Management and Information Systems Components of Successful ATCS

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Much of the focus in the development of and debates surrounding Advanced Train Control Systems (ATCS) has centered on the technical aspects of the various hardware and software components that constitute such a system. However, numerous failures of advanced technologies in the service sector point to the need for careful consideration of the organizational and strategic needs of such a system before final design. One way of determining these needs is by looking at how ATCS can be used to support the overall strategy of the railroad. Once this relationship between ATCS and the railroad's strategy has been defined, a hierarchy of intelligent information systems components vital to linking strategy and implementation within the ATCS context can be formulated.

The development of Advanced Train Control Systems (ATCS) has primarily focused on the technical aspects of train and track hardware. Although such research is important, it often fails to "see the forest for the trees"; that is, the basic question of why ATCS are necessary and how they will affect the management of rail operations has received very little attention in the literature to date. The purpose of this paper is to analyze the management information system (MIS) needs of ATCS from the viewpoint of management strategy. Before this analysis, however, it is useful to first understand why this viewpoint is of vital importance.

As a component of the service economy, the railroad industry must carefully consider the implication of massive technological investments in terms of their impact on profit or loss. As described by Roach (*1*) and Hackett (*2*), the service sector has been a major consumer of computer technology in the past decade—it consumes at least 80 percent of all such investments and spends in excess of $3,000 per employee per year on computers. Unfortunately, the growth of productivity has not been even close to that which one would predict from such massive investments in technology. In fact, this lag in productivity has caused Hackett (*2*) to coin the term "service-sector sinkhole."

Why has this investment not been fruitful? As Hackett (*2*) and others (*3*,*4*) have noted, much of the problem lies in automation of poorly planned and executed production processes. The simple automation of a production system that is (a) outdated, (b) poorly organized, or (c) inappropriate for the type of service being produced will lead to little productivity growth, if any. The moral of this story is that management must first decide upon an operating strategy and related implementation plan before investing in technology. As Hackett (*2*, p. 403) states, "Companies that persist in developing their operating strategy solely from a technology perspective can look forward to tougher competition as their rivals realize the incremental benefits of an integrated, holistic approach" to technology and process change.

Failing to match strategy, organization structure, and information systems can be a serious pitfall. Only by forging congruent strategies, technologies, and structures can the effort succeed. To illustrate this relationship, two opposing scheduling strategies for freight railroads will be defined and the implications of these strategies on organization structure and information systems will be discussed.

TWO SCHEDULING STRATEGIES

The design implications of two polar cases of scheduling strategy are considered: a master scheduling strategy and a real-time scheduling strategy. The extreme cases are selected to illustrate the point that scheduling strategy defines the appropriate choice of organization structure and information systems for the scheduling function. In practice, scheduling strategies incorporate characteristics of each extreme, and therefore hybrid designs are warranted.

A *master scheduling strategy* is defined to be the periodic establishment of timetables that govern arrival and departure times based on a periodic review of demand levels and resource availability. Once established, the schedule would be in effect until the next scheduling period and subject to only minor revisions in the interim. This strategy is analogous to airline scheduling strategies. Airline departure and arrival times have long planning horizons and are based on forecasts of demand and resource availability. Although these schedules are subject to some revision, generally speaking, the flight will take place even if volume is low. Like the airlines, railroads pursuing a master scheduling strategy would publish timetables, which would serve as a marketing tool as well as a guide for operations supervisors.

Real-time scheduling operates over a considerably shorter planning interval. Under this strategy, timetables are continually revised as capacity on the network and demand in the marketplace change. Arrival and departure times would be set for an indefinite period. Real-time scheduling strategies are analogous to trucking schedules, which are determined daily according to demand and resource availability. Publication of timetables, because of the short planning horizon, would not be feasible.

A lack of flexibility characterizes master scheduling strategies because network interdependencies are only evaluated

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when the master schedule is developed. Deviations from the planned schedule would have dynamic consequences for the rest of the network; therefore, schedule revisions are discouraged. For example, operations supervisors would be discouraged from consolidating trains when volume is low.

Real-time schedules are highly flexible; the dynamic implications of changes to planned arrivals and departures are evaluated continually. For example, the impact of a proposed consolidation would be evaluated immediately and new timetables would be generated for dispatchers and yardmasters affected by the consolidation.

Master schedules must build large amounts of slack time into planned arrivals and departures (*5*). Because the schedule cannot be adjusted daily, enough slack time must be added to ensure that unforeseen events, such as unanticipated demand levels or equipment failures, do not affect system performance. In other words, because master scheduling strategies do not provide an efficient means of handling schedule exceptions, slack time must be added so that unforeseen events do not create such exceptions. Slack time in the schedule implies slack resources on the network in terms of equipment cycle times and excess infrastructure capacity (*5*).

A real-time scheduling strategy is characterized by small amounts of slack in arrival and departure times. The network schedule has tighter timetables, which means unforeseen events that would be absorbed by slack in a master scheduling strategy would constitute an exception under the real-time strategy. However, because real-time scheduling constantly updates timetables, these exceptions can be processed and new arrival and departure times produced for portions of the network affected by the schedule disruption (*5*). In short, real-time scheduling requires less slack resource, because the capacity of the network can be continually reallocated.

The need for coordination and communication is high under a real-time scheduling strategy. Exceptions to planned schedules must be quickly transmitted to a management group that will evaluate their impact and issue revised timetables to operations supervisors. Coordination and communication demands are low under a master scheduling strategy, because slack absorbs most exceptions and the timetable is revised infrequently.

Real-time scheduling strategies transfer the authority over local scheduling decisions to a group with network perspective; in contrast, master scheduling strategies are characterized by high autonomy for local supervisors. Because the master scheduling process is not designed to address variability in daily operations, dispatchers and yardmasters must be empowered to make immediate judgments. Granting this autonomy to supervisors surrenders control over some decision making (*6*). Control over local decisions can be exercised by establishing rules and procedures for operations (*5*). The master schedule, by prescribing arrival and departure times, functions as a system of rules and procedures. Rules and procedures cannot, however, anticipate all events.

To illustrate these differences, consider the respective response to a major schedule disruption. A master scheduling strategy would rely on local supervisors to recover from the disruption as much as possible and allow the impacts of the disruption to work through the system. The master schedule would again control operations after all the impacts of the disruption had been absorbed. The same disruption in a real-time scheduling environment would prompt immediate intervention by the network control group. Revised timetables would be established that more quickly restore the system to its performance objectives.

Under a master scheduling strategy, interaction with the marketing function would occur only at the master scheduling level. Marketing's input would be incorporated into the master schedule. But once the schedule has been established, revisions to accommodate new business or customer requests would be restricted. Real-time scheduling strategies, on the other hand, interact with the marketing function continually to evaluate the impact of scheduling decisions on customer relations or on proposed new business on the network.

In terms of reliability, master scheduling strategies yield more consistent performance (i.e., lower variance) than real-time strategies. Because slack time in the master schedule absorbs most disruptions, adherence to planned arrival and departure is high. Real-time scheduling, because of the continual reallocation of resources, produces inconsistent arrival and departure times. For example, under a master scheduling strategy, a train set to depart at 6 o'clock would do so each day. Under a real-time scheduling strategy, the same train departure might be delayed, advanced, or canceled on a given day.

By other measures, such as transit time or cost, real-time scheduling strategies may produce better results. If the objective is to minimize mean transit time, a real-time strategy produces better results, because of the reduction in slack time. For example, real-time scheduling allows trains to be released early, thereby providing more opportunities for cars to make tight time connections. If the objective is to minimize cost, then a real-time scheduling process produces better results, because of the reduction in slack resource. For example, real-time strategy provides opportunities to make rational train consolidations. Consolidations, of course, generate delays for some traffic. Thus, variance is higher under real-time scheduling. The differences between the two scheduling strategies are summarized in Figure 1.

ORGANIZATION DESIGN ISSUES

In the scheduling of freight railroads, three design elements (i.e., management functions) within the scheduling process are subject to organizational design decisions. The *master scheduling group*, located at the highest level of the organization, establishes timetables for the entire rail network. Im-

Master Scheduling ⟶	⟵ Real Time Scheduling
– Low Variance	– Low Mean Transit Time
– Flexibility Low	– Flexibility High
– Slack Resource High	– Slack Resource Low
– Information System Cost Low	– Information System Cost High
– Scheduling Organization Costs Low	– Scheduling Organization Costs High
– Planning Horizon Long	– Planning Horizon Short
– Resource/Demand Information Uncertain	– Resource/Demand Information Certain

FIGURE 1 Strategy-structure continuum.

plementation of these schedules on a daily basis is the responsibility of *district dispatchers and yardmasters*. In between these two groups is a role for a group of managers who coordinate the interdependent actions of dispatchers and yardmasters, process exceptions to the schedule, and, in general, enforce the master schedule. Because of its position in the scheduling hierarchy, this function will be referred to as the *intermediate group*.

The emergence of three design elements in the scheduling process is attributable to the following dimensions along which these groups naturally differentiate themselves: their planning horizons, their goals and objectives, and the degree of uncertainty inherent in their task (*7*).

In terms of time, yardmasters and district dispatchers have short planning horizons (*6*). They schedule, over the length of their shift, switching in a yard or meets and passes in their district. The master scheduling function periodically establishes timetables that will govern the railroad's daily operations over a long time horizon. The intermediate group looks forward over several shifts or days and assesses the impact of unforeseen events on the planned schedule. It then revises the schedule to keep the system close to the performance objectives.

Temporal differences between the groups are also evident in the timeliness of feedback from decisions (*7*). Dispatchers and yardmasters receive prompt feedback on the results of their decisions—departure and arrival times were either met or missed. Intermediate group members can determine within a few days whether schedule adjustments have been effective. Master schedule developers evaluate the results of decisions by reviewing average system performance over the planning period.

The planning horizon of these groups also differs in terms of scope (*7*). Dispatchers and yardmasters have a comparatively narrow scope; they are concerned with the district or yard to which they are assigned. In contrast, the master scheduling group has a global scope. It must consider the network implications of scheduling decisions when setting timetables. The scope of the intermediate group synthesizes those of the others, because it must coordinate series of local decisions with network objectives.

Dispatchers and yardmasters have task-specific goals (*6*). For example, yardmasters must assemble a block of cars to make an impending departure and dispatchers must ensure on-time arrival to the next yard. The objectives of the master scheduling group are not easily identified with specific dispatches. Master schedule developers must incorporate the strategic objectives for performance and asset utilization into the timetables planned for the system. The goals of the intermediate group lie between task-specific and strategic, because the function must ensure that the daily traffic movement tasks are accomplished while attempting to maintain the integrity of the overall scheduling plan.

Railroad operations supervisors arguably face a highly uncertain subenvironment that is, for example, subject to variations in daily demand and equipment failures. The master schedulers, on the other hand, confront gradual changes in conditions over time and, for the most part, ignore daily variability (*7*). For example, the master scheduling group would consider a trend that indicated an increase in the average demand for service between an origin/destination pair, but ignore the daily variability in the demand level. The intermediate group must make schedule revisions that absorb the daily variability in local operations, while protecting the objectives of the master schedule.

In addition to the differences described above, there is a natural flow of information among these three groups that supports the differentiation argument. Master scheduling communicates planned timetables to the intermediate group and receives from the intermediate group information regarding the performance of the system. The intermediate group communicates schedule revisions to dispatchers and yardmasters and receives information from these line supervisors on schedule exceptions.

In summary, there is sufficient differentiation between the tasks in the scheduling function to classify each as a design element. Because of the pyramid-like flow of information and scope of responsibility (i.e., a small group of managers, the master schedulers, have global responsibility and communicate information to a large decentralized group of managers, the line supervisors), the scheduling function has a hierarchical structure. The crucial design decision is how to structure the design variables (i.e., the amount of authority and the communication links) for each design element in this hierarchy (*8*).

The amount of authority and autonomy assigned to each element is an important design variable because it will determine the degree of integration in the network. Assigning high autonomy to supervisors for scheduling decisions determines that the system will be decentralized and less integrated. On the other hand, establishing ultimate scheduling authority in the master scheduling group provides for better integration, because scheduling decisions will be made from a network perspective.

The degree of control that a master scheduling group is able to exercise over the daily scheduling decisions made by supervisors will be limited by the communication links established between the groups. For example, if the daily decisions of local supervisors are to be monitored by the master scheduling group, an expedient communication process must be established. Interaction between the scheduling function and other departments in the organization, likewise, depends on the type of communication process. In this paper, communication links between the sales and marketing function and the scheduling hierarchy will serve as a paradigm for this aspect of organization design.

DESIGN IMPLICATIONS OF SCHEDULING STRATEGY

It will be argued here that the appropriate choice of design variables depends on the scheduling strategy adopted by the railroad. The relationship between strategy and structure is based on the concept that organization design makes an economic difference (*9*). For example, if a firm adopts a strategy that is inconsistent with its structure, administrative problems will arise that decrease economic performance. Only after adjusting its design does the firm operate efficiently.

Galbraith (*5*) views organizations as information-processing systems. Therefore, the amount of information that must be processed for the firm to complete its tasks must be considered in the organizational design process. The two scheduling strategies outlined above demand different information-processing capacities and, therefore, beget different organizational designs.

According the Galbraith, increasing the amount of uncertainty in the performance of the firm's tasks demands increased information-processing capacity in the organization. He defines uncertainty as the difference between the amount of information the firm has and the amount it requires to make decisions that accomplish the organization's goals. If a railroad pursues a real-time scheduling strategy, operations supervisors require increased information regarding the impacts of their decisions on the overall schedule. Likewise, they need to know the local impact of decisions made by other supervisors. Furthermore, tighter schedules decrease the number of disruptions that are absorbed by slack time and increase the number of exceptions that force schedule revisions. Real-time scheduling strategies, therefore, increase the amount of information needed to perform subtasks and demand that the organization increase its capacity to communicate information.

Galbraith (*5*) proposes two strategies to increase the information-processing capacity of the firm: investment in vertical information systems and creation of lateral relations. Lateral relations establish direct communication links between interdependent subtasks that cut across normal hierarchical lines of authority. Decision making is transferred from the normal hierarchical process to the lateral process. The speed of communication between the groups increases, because information no longer needs to be transmitted through the hierarchy.

Establishing such a communication link is crucial to a real-time scheduling strategy. The intermediate scheduling group can be designed to provide this important lateral communications link. In this design, the intermediate group communicates directly with line supervisors, circumventing the operations hierarchy. Information on schedule exceptions flows directly to the intermediate group where the global impact of the deviation can be analyzed. The intermediate group makes revisions to minimize the impact of the exceptions and communicates new timetables directly to the line supervisors affected by the change.

Without this design, railroads would have to coordinate interdependent supervisory decisions by processing the exception information through the operations hierarchy. Hierarchies have many disadvantages. Among them is a time-consuming decision-making process (*6*). For example, coordinating decisions between dispatchers would be the responsibility of the first common supervisor in the hierarchy. Each dispatcher would have to transmit information through the hierarchy to this supervisor, who in turn would make a scheduling decision and inform the dispatchers of the revised schedule. In a network as large and as interdependent as a railroad, this supervisor would be far up the hierarchy. Therefore, substantial time would be required to transmit information. A large number of schedule exceptions would quickly overload this communication and decision process.

A master scheduling strategy does not require the establishment of a distinct intermediate group with direct communication channels to supervisors, because it does not increase the amount of information required by the firm to perform its task. Uncertainty in the supervisor's task is not reduced under a master scheduling strategy; rather, the difference between the amount of information available versus what is needed is reduced. Slack time in the master schedule absorbs most exceptions. Therefore, dispatchers pass on only a limited amount of information. Because there is no increase in information flow, special designs to increase communication are not warranted.

The functions of the intermediate group under a master scheduling strategy are absorbed by the operations hierarchy. The hierarchy coordinates the actions of supervisors by enforcing the master schedule. It communicates the information required for the master scheduling process by periodically passing aggregate performance data to the master scheduling group. The speed of communication is not crucial to a master scheduling strategy.

Once the needed communication links have been established within the scheduling structure for each strategy, the degree of authority and autonomy must be assigned to the design elements. As previously stated, real-time scheduling strategies transfer authority over daily scheduling decisions to a group with a network perspective. It is also essential that the group with this authority have adequate communication links to supervisors. Therefore, scheduling authority is transferred from local supervisors to the intermediate group that possesses both a network perspective and adequate communication links. In addition, because the planning horizon has now become indefinite, the role of the master scheduling group loses importance. Scheduling authority is, thus, entrusted solely to the intermediate group under a real-time scheduling strategy.

Because the functions of the intermediate group are absorbed by the operations hierarchy under a master scheduling strategy, scheduling authority that requires a network perspective must be allocated to the master scheduling group. However, because this group relies on a time-consuming hierarchical process to communicate with line supervisors, some autonomy must be entrusted to the line supervisors. For example, the master scheduling group must delegate the handling of exceptions, because it lacks the necessary communication capacity.

The final design variable is to establish a communications link with the sales and marketing group. The objective is to design a communications link between the marketing function and the primary scheduling authority that circumvents unnecessary intermediaries. Under a real-time scheduling strategy, a direct communications link should be established between the intermediate group and the sales and marketing function. By selecting this link, the marketing department can easily evaluate the systemwide implications of new traffic and be informed of delays.

The primary link between scheduling and marketing under a master scheduling strategy is at the master scheduling level. Communication between these groups allows the firm to incorporate marketing objectives into its scheduling strategy. There is no communications link that would allow marketing to easily revise the schedule once established. However, informal communications at the line-supervisor level might allow for adjustments within the available slack time.

The alternative designs are presented in Figures 2 and 3. Because the master scheduling strategy requires no changes

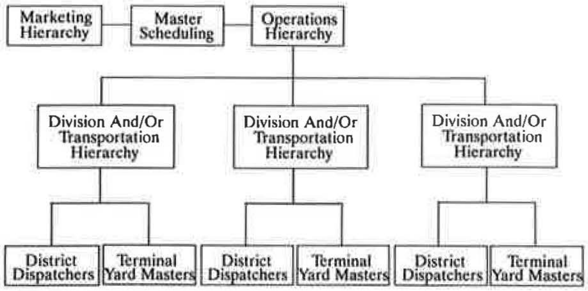

FIGURE 2 Organizational structure for a master scheduling strategy.

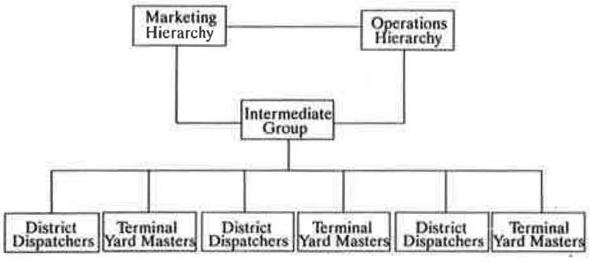

FIGURE 3 Organization structure for a real-time scheduling strategy.

in organization structure, it can be implemented inexpensively. The real-time scheduling strategy demands a structure with an independent intermediate group established outside the operations hierarchy. Costs associated with this design include personnel expense, organization friction arising from dual reporting for line supervisors (line supervisors report to both operations and the intermediate group), and increased communications cost.

The primary organization design impact from the choice of scheduling strategy is on the intermediate group. Under a master scheduling strategy, the role of the intermediate group is delegated to the operations/transportation hierarchy; whereas, under a real-time scheduling strategy, the intermediate group must be established outside the operations hierarchy and circumvent the normal channels of communication. Note the role of the master scheduling group is obviated under real-time scheduling, and the intermediate group has no distinct form under a master scheduling strategy. In summary, what has happened is that the integrating function (i.e., the group of managers with network perspective) is moved closer to the line supervisors as the planning horizon is shortened and slack resource is reduced.

IMPLICATIONS FOR MIS DEVELOPMENT

The selection of vertical information systems, Galbraith's (*5*) second approach to increasing information capacity, is likewise affected by the scheduling strategy decision. Accepting Galbraith's view of organizations as information-processing systems, it is impossible to separate decisions on design from those on information systems. Therefore, if the structure of the scheduling group is affected by the scheduling strategy decision, then the choice of information systems should be likewise affected.

Information systems increase the information capacity of the organization in two ways. First, a data-processing system increases the speed of data collection. It assembles data from the lowest levels of the hierarchy and transmits the data directly to the decision-making level. Second, expert systems can make decisions more quickly than managers.

Scheduling information systems can be categorized along two dimensions: scope of the data base and frequency of the decision (*5*). The scope of the data base from which scheduling decisions are made may be local or global. ("Local" has a relative meaning in this context because scheduling decisions made at the regional or divisional level are local relative to a networkwide data base.) The primary deficiency of expert systems that use local data bases in that network interdependencies are not considered. At the other extreme of this continuum is an expert system that uses a global data base and, thereby, ameliorates suboptimization problems inherent in decisions based on local data bases. The main trade-off is the higher cost of an expert system that utilizes global data bases versus the cost of suboptimal decisions arising from decisions based on local data bases.

In terms of scheduling frequency, information systems can assemble data and make decisions on a periodic or continuous basis. Periodic systems would be appropriate for performing a master scheduling task. Although these systems account for interdependence between subtasks when developing schedules, they do not overcome the inherent problem of long time-horizon planning. That is, master schedules begin to decay as unplanned events occur and, therefore, must contain adequate slack to eliminate the need to process exceptions (*5*).

Information-processing and decision-support systems are useful in the master scheduling process, because they allow the schedule planners to quickly evaluate alternative master plans and provide a means of incorporating networkwide data in the scheduling process. Expert systems using local data bases may also find applications in master scheduling environments. For example, computer-aided dispatching could be used to minimize cost within the time constraints established by the master schedule.

Continuous decision-making systems allow for a truncated planning horizon within which data are assembled and scheduling decisions made. These systems employ a global data base with sufficient decision-making capability to process exceptions quickly and make schedule adjustments. Continuous decision systems are most appropriately implemented with real-time scheduling strategies, because a real-time scheduling strategy requires the continual evaluation of the network implications of schedule deviations and adjustments.

In summary, the master scheduling strategy is best supported by a periodic decision system that utilizes a global data base. The real-time scheduling strategy should be supported with a continuous decision-making system that utilizes a global data base. Continuous decision-making systems are, of course, more expensive than periodic systems. Therefore, a real-time scheduling strategy requires a more expensive information system than a master scheduling strategy. The trade-offs among various choices of information systems are summarized in Figure 4.

The choice of information system can have organization structure implications beyond the design of the scheduling group. Choosing to schedule based on a local data base sys-

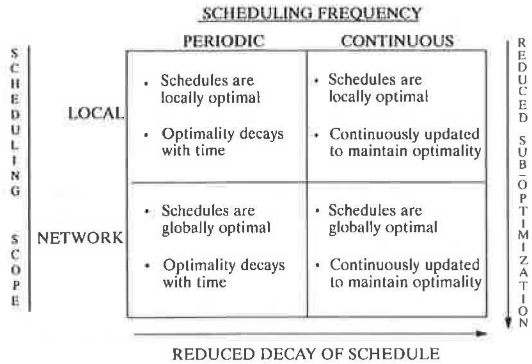

FIGURE 4 MIS implications of a scheduling strategy (5).

tem, for example, determines that the firm will be decentralized, with interdependence managed through hierarchical channels (*1*). Continuous decision making using global data bases allows the firm to truncate its hierarchy, because an automated data-collection and decision-making system allows for an increased span of control, thereby eliminating the need for large numbers of managers.

The power of decision-support systems to supplant portions of a hierarchy was demonstrated by Dawson and McLoughlin (*10*), who studied the impact of introducing TOPS (Total Operations-Processing System) on the role of supervisors at British Rail. The system was designed to provide accurate information about local operations to a central control facility. Some organization theorists had suggested that such a system would erode the traditional supervisory role by enabling higher-level managers to make local decisions. Others suggested that computerization would enhance the role of supervisors and create a further decentralized organization.

Dawson and McLoughlin (*10*) found that the system did increase the control of the operations by high levels of management. However, the role of the supervisor was enhanced rather than diminished. The new information flows and communication channels provided by the computer obviated the need for a division hierarchy. Information about operating conditions and performance at remote locations became available to headquarters management, and access to a real-time data base was provided to the local level. This meant that much of the decision-making responsibility at the division level could be delegated to the supervisors, whose positions could be redefined as area freight assistants. (British Rail was ultimately frustrated by labor unions in its attempt to eliminate the divisional hierarchy.)

NEED TO MATCH STRATEGY, STRUCTURE, AND DECISION ANALYSIS

The design of the scheduling group, choice of information system, and scheduling strategy must be matched if the strategy is to succeed. Without increasing the information-processing capacity of the organization, a real-time scheduling strategy is destined to fail, because the firm will be unable to process the needed information and make appropriate decisions. As a result, slack must be introduced into the schedule; and the firm, by default, will adopt a master scheduling strategy (*5*). Similarly, the investment in the necessary information systems and organization redesign to support a real-time scheduling strategy would generate needless expense for a firm pursuing a master scheduling strategy. Only by selecting the information system and organization structure that matches its scheduling strategy does the firm realize the economic benefits of its scheduling choice.

Contingency theory of organization structure suggests that there is no one best design for all organizations; rather there is one best design for each organization (*11*). Intermediate group designs that circumvent the operations hierarchy are not necessarily better. The are best for real-time scheduling strategies, but completely inappropriate for master scheduling strategies. Similarly, continuous-scheduling decision systems using global data bases are not necessarily better than systems that make periodic decisions. They are, however, best for real-time scheduling strategies.

According to the argument presented here, the structure of the scheduling function follows the scheduling strategy decision. But if an organization refuses to adjust its structure, then its scheduling options are limited. The firm is, therefore, also constrained by its structure (*12*). The divisional hierarchy structure found in the railroad industry has many rational features well founded in organization design theory. In addition, railroads have a long history of employing the operations hierarchy to implement schedules. Firms may be unwilling to disrupt these established reporting procedures by introducing the intermediate scheduling group. Therefore, it may be difficult to implement the necessary changes to adopt the real-time scheduling strategy.

Assuming real-time scheduling strategies are not precluded by inertia, how will firms decide which scheduling strategy to adopt? The principal cost and service trade-offs to consider are as follows:

1. The cost of the organization structure dictated by a real-time scheduling strategy, including personnel, communications, and organization friction costs,
2. The higher cost of the decision-support systems needed to support real-time scheduling versus master scheduling,
3. The costs of the slack resource created by a master scheduling strategy, and
4. The higher reliability of master scheduling strategies versus the lower mean transit times of real-time scheduling.

Real-time scheduling has higher variable costs associated with organization structure and decision-support systems; whereas, the master scheduling approach has greater fixed costs in terms of excess capacity or slack resources. Another factor to consider is how much of the cost of slack resource is avoidable. For example, it may be difficult to decrease the fixed cost of infrastructure even if a scheduling strategy that reduces the need for the excess capacity is adopted. Because adoption of a real-time scheduling strategy will surely increase short-run variable costs, the uncertainty of eliminating the cost of slack resource may make firms reluctant to change from a master to a real-time scheduling strategy.

SCHEDULING STRATEGY FOLLOWS MARKETING STRATEGY

Both revenue and costs must be considered when making strategic decisions. Choosing a scheduling strategy based on a comparison of the cost to introduce real-time scheduling versus the cost of maintaining slack resource ignores the revenue component of the profit equation. Each of the proposed scheduling strategies emphasizes different service attributes. Therefore, the key strategic decision may be the choice of marketing strategy, because different service attributes will appeal to different markets. That is, once a marketing strategy has been selected, the scheduling strategy, design of the intermediate group, and choice of information system follow naturally.

Chandler (*9*) proposed that organization structure follows the firm's growth strategy. He identified four key growth strategies: volume expansion, geographic expansion, vertical integration, and product diversification. Volume expansion entails increasing the marketshare of a single product in one market. The increased volume overloads the existing structure and requires a more extensive functional hierarchy. Creating multiple field offices and duplicating a portion of the hierarchy is warranted when the sales strategy incorporates entry into new geographic markets with a single product. New functions or departments are added to the hierarchy when the firm pursues a forward or backward integration strategy. The firm becomes decentralized when it expands into new product markets. Ultimately, it adopts a holding company form when diversification leads into unrelated product markets. Strategic planning may incorporate portions of all the above strategies that lead to complex, hybrid firm structures.

The design implications of scheduling strategy were analyzed above in terms of two polar cases. The impact of marketing strategy on the choice of scheduling will now be illustrated in the same way. Again, this argument is intended to demonstrate a relationship between marketing and scheduling strategy. It suggests a reason, other than cost, for a firm to choose one of the two scheduling strategies. It does not preclude wholly different or hybrid marketing strategies; rather, it suggests that there should be some congruence between the firm's scheduling strategy and its marketing strategy. Two marketing strategies will be considered: focus and expansion. It will be argued that the focus strategy affords no role for real-time network scheduling, but that the expansion strategy cannot succeed without a real-time scheduling strategy.

A *focus growth strategy* is when the firm concentrates on traditional rail markets where rail has a distinct economic advantage. Demand for rail service is well established in these markets and operational efficiencies are the key source of competitive advantage. Although the market may be elastic in terms of reliability, it is comparatively inelastic in terms of transit time. In short, dependable rail service satisfies the freight transportation demand in these markets.

Selecting a real-time scheduling strategy would be inconsistent with this marketing strategy. In terms of the scheduling strategy following the marketing strategy process, if a railroad adopts a focus strategy and real-time scheduling strategy, the market would not compensate it for the resulting improvements in transit time. The firm would be, therefore, inefficient because it could maintain the same revenue base without the variable expense created by real-time scheduling.

However, the market for freight transportation service is much larger than that of the traditional rail shippers. A railroad could, alternatively, adopt an *expansion growth strategy* in which the firm aggressively pursues intermodal traffic and, generally, seeks to capture traffic currently moved by truck. A real-time scheduling function would be required to deal with this market's demand for reduced transit time, increased integration between operations and sales, and an expanded customer service function.

Improved transit time would require elimination of slack time from the schedule. In addition, the network would have to recover quickly from disruptions, thereby minimizing delays arising from unusual events. Without adopting a real-time scheduling strategy, the firm cannot make the necessary reductions in transit time. A focus strategy is adopted by default because only the focus strategy market base will be sated by the performance level.

The expansion strategy also demands increased integration of the operations and marketing functions. The master scheduling strategy provides for formal interfunctional relations only at the highest level. The functional hierarchy would be quickly overloaded with the volume of decisions regarding the feasibility of proposed services for new shippers in the expanded market. Because a time-consuming decision process is likely to reduce the railroad competitiveness in these markets, structural adjustments to increase the organization's ability to process decisions are warranted. The intermediate scheduling group would be positioned to evaluate the feasibility of proposed services quickly by virtue of their global perspective and access to line supervisors.

Entry into new markets is likely to increase the amount of price and service negotiations between the marketing department and customers. To negotiate price effectively, marketing executives need accurate cost information. Because of different shipment characteristics, some business fits well with existing traffic patterns, while some generates high amounts of variable cost. The dynamic implications of additional traffic must be evaluated to price service correctly. The intermediate real-time scheduling function would be positioned to provide the relevant cost information quickly. Processing these pricing decisions through the existing hierarchical structure would be too time consuming.

The expansion strategy also increases the importance of the customer service function. Customers in more service-elastic markets will require more information about shipments in transit and increased responsiveness from the operations department. For example, customers using just-in-time inventory systems need accurate shipment-tracing information as well as reliable delivery. In addition, customers may require increased flexibility such as in-route reconsignment. Customer service personnel need accurate information about location and about the possibilities of changing current plans. Therefore, the interface between customer service and operations must avoid bureaucratic delays typical of hierarchical designs. The intermediate scheduling function would possess the network information to address these customer service demands.

In summary, a real-time scheduling strategy and the design adjustments and information systems needed to support it are essential for a marketing strategy that relies on expansion or entry into markets presently controlled by motor carriers. The less-expensive master scheduling strategy is preferred for marketing strategies that focus on traditional rail markets.

INDUSTRY SURVEY

To see if the arguments presented above were realistic, a group of five large North American railroads were surveyed regarding their scheduling practices. The railroads were queried as to whether they employed master scheduling or real-time scheduling and were asked if real-time scheduling groups were positioned outside the normal hierarchical channels. They were asked about the communication links and information systems in use or under development to support the scheduling function. The reasons they chose their scheduling strategy were also discussed. Finally, the connection between scheduling strategy and marketing strategy was investigated.

Figure 5 presents a table that summarizes the responses of the railroads to questions regarding their scheduling practices. Except for Railroad C, all the railroads in the survey had master schedules in use or under development. Except for railroad B, all the railroads that included master schedules as part of their scheduling strategy intended to override the master schedule regularly. Railroad E described the master schedule as a rough guideline that was rarely adhered to in practice. Both Railroads C and E identified the inaccuracy of forecasts of demand and resource availability as the primary limitation of a master schedule.

Railroads that either chose to override the master schedule or had no master schedule were able to identify centralized, real-time scheduling groups in their organization. The scheduling groups were generally located at the companies' operations headquarters and were composed of representatives from the divisions plus system train control managers. Interestingly, all the railroads that employed real-time decision making established a reporting structure outside the operations hierarchy. Each of these railroads identified the intermediate group described in this paper as having the same characteristics, in terms of organizational structure, as their real-time scheduling group. It should be noted that real-time scheduling for these railroads consisted of the development of daily or twice-daily scheduling plans.

Several of the railroads expressed a need for improved data collection and expert systems to support the real-time scheduling function. Presently, the real-time scheduling process makes use of telephone conference calls to speed communication. Approximate demand levels are developed by the division representatives. Managerial experience was cited as the primary scheduling decision tool.

None of the railroads had optimization systems for use in either the master or real-time scheduling process. However, all expressed a strong interest in such systems. The railroads in the survey appeared to have technology, either in place or in development, that would support scheduling decisions. Railroad C, for example, reported that a system to be used to make daily scheduling decisions was under development. Railroad B has several systems under development that could support real-time scheduling. Most of the railroads had car-monitoring and trip-planning capabilities, and most had aggregate data on performance available. Finally, some of the railroads had computer-aided dispatching systems in place.

Both marketing and cost control were cited as reasons behind the choice of scheduling strategy. Railroad B, for example, believed that a master scheduling strategy would improve reliability, which would result in increased customer satisfaction. Several of the railroads surveyed identified special scheduling processes for time-sensitive traffic, such as intermodal and automotive traffic. For example, master schedules with very low slack are used for many intermodal trains. The railroads augment these low-slack master schedules with real-time support in the event of schedule disruptions. Several railroads identified flexible scheduling policies to protect automotive traffic. In addition, some firms assign the responsibility of protecting service on important traffic to a member of their real-time scheduling group.

Cost reduction from the consolidation of trains was cited as a primary reason for real-time scheduling. Railroad C expressed the opinion that the railroad was compensated to "move freight, not trains." Therefore, they tried to let demand dictate the service level. In general, most of the railroads believed that because demand fluctuated widely from day to day, the evaluation of demand and available resources (i.e., real-time scheduling) was necessary to control variable cost.

Thus, the alternative scheduling strategies described in this paper appear to accurately describe the scheduling strategies in practice. The strategies are not, however, mutually exclusive. Many firms employ hybrid scheduling processes that have master and real-time scheduling characteristics.

A PROTOTYPE MIS STRUCTURE

It has been argued that strategy determines the appropriate organization design and information system. However, this is not intended to diminish the role of technological innovation, which can make new strategies and structures feasible. The argument is intended to imply that, for a firm to capitalize on advances in technology, it must adjust its strategy and structure accordingly.

Research currently under way could provide new opportunities for railroad scheduling and marketing strategies, and for innovative organization structures. Harker (*13*) has presented a structure for the development of intelligent (i.e., model-based) information systems that enable the railroad to adapt to its chosen organizational and marketing strategies:

Schedule Policy Evaluation
⇅
Tactical Scheduling of Trains
⇅
Real-Time Scheduling
–trains
–locomotives
–crews
–cars
⇅
Computer-Aided Dispatching
⇅
Optimal Train Control

Once an overall strategy has been decided on how schedules (e.g., local or networkwide) will be generated, one must implement this policy on a weekly or monthly basis. This tactical scheduling of trains differs from the above strategic question in that all trains at the tactical level will have some type of

	A	B	C	D	E
Master Scheduling?	Yes	Yes	No	Yes	Yes
Override?	Yes	No	N/A	Yes	Yes
Real Time Decision Making?	Yes	No	Yes	Yes	Yes
Intermediate Group with Unique Reporting Structure	Yes	N/A	Yes	Yes	Yes

Source: Interviews with 5 Class I North American Railroads

FIGURE 5 Survey results.

schedule. Thus, for those trains that must be scheduled (passenger, intermodal, etc.), the tactical scheduling procedure will create a set of feasible schedules; that is, a set of schedules that are logically consistent in the sense that an operating plan exists that can achieve the times stated in the schedules with high probability given the delays encountered by each train as a result of random occurrences (wind, breakdowns, etc.) and interference with other trains. For trains that run on a tonnage basis, scheduled slots would exist. That is, trains would not be permitted to depart at random but must depart within a stated time window if they are to be operated on a given day. Thus, a tactical scheduling system must also have the capability to create such slots and check that they are feasible when considered alone and when combined with the other scheduled traffic.

Given the tactical schedules, the purpose of the real-time models is to develop operating plans that will achieve the stated schedules as best as possible given that events have occurred (breakdowns, crew shortages, etc.) that disrupt the plan of operations on which the tactical schedules are based. For trains, one wishes to develop a plan of arrival and departure times at each major yard or, more generally, at each point where the planning of the train operations changes (i.e., a boundary of the dispatchers' territories). For crews, locomotives, and cars, one attempts to plan their movements to guarantee that sufficient resources are available at each yard to achieve the tactical schedule plan. These models are the "heart and mind" of the intermediate group described previously. That is, these real-time models serve as the vital link between the overall strategic mission of the railroad and its implementation on a day-to-day basis.

After defining the arrival and departure times of the trains at the boundaries of the dispatchers' territories (i.e., a planning line), the computer-aided dispatching system attempts to schedule the meets and passes along a rail line with planned arrival and departure times at intermediate points (sidings, beginnings and ends of double track, etc.) to ensure compliance with the times from the train scheduling model.

The dispatching system provides each train with a specific goal in terms of the time and velocity at which it should reach each point on its path. The engineer and the on-board computer system must then calculate a velocity profile (a combination of throttle and dynamic/air brake settings) that will achieve this goal in a safe and fuel-efficient manner. The train must solve a pacing problem that is quite more complex due to the nature of train forces and handling techniques.

The above discussion has described the flow of information down the model hierarchy. Of course, the reverse flow is also very important. The train must constantly inform the dispatching model of its location and performance, the dispatching system must inform the network control model of the status of planning lines, and the performance of the network control system (the interline planner) must be monitored to assess the long-term viability of various schedule policies. It is precisely this flow of information that must be coupled with the organizational design of the railroad.

CONCLUSION

The research program underway at the University of Pennsylvania described by Harker (*13*) is attempting to build model-based information systems technology to deal with all of the issues outlined in the previous section. In fact, the argument presented in this paper implies that the tactical and real-time scheduling systems and the computer-assisted dispatching methodology are the most important pieces of ATCS in that they link together the strategic goals of the railroad and resulting organizational structure. That is, the type of MIS structure described above is the vital lubricant in Galbraith's (*5*,*14*) flow of information. Without such systems, it seems clear that ATCS will not achieve their promise.

Thus, much more attention must be given to the development of the MIS component of ATCS. However, there will never emerge one standard for the entire industry as many envision because of the need to adapt such systems to the particular strategy chosen by each railroad. The framework presented by Harker (*13*) and outlined above is the closest to a standard that will be achieved in this area. It is the goal of the research program described by Harker (*9*) to develop MIS technology that can be adapted to the individual strategies each railroad elects to implement. This is a challenge, but one that must be met if the "service-sector sinkhole" is to be avoided.

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REFERENCES

1. S. S. Roach. Technology and the Services Sector: America's Hidden Competitive Challenge. In *Technology in Services: Policies for Growth, Trade, and Employment* (B. R. Guile and J. B. Quinn, eds.), National Academy Press, Washington, D.C., 1988, pp. 118–138.
2. G. P. Hackett. Investment in Technology—The Service Sector Sinkhole? *Sloan Management Review*, Winter 1990, pp. 97–103.
3. J. L. Heskett. *Managing in the Service Economy*. Harvard Business School Press, Boston, Mass., 1986.

4. J. B. Quinn, J. J. Baruch, and P. C. Paquette. Technology in Services. *Scientific American*, Vol. 257, No. 6, December 1987, pp. 50–58.
5. J. R. Galbraith. *Organization Design*. Addison-Wesley Publishing Co., Reading, Mass., 1977.
6. D. Robey. *Designing Organizations*, 3rd ed. Richard D. Irwin, Inc., Homewood, Ill., 1991.
7. P. R. Lawrence and J. W. Lorsch. Differentiation and Integration in Complex Organizations. *Administrative Science Quarterly*, June 1967, pp. 1–47.
8. R. Duncan. What Is the Right Organization Structure? *Organizational Dynamics*, Winter 1979, pp. 59–79.
9. A. D. Chandler. *Strategy and Structure*. MIT Press, Cambridge, Mass., 1962.
10. P. Dawson and I. McLoughlin. Computer Technology and the Redefinition of Supervision: A Study of the Effects of Computerization on Railway Freight Supervisors. *Journal of Management Studies*, Vol. 23, No. 1, 1986, pp. 116–131.
11. J. L. Gibson, J. M. Ivanovich, and J. H. Donnelly, Jr. *Organizations: Behavior, Structure, and Process*. Business Publications, Inc., Plano, Tex., 1988.
12. D. D. Wyckoff. *Railroad Management*, D.C. Heath and Co., Lexington, Mass., 1977.
13. P. T. Harker. The Use of ATCS in Scheduling and Operating Railroads: Models, Algorithms, and Applications. In *Transportation Research Record 1263*, TRB, National Research Council, Washington, D.C., 1990, pp. 101–110.
14. J. R. Galbraith and D. A. Nathason. *Strategy Implementation: The Role of Structure and Process*. West Publishing Co., St. Paul, Minn., 1978.