] one of the greater lights of DSS, has given us these oft-quoted counsels of perfection:

> To be of help in management problem solving a computer system must be a flexible interactive system that is easily used by a manager ignorant or computers. It must be flexible so that the structure of the problem solution process can be changed. It must be interactive so that the time between the suggestion of an alternative and the machine response with the answer is short enough not to impede man's [sic] natural problem solving facilities. In addition, it must be easy for a manager to use who has little knowledge of the data base. The mechanics of interaction must not interfere with the problem solving process.

3.4.1 Little's List. Little[31] proposed a similar list of attributes of a good DSS (given here in expanded form):

1. Simple and easy to understand. Edelman's First Law of Management Systems and Sciences is particularly relevant:

> No manager with real responsibilities for a real business will base important decisions on the outcome of a process which he himself does not adequately understand.[32]

Only the important phenomena should be modeled. The implementor should resist the urge to incorporate more detail until the users demonstrate the readiness and the desire to use it. This suggests a couple of complexity-hiding strategies: One is the careful design of the user interface to make a complex program look simple.* The other is the selective revelation of additional features and capabilities as the users express the need for them.

2. <u>Robust or "bomb proof</u>." The user should find it difficult to get bad answers. One strategy is to provide internal checks on the sensibility of inputs and outputs. A good DSS will warn the user if its underlying assumptions are violated.

For example, Keen and Scott Morton discussed a system developed by a manufacturing firm to predict how its competitors would bid on special contracts, the Bidding Intelligence System.

> [O]ne of BIS's forecasting routines occasionally produced estimates that the winning bid for a contract would be a negative price; the executive vice-president found this very disturbing and assumed that the routine was programmed incorrectly. Of course, the real problem was that the particular input data, although valid, did not meet the requirements or assumptions for this type of statistical analysis. . . . a response such as "No forecast possible; analysis suggests negative bid. Please check data," would prevent a potentially expensive loss of user confidence in the system. 33

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* It is sometimes said, "The system <u>is</u> what it looks like."

Robust also implies correctness and reliability. The need for user involvement and feedback should be balanced by the potentially damaging consequences of releasing a system prematurely. Computer crashes and errors decrease confidence. Users are asked to invest much effort in the new system. The quid pro quo is that the DSS should not crash, give garbage answers, or make mistakes.

3. Easy to control. The users should be able to make the model reflect their own understanding of reality, not that of the builder. A user should be able to set parameters to make the model behave in any way desired. While this may open the door to "fudging the data" to achieve a preconceived result, it is not hard to imagine a manager rejecting the use of a tool for fear that it will coerce him or her into an unacceptable action.

4. Adaptive. One should be able to both update a model's parameters and change its structure as new information and insight is gained. The effectiveness of the system will depend upon its ability to evolve through usage. The design and implementation of a prototype DSS will almost always result in a new awareness and understanding of the problem and the decision process, and sometimes in a redefinition of the problem itself.

5. Complete on important issues. Completeness conflicts with simplicity, however, and requires structures which can incorporate many phenomena without getting bogged down. As one strategy to resolve this dialectic, Little proposed the

concept of a decision calculus, which is essentially a hybrid model which incorporates managers' subjective assessments of complex relationships. This approach was, in fact, used in the MIT Service Planning Model. The PMAKE functions are estimates of the way a yard will perform under certain conditions.

Another strategy is to use a series of models. The weaknesses of one model should be the strong points of another.

6. Easy to communicate with. The user should be able to change inputs easily and obtain outputs quickly. The format, language, and level of detail should be determined by the user, rather than constrained by the internal representation of the model structure and data.[34]

Another consideration is the need to obtain closure. The human mind has a limited short-term memory. As the amount of information and the length of time increases, the pressure to complete a task builds up. Closure may be thought of as the relief from this internal pressure upon completion of a task.[35] The need for long uninterruptable sequences of interaction requiring great concentration should be avoided.

More to the point, the long waits between proposals of alternatives and the evaluation of those alternatives is quite undesirable. Some[36] have argued that since a decision made once a year hardly needs a system that can yield answers in seconds, an interactive mode is unnecessary. This argument, however, misses the point. Since a computer analysis of alternatives will no doubt be made iteratively, the critical element is not the decision deadline, but the interruption in the user's thought processes.

3.4.2 <u>A Role for Optimization</u>. Little's list has a bias, however. To one degree or another, several of these goals militate for a simulation approach to decision support. For example, simulation is relatively straightforward (ipso facto simple and easy to understand) when compared to optimization models which (as Keen and Scott Morton[37] note) are often based on powerful abstract methodologies which managers rightly find unrealistic and difficult to understand. Further, the ability of simulation to replicate a manager's environment in his or her own terms is difficult to match with optimization techniques.

Simulation is limited to the analysis of alternatives. In and of itself, simulation will not tell which of the many policy variables should be adjusted to achieve a desired change. For example, suppose management wishes to improve the transit time through a certain rail corridor. Should the train schedules be adjusted? If so, which trains? Should another crew be added at some yard?

If management starts with a basically good operating plan and is content to make only marginal changes (i.e., no radical revisions), then reliance on human insight is probably both desirable and feasible. On the other hand, if management wishes to explore several very different strategies, then problems arise. The mind of the designer will be dominated somewhat by the previously developed strategy, thus limiting creativity. The process will also be tedious, and wasteful of human creativity.

Optimization does have a place. Brill,[38] for example, discussed the joint use of optimization models with simulation, employing several approaches. There exist perfectly good techniques which can generate mediocre operating plans, leaving the fun part to the humans. By placing constraints upon the optimization process, e.g., which policy variables may be changed, one may outline the broad features of an alternative. A good heuristic may generate a plan that is "95 per cent complete," allowing the user to make whatever marginal adjustments are deemed necessary.

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CHAPTER 4

THE BOSTON & MAINE CASE STUDY: AN INNOVATION IN OPERATIONS MANAGEMENT

4.1 Introduction.

The Boston & Maine case study[1] is an important experiment in both interdepartmental operations planning and in providing computer support for several phases of the management process. The management process which has evolved at the B&M during and since the case study represents a considerable movement from an almost blind "muddling through" toward the normative process suggested by Task Force VI of the Freight Car Utilization Program and outlined in Chapter 1. Implementation of the Task Force VI recommendations was, in fact, a conscious goal of the project.

An examination of the events which took place during the case study itself is necessary to understand the organizational changes required for effective operations management and the difficulties of achieving these changes. An analysis of the new decisionmaking process will be very helpful in determining appropriate areas for computer support.

4.2 The Boston & Maine Case Study.

Radical changes in organization and management processes resulted from the Boston & Maine's participation in Phase II of the Freight Car Utilization Program.

> A series of operating changes were implemented between January and July 1979 that, for the first time in at least recent B&M history, represented the joint efforts of marketing and operations as approved by an interdepartmental service committee and ultimately by senior management. Hence, a fundamentally different approach to operations planning had been developed and implemented by the service committee, which by now was serving as an important means of coordinating operating and marketing decisions.[2]

At the start of the project, however, B&M was ill-prepared for any effective effort in operations management.* Interdepartmental planning of operations was minimal; neither the necessary data systems nor the organizations existed to support it.[3]

B&M measured origin to destination trip times only for the overhead moves, and, partly as a result, developed operating/service plans only for overhead and high priority traffic.

The determination of costs was poor, and there was no formal means of balancing cost against service or even balancing labor costs with car utilization.

The operating plan was poorly defined. In fact,

> the blocking strategy was documented through a special effort for USRA. Train schedules and priorities [were] basically undocumented. There [was] no formal mechanism for empty car distribution . . . .[4]

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* Among the recommendations made by Task Force VI at the close of Phase I was a list of prerequisites for an effective commitment to improved service reliability and car utilization.[5] The B&M had virtually none of these.

The case study grew out of work MIT had done with B&M during Phase I of the FCUP[6] which left B&M top management anxious to participate in Phase II. The project itself passed through several distinct stages.

4.2.1 Preliminary Stage. Early in the Phase II project, the B&M formed an interdepartmental working committee to work with MIT. During the life of the case study, this group evolved into a formal Service Committee with considerable power and responsibilities in the management of operations. Chaired by a "neutral party," W. Rennicke, Assistant to the President, it consisted of mid-level representatives drawn from several departments: Transportation, Marketing, Data Processing, Engineering, Mechanical, and Labor Relations.

During the preliminary stage, lasting from September 1977 until March of the next year, the committee members and the MIT people got to know each other, drafted initial statements of problems, and completed some preliminary studies. By March the committee had drawn up a work plan to implement the recommendations of Task Force VI.

4.2.2 Startup Period. During the startup period, MIT and the B&M assembled the tools necessary for the development and analysis of alternative operating plans. These consisted of information systems and the MIT Service Planning Model, which was not ready until late that summer.

In the meantime, a subgroup of the committee undertook an analysis of car distribution, which resulted in B&M joining the Freight Car Clearinghouse. MIT suggested several broad operating alternatives to be reviewed by the committee.

> This review, several months in advance of the intensive evaluation of operating strategies, proved very useful in that it showed the service committee and senior management what an operating "strategy" looked like. Hence, by the time the startup period ended, people understood what the next step would be.[7]

4.2.3 Analysis Stage. When the SPM became available in September, analysis began in earnest. The now formalized Service Committee directed the analysis of three different operating strategies as well as the current strategy. The MIT model was utilized to study the service/cost tradeoffs of different operating plans.

> The specific information needed for the model including train schedules, blocks, yard crews, and appropriate costs focussed the planning effort and defined the role of the committee members. The model produced output that could easily be reviewed, while changes in model input provided a continuing topic for debate. In short, the use of the network model gave factual support to a process that otherwise might have degenerated into endless qualitative debates.[8]

In addition to the outputs of the SPM, a number of other, less readily quantifiable factors were important. For example, the analysis of power utilization and estimates of market response to changes in service played an important role. If only the transportation costs calculated by the SPM were taken into account, the existing operating plan would have been the least expensive. However, when the savings from faster power turnaround and the increase in traffic resulting from improved service were considered, a very different strategy was chosen.

In December, the Service Committee presented its recommendations to senior management. The recommendations were generally approved with some modifications.

4.2.4 Implementation. Much work, including more analyses, remained in order to put the new strategy into effect. The new strategy, as approved by senior management, was by no means a well-defined operating/service plan. The Service Committee had to prioritize service changes, determine realistic schedules, identify labor constraints, and assess impacts upon locomotive assignments and maintenance of way-tasks which received little or no computer support. The SPM was used in calculating the service standards and in determining the car hire budget.

The committee also monitored operations under the new plan, comparing actual performance with desired performance and looking for problems in implementation.

4.2.5 Results. The changes implemented in the spring of 1979 produced a 5 to 10 percent improvement in trip times and reliability, improved profitability and improved the potential for growth in traffic. When compared with 1978, the first six months of 1979 experienced a 9 percent growth in gross ton-miles with only a 5 percent increase in yard and train labor costs, no increase in car costs, and no increase in locomotive requirements.

Net ton-miles increased by 12 percent, and car utilization by 8 percent. The reduction in the percentage of empty miles can be attributed, in great part, to B&M's participation in the Clearinghouse.

A number of organizational problems arose during the case study. In spite of them, or perhaps because of them,* the power of the Service Committee has grown, and the new interdepartmental operations management process is becoming institutionalized.

4.3 The Present Planning Process on the Boston & Maine.

Since the case study, the operations planning process has become more formal. A quarterly planning cycle is seen as a goal.** In addition to the creation of the Service Committee, a number of organizational changes were made either prior to or during the project:

- o Expansion of the Traffic Department into a Marketing Department.
- o Creation of a Management Information Systems Department.

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* For example, the participation of Transportation in the Service Committee was minimal, and just as recommendations were being drawn up, the Vice President of Operations announced unilateral plans to close a certain yard. This action was inconsistent with the committee's recommendations, but in the senior management meeting, the decision was not challenged. The Service Committee, however, monitored the new operations very closely and found that costs increased initially despite Transportation's prediction of savings. Rennicke, the chairman, followed the problem until the costs were brought under control.[9]

** However, the first new plan since the spring of 1979 became effective January 14, 1980. The most recent cycle was completed about three months later, closer to the goal.

- o Creation of a Car Utilization Department.
- o Reorganization of the Transportation Department and creation of a formal planning group.

All of these groups have specific responsibilities in the strategic management of operations. The steps in the process are depicted in Figure 4.1.

Partitioning this process into phases can aid analysis and the selection of the most profitable areas for computer-based support. The process naturally divides into five phases (based on Simon's[10] paradigm, but quite similar to the division used by Gerrity[11]):

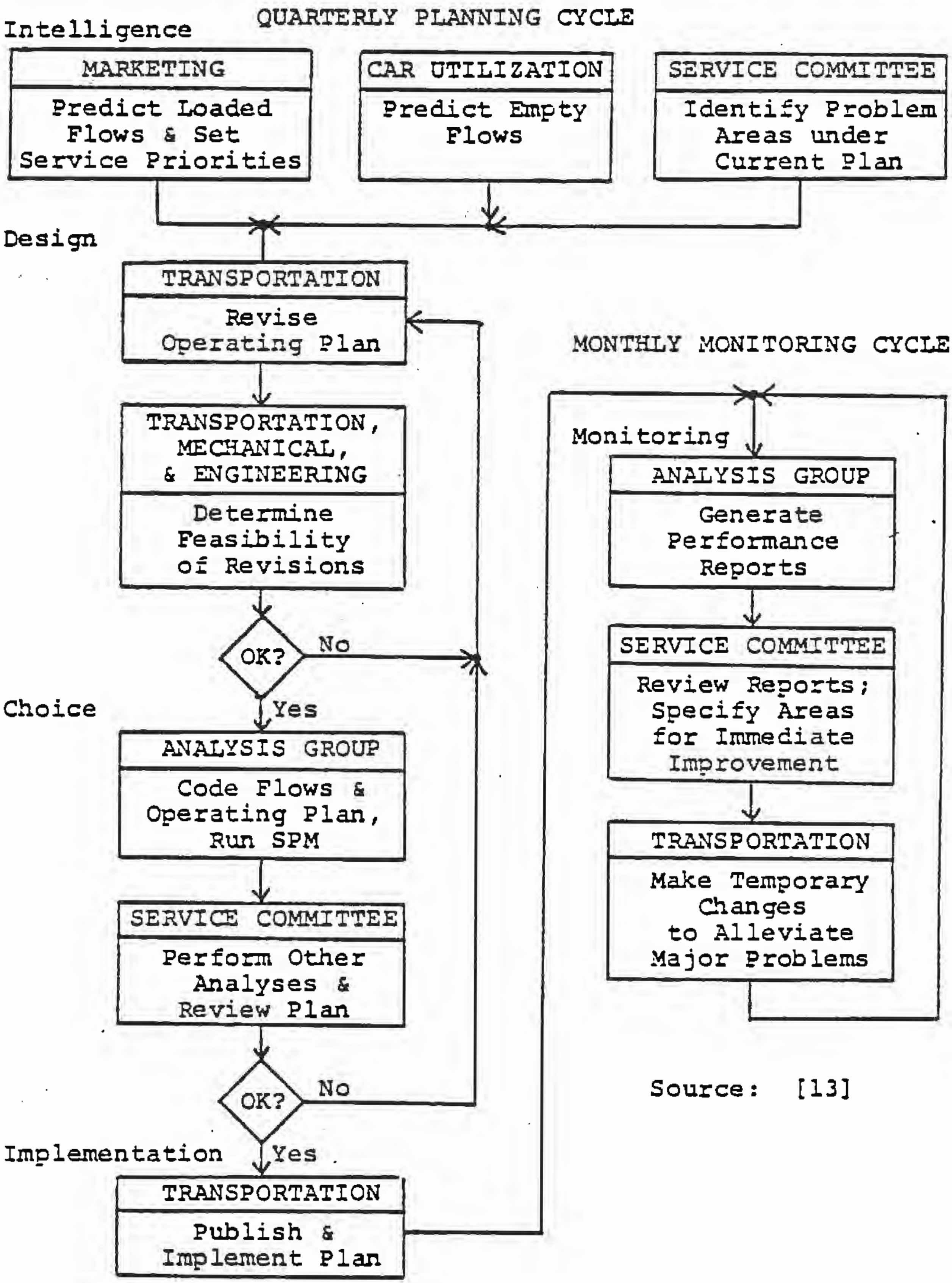
- o Intelligence: Gathering information and identifying problems (as in "military intelligence").
- O Design: Identifying and developing alternatives.
- o Choice: Analysis and evaluation of alternatives and selection of a course of action.
- o Implementation: Putting chosen course of action into effect.
- o Monitoring: Monitoring, evaluation, and identification of problems in the implemented alternative and taking short-term corrective action.

In general, as suggested by Figure 4.1, the major activity flows in this sequence. At a lower level of abstraction, however, the process is far more complex.

> Each phase in making a particular decision is itself a complex decisionmaking process. The design phase, for example, may call for new intelligence activities; problems at any given level generate subproblems that in turn have their intelligence, design, and choice phases, and so on. There are wheels within wheels.[12]

FIGURE 4.1

THE PLANNING AND MONITORING CYCLES



Source: [13]

4.3.1 Overview of the Planning and Monitoring Cycles. At the start of the planning cycle, the Marketing Department develops estimates of traffic flows and identifies service constraints and service priorities, which serve to direct planning efforts toward the more important traffic.

The Car Utilization Department, in conjunction with Marketing, predicts the flows of empty cars.

The planning group in Transportation then revises the operating plan, taking into account the expected traffic, the service priorities, and the problem areas identified by the Service Committee. A number of departments, primarily Transportation, Mechanical, and Engineering, must examine the proposed alternative plan to determine its feasibility.

The analysis group codes the traffic flows, the new operating plan, and other information as input to the Service Planning Model, which predicts the service impacts of the plan. (This is done presently by MIT, but the capability is being transferred to the B&M.)

The Service Committee reviews the plan, service predictions computed by the SPM, and the estimates of costs. The planning group and the committee must perform their own analyses to determine other impacts. If the new plan is approved, implementation can begin in a couple of weeks. If not, negotiations among the several departments must begin in order to modify the plan.

When approved, the new operating plan and the standards as predicted by the SPM are distributed and implemented by Transportation.

While the plan is in effect, monthly reports generated by MIT enable the Service Committee to monitor train, yard, and trip time performance in order to determine adherence to the plan and the service standards.[14] The Service Committee specifies areas for immediate improvement as well as those to be worked on in the next planning cycle, and Transportation can make marginal changes to alleviate major problems.

This overview is deceptively simple. Each of the boxes in Figure 4.1 is itself a complicated procedure. Two of these, the revision of the operating plan and the additional analyses performed by the Service Committee, warrant further attention.

4.3.2 <u>The Design of Operating Alternatives</u>. The design of an operating plan is a laborious manual process. In the first planning cycle since the case study, completed nearly a year later, only one alternative was proposed, rather than several, as in the case study itself.

At the B&M, the creation of an alternative is primarily the responsibility of one analyst, Jon Gbur.[15] He begins with the traffic projections for both loads and empties. On the B&M, the blocking policy is taken as a given, so the traffic flows are expressed in terms of block volumes. The origin to destination volumes are aggregated to yield the "block-to-block" reports, which detail the block volumes and the volumes which move on connecting blocks.

Using the block-to-block reports and a map of the network, he calculates the number of trains needed to handle the traffic and plots their routes.

Schedules are determined by a number of informal heuristics. General goals are to minimize connection delays, to evenly distribute the traffic among the trains, and to minimize the number of crews and powersets required.

At interchange points which experience peaks in the arrival times of traffic from connecting carriers, departure times are set to minimize the expected delay. At other interchange points, where arrivals are more evenly distributed, schedules are set by other considerations, primarily to minimize the delay in connections with other B&M trains.

Finally, he distributes the blocks among the trains, a "manual mental exercise," which attempts to balance the volumes and workloads among trains as well as to minimize connection delays.

When the first draft of the plan is complete, the analyst examines it in detail, asking a number of questions: What are the effects of arriving at the scheduled time? Will there be congestion with passenger service? What are the connection probabilities? Will tonnage restrictions be exceeded? How will power be used? and so on.

After examination, he may wish to make a number of changes before coding the plan for the MIT Service Planning Model.

The design process consumes much of the analyst's time and is not now supported by any computer aid. Gbur has expressed interest in an "interactive" version of the SPM and some design aid which could identify places and times that certain constraints are likely to be exceeded.

4.3.3 Analyses Required. After alternative operating plans have been developed, the Service Committee requires a number of different analyses to evaluate the options and to suggest possible improvements. For these purposes, the SPM has been very useful in calculating the expected values of a number of important measures:

- Origin to destination trip time distributions, average and median trip times, and reliability. Trip time data are printed in disaggregate form, but are also aggregated by geographic markets.
- Yard delay time distributions, yard volumes, and car hire costs.
- Block volumes, train volumes, train mileage, and line haul car costs.
- Car costs disaggregated by origin/destination pairs.
- Labor costs.

The predicted service level measures are also used as service standards in the operating/service plan. Road crew costs, it should be noted, are predicted using simple formulae, and yard crew costs are highly dependent upon accurate judgments of the number of crews required.

In addition to the outputs of the SPM, a number of other analyses are important, most of which are done manually:

- o Determination of realistic schedules. The SPM simulates an average day. However, the average week has high volume days and low volume days. This requires that more trains be scheduled on some days than on others.
- o Analysis of motive power requirements and utilization.
- o Analysis of maintenance of way requirements.
- o Estimation of crew requirements at the various yards.
- o Identification of needs for new interline agreements.
- o Other feasibility analyses, such as identification of yard and line congestion and labor work rule constraints.
- o Analysis of effects upon local pickup and delivery services.
- o Analysis of the effects of service changes on market demand.

Much documentation is also done manually. Transcription of the operating plan for use in the field is currently done by hand.* Summary documents detailing results of the analyses and key differences between alternatives are also created manually.

4.4 Summary.

The Boston & Maine has moved a great distance toward the rational actor model of decisionmaking. Necessary changes in

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* Automation of this clerical function is now under consideration.

organizational structures and procedures were made possible by the computer systems introduced to support the new decision process. The information from the data systems (which support the Intelligence and Monitoring phases) and the analyses of alternatives from the Service Planning Model (supporting the Choice phase) provided a focus for the efforts of the Service Committee and prevented the process from degenerating into endless debates over subjective judgments.

Some of the key factors in the project's success were:

- Top management support.
- Commitment of several full time personnel.
- Considerable time spent in entry/unfreezing.
- Interdepartmental involvement.
- Close cooperation between users and implementors.
- Evolutionary approach.

There are, however, significant bottlenecks and problems in the new operations management process. In both the design and choice phases, a great number of time consuming manual analyses are required. The actual work of designing an operating plan is virtually unsupported by any computer system. The operations management process and the computer systems must continue to evolve.

Chapter 4 References

1. Martland et al., A Case Study of the Boston & Maine.

2. Ibid., p. 3.17.

3. Carl D. Martland, memo to William Rennicke, February 27, 1978, reprinted in A Case Study of the Boston & Maine, Appendix C.

4. Industry Task Force, Case Studies, pp. 11-16.

5. Martland, memo to Rennicke, February 27, 1978, p. 2.

6. Industry Task Force, Case Studies, pp. 64-95.

7. Martland et al., A Case Study of the Boston & Maine, p. 3.16.

8. Ibid., p. 4.7.

CHAPTER 5

A DSS FOR RAILROAD OPERATIONS MANAGEMENT

5.1 Introduction.

This chapter develops a number of objectives for applying computer support to the management control of operations. Chapter 6 suggests some computer system design alternatives and proposes a sequence of stages to meet these objectives.

Experience in using the MIT Service Planning Model and the new data management systems on the Boston & Maine is invaluable for the development of goals and the creation of a broad-brush outline of what an appropriate Decision Support System should look like. The organization and the decision process have already moved a great distance toward the normative model of decisionmaking.

A good step would be to refine this new process and develop a DSS to support these refinements. This appears reasonable since the B&M management and staff are willing (and, in some cases, even eager) to utilize interdepartmental planning and computer-based analysis, in spite of the considerable inconvenience and costs involved and in spite of the technical shortcomings of the available tools. A DSS which provides analyses of at least the same quality and which improves the process in other ways very likely will gain acceptance.

5.2 Problems.

Looking at the present process on the B&M, one finds a number of bottlenecks and technical shortcomings. There are also some problems, such as data availability, which have been met, but which nevertheless remain current issues.

Although the benefits are real, the costs are substantial. The benefits accrue to the organization in general, but, in a very real sense, the costs accrue to the managers. Good managers and analysts are scarce resources, and a manager's own time and energy are scarcer still. The managers and their staff have to invest a great deal of themselves in learning the theory underlying the analysis and in learning (or discovering) the proper use of the reports it generates. Making room for meetings, committing their energy to the process, wading through printouts, and putting up with the other bottlenecks and ambiguities are all severe drains on them. Added to this are the costs of lower level staff support, computer time, and data gathering.

These costs reduce the frequency and depth of analysis in the management of operations and, upon the departure of certain key personnel, for example, become a temptation to return to the simpler world of Lindblom's "disjoint marginal incrementalism."

5.2.1 Bottlenecks. Significant bottlenecks spread the process out over a period of weeks and greatly increase the cost of considering new alternatives or refining old ones.

The biggest bottleneck is in the design of the operating plans themselves. As noted in Chapter 4, this is largely a manual process which relies on formal and informal heuristics and requires a great amount of calculation. The analytic power of the MIT Service Planning Model is virtually inaccessible at this stage. The design is spread out over a period of several days, but requires the advice and knowledge of several departments from time to time in order to distinguish feasible alternatives from infeasible ones.

Marketing has some influence on the process, and this is a significant advance over the previous planning process. However, its only input consists of "service priorities" identifying areas of performance it wishes improved. Such service priorities may be based on the knowledge or intuition that a certain level of improvement over some corridor will bring a certain increase in demand.

Currently the only mechanized portion of the process, the running of the SPM itself, is done by a group outside the railroad, MIT. Bringing this step inside would eliminate a couple of automobile trips, but in any event, running the SPM requires the manual transcription and recoding of the candidate operating plans and traffic projections, with the consequent delays and potential for mistakes.

After the model is run (in batch mode), and the printouts are returned to B&M, Transportation first reviews the results to check for obvious errors or possible improvements. If either are found, the model must be run again. The staff must then dig through the printout, looking for key indicators and performing ancillary calculations.

The Service Committee then reviews the alternatives and the predictions in order to make a selection or to suggest possible revisions. For both groups the output of the model is difficult to assimilate, and the comparison of different plans is laborious. A great number of manual calculations remain to get useful information, and therefore the temptation is great to focus on the aggregate statistics, such as total car hours. If the committee is not satisfied with the alternatives presented, either the whole process must be repeated or marginal changes are made intuitively. For both groups, "What if . . . ?" becomes a costly question, which must be asked early in the process or not at all.

After a new plan has been selected, it must be implemented. If changes are large, some guidance in phasing in the new plan would be helpful. If a hitch develops during implementation (as happened when B&M could not reach a new interline agreement with Conrail[1]), a revised plan may be in order, and delays may be costly.

5.2.2 <u>Technical Shortcomings</u>. Even though the SPM is quite accurate when compared to other simulation models, it has some irritating technical shortcomings, which hurt its accuracy, credibility, and usability.

Probably the chief limitation is the use of a daily schedule of operations and a daily cycle of traffic. If an operating plan calls for more trains along a route on peak days than on average days, such a plan cannot be coded for the SPM. Instead, an "average plan" must be created and evaluated using average traffic flows. Since train schedules will be different, one will lose some of the benefits of using PMAKE functions to model the yards, rather than some simpler model, such as fixed yard delays. Even after an alternative strategy has been selected, much work will remain to create a viable operating plan, choosing the correct number of trains for each day to handle the variations in workloads, and then scheduling these trains.

Another limitation is the specific form of the PMAKE function and the certain variables it uses. The effects of congestion, for example, are modeled primarily by manually changing the yard performance parameters. Additionally, the effects of the variability of line haul times, which may be different over each link in the network, are not specifically modeled.

These limitations result in the problem of translating an average operating plan, created for the SPM, into a plan feasible for the actual railroad, and they prevent the use of the model in answering a number of important questions, for example:

- What is this weekly peak costing us? One needs to model a weekly cycle of trains and traffic and to explicitly model congestion effects in the yards.

- o What will happen if I cancel this train on Mondays? At a minimum, one needs to model weekly operations.
- o What is the global effect of single-tracking a certain section of main line? This may be asked in investment or maintenance scheduling situations. Since the contemplated change may affect reliability as well as average time of line haul movements, one may want the yard model to reflect this.
- o If we believe that this yard behaves in such-and-such a way when it gets overloaded, what are the system-wide effects of a ten percent increase in traffic over this corridor? One needs to model yard congestion effects.

5.2.3 Unsupported Operating Decisions. Looking at the six major decision involved in creating an operating/service plan (Chapter 1), one finds some decisions are much better supported than others.

- o Blocking strategy.
- o Train routing and block to train assignments.
- o Train schedules.
- o Power distribution.
- o Yard performance levels.
- o Empty car distribution policy.

The first three are the best understood and, consequently, are the best supported.* The Service Planning Model ignores locomotive and empty car distribution completely. Although the

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* McCarren[2] identified only the first three as the "fundamental decisions" (subsuming power distribution under train schedules) and specifically addressed only these three in the design of the Service Planning Model.

analyst can use manual methods to evaluate power distribution alternatives, the determination of the empty car distribution policy is unsupported. In fact, the formal planning process, as depicted in Figure 4.1, takes this decision as a given.

5.2.4 Information Problems. An effective data collection and information management system is, of course, a prerequisite to any meaningful management of operations. A means of estimating the future demand and quantifying the uncertainties is necessary for the planning of operations. Finally, a knowledge of the physical railroad, its performance, and its cost structures is required for the effective planning and management of efficient and marketable operations.

In creating models and other tools to aid the management of a system as complex as a railroad, and especially the railroad operating in a business environment, McCoubrey and Sulg's Rule[3] is particularly relevant:

> Assume the data you want doesn't exist,
> no matter what people tell you.

Data collection has been the downfall of a number of modeling efforts, as well as information systems. The AAR model is probably most famous for the enormous effort required to assemble the data base. In another case, Martland[4] reported that in his study of the Louisville and Nashville, it took more time to assemble data and recalibrate the L&N Network Simulation Model (which had fallen into disuse) than it took to design, program, collect data for, and calibrate the MIT Service Planning Model for a similar application on the Boston & Maine.

To a large extent the problems of information have been "solved" in the current decision process on the Boston and Maine, partly through the strategy of making do without "hard" data. Nevertheless many live issues remain, and many railroads will have to confront the problems anew, finding their own ways of gathering information.

There are a number of intertwined issues to be addressed:

- What constitutes useful data.
- From whence it comes.
- How to get along without it.
- Calibration of models.

A. What constitutes useful data. There seems to be a human tendency to confuse data with information, data being facts, and information being facts useful for some purpose. This has shown up markedly in the modeling of yards in network models. The complicated submodels of classification yards, characteristic of many modeling efforts, are apparently wasted effort. In spite of all the measurements collected, not enough is known about yard operations (that is, the interrelations among all these data) to build good engineering models. Experience with simple yard models in the SPM suggests that a large number of engineering measurements (data) can be reliably reduced to a small number of coefficients (information).

In estimating demand and costs, one may get into trouble by utilizing existing data which, though correct, are inappropriate for planning purposes. Historical traffic data can be useful for calibrating and validating models and for identification of operating problems. However, the purpose of a DSS is to plan the future operations and performance of the railroad, and there unfortunately exists no empirical data on the future. Past experience must serve as a guide, not as a prediction.

One needs the ability to alter projected volumes as a function of service levels and other factors. Too often the demand for rail services is taken as a given, and railroad management becomes a cost minimization problem. Since a primary purpose of interdepartmental planning is to tailor rail services to the several markets, one needs the ability to explore the interactions among the operating plan, the service levels, and the resultant volumes. Since there are many unknowns in the economic environment, one may wish to test the robustness of an operating/service plan by trying it out with several scenarios of traffic flow.

The true costs to the railroad of the various factor inputs (e.g., cars, power, and, in some instances, labor) are often not to be found on any accounting system, but are, at least penultimately, matters of managerial judgment. For example, suppose an interdepartmental committee is considering a plan which will delay the movement of empties by exactly one day. The cost of this delay is to be found nowhere. The transportation manager may wish to use the per diem charge (particularly if car hire is placed in the transportation budget), but this is only a measure of the money which changes hands. The marketing manager may advocate the use of the economic cost, the opportunity cost, since some or all of these empties could be earning revenue for that day. This will be difficult to calculate since one car could be earning revenue for that day, while another could be just standing idle, awaiting an expected order (as happens during periods of reduced demand), in which case the opportunity cost would be zero. On the other hand, if the delay in supplying a car means that the shipment is lost, then the opportunity cost will include the profit lost on the entire trip.

B. From whence it comes. The term, data, etomologically comes from "things which are given." However, most of the data required by any computer based aid to operations management are not to be found in any data base, including filing cabinets and desk drawers. In some cases no data exist, sometimes erroneous data exist, and sometimes the wrong data exist, as in the cases of traffic flows and factor costs.

As an example of the first, in both the Boston & Maine and the Santa Fe case studies, the existing operating plans were undocumented. Train schedules existed, but the times were unrealistic. One could not calibrate a simulation model using historical data. One could not even create credible operating alternatives, since there was no reliable guide to the system constraints.

As another example, yard performance data are unlikely to exist. If one elects to create this information using a detailed yard simulation model, many physical measurements must be made. If one attempts to fit a simple model to empirical data gleaned from car movement records (assuming their existence), such a model will be accurate only under conditions similar to those experienced in the past. If a yard has been continually congested in the past, for example, an empirically derived model cannot accurately predict the yard's behavior when congestion is relieved.

Records of historical traffic flows and performance are likely to be erroneous and incomplete as well as difficult to access. Past flows may come from a computer tape of waybill information or car movement records, _if_ one is lucky enough to have such a tape, _if_ both system cars as well as foreign cars are included, _if_ local movements are included, _if_ the data are accurate, and _if_ programs are available to extract the information. The "if's" leave many holes which can be filled only with great difficulty. For example, car service rules, among other things, preclude the use of simple means, e.g., linear programming, to generate missing flows.

C. _How to get along without it_. Managers make decisions every day on the basis of limited or unreliable information. To say that some piece of data is essential to make a decision is therefore hyperbole, even though the uncertainties in information may reduce the effectiveness of decisions.

There are several ways to deal with unavailable data, and all rely on human judgment. The first is to assume that the accuracy of the data is not crucial to the outcome of the decision. For example, in defining a blocking strategy the most important constraints may be the number of blocks which can be made at each yard, and the yard costs may play a relatively minor role, e.g., breaking a tie between two alternative reclassification points for certain traffic. If this is the case, accurate cost data is unimportant; a mere ordinal ranking of the yards according to costs will be sufficient.

The second approach is to use judgments in place of data. The prediction of demand and its response to price and service level are very much matters of judgment, even when much data and empirical estimates are available.

Yard performance is mandated as well as predicted, and both currently require great judgment. In the Boston & Maine study, for example, the PMAKE functions had very little empirical basis at all, but were picked by Martland and adjusted to match the yard performance levels deemed desirable and feasible. The main difficulty is that the parameters currently used in the functions have no real world significance, so that it is difficult to calibrate the functions to one's judgments which are based on experience.

A third approach, compatible with the others, is "sensitivity testing."* One may develop or analyze an operating

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* This, rather than a lack of courage or confidence in the OR analyst, is a more likely explanation of the plant

plan using several scenarios, varying yard performance in some and traffic flows in others. This approach, however, adds to the computer expense (which may be unavoidable), and the mountains of output which must be integrated by staff and comprehended by managers become a nuisance (which may be mitigated).

D. Calibration. Any model used to support decision-making should accurately reflect the actual operations of the railroad. However, calibration can become a trap for the unwary. In the Boston & Maine case study, for example, there were insufficient data to calibrate the model empirically, so the judgments of the managers and analysts were utilized to estimate yard performance parameters. If the project had been held up for the development of the necessary data systems, serious delays would have resulted.

When empirical performance data are available, one must resist the temptation to all numerous ad hoc correction factors in order to force predictions to agree with observed performance. Such adjustments may be helpful only if the errors in prediction are systematic. Otherwise, the corrections may become just another source of error. If the object of analysis is to compare alternatives, and one is able to consider differences only, then systematic error should cancel each other out.

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manager's behavior in Little's anecdote (chapter 2). Optimization models require a great number of parameters, many of which are sheer guesses. A good manager recognizes this, even though the OR analyst did not.

The object of simulation is to model the future, not the past. Calibrating a model to accurately reflect past performance may be inappropriate as well as unnecessary. When a simulation model is used to create service standards, then the standards should reflect desired service rather than an inadequate past performance.

5.3 Selecting Areas to Support.

Breaking the management process into the phases described in Chapter 4 is helpful in designing a DSS. Several of these phases--Intelligence, Choice, and Monitoring--already receive some computer support. One must determine the most profitable areas for additional support, those places where investment in computer systems will yield the greatest improvements in the decision process.

Distinguishing between the unstructured portions of the task, requiring judgment, and the structured portions, capable of automation, can be of great help in identifying appropriate applications of computer technology. This division tends to break down in certain instances, in the modeling of classification yard performance, for example. Classification operations obviously have structure, but their complexity obscures that face, and experience in the detailed simulation of yards has been disappointing. Another area is the prediction of demand. Modal split demand models do exist, but in the absence of the necessary data, the estimation of traffic flows becomes very much a matter of judgment. In these cases, the question is not one of technical feasibility, but one of economics: How much is better information really worth?

5.3.1 Intelligence. The intelligence phase includes data gathering and the incorporation of judgments into the analysis. Intelligence also includes some problem identification, but this will be discussed under "monitoring" below.

Good information systems are particularly important. Historical data gathered and stored in any number of Management Information Systems during the course of normal operations may be quite useful. These systems must continue to evolve, responding to pressure from several quarters for more accurate, timely, and complete data on operations, particularly costs. The changing nature of the feeder systems underscores the importance of not tying a DSS tightly to any particular computer data base. Instead, the need is to create a series of data scavenging programs which can evolve along with the MIS.

Often the necessary data do not exist, and managerial judgment must suffice. The use of judgments and subjective estimates can be facilitated.

Extrapolation of demand. As an example, a great deal of judgment is required to predict future demand, even when data on past demand can serve as a reference point. As noted previously, records of historical demand are often erroneous and incomplete. Past demand may, in fact, be anomalous, influenced by factors which are not expected to recur. Historical flows of empty cars may be unavailable, or flows of loaded cars may be predicted at a very aggregate level. To support judgments in such instances, a means of manufacturing msissing data from some set of assumptions may be quite useful. For example, the following formula may help in artifically disagregating traffic projections:

$$F_{ij} \propto O_i \cdot T_j$$

where

F_{ij} is the flow from yard i to yard j,

O_i is the percentage of cars originating at i, and

T_j is the percentage of cars terminating at j.

Another useful tool is a means of editing the base of traffic flows to reflect general assumptions, e.g., a five percent increase in certain markets. This can be used to test the flexibility of a plan as well as to take the effects of service level changes into account.

Judgments in analysis. The current SPM does, in fact, incorporate judgments concerning the ways in which classification yard performance reacts to certain factors, e.g., train schedules and volume. These are the PMAKE functions. Using these guesses, the SPM apparently performs as well as any model which simulates yard operations in detail.

The incorporation of judgments can be expedited, however. As currently implemented on the SPM, the PMAKE functions are semi-rigid, having a fixed form and parameters which have little operational significance. One possible improvement would be to create a small computer program to derive the parameters (if not the form) from the answers to questions having some real world significance, e.g., "Given such-and-such a yard situation with arrivals and departures at these times, what would be the effect of an extra hour in scheduled connect time?" or "Given the same yard situation, what would be the effect of an additional arrival at such-and-such a time?"

Another approach, suggested by Martland,[5] would be to derive the parameters from a detailed yard model. This has the advantage of being able to predict performance under completely different conditions, where human judgment fails. For example, an alternative may propose significant expansion of some yards, in which case past experience may be a less reliable guide to future performance than a simulation model. However, the costs of data collection and calibration may be considerable, and human judgment may be quite satisfactory for most yards in the network.

Other judgmental factors enter into the analysis. Crew requirements for each yard can be estimated as a function of yard volume and the number of blocks to be made. Switch engine requirements are similarly estimated. Train schedules are also a matter of judgment, depending upon the track characteristics, engine horsepower, and trailing weight. All these judgments can be quantified, entered into a data base, and uniformly applied in all analyses.

5.3.2 Design. Since the decision process is now supported by computer-based tools which can evaluate complete operating plans, create service standards, and monitor performance, the greatest leverage in applying additional computer power lies in supporting the creation of the plans themselves. This bottleneck lies in all the feedback loops of the decision process, creating a discontinuity at each iteration. Its elimination should, at the very least, allow a process that now takes weeks to transpire in only days. Moreover, the interactive design and evaluation of operating plans will facilitate a new process in which "What if?" is frequently asked, and management can gain insight by playing with a model of the railroad.

This design phase can be supported at several levels. Risk increases at each level, but potential benefits may be greatest at the highest level.

The first level is to allow the user to easily edit, save, recall, and display the operating plan. Among other things, this will eliminate the transcription and recoding of operating plans for input to a network simulation model. This requires that considerable thought and experimentation be devoted to a command language and the means of displaying the data as well as to the internal computer data structures.

One needs the capability to define and redefine yard blocks, the assignment of blocks to trains, and train schedules and routing. The concept of closure is vital here. For example, it should be hard to lose one's place when editing an operating plan, or, if a train is deleted from the plan, there should not be blocks still assigned to it.

A difficult way to enter train schedules is to list each yard it visits along with the corresponding arrival and departure times. This requires the schedule to be calculated from the yard to yard transit times (which depend upon other factors) and the time required to do work at each yard. If one wishes to change the schedule, retyping the times to be changed is also laborious and can give rise to errors. If one adds or deletes train blocks, the schedule should be adjusted.

If one train is scheduled so that a key connection with a second train can be made, then if the analyst changes the schedule of the second train, the schedule of the first must be changed as well.

As an alternative, one may proceed as follows: To create a train schedule, simply indicate the yards it visits and an arrival or departure time at some yard. (A sufficiently smart program may deduce the train's route by simply taking the "shortest" path between indicated points.) The computer could create a schedule from information associated with each yard to yard link in the data base, and the line haul times can be manually adjusted, if desired.

Initially the train will make no stops since no traffic has been assigned to it, so the departure time at each yard will be the same as the arrival time. As work is assigned along the way, the computer can adjust the schedule by adding appropriate delays at each stop on the route.

If it is decided that a certain connection should be important in determining the train's schedule, one can specify the connection and the available connect time desired. The computer can adjust the schedule, and if the arrival time of the connecting train is changed, the schedule can be adjusted accordingly.

At the <u>second level</u> one can add a simple accounting model to help keep track of traffic volumes. As one defines yard blocks, train schedules, and train blocks (that is, assigns yard blocks to trains), one needs a means of keeping track of the traffic flows assigned to yard blocks and trains, the flows unassigned, and the expected train volumes and workloads.* One also needs an effective means of displaying such information. At each yard one may have a list of the numbers of cars going to each destination and the number of cars which will pass through each intermediate switching point. This list will indicate which flows have been assigned to blocks and which have not, and it will indicate the volumes of the blocks already defined.

Similarly one may want a list of link volumes to aid in the routing of trains.

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* This is the purpose of the Canadian National CANAT system.

At the <u>third level</u> more complex analytical techniques can be employed to aid design.

In designing an operating plan, the analyst makes use of formal and informal heuristics, supported by manual accounting schemes and screening models. For example, in scheduling trains, the analyst may begin by starting a train at a time which will minimize the delay caused by a connection with some other carrier. Block volumes may be crudely estimated and assigned to trains to equalize train length or to minimize delay. However, to satisfy both criteria or to satisfy just one with any amount of accuracy requires a prohibitive amount of manual calculations.

The heuristics can be aided by a strategy of analyzing selected portions of an incomplete plan using the analytic techniques of the SPM or some simpler models, which can analyze selected portions of incomplete operating plans very quickly. This also requires the ability to select the areas of interest and a means to highlight the significant differences between options.

In analyzing performance, there are several possibilities. One may utilize the very simple models which are incorporated into the objective functions of a number of optimization models; these may supply a gross figure of merit, but one must be careful in their use. Another approach is to utilize the techniques of the SPM to analyze a limited number of origin-destination pairs. One could take more or less complex approaches, but risk as well as cost increase with complexity.

Other analyses, which are also useful in the evaluation and choice phase, can be utilized to aid design by giving estimates of costs and testing for feasibility. For example, time-distance graphs, which can be created from train schedules, may be helpful in spotting line haul congestion problems. Train-to-train power cycle graphs, which be generated, either automatically or with minimal human help, from train schedules and specifications of locomotive consists, can help determine overall power requirements.

The computer can identify train schedules which may exceed the hours of service regulation, identify congestion at yards caused by the bunching of arrivals and departures, and identify congestion at yards caused by a large number of blocks (some of which may simply have been set off there). A computer generated lineup of trains and block volumes, and a graph of yard volumes at each yard can be useful in correcting as well as identifying the causes of congestion.

At the fourth level heuristics may be automated. The most important ingredient of the design process is inspiration, but the other 95 percent can be sheer drudgery. Computers are perfectly capable of generating mediocre operating plans by themselves. This suggests a strategy of using tightly controlled and simple heuristics in order that an analyst can specify the most important parameters of a plan, such as the blocking policy and train schedules, and the computer can fill in the details quite satisfactorily.

The automation of yard block definition is probably the easiest to implement. Properly controlled, the techniques described by Martland[6] and Suzuki[7] are likely to be effective. (See Appendix B.) Heuristics to assign blocks to trains or to adjust train schedules will be more complex, requiring great analysis of the alternatives, and, therefore, will involve more risk. On a small railroad like the Boston & Maine, where the operating alternatives are more limited (e.g., fewer alternative routes), the benefits of such heuristic optimization are likely to be less than on a larger network.

5.3.3 Choice. The choice phase includes the evaluation of alternatives and the selection of a plan for action. Choice can be aided by automating more analyses, improving existing analyses, and facilitating the communication of the results of such analyses. At the present time, perhaps only certain modifications to the report presentation formats can be justified. However, this will change when the design phase is better supported, since the users may be quickly overwhelmed by the volume of computer analyses and the need for additional manual calculations.

A. Evaluation. One way to improve the estimation of network performance would be to modify the present analysis by the SPM to simulate a weekly cycle of trains and traffic. Another would be to utilize a time-event simulation model in order to cover the weak points of the SPM, e.g., its inability to simulate the effects of overloading trains.

Some additional analyses are rather straightforward and can be implemented with only moderate effort. A few of these have already been suggested to support the design phase. Two others involve the calculation of costs:

Yard costs and crew requirements may depend upon the judgments of field personnel, but they can be calculated if these judgments are quantified. One approach, used in the Santa Fe study, is to present trainmasters with various scenarios of yard voluems and the numbers of blocks to be made and ask how many crews would be required. The results may be used by the computer in tabular form or used to estimate a continuous function.

In the present evaluation process, linehaul costs are assumed to be a linear function of train-miles and car-miles. This may be a close approximation for budgeting purposes, but there are instances in which the marginal cost of extending a train's route or schedule may be either much cheaper or more costly than the average, due to a number of labor-related constraints. In such cases, a more detailed cost accounting model will be useful.

B. Selection. Report presentation formats and the need to reduce large volumes of data to meaningful information are important issues in supporting the choice phase.

Communication is very important in interdepartmental decisionmaking, where several managers and their staff need to work together and explain their ideas and intuitions to each other. The computer-generated reports must be flexible, understandable, and easy to read. Each participant in the process looks for different measurements and may want a different presentation format, e.g., detailed vs. aggregate or tabular vs. graphical. If they want aggregate information the bases of aggregation may vary. If they want detailed information, they will not want all the details at once, but only certain details, and these will vary each time.

It is easy to provide canned reports, but this is not enough. As users become more sophisticated, change their approaches to the problem, or wish to narrow their focus to certain features, they will require a great flexibility in asking questions. This will be difficult to provide, but may very well be worth the effort.

In addition to displaying the results of the analysis of a single plan using a single economic scenario, one should have the capability of comparing significant features of a number of different plans with a number of scenarios.

5.3.4 Implementation. Implementation is currently supported primarily by the use of the SPM to create service standards. Other reports can be useful in communicating decisions to those responsible for their implementation.

At the very least, an easy to read transcription of the operating plan can be generated along with a summary of the service standards.

Other reports may help explain the expected impacts to those affected. The Norfolk & Western, for example, has modified the AAR Network Model to create pro forma morning reports, identical in form to the actual reports used by yardmasters every day.

5.3.5 Monitoring. Recently MIT has been creating reports comparing the actual performance of the B&M with the service standards, on the basis of origin-destination pairs.[8] Other analyses are possible, given the necessary data. For example, using car movement records, one may empirically estimate PMAKE functions which can be compared with those used in developing the service standards, or one may analyze the performance of specific train connections. Either of these may prove more useful in identifying the sources of problems than the origin to destination performance measurements. Rothberg et al.[9] and Messner[10] have proposed accounting models to equitably allocate the accountability for car time to those whose actions directly affect it.

5.3.6 Empty Distribution Policy.[11] Of the six major policy decisions, only empty car distribution falls outside the iterative design and choice cycle (Figure 4.1). The Car Utilization Department is responsible for predicting empty flows based on an a priori distribution policy. However, the goodness of a distribution policy depends upon the other elements of the operating plan.

This suggests the desirability of planning distribution in concert with the other strategic operating decisions. Two computer-based tools may help bring distribution policy within the formal strategic operations planning process:

First, a means to predict empty flows given a distribution policy and predictions of loaded flows.

Second, a means to calculate the costs of a distribution policy given the other elements of an operating plan.

5.4 Summary.

An analysis of the new strategic operations management process on the Boston & Maine is necessary to:

- o Identify areas of the process in need of additional computer support.
- o Suggest specific tools and techniques for appropriate computer support.
- o Identify important issues and problems to be resolved by any railroad seeking to improve managerial effectiveness in this area.

A review of the management process discloses four major types of problems:

- o Bottlenecks in the decision process.
- o Technical limits to analysis.
- o Unsupported decisions.
- o Information availability.

The bottlenecks, technical limits, and unsupported decisions are current problems on the B&M and hinder the effective use of the managers' and analysts' time and talents. The information problems have been provisionally solved on the B&M, but as newer uses for accurate data are discovered, present solutions will become inadequate. Any railroad attempting to improve operations management will confront the same problems--only they will be different, and each railroad must find its own way to deal with them.

Dividing the management process into types of activity and distinguishing between structured and unstructured tasks aids in developing concrete suggestions for additional computer-based support. Each of the five phases of the process--Intelligence, Design, Choice, Implementation, and Monitoring--can be supported better.

The Design phase is, however, the area of greatest need, since it is now a largely manual process and constitutes the most serious bottleneck in the overall management cycle.

Chapter 6 will propose a plan for implementing additional computer support, with specific emphasis on the Design phase.

Chapter 5 References

1. Martland et al., A Case Study of the Boston & Main, p. B-10.

2. McCarren, Railroad Operating Plans: Development and Evaluation, pp. 14-15.

   McCarren and Martland, The MIT Service Planning Model, pp. 7-8.

3. Quoted in Keen and Scott Morton, Decision Support Systems, p. 184.

4. Martland, personal comment.

5. Ibid.

6. Morgenbesser, Martland, and Laughlin, Economics of Running More Trains on the Louisville and Nashville Railroad, Appendix B.

7. Suzuki, "A Method of Planning Yard Pass Trains on a General Network."

8. Michael G. Messner, A System for Controlling a Railroad's On-Line Freight Car Cycle, M.S. Thesis, MIT, 1980.

9. Rothberg, Sussman, and Martland, The Design of a Management Control System for Railroad Freight Terminals.

10. Messner, A System for Controlling a Railroad's On-Line Freight Car Cycle.

11. Craig Phillip (MIT doctoral student) is working on a DSS for empty car distribution policy.

CHAPTER 6

DESIGN AND IMPLEMENTATION

6.1 Introduction.

The last chapter analyzed the new operations management process at the Boston & Maine in order to identify specific areas for additional computer-based support and to suggest alternative tools and techniques which can provide this support. This chapter will suggest an overall plan for the further evolution of computer support for strategic operating decisions at the B&M. On those railroads which have only a rudimentary operations management process and poor data management systems, the design/implementation plan must be modified accordingly.

The design and implementation process should proceed in a series of evolutionary steps with close consultation between the users and the builders. An appropriate path will depend very much upon the particular organization and the greatest needs identified by management.

The Canadian National, for example, has proceeded from implementing data systems, which support the Intelligence phase, to developing the CANAT system, which can support Design. CANAT is a sophisticated accounting model which helps a planner in defining blocks, trains, and train routes and in assigning blocks to the trains. CANAT keeps track of these elements of the operating plan and derives statistics such as block, yard, and train volumes, and traffic which has not yet been assigned to blocks. CN's next step will be to support the choice phase with a simulation model.[1]

Providing support to Intelligence, Design, and Choice, in that order, may or may not be a viable way to go for other railroads, as well. It will make the development of software easier. However, the greatest payoffs will be delayed until tools become available to evaluate operating alternatives and to create service standards. To build support for a new decision-making process and to involve users in the design of the system, concrete benefits should come earlier in implementation. Thus, technical risk must be balanced with organizational risk.

6.2 A Design/Implementation Plan.

In the present management process on the Boston & Maine, where Intelligence, Choice, and Monitoring are more or less adequately supported, adding computer support to the Design phase will result in immediate benefits, since Design is now the biggest bottleneck in the management cycle.

Implementation may proceed in several stages, roughly following the four levels of Design support identified in Chapter 5. The stages proposed here are not rigid. In many cases, features can be implemented in a different order. One may wish, for example, to automate a blocking heuristic before adding a power cycle analysis program.

In brief, the stages are as follows:

Stage 0. Create a basic breadboard version for testing.

Stage 1. Provide for easy editing of operating plans.

Stage 2. Clean up user interface and add traffic volume accounting capability.

Stage 3. Add a collection of analysis modules.

Stage 4. Automate some heuristics.

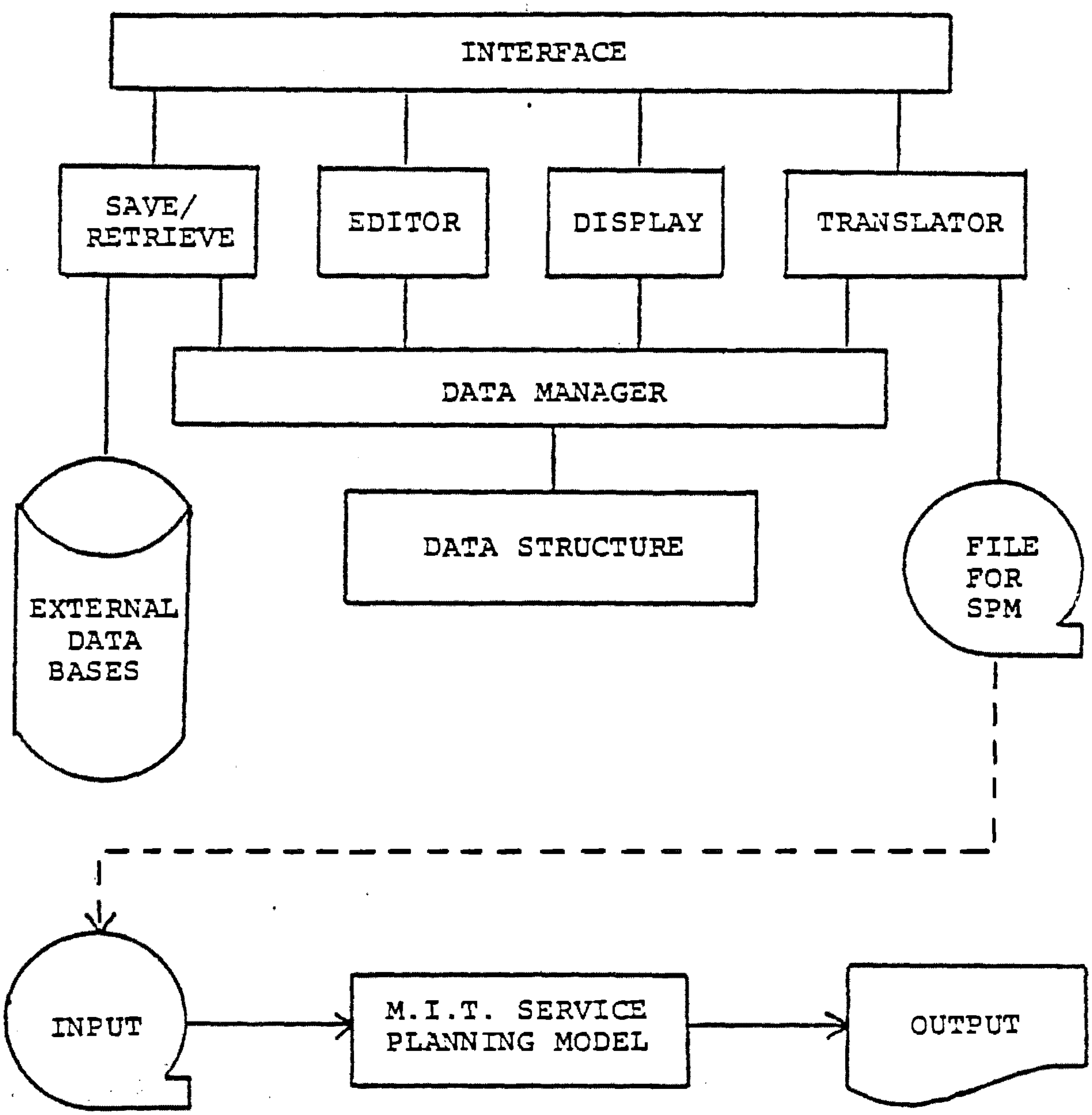
Stage 5. Provide more support for the Choice phase.

The technology involved in creating a Decision Support System already exists, for the most part. Implementors can and should kludge together existing computer software wherever possible, in order to build prototype systems as quickly as possible. Techniques need not be elaborate, particularly in the earlier stages of evolution. A quick-and-dirty system is a minimal investment, a research tool enabling the implementors and the users to gain valuable information about the best uses of the DSS and a clearer picture of the goal toward which the system should evolve. This will also reduce the risk involved, and the project team will be more willing to start over, as may be necessary.

6.2.1 Stage 0. This is a breadboard version, whose major purpose is to develop data structures, primitive (elementary) operators to manipulate and display the data, and an interface to the MIT network model. (Figure 6.1) The stage 0 system is separate from the MIT Service Planning Model. Its

FIGURE 6.1

STAGE 0, BREADBOARD VERSION



functional capability is limited to storing and retrieving data files, manual editing and display of data, and translating data into a form compatible with the present SPM.

It is composed of several parts:

- o <u>A simple interface</u>. At this point no effort should be made at human engineering.
- o <u>Internal data structure</u>. Considerable effort should be invested in designing the data structures. A good technical design will reduce software development costs and improve execution efficiency.
- o <u>Data manager</u>. This is a collection of primitive routines whose purpose is to access the data structure or modify its elements. These routines can assure internal data consistency, and, as features are added, they will help insulate existing modules from change.
- o <u>Save/retrieve module</u>. This will probably be a collection of routines, whose purpose is to transfer the internal data structure to and from permanent data files.*
- o <u>Translator</u>. The purpose of this module is to create a

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* It is important to save and protect a number of working copies of the data base. Users should feel free to play with the system, knowing that they will always be able to get back to their original operating plans, etc. and that they cannot inadvertently mess up the work of others. However, proliferation of files can be costly in terms of both time and storage. One means of reducing costs is to segment the data base, e.g., use separate files for traffic flows, yard block definitions, etc. These files may be self-defining. Another strategy (compatible with the first) is to create a tree structure in which the files which are the leaves contain modifications to the files which are the branches.

data file suitable for input to the SPM. It will be similar to the save function.

- o <u>Editor</u>. The Stage 0 editor should be sufficient only to make all possible modifications to the data base. Stage 1 will develop the editing capability.

- o <u>Display module</u>. This is also composed of several routines, whose purpose is to regurgitate selected parts of the data base. It should also be able to identify undefined portions of the operating plan.

6.2.2 <u>Stage 1</u>. After the basic techniques have been developed, a number of features can be added to facilitate manual editing of the operating plan. For example, submodules can be added to the editor to do the following:

- o <u>Aid in train route definition</u>. The object is to avoid the need to specify every yard along the train's path. There are several approaches. For example, standard routes may be stored in the data base and referenced when a new train symbol is defined (as done in the CANAT system). Alternatively, the computer may select the shortest path (in terms of mileage, delay, or cost) connecting the origin, destination, and any intermediate yards specified.*

- o <u>Aid in train schedule definition</u>. As long as care is taken to provide a manual schedule editing capability and a measure of control over the procedures, automating the calculation of train schedules can be beneficial. Formal procedures and informal rules of thumb

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* See Boesch,[2] Dreyfus,[3] and Defenderfer[4] for discussions of applicable shortest-path algorithms.

are used in setting train schedules. The schedules are, by definition, dependent upon the link transit times and the yard delays along the way. Transit times can be estimated from rail line characteristics (reduced to one or two variables) and train characteristics (power and tonnage). Similarly, yard delays can be estimated as a function of the work done at each yard. Judgment is still required to take account of other factors, such as line and yard congestion and time incentives to the train crews.

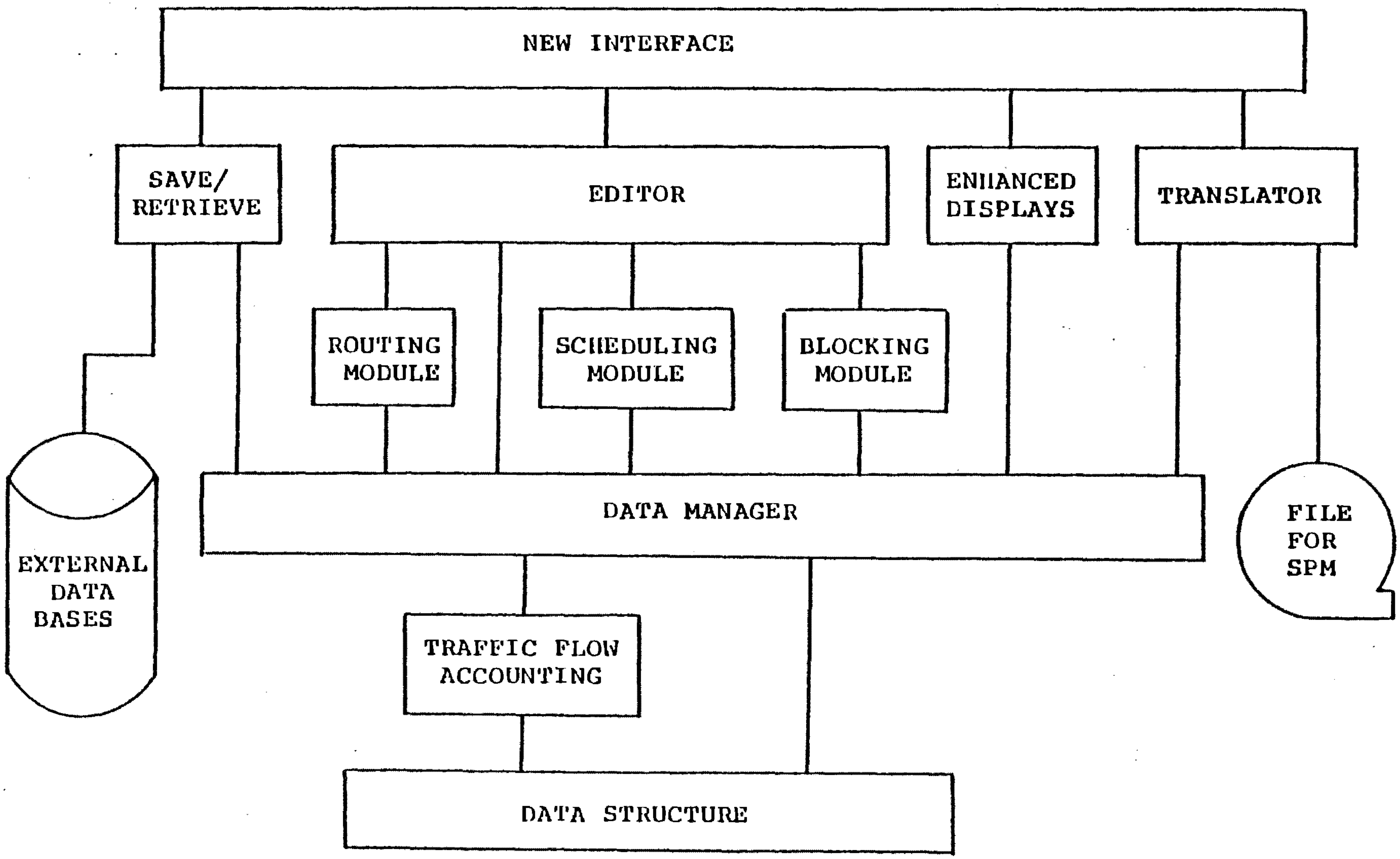
- Aid in defining yard blocks. In defining yard blocks, one may wish to avoid the complete enumeration of the destinations included in each block. Such a procedure is laborious and prone to errors. An alternative is to assume, unless otherwise specified, that each block carries traffic for its destination yard and all points beyond which are not included in other blocks. Again, the computer can use a shortest-path algorithm to decide which yards are "points beyond."

At this point, the system can be of some limited use to the staff responsible for designing alternative operating plans. It should be shown to them, and they should test it with an intermediary at the console. Builders and users should seriously discuss the user interface, e.g., command structures and display requirements, and reevaluate the future path of evolution, setting priorities for additional features, for example.

6.2.3 Stage 2. (Figure 6.2) At this stage, there are two tasks to be done: Clean up the user interface and begin adding analysis capabilities. These require changes in three

FIGURE 6.2

STAGE 2, WITH EDITING MODULES AND
TRAFFIC FLOW ACCOUNTING MODEL ADDED



areas.

- Command structure. Up until now, the input formats have been rigid and tedious, possibly requiring, for example, the use of numbers to identify yards, blocks, and trains. The design of the new user interface should have three goals: To provide a flexible, easy to use command language; to allow continued evolution of the system, adding new commands and possibly redesigning the user interface itself; and to do this cheaply. There are a number of ways to accomplish these goals, depending upon the desired sophistication of the user interface. Heindel and Roberto,[5] for example, have made available an interactive language design system.*

- Display. After seeing the prototype displays, the users will undoubtedly have suggestions for improvement. This may be a good time to support the implementation phase by providing a well formatted description of the operating plan. More display features must be added to support the traffic volume accounting model as well.

- Traffic volume accounting model.** A definitional model to keep track of traffic flows is very important in the design phase. In designing a blocking plan,

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* Heindel and Roberto's book provides listing in both FORTRAN and PL/I for all routines except four machine-dependent subroutines.

** Although this may be considered an analysis function, most of the actual computer code will reside within the data manager module, since the accounting information should be updated automatically with each change in the operating plan (or traffic flows).

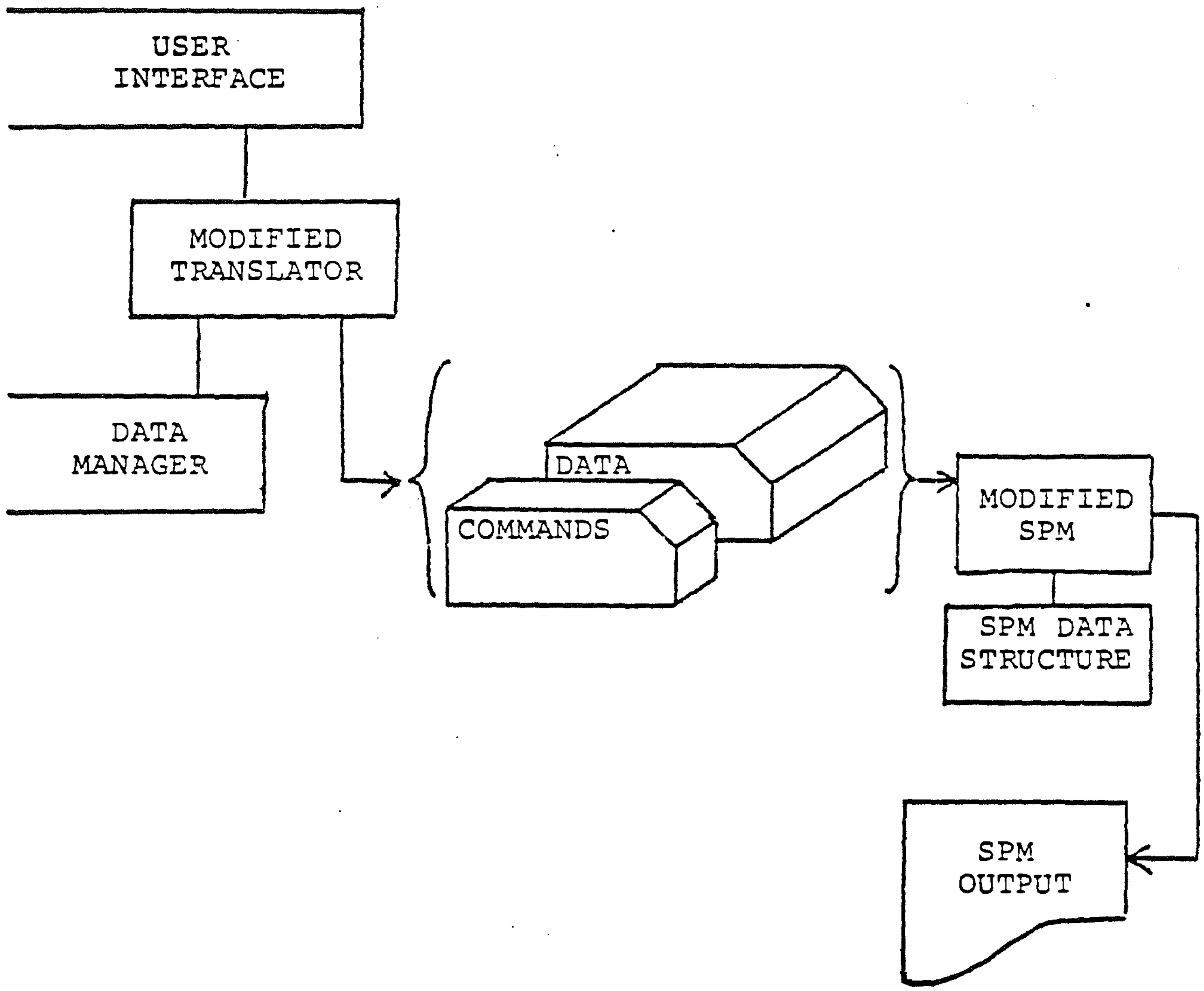
one should know, at a minimum, for each yard, the number of cars going to each destination, including those which have been sent to the yard from other origins. In assigning blocks to trains, one should know the block volumes. (However, if blocks are assigned to more than one train, a purely definitional model can not tell how much of each block goes on each train, since this depends upon the train schedules and yard performance.) Yard and link volumes are also important for spotting congestion and routing trains.

6.2.4 Stage 3. More useful analyses can be added. Some of these will be useful in the choice phase as well as in design. (Recall that design involves much choice behavior.) In providing tools to evaluate performance for the purposes of design, there are several options.

- Modify the SPM. The SPM calculates performance for each origin-destination pair independently of every other pair. This internal structure of the SPM can be exploited to provide superficial analyses of alternatives by confining calculations to a specific set of origin-destination pairs. There are several ways to implement this option:
  - The minimal modification would be to provide for a command or "options" card in the input file to the SPM. The options card would direct the SPM to perform only certain analyses. (Figure 6.3)
  - Modify the SPM to be a subprogram of the interface module, so that analysis can be directed interactively. After any editing, however, before an analysis session can proceed, the translator module must translate the data base to

FIGURE 6.3

STAGE 3, USE OF COMMAND CARDS



a SPM compatible file. (Figure 6.4)

- o Make the SPM a subprogram as before and modify the translator to insert data directly into the SPM's data base, rather than output it to an intermediate file. (Figure 6.5)

o Rewrite the SPM. Presently the SPM probably has only two major technical limitations--its inability to model weekly cycles and its inability to model congestion. If the SPM is to be used interactively, however, a third will surface--execution speed. If it is used to model large networks, then computer memory requirements will get out of hand. Rewriting the SPM to alleviate these limitations, with the goal of providing both limited and comprehensive performance analyses, may therefore be a viable alternative. (Figure 6.6)

o Create (or obtain) one or more quick and dirty analytic models. For example, one may calculate origin to destination transit times by assuming that yard delay is a function of the yard and the number of possible connections. If blocks have not been assigned to trains, delay may be a function of block volume and link volume.

There are other analytic tools which can be added. The following examples can be implemented as independent modules.

o Time-distance graphs. The SPM does not model linehaul congestion at all. Thus the user is responsible for ensuring that the train schedules are feasible. Time-distance graphs, a familiar means of displaying schedules, can be plotted automatically for any specified segment of line. Except for optional schedules for passenger service, no new information is required

FIGURE 6.4

STAGE 3, THE SPM AS A SUBPROGRAM

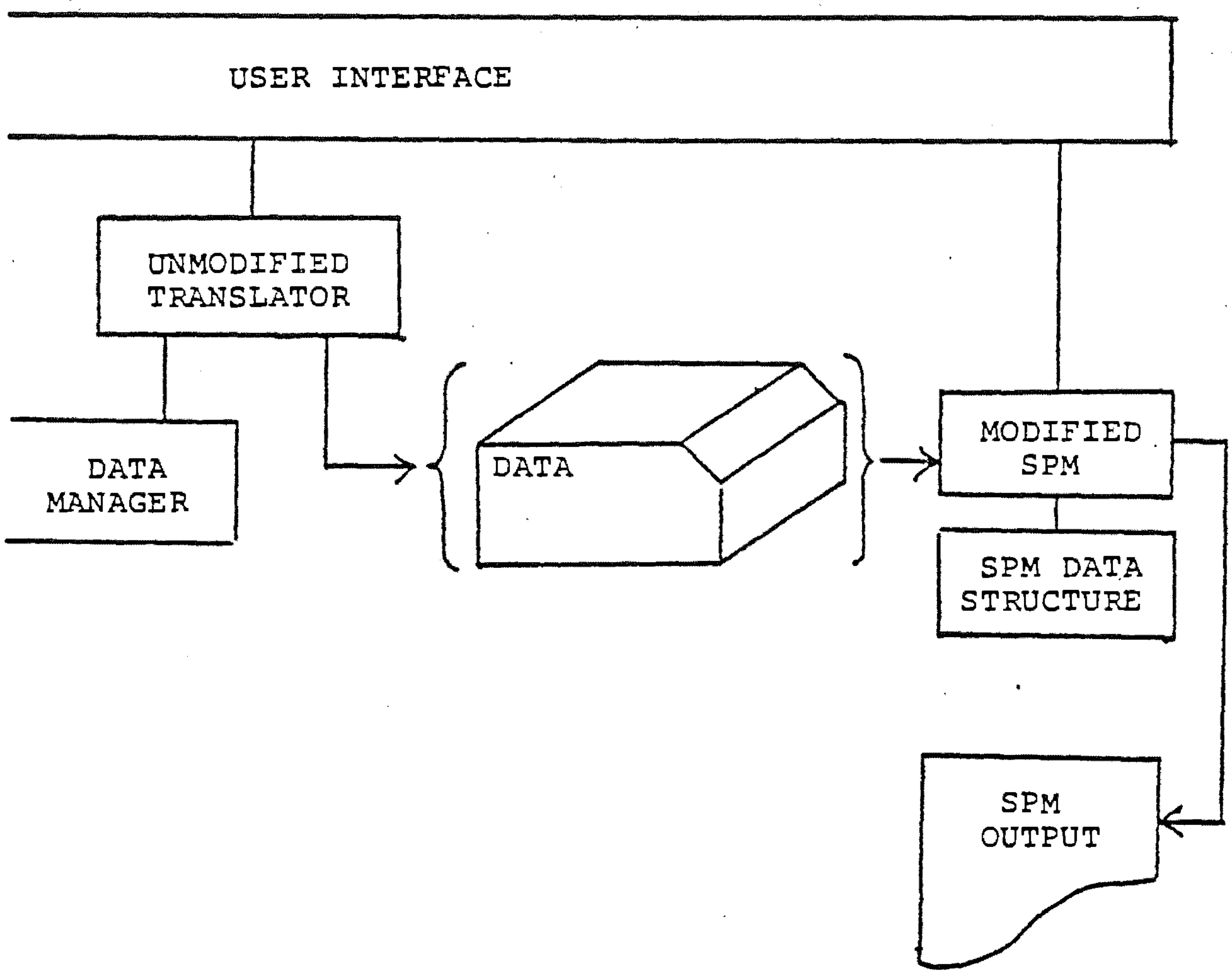


FIGURE 6.5

STAGE 3, TRANSLATOR INTERFACED WITH SPM DATA STRUCTURE

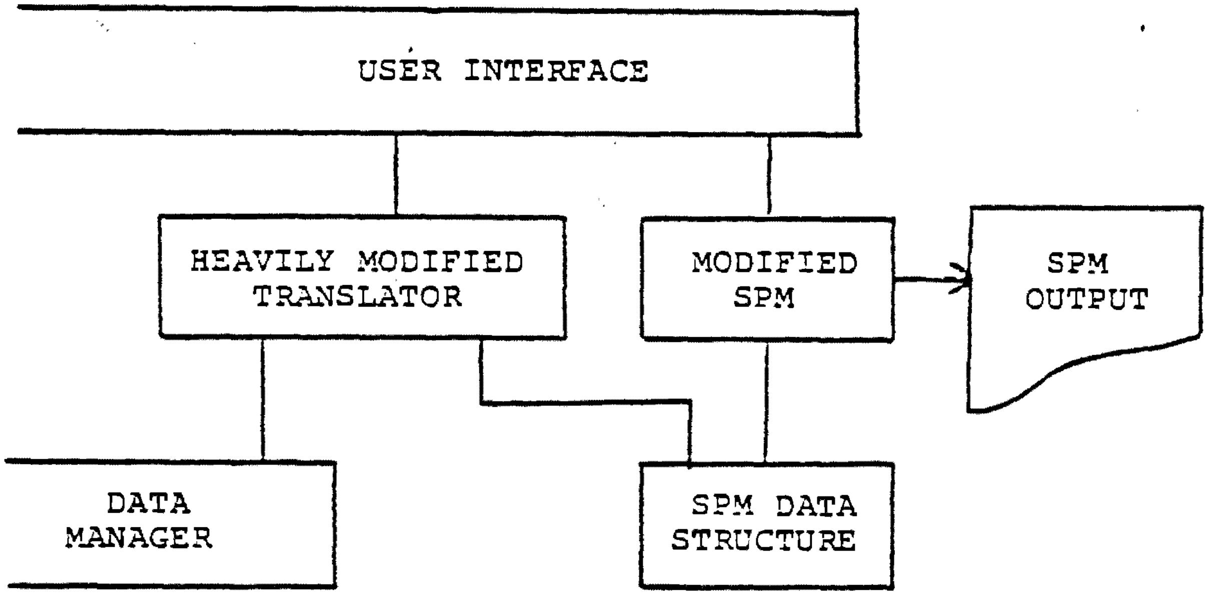
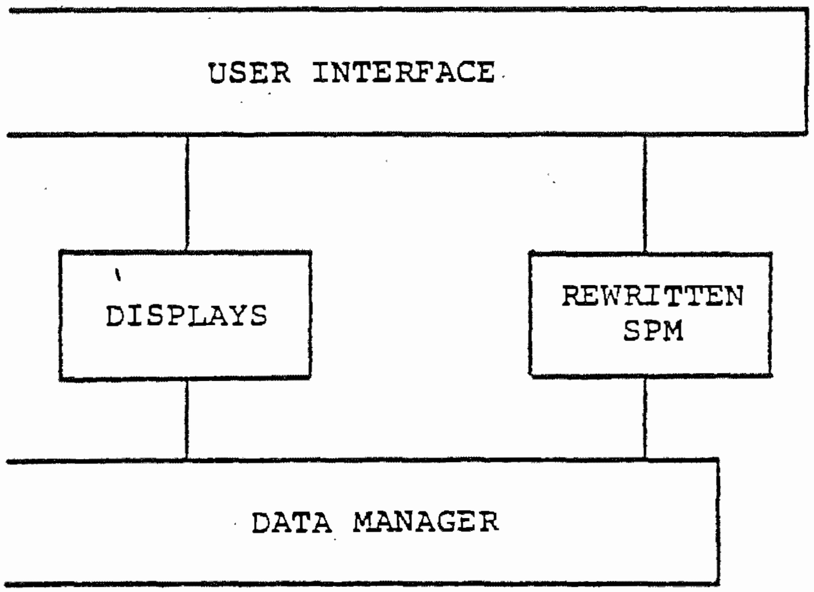


FIGURE 6.6

STAGE 3, WITH REWRITTEN SPM



(TRANSLATOR REMOVED)

beyond the stage 0 data base.

- <u>Power cycle analysis</u>. On the B&M, as on other roads, the power distribution policy is to specify a definite plan for cycling powersets from one train to the next. Creating a power cycle graph, annotated with layover times, is presently done manually, but this can be done automatically if information about the locomotive consist is appended to each train descriptor in the data base. If deadheading is prohibited, and each train is allowed only one type of powerset, then the analysis is trivial. McGaughey et al.[6] have used the out-of-kilter algorithm* to solve the more general case.

- <u>Yard congestion analysis</u>. Congestion in the receiving and departure yards and the classification tracks will, of course, hurt performance and may lead to inefficient use of yard resources. There are several approaches to identifying yard congestion:

  - Scan all yards to flag situations in which the number of arrivals and departures (excluding through trains) within a certain interval exceeds a threshold value.

  - At each yard, print a list of arrivals and departures, annotated with setoffs, pickups, and estimated volumes.

  - Draw plots of arriving cars, departing cars, and yard inventories as a function of time.

The second and third examples will need analytic capabilities similar to the SPM to provide accurate

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* A formal version of "disjoint marginal incrementalism."

estimates of block volumes, but crude estimates may be generated by other means.

o <u>Calculation of yard costs</u>. If, as suggested earlier, requirements for yard crews and other resources can be expressed as a function of yard volume and the number of blocks handled, then it is a simple matter to calculate costs. Yard volumes are available from the traffic volume accounting model discussed at stage 2, and it is easy to count the blocks at each yard. Great ingenuity is required only in devising an easy means to elicit the yard cost functions from managerial judgments. Of course, more sophisticated models can be developed. Martland and Rennicke,[7] for example, made empirical measurements relating average crews worked to the shift and daily volumes at two B&M yards.

By this time, certain optimization techniques may be applied profitably. On the other hand, with the addition of the analytic modules at stage 3, the users may believe that the DSS sufficiently supports the design phase and that the system builders should concentrate on Intelligence or Choice. Thus stage 4 must be considered optional.

6.2.5 <u>Stage 4</u>. Applying optimization techniques and automated heuristics involves more risk of technical failure than features added at previous stages. In some instances, optimization may turn out to be no more effective than well-supported human judgment. On the other hand, such techniques can be used to generate greatly differing basic strategies and to relieve the tedium of making the "obvious" choices. A key problem is to devise methods to control the automated heuristics so that they change only those parts of the operating plan which the user desires; one does not want to have one's painstaking work in relieving congestion at a certain yard wiped out by some stupid algorithm. One of several possible approaches is to append flags to the data structure to indicate which changes are off limits, e.g., which blocks must be made regardless of volume.

Heuristics can be applied to several of the key decisions involved in creating an operating plan.

- <u>Yard block definition</u>. Automating the definition of yard blocks may be the easiest to implement. Some techniques are discussed in Appendix B.
- <u>Assignment of blocks to trains</u>. This is an involved combinatorial problem, which may be attacked by testing random swaps of blocks among trains. Evaluation of alternative assignments, however, requires a great deal of analysis. Train schedules and yard delays, for example, must be taken into account; otherwise, a ludicrous assignment may result, e.g., blocks being assigned to consecutive trains rather than being spaced apart.

6.2.6 <u>Stage 5</u>. By this point, a great number of editing, display, analytic, and accounting modules have been applied to support the Design phase. Attention should be paid to the other phases, particularly Choice.

With the addition of many modules for quick analyses, a serious information management problem will develop. The system users, particularly the staff responsible for designing alternatives, may soon find themselves buried in data. The system builders should turn their attention to devising means to compare the evaluations of two or more alternatives and to display the key differences.

- Analysis analysis. One approach is to analyze several alternatives as they are generated, storing the raw results as well as the alternatives themselves on disk files, and use an interactive program to make comparisons as needed. Of course, this may require enormous data files. The opposite approach is to run the analyses at the time the comparison is requested, saving only those data specified by the user and deleting the scratch files when the comparison is completed.

More analytical modules should be added to evaluate an operating plan more completely and to help integrate the development of the empty car distribution policy into the quarterly planning cycle. The analyses described here are considerably more complex than most of those listed at stage 3 (the exception being the SPM type analyses).

- Scenario generation (editing the traffic base to reflect assumptions). This falls primarily under the rubric of incorporating judgments into analysis, but the ability to create various scenarios is important in testing alternatives. It is desirable to begin with a traffic data base as disaggregate as practicable, so that commodity-related assumptions (e.g., a 12 percent decrease in paper products traffic) can be handled. The basic operations of the scenario generation module are to multiply all traffic in a certain user-defined category by a factor and to aggregate by geographic location. These capabilities will enable the users to:

  - Project past demand into the future by accounting for anomalies and trends.
  - Modify service-elastic demand projections in accordance with service levels predicted by analysis of the operating plan.
  - Test the flexibility of the operating/service plan and create very specific contingency plans.

- Road crew costs. Cost accounting for road crew expense is difficult due to the complexity of work rules, but still possible to automate in principle. Perritt,[8] for example, suggested a model for road crew costs which takes into account the dual bases of pay (mileage and time), deadheading, and payments for time held away from home terminal, initial terminal delay, and final terminal delay. Analysis is complicated by the use of extra boards to fill vacancies (analogous to a "safety stock" in inventory control), but judgments may be incorporated to great advantage. On certain roads which have negotiated reduced crew size agreements, savings can be realized on crews only after all protected positions have been assigned. These complications make computer analysis all the more attractive.

- Enhanced network performance analysis. Although the SPM is very useful in evaluating alternatives in a wide range of situations, it has, like all analytic tools, weaknesses which limit its generally applicability to the more common decisions faced in operations management. As these limits are reached, managers will want more reliable evaluation methods. There are two approaches:

- o Obtain or create a more conventional time-event simulation model.
- o Extend the SPM: Use a detailed yard simulation model to calibrate the SPM's PMAKE functions and to estimate yard costs. Use a detailed line simulation model to calculate line-haul delays and reliability, which can be used to create realistic schedules.

o Empty distribution policy analysis. In the current B & M formal planning process, the empty distribution policy is taken as given. If distribution is to be well integrated with the rest of the operating/service plan, two tools are necessary:

- o A means of deriving the flows of empty cars given loaded flows and the distribution policy. Since car types and ownership are not interchangeable, this may require extremely disaggregate demand data.
- o A means of calculating the costs involved in moving and storing empty cars.

6.3 Comments.

Chapters 4 through 6 complete one pass through the Decision Analysis loop depicted in Figure 3.3, the Predesign Cycle. The next task should be to complete a pass through the Entry loop. Both loops should be repeated before the implementors and users may consider themselves ready to move on to the Design Cycle, shown in Figure 3.4.

The proposed plan for design and implementation should in no way be considered a final prescription. In fact, if the user-managers do not rewrite at least half of it, they are probably not upholding their responsibilities as members of the design team. The plan and the ideas contained in earlier chapters should help team members generate better suggestions.

Personnel required during the earlier stages of development (up through stage 2) will be relatively modest. In addition to the B&M staff already devoted to supporting the new management process, there should be, at a minimum, a full-time person playing the role of the integrating agent. A full-time transportation analyst and a software specialist, between them conversant with the techniques and tools to be implemented, will be required, as well as one or two computer programmers. At stage 3, staff requirements will probably double, and as the Service Committee learns to utilize their new capabilities their staff must grow as well. Staff needs will jump again at stage 5, when the Service Committee receives the capabilities to thoroughly test operating alternatives, to develop specific contingency plans, and to evaluate empty distribution policies.

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CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 Introduction.

The effective management of freight operations is important to the health of the railroads as well as to the public they serve. The highly structured aspects of railroad operations suggest that computers can be applied to operations management with great advantage. Yet, despite a decade and a half of effort, computers have failed to make a significant impact upon operations management. Although a large number of promising tools and techniques have appeared in the literature, most of these projects have died in obscurity.

The purpose of this study is to identify the causes of the many failures and, more positively, to suggest an alternative approach to creating a more effective operations management process supported by the power of the computer.

7.2 Summary.

Chapter 1 reviewed the normative model of operations management recommended by Task Force I-6 of the Freight Car Utilization Program and identified the six major, interrelated decisions involved in strategic management:

- o Definition of blocking policy.
- o Routing of trains and assigning blocks to trains.
- o Creation of train schedules.

- o Definition of motive power distribution policy.
- o Definition of desired yard performance levels.
- o Definition of empty car distribution policy.

An analysis of the interrelations among these decisions and the important technical and business factors to be considered indicates that although the operations themselves are highly structured, making computer-based support possible, the management of operations must depend upon the judgments and the experience of managers.

Chapter 2 analyzed a number of efforts to utilize computers in supporting strategic operating decisions and identified the inherent strengths and weaknesses in each approach. These efforts fall into two general groups:

- o The use of optimization techniques
- o The use of simulation models.

Optimization inappropriately tries to replace essential managerial judgment, while simulation needs to be supplemented with other tools in order to adequately support judgment.

Chapter 3 reviewed the work and ideas of a number of people in applying computers to managerial tasks in a variety of industries. The lessons learned from these experiences indicate that it is not the incompetence, in the narrow sense, of the managers and computer system builders which lay behind the numerous failures in applying computer support to railroad operations management. The basic cause is, rather, a design and implementation process which does not reflect the fundamental differences between automating a well-defined, structured task and providing support to an ambiguous, semi-structured managerial function.

An alternative approach, labelled, "Decision Support Systems," has evolved over the last decade. This approach has a number of characteristics which contrast with most past and much current practice:

- Assists managers with semi-structured tasks.
- Supports, rather than replaces managerial judgment.
- Strives to improve the effectiveness of decision-making rather than its efficiency.
- Focuses upon the decisions and the management process, rather than upon the creation of artifacts--algorithms and computer systems.
- Requires the active participation of users in an evolutionary design and implementation process.
- Places a heavy emphasis upon the evolution of the organizational structures, procedures, people, and computer support as an integrated whole.

The remaining chapters were devoted to the analysis of the process of operations management and the development of a reasonable design and implementation plan to create a decision support system for strategic operations management.

Chapter 4 reviewed the Boston & Maine case study and described the B&M's new operations management process. The B&M case study is a significant experiment, both in reshaping fundamentally the management structures and procedures of that railroad and in providing computer support for an interdepartmental operations management process. One of the important lessons of the study is that changing the structures and procedures is the hard part, and success requires a major effort in unfreezing and moving the organization.

Chapter 5 analyzed the B&M experience, especially the current decisionmaking process, in order to:

- Identify areas of the current process in need of computer support beyond the data systems and the network simulation model introduced during the case study.
- Suggest appropriate tools and techniques to provide additional support.
- Identify important issues and problems which must be addressed by any railroad wishing to improve the effectiveness of its operations management.

The creation of operating alternatives is now done manually. Considerable benefits will result from supporting this Design phase of the decision process, since it is currently the major bottleneck, lying in all feedback loops.

There are a wide range of alternatives in providing tools to facilitate the creation of good operating plans. These range from a means to interactively edit operating plans through automated heuristics and optimization tools (which, however, must remain under the tight control of the users).

There are appropriate means to support the other phases, as well. However, benefits from such support will be delayed until Design is adequately supported.

Chapter 6 proposed an overall design and implementation plan for the further evolution of computer support and the operations management process on the B&M. The plan consists of a series of stages, with evaluation and redirection at the end of each stage. There is an emphasis on utilizing existing computer software and quick-and-dirty techniques wherever possible in order that prototype systems may be quickly assembled for experimentation by the managers and transportation analysts.

7.3 Conclusions.

In general, experience in applying (and misapplying) computers to railroad managerial tasks coheres well with the experiences of the Decision Support System practitioners in other fields. With regard to railroad operations management, the decision-centered approach advocated in Chapter 3 is, unhappily, supported by a large body of negative anecdotal evidence as well as the positive evidence afforded by the B&M case study. Three of the following conclusions (1, 2, and 5) may be taken as confirmations of Keen and Scott Morton's generalizations. They are included here because they have been strongly confirmed and because there are those who believe that their own situation is so different that they can beat the system.

1. The effective support of strategic operating decisions <u>requires little or no advance in techniques</u>.* The primary need is not newer, more sophisticated and complex computer systems, but more effective implementation and refinement of existing technology. The analysis of Chapter 5 and the suggested implementation plan of Chapter 6 indicate great benefits possible from assembling and refining a collection of well-known tools and techniques. No tool or technique has been suggested which is not well within the technical state-of-the-art.

2. Nevertheless, <u>design and implementation must be evolutionary</u>.** One can not create a viable DSS by laying out a detailed specification in advance, even for the Boston & Maine, where most of the necessary organizational changes have already taken place. Many of the support tools described in Chapter 6 have never existed. Some have existed only in isolation. Implementation is also a process of discovering how the utilize the capabilities afforded by an integrated set of such tools. This new knowledge must inform the design process. (Experience in other applications suggests that the more interesting uses of any DSS are the unanticipated uses.)

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* This is probably not true of tactical operating decisions.

** Alternatively, one might say that like "jumbo shrimp" (and another term used in this thesis), the term, "Turn-Key Decision Support System," is self-contradictory.

3. The use of adequate data systems and a well-designed simulation model is the absolute minimum level of computer-based support required for the successful creation and institutionalization of the interdepartmental strategic operations planning process recommended by Task Force I-6 of the FCUP. Without the analyses, the best that can be done is Lindblom's "muddling through." Without adequate information and feedback, muddling through becomes blind muddling.

4. However, to provide only this minimum support will hinder the consolidation of the radical changes in organizational structure and procedures required by the Task Force recommendations. At the very least, additional support should be provided to the design of operating alternatives, which is otherwise a long manual process. The heavy commitments and increased workloads required of both managers and staff, and the difficulty of measuring concrete benefits make it tempting to lengthen the planning cycle or even to revert to the old way of doing things after the novelty wears off, particularly when key personnel leave the organization. As long as this temptation exists, the organization cannot be considered refrozen.

5. The successful creation of an effective management process and implementation of appropriate computer tools to support it require the close cooperation of DSS implementors, software designers, programmers, managers, transportation analysts, and other users working as a team. User involvement

in design is much more than consulting the clients at key points. If users do not take an active role in the design of their own systems, then all are condemned to endless cycles of "That's impressive, but . . . ."*

The effective DSS implementor must be an integrator, integrating the efforts of a team of user-managers and technicians. The difficulties in applying computer-based techniques to railroad operations management can only partially be ascribed to recalcitrant or ignorant managers. Their reservations and hesitations are often quite legitimate. Likewise, the failures cannot be attributed primarily to technical incompetence on the part of the system builders. They have, in fact, produced a number of fine tools and techniques. There is, however, a deep misunderstanding between the two groups. Implementation can be successful only if each understands and appreciates the other's needs and capabilities.

6. The creation of an effective management process <u>requires</u> the efforts and expertise of a <u>relatively large number of people</u>, not just the provision of the necessary computer systems. No railroad should expect results from a token commitment of three or four full-time staff positions.

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* There are, in fact, sound reasons for the "buts." One should not assume, without substantial investigation, that the "That's Impressive But" syndrome is simply a counter-implementation game, similar to the "Why Don't You Yes But" game of Transactional Analysis.

The success of the Boston & Maine case study, for example, required the heavy commitment of the members of the Service Committee, particularly its chairman, as well as the equivalent of three to four full-time people from MIT. The Santa Fe case study, a less ambitious project on a larger railroad, required the equivalent of four full-time people, and only a half-time position was devoted to software development.

A strategy which commits a low level of resources to such a project for a long period of time cannot foster the necessary change. It is absurd to think that an effort perceived as having little urgency can, in the long run, succeed in unfreezing the management process.

7. A project to create substantial change in the management of operations and to design and implement supporting computer systems will transcend every department. It therefore must report to top management, rather than reside in any department.

"Software development" cannot be split off and given to the Data Processing department. The procedures of the DP shop are generally incompatible with the team approach and are oriented delivering well-specified products, rather than evolutionary development. This does not rule out any involvement by DP personnel, but clear lines of responsibility must be drawn among the team members. That is, the DP people must see themselves as working for the project manager, not the DP manager.

7.4 Corollaries.

These conclusions have some important corollaries. They are expressed here as caveats, each of which are currently being violated:

1. Projects which have their home in remote corners of the organization, such as Planning departments, particularly those efforts which live off the organizational slack, have little chance of making an impact on operations management. Such activities are rightly seen as subversive and are rejected by the homeostatic organization. Without top management support, they are particularly susceptible to counter-implementation. Creating the computer-based tools is relatively easy. The hard part is unfreezing the organization and getting that top management support.

2. When applied to the support of managerial decision-making, the traditional mode of contracting out research or software development work is questionable. The key word here is "out." The farther out, the poorer the communication and cooperation between the would-be users and the system builders. Yet a great deal of AAR and FRA resources have been expended in this manner, and some railroads continue to buy management support tools as if they were accounting systems.

3. To talk of transferring the technology of decision support from one railroad to another is the kiss of death. Each railroad is different, with varying structures,

procedures, people, and operational problems. Change must begin anew each time. Doing an organizational end-run produces the phenomenon of counter-implementation. The computer programs themselves cannot be simply plugged in either. Data bases are different. The users may wish to do their tasks differently, requiring a new user interface as well as new analytic tools.

7.5 Recommendations.

1. The Boston & Maine should hire several new people to fill the positions of integrating agent, transportation analyst, software specialist, and programmer, as described in section 6.3. These people should report to Rennicke, the chairman of the Service Committee, not to the Data Processing Department or even the Transportation Planning Group. The B&M should commit the other resources necessary for the continued evolution of computer support along the lines described in Chapter 6. A continuity in the high level of effort following the B&M case study is necessary in order to keep the organization in its unfrozen state and to continue the momentum for change. Continued evolution is necessary to capture the full benefits of a planning process in which "What if . . . ?" is no longer a prohibitively expensive question.

2. In transferring the general process and the lessons learned from the Boston & Maine to other railroads,

implementors should pay particular attention to the entry/ unfreezing aspects of the Predesign process. Specific attention should also be given to providing early computer support to the design phase. Leavitt's organizational analysis suggests that the difficulty of changing organizational structures and redefining managerial tasks can be mitigated by providing good computer support to the new management process.

APPENDIX A

THEORY OF THE M.I.T. SERVICE PLANNING MODEL

A.1 General.

The Service Planning Model was developed at MIT by Reilly McCarren[1] as his thesis research. For planning operating strategy, it is a significant improvement over other models. In calculating trip time and yard time distributions, the SPM does not simulate the internal workings of yards or the mechanisms of line-haul delays. It simply uses train schedules and yard performance parameters, estimated by analysts, to calculate the probabilities that connections will be made.

These probability functions, generally known as PMAKE (Probability of Making a connection), were described by Kerr, et al.[2] The choice of the parameters to include and the exact form of the function have not been permanently settled. The following is a descritpoin of the PMAKE calculations as implemented currently in the SPM.

The PMAKE is actually a conditional probability function. That is, it is the conditional probability of making a connection given the values of certain variables and given that no previous connections were made.

For example, suppose a car arrives at yard Y on train A. The probability that it will be reclassified and leave on the next appropriate train, train B, can be calculated as a function:

$PMAKE_Y$ (CREWS, VOLUMES, ARRTIME, DEPTIME)

where

CREWS is the number of yard crews on duty during each shift (trick),

VOLUMES is the volumes of cars processed during each shift,

ARRTIME is the scheduled time of train A,

DEPTIME is the scheduled departure time of train A.

This function subsumes the probabilities that the car will miss the connection for such diverse reasons as a missing way-bill, the car being sent to the repair track, the train being cancelled, the train being full, and so on.

As implemented in the current SPM, the function takes the following form:

$$PMAKE_Y = \frac{Pmax_Y}{1 + \exp\left(A_Y + B_Y \cdot CRWS + C_Y \cdot VOL + D_Y \cdot ACT\right)}$$

where

$Pmax_Y$, A_Y, C_Y, D_Y are yard performance parameters,

CRWS is the number of crews on duty during the shift in which the train arrives,

VOL is the yard volume for that shift,

ACT is the available connect time (DEPTIME-ARRTIME).

For this calculation, if there are no crews on duty when the train is scheduled to arrive, it is assumed that the train arrives at the beginning of the <u>next active shift</u>.

Remembering that $PMAKE_Y$ is the probability of making a connection conditional upon missing all previous trains, suppose that trains C, D, and E (in that order) leaving after train B, can also carry the car. Then

$$P\{\text{car leaves on B}\} = PMAKE_Y(B).$$

(Let $PMAKE_Y(X)$ be shorthand for the original expression with only the departing train changed.) But

$$P\{\text{car leaves on C}\} = (1-PMAKE_Y(B))\cdot PMAKE_Y(C)$$

and

$$P\{\text{car leaves on D}\} = (1-PMAKE_Y(B))\cdot(1-PMAKE_Y(C))\cdot PMAKE_Y(D)$$

and so on.

A.2 Transit Time Calculations in the SPM.

The SPM uses several inputs in calculating origin to destination transit time distributions. It needs the parameters for the PMAKE functions (also the CREWS and VOLUMES variables), train schedules, train block definitions, and origin terminal arrival distributions.

Each train block definition specifies the origin of the block, the train on which it departs, the block's destination, and the destination yards for which it carries traffic.

The origin yard arrival distributions specify the probability that a car coming onto the railroad at a specified yard (an origin yard), either from industry or from interchange, will arrive at a certain hour of the day. (Local traffic movements are not modeled by the SPM.)

A.2.1 The procedure. Suppose a car must move from yard O to yard D. (In the diagram, each arc represents a daily train which can carry the car to the next yard.) The SPM calculates trip time distributions in the following manner:

For a hypothetical random car which must move from O to D on a given day (the SPM assumes a daily cycle of traffic and trains), the SPM calculates for each possible hour of arrival, h, at yard O, the conditional probabilities that the car will be on each train which can carry it to the next yard, I_1. (To simplify calculations, the SPM assumes that the car will leave on the last train on the fourth day if it hasn't left before.)

By consulting the train schedule, the SPM will obtain the conditional (conditional upon arrival at yard O at hour h) probability distributions for transit time (measured from arrival at yard O to arrival at yard I_1) and for yard time at yard O. These are aggregated by weighting with the probability that the car will arrive at yard O at the given hour h. (These resulting marginal probability distributions are in turn aggregated, by weighting with O-D traffic volumes, to accumulate "market" and yard performance statistics.)

At this point the model has the total <u>transit</u> <u>time</u> distribution from arrival at yard O to arrival at yard I_1. Information dealing with the <u>arrival</u> <u>time</u> distribution is thrown away except to construct a distribution of the probability of arrival at yard I_1 as a function of the time of day.

Note that the model has just calculated the transit time distribution for an origin-destination pair other than the one we are currently interested in. The present version of the SPM will not recognize this fact and will forget this valuable information as it pursues the current calculations.

The SPM assumes that delays on each segment of the trip are independent. That is, the time it takes to move from I_1 to I_2 does not depend upon the time it took to move from O to I_1. However, if there is more than one train per day which an take traffic from I_1 to I_2, this assumption will almost surely be false, though probably not grievously false.

With this assumption in mind, the next step is to calculate the delays on the I_1 to I_2 leg of the journey. The SPM aggregates the flows across the daily runs of each train in order to get a 24-hour arrival distrubtion at yard I_1. The model then grinds through connection probabilities at yard I_1 to find a yard time distribution at yard I_1 and a distribution of transit times from arrival at yard I_1 to arrival at yard I_2.

The two transit time distributions are then convoluted to get a total transit time distribution. That is,

$$P_{O-I_2/O}\left\{\tilde{t}=h\right\} = \sum_{i=0}^{h} P_{O-I_1/O}\left\{\tilde{t}=i\right\} \cdot P_{I_1-I_2/O}\left\{\tilde{t}=h-i\right\}$$

where

$P_{i-j/k}\left\{\tilde{t}=h\right\}$ is the probability that the transit time, t, from arrival at i to arrival at j, is equal to h, given that the car originated at k.

The model continues in this way, calculating link distributions and convoluting, until the car arrives at the destination yard, D.

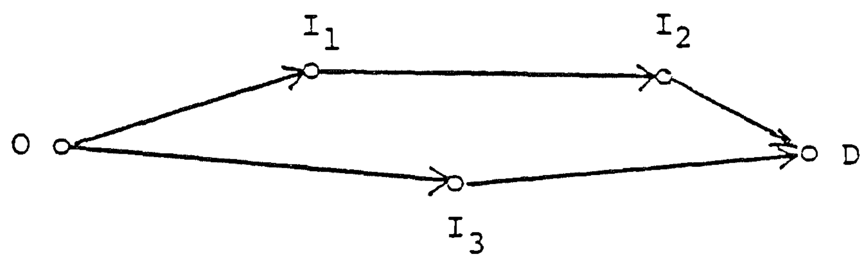
In this example, yard I_1 could be a classification point, where the block is broken up and the cars reclassified into new blocks. It could also be a block switch point. In this case, the block could have yard I_2 as its destination, but the train which picks it up at O only carries it as far as yard I_1 and then continues on to some yard not shown in the diagram. The block would sit at yard I_1, already made (the cars would not have to be reclassified), until it is picked up by one of several possible trains which could carry it to yard I_2. Conceptually, the SPM treats a block switch just like a reclassification except that the yard performance parameters are different, yielding a higher probability of making a connection (for the same available connect time).

A.3 Problems.

There are three limitations inherent in the approach taken. The SPM also throws away useful data, a problem which can be fixed.

A.3.1 Independence assumption. The independence assumption was previously mentioned. In cases where this assumption does not hold, it is conceivable that the SPM could yield misleading results to an analyst who is investigating the effects of small changes in the operating plan (moving train schedules back and forth, for example). In general, the variance of a convoluted distribution will be misstated by an amount equal to twice the covariance of the distributions being convoluted.

A.3.2 Single path restrictions. A second limitation is that the procedure does not allow more than one path through the network for a given O-D pair. For example, the following would be illegal:

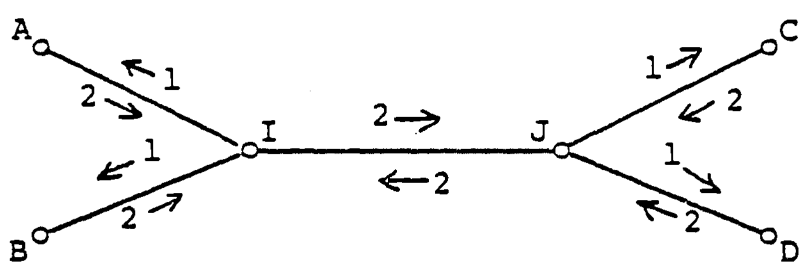


McCarren believed that it is poor practice to run a railroad this way and was therefore unconcerned about this limitation. Others have expressed interest in removing the multiple path prohibition. A multiple path could very well be appropriate in a situation where both paths are equally desirable. Adding the second path might effectively double train frequency from the origin yard.

A.3.3 Arrival distribution. The third limitation is that it is impossible to get a distribution for destination arrival times. This can not be reconstructed from the transit time distribution, since the transit time is dependent upon the time of day that the car is submitted to the originating yard. However, it is possible to get an arrival distribution by time of day, as opposed to day and time, but this would not be as useful. It is conceivable that the arrival time distribution could be more important than the transit time distribution.

After all, it is the date and time of arrival that the receivers directly perceive. Changing train schedules so that shipments are delivered at 5:00 p.m. rather than 8:00 p.m. is worth much less than an improvement which will deliver cars at 9:00 a.m. rather than 12:00 noon.

A.3.4 Computational inefficiency. The major problem with the SPM, which is not inherent in its underlying theory, is its computational inefficiency. In its present form, the SPM repeats many calculations needlessly. For example, consider the following network:



In calculating transit time distributions for the flows among yards A, B, C, and D,

$P_{A-I/A}$, $P_{B-I/B}$, $P_{C-J/C}$, $P_{D-J/D}$ are calculated 3 times

$P_{I-J/A}$, $P_{I-J/B}$, $P_{J-I/C}$, $P_{J-I/D}$ are calculated twice,

$P_{I-B/A}$, $P_{I-A/B}$, $P_{J-D/C}$, $P_{J-C/D}$ are calculated once,

and, if there is only one train per day running between I and J so that $P_{J-C/A} = P_{J-C/B} = P_{J-C/I}$, then

$P_{J-C/I}$, $P_{J-D/I}$, $P_{I-A/J}$, $P_{I-B/J}$ are calculated twice.

In this case, out of 32 calculations, up to 16 are redundant. This does not include convolutions which could be eliminated.

The graph is labeled with the number of redundant calculations for each leg.

If the number of terminal yards at each end is doubled, then out of 144 calculations, 96 will be redundant. In general, the proportion of redundant calculations increases as the number of O-D pairs increases. These redundant calculations pose a significant barrier to implementing an interactive computer model.

Appendix A References

1. McCarren, Railroad Operating Plans: Development and Evaluation.

   McCarren and Martland, The MIT Service Planning Model.

2. Kerr et al., Models for Investigating Train Connection Reliability at Rail Classification Yards.

APPENDIX B

AUTOMATION OF YARD BLOCK DEFINITION

B.1 Introduction.

The goodness of a blocking strategy is heavily dependent upon traffic patterns, train schedules and makeup, yard characteristics and performance, costs, and the levels of performance desired. One can, however, define a reasonably good tentative blocking strategy by assuming an expected average connection delay for each yard, independent of train schedules and makeup.

Several approaches have been taken, three of which are described below. None will indicate which yards should do classification and which yards should be closed (or built). In all cases, this decision is taken as given, that is, left up to human judgment. In addition, since none of the approaches considers the actual assignment of blocks to trains, they are unable to:

- Account for block switches (or preblocking) in any cost/benefit calculations.
- Allow for constraints on the number of blocks which can be carried on any train.
- Equalize train lengths (important if one wishes to cycle powersets from train to train).

Machine generated blocking plans must be considered tentative, and provisions must be made for easy modifications by the transportation analysts in order for automated blocking to be useful.

B.2 The University of Maryland Optimization Model.

The most ambitious effort has been the University of Maryland[1] optimization model, a mathematical programming formulation which relates expected yard delay to block volume, in order to take account of the effects of train frequency. It explicitly relates time to cost and attempts to minimize total cost subject to several constraints, e.g., minimum and maximum block size, maximum yard volumes, and maximum number of blocks to be made at each yard. It does not allow different cost-time tradeoffs for different origin-destination pairs.

The model was tested on the Norfolk and Western using a 33 yard network, and the results received an encouraging response from N&W. The solution of the problem was quite expensive using available mathematical programming software packages, requiring much human intervention and judgment. Bodin suggested that a more efficient (by a factor of ten) algorithm can be developed.

B.3 Martland's Pencil and Paper Method.

Martland, et al.[2] used a simple pencil and paper method to develop a blocking plan for a section of the Louisville and Nashville. The heuristic used was to block for the longest next move. That is,

> At each yard, look at all the unblocked flows and define the feasible block (i.e., containing a minimum number of cars) which will travel the longest distance. Repeat until all flows are assigned to some block. If this results in too many blocks at some yard, the minimum block size for that yard can be adjusted and the process repeated.

To make the approach manageable, one must begin at the periphery of the network and work in. When loops in the network are encountered, the method gets a little messy, and it may be necessary to return to some yards to readjust the blocking. If a yard volume constraint is encountered, some ad hoc adjustments must be made to alleviate congestion. Since it is a manual process, a number of ad hoc constraints (such as a requirement that certain blocks be made regardless of volume) can be accomodated.

This approach can be mechanized with little difficulty, but it has several drawbacks:

- Differences in yard performance are ignored.
- Although efficient, the simple heuristic is not particularly effective.
- Costs are not considered at all.

B.4 Suzuki's Heuristic.

Suzuki[3] also formulated a mathematical programming approach to the problem, but went about solving it heuristically:

1. Start with a blocking plan defined so that no blocks bypass yards, that is, all blocks go only to the next yard.

2. Look for the most profitable place where a new block (bypassing one or more yards) can be added. If one exists, then add it and look again.

3. If none exist, then look for blocks which have been made unprofitable by the addition of other blocks. If any exist, then delete them and return to step 2. If none exist, then stop.

He enhanced this simple heuristic to tentatively add blocks which were unprofitable by themselves, but might, when added, allow some other block to be deleted. He reported that

> The algorithm was programmed in Fortran and was tested on FACOM 230/60 and CDC 3600. Among the problems handled there was one with thirty six yards through which about 20 000 freight cars are transported daily. In this problem [yard bypass blocks] were set up on 136 sections and then 22 [blocks] removed in the optimization stage. The results show a considerable reduction of standing time of freight cars compared to the one in practice. The computation time was ten to twenty minutes.[4]

Suzuki's approach is helpful but not directly applicable to the real world since it neglects yard capacity constraints and relates time to cost in a somewhat obscure manner. Nevertheless it appears redeemable; its method is clear and understandable, it is more controllable and can be modified to add the yard constraints, and it is relatively efficient. It can, in fact, be made more efficient; Suzuki apparently took a brute force approach to the evaluation of potential new blocks, examining them all at step 2.

B.5 Conclusion.

Although any of these methods can create a more or less satisfactory blocking strategy, it must be emphasized that none, not even the University of Maryland model, will produce an "optimal" strategy, the goodness of the blocking strategy being contingent upon all the other factors in the operating plan.

The Martland and Suzuki approaches may be useful in the interactive design of an operating/service plan if they are modified to allow for more constraints and to provide tight control over which yards and flows may be considered and which blocks may be modified.

Appendix B References

1. Bodin and Berman, A Model for the Classification of Rail Freight Cars.

   Bodin et al., "A Model for the Blocking of Trains."

   Kedar, "Developing an Optimum Classification Strategy for Rail Freight Cars."

2. Morgenbesser, Martland, and Laughlin, Economics of Running More Trains on the Louisville and Nashville Railroad, Appendix B.

3. Suzuki, "A Method of Planning Yard Pass Trains on a General Network."

   Suzuki's method is similar to that of Truskolaski:

   Truskolaski, "Application of digital computers to the optimization of freight train formation plans."

   Idem, "Comments on the use of optimization techniques in planning freight transport operations."

4. Suzuki, "A Method of Planning Yard Pass Trains on a General Network," p. 360.

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