PERFORMANCE STANDARDS FOR RAIL TERMINALS:

CASE STUDIES FROM THE U.S. AND FRANCE

by

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ABSTRACT

The headquarters of a railroad must (1) delegate the operation of a terminal to local managers, and (2) establish a set of standards that ensures the performance of the terminal is consistent with the system's budget and its goals for origin-to-destination trip time and reliability. To do so, a performance standard must help predict terminal performance, help spot problems by showing where performance has been below what was predicted, and finally, inform the terminal manager of the needs of the system and motivate him to perform as predicted.

A standard will fulfill these three roles, and thereby elicit terminal performance consistent with system needs, to the extent it both (1) is simply calculated and stated, and (2) respects the constraints of the terminal manager. The roots of these constraints are operating conditions such as the pattern of inbound traffic and train movements, whose variation is continuous and never fully predictable.

Analyses of data from two classification yards leads to a set of proposed standards. These include standards for the use of switching locomotives, the processing time of cars, and the reliability with which the yard permits cars to make connections between trains. These standards can be put in place using volume-variable budgets and weekly performance reports that juxtapose total cost (actual and budget) with service performance (actual and standard).

Thesis Supervisor: Carl D. Martland

Title: Principle Research Associate

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I would like to express my graditude to my thesis supervisor, Carl Martland, for his patient and wise guidance; to each of the employees of the Boston and Maine Corp. and the French National Railways who helped me, and in particular, Arsene Felten of the SNCF's Metz Region; and to each of the people of the transportation program of MIT who have, in one way or another, lent me their support. Maryvonne, tu sais le reste.

Author's Note

The author wishes to emphasize that the two railroad freight terminals that are the subject of this study are not meant to be representative of the rail systems of their two countries. Rather, this study analyzes these two very different terminals as a means of illuminating how the standards that the study proposes might be used to improve any terminal's performance.

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CHAPTER ONE:

INTRODUCTION

1.1 The Essential Role of the Classification Yard in a Railroad System. The technology of the train is such that a railcar can moved along a track at a reasonable cost only if coupled to a number of other cars in a train. One way to attain this minimum efficient train load is to delay the departure of the car from its point of origin until the required number of cars, all with the same destination, have accumulated at that same point of origin, at which point a train can be run directly to the cars' common destination. This is the unit train. It lends itself to goods flowing in high volume with geographically compact patterns of collection and distribution. The extreme example is coal moving from mine to power plant.

More generally, however, the rate of shipment of other cars headed for the same destination is low enough that to wait for the buildup of the minimum number would imply unacceptable delay for the original car, not to mention a mammoth car fleet. Therefore, a car typically leaves its point of origin in a train of cars headed not to the same destination but merely in the same general direction. At one or more points in the car's trip, the train in which the car is moving arrives at a classification yard, where its cars are sorted by direction of travel and regrouped into both mainline trains containing cars for the same direction and local trains bearing cars for destinations along lines in the vicinity of the yard.

Despite a declining traffic base due to the expansion of highways, the concomitant development of competition from trucking, and the development of unit trains for bulk goods moving in concentrated flows, railroads around the world continue to carry much freight in isolated cars. The classification yard lets the railroad move such cars between the many origins and destinations on its network while maintaining (1) an adequate load on each train, and (2) a frequency of departure of cars from each origin that is acceptable to the railroad's customers.

The performance of a rail system may be guaged along two distinct dimensions: cost and service. Two catagories of cost that will be critical to our study are operating costs and capital costs. The cost of a railroad's capital equipment, including its rolling stock and fixed plant, is best measured in terms of opportunity cost, i.e. the revenue forgone by diverting a piece of capital equipment from its best alternative use. Two common measures of a railroad's service performance are the mean origin-to-destination (O-D) trip time it provides to each customer, and the reliability of that time. (A related measure is the mean response time to a shipper's call for a railcar to load, and reliability of that response, which depends in part on the rapidity and reliability of the railroad's movement of empty cars.)

The time that cars spend making connections from inbound to outbound trains at classification yards is the largest component of the car cycle and the central source of unreliability in origin-to-destination trip times. [1] The cost performance measures we will be concentrating upon in the classification yard are the operating costs of the switching locomotives that sort the cars and assemble them into outbound train, the clerical workers and overhead costs associated with the switchers' operation, and the opportunity cost of cars during the time they spend in the yard (which is approximated in the U.S. by the "per diem" cost of each car that is set by the Interstate Commerce Commission). We need a measure of the service performance of the yard that shows how the yard contributes to O-D performance. Such a measure is the yard's connection reliability. This reliability may be represented by a upward-sloping curve that shows the probability that a car will make a connection between an inbound and outbound train as an increasing function of the available time between them. This is known as a PMAKE function (for Probability of MAKing the connection), and has been developed by the M.I.T. Rail Group. [2]

A railroad is always trying to balance the twin pressures to cut costs and improve service in a way that will improve profits or reduce deficits. The weak link in the chain of understanding that is needed to strike this balance has proven to be the link between service levels and revenues. General models of the demand for freight transportation developed have been unable to account for enough of the factors affecting freight demand to see widespread use by railroads. Instead, a railroad typically tries to find what service levels will attract and retain the business associated with specific shippers, corridors, or commodities.

A railroad's revenues certainly depend in part on the origin-to-destination trip time and reliability it can offer to those who ship railcars over its lines. As noted above, this O-D performance will be largely determined by the connection reliability of the classification yards through which a car passes en route. In this thesis, however, because of the difficultly of linking O-D performance to revenue in any general way, we will not try to make an explicit link between yard performance and railroad profitability. Instead, we will assume that the yard manager's goal is to acheive a performance in terms of the dual measures of cost and connection reliability that is satisfactory to headquarters. This statement is less intellectually satisfying than the following, which is the one that microeconomics would make: If all other aspects of its operation are held constant, a railroad will continue to spend more money to improve the connection reliability of its yard until the marginal cost of additional connection reliability equals the marginal revenue to be gained because of the additional business attracted by the resulting better O-D performance. However, the first statement illuminates much better the environment in which the yard manager and his superiors work.

1.2 A Brief Comparison of the Railroads in the U.S. and France.

This thesis will show how similar kinds of standards can be used for management control of classification yards in the U.S. and France. The two systems have some common features, but operate in significantly different settings. The French population of 53 million lives in an area about the size of Texas. This population is not only more dense than in the U.S., but more centered around urban agglomerations. This concentration has justified investment in a high-density rail passenger network from which freight service benefits..

In France, the government has taken a greater role in railroad investment than in the U.S. While American freight railroading comprises a number of private companies, most of which make a modest profit, the French National Railways (SNCF) is a nationalized firm subsidized by the French government. A shipper in the U.S. can typically choose among several competing railroads in routing his shipments. In contrast, the SNCF has a rail monopoly. Like the U.S. railroads, however, the SNCF must compete with carriers in other modes. In the railroad's competition with the truck, rail has the disadvantage of shorter hauls in France than in the U.S., but the advantage granted by France's urban concentration of being able to get within a practical distance of a larger fraction of the country's commercial activities. Exhibit 1-1 summarizes the key quantitative differences between the two systems.

In comparison with U.S. railroads, the SNCF places much more weight on schedule adherence by freight trains. This is imposed by the presence on most lines of frequent, high-speed passenger trains. On U.S. railroads, freight trains move at fairly uniform speeds, and passenger trains are few. In France, on the other hand, 50 mile-per-hour freight trains must be moved between frequent, 100-mile-per-hour passenger trains. On American railroads, consequently, the train schedule is usually a guideline that managers apply flexibly according to daily conditions, whereas on the SNCF it is observed to the minute whenever possible.

Another important difference is that the SNCF offers two kinds of service to shippers using the individual railcar, as opposed to the unit train: Ordinary Service and Accellerated Service. This study confines itself to Ordinary Service, to which American rail service is most analogous. (Some unit train services of U.S.

EXHIBIT 1-1

SELECTED 1975 STATISTICS - U.S. AND FRENCH RAILROADS. (source: Union Pacific Railroad Co., A Survey of Railroads in Selected Industrial Countries, New York, 1977)

	U.S. Railroads[a]	French National Railways
route length (miles)	200,000	22,478
revenue freight ton-miles (millions)	754,252	42,860[b]
average length of freight haul (miles)	515[c]	181
revenue passenger miles (millions)	5,736	31,346
number of employees	487,789	281,679

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a - includes line-haul U.S. railroads having annual revenues over $5 million.

b - full car loads only.

c - average haul of all these railroads considered as one system. Average haul of these railroads individually was 309 miles.

railroads, notably for perishables and for trailers or containers on flat cars, is more like the SNCF's Accellerated Service in its greater emphasis on service over cost.)

In the absence of dense priority traffic, the managers of American rail terminals can rationally sacrifice schedule adherence in favor of other objectives, which may lead for example to the delay of the departure of an outbound train so that some high-priority cars can have time to make their connection to it. This also happens in the SNCF's Accelerated Service, where a train may be held at a yard past its scheduled departure for cars that arrived late, but the train will then depart in an alternate time slot that is fixed in advance for whatever train may need it.

Given the flexibility with which an American railroad typically applies its train schedule, headquarters has a great need to control the day-to-day decisions of line operations managers. The frequent, high-speed passenger trains of the SNCF change the time horizon on which the bulk of operating decisions are made. A new operating plan is installed every six months. The high train density of trains permits few changes in the operating plan once it is in place, and leave the dispatcher and yard manager with a smaller range of day-to-day choices.

1.3 A Preview of the Coming Chapters. This thesis will bring to light the differences among and the respective advantages of a number of kinds of performance standards for the management of rail classification yards. The standards refer to the yard's performance in terms of the physical measures of yard activity, and to the cost and service performance that the physical measures imply. Our thesis is that a performance standard should have three purposes -- prediction, troubleshooting, and motivation -- and that to accomplish these purposes, a standard must respect a yard manager's constraints, which may take the form of (1) a lack of full control over the determinants of this performance measure, or (2) a need to fulfill other performance standards.

Having set the stage in the present chapter, we will examine in Chapter Two in qualitative terms how several specific kinds of standards can be anticipated to fulfill the triple role of prediction, troubleshooting, motivation. Chapter Three presents a series of data analyses that test each of these kinds of standards using data from two rail classification yards, one in the United States and one in France. In Chapter Four, we will see how the standards calculated in Chapter Three can be used in reports that are part of the railroad's management information system. Chapter Five presents a summary and conclusions.

CHAPTER TWO:

A THEORY OF PERFORMANCE STANDARDS

FOR THE CLASSIFICATION YARD

Before we can see how standards can help improvement the management of a railroad yard, we must examine what a railroad yard is, what a performance standard should do, and what specific kinds of performance standards we might apply to the yard. This is the purpose of this Chapter. Section 2.1 reviews the workings of a rail terminal, including its physical elements, what it does, the short-run and long-run decisions that affect the yard's performance, and the ways in which we can measure that performance. Section 2.2 defines the roles of a performance standard, those of predictor, troubleshooter, and motivator, and shows how these roles are interrelated. Section 2.3 introduces several specific measures of performance, including switcher use, the use of ancillary yard personnel, fuel use, average processing time, and connection reliability. It shows how these performance measures can be controlled using several kinds of standards, each of which we can distinguish by the complexity of the computations leading to the standard, and the degree to which the standard varies with other yard activity measures. In the case of each standard, we then show how these characteristics improve or hurt the ability of managers to use the standard as predictor, troubleshooter, and motivator.

2.1. How a Classification Yard Works.

In this section, we will discuss what a classification yard does, the kinds of decision its managers can make, and how their performance can be measured. Subsection 2.11 discusses the classification yard in the context of the rail terminal of which it is typically the principle feature. Subsection 2.12 analyzes the components of the time a car spends in the yard. Finally, Subsection 2.13 shows how changes in a condition that is largely out of the control of the yard manager -- inbound volume -- can, depending on his reaction to it, affect yard performance in contrasting ways.

2.11. The Rail Terminal: Functions, Decision Variables, and Performance Measures.

Before we can speak of terminal management, we must examine in more detail the function and needs of a rail classification yard. Chapter One described the classification yard as a place where trains enter and their constituent railcars are sorted according to their direction of travel. In this section, we will see that such yards typically are parts of rail terminals. These terminals don't just sort railcars, but also service locomotives, serve as a base for train crews, and handle the paperwork and other communications associated with these three functions. A framework for seeing the overall working of a rail terminal provided by C. D. Martland's description of transportation terminals in general. [3] In this subsection, we will apply this description to the rail terminal.

To understand yard operations requires that we understand what flows through the terminal, what the terminal needs in order to accomplish its tasks, the factors affecting yard operations over which the yard does and does not have control, how terminal performance can be measured, and issues on which the yard manager and his superiors must focus. We must follow at least four flows through the yard:

1) Loaded and unloaded railcars, which are received in inbound trains, must be inspected and possibly repaired, and then classified by outbound block. A block is a group of cars for a common destination point where they will either be passed to another railroad, classified again, or placed in local trains for final destination. These blocks are assembled into outbound trains, and inspected again before departure. This flow through the terminal is

the flow with which we will be primarily concerned in this thesis. At a classification yard, the processing of a car typically entail the following steps: the car enters the yard on an inbound train, whose locomotives (and, in the U.S., caboose) are then detached. A small locomotive, adapted for use in the yard and which we will refer to as a "switcher", then attaches to the cars. It moves each of them onto a track in the yard corresponding to the car's outbound block. At larger yards, this process is often assisted by a "hump," or raised portion of track over which the switcher pushes cars, from where each one rolls into its appropriate classification track. Several hours before the departure of the outbound train that is to pick up the cars that have accumulated for a given block, these cars must be assembled. This means they must be pushed together by a switcher, their couplers and brake hoses must be attached, and in some cases the attached cars must be moved to a departure track. Our focus on the flow of cars through the terminal will lead us to refer to "the classification yard" rather than the "terminal" throughout the rest of this thesis.

The remaining three flows through the rail terminal include:

2) The locomotives (and the cabooses) that must be removed from inbound trains, serviced and maintained, and placed on outbound trains.
3) The crews of mainline trains, for whom the labor agreement typically specifies minimum periods of rest between train

assignments.

4) The paperwork and other communication tasks associated with all these elements.

In order to accomplish its tasks, the yard requires

1) an interface with the rest of the railroad, including tracks to receive inbound trains, information on the estimated arrival time and the contents of inbound trains, and a dispatching process that determines when trains depart the yard. A final element of the yard's interface with the rest of the railroad are the performance standards that are the subject of this thesis. We will see in Chapter Four that one function of these standards is to ensure that yard performance contributes to the needs of the system.

2) A means to move cars, cabooses, crews, and paperwork and other information within the yard.

3) Places to hold queues of inbound trains, cars in process, and outbound trains; places for queues of paperwork; and facilities for crews between assignments.

4) An operating plan to guide the people responsible for managing the various yard processes.

For the purposes of this study, we will find useful a splitting of the factors affecting yard operations into two categories: those the yard manager typically controls, and those he doesn't. Factors over which the yard manager has little or no control include

1) the railroad's operating plan for its whole system, which

determines how much traffic must be handled by this yard,

2) the pattern of arriving trains and cars, including the average arrival rate, the degree to which it is cyclical, and its predictability,
3) the capacity provided for holding queues, and
4) the pattern of outbound departures and the capacities of the outbound trains.

On the other hand, the yard manager has much control over the ways in which queues are handled, which implies the servicing rate for each process within the yard. This rate can be varied by reallocating yard personnel, switchers, and other resources.

The performance of a yard may be measured along any of the following dimensions:

1) The degree of utilization of the yard's resources, including people, trackage, and equipment such as switching locomotives, as well as the utilization of line-haul locomotives and train crews.
2) The average time and reliability of the time needed to move cars through the yard.
3) The costs of yard operations, which may be analyzed using the concepts of total and average cost, fixed and variable costs, or capital and operating costs.
4) The capacity of the yard to hold and process cars.

The manager of the terminal or his superiors must focus their attention on the following set of issues. We will address each in this thesis:

1) The tradeoff between all costs and the level of service that the yard helps provide. Our discussion begins with Section 2.13's explanation of the effect of inbound volume.
2) The tradeoff between yard operating costs and the cost of railcars. We discuss this tradeoff in Section 4.1.
3) The prediction of origin-to-destination performance as the sum of movements along a series of line segments between classification yards, and processing times at these yards. The heart of this process is the PMAKE function for the yard, which we discuss in Section 2.32.
4) Allocating responsibility for the utilization of rolling stock and for the opportunity cost of this capital equipment. We present this issue conceptually in Section 2.12, and describe in Chapter Four precisely how the means for such an allocation might be put in place.
5) Establishing terminal performance standards that relate to the operating plan and to the measurable aspects of terminal operations. We propose a specific set of such standards in Section 2.3 and test them in Chapter Three.

2.12. The Components of the Yard Time of a Car.

Section 2.11 mentioned that one measure of the performance of a terminal is the average time and the reliability of the time needed to move cars through the terminal's classification yard. We will be particularly concerned with the average amount of time cars spend in the yard. We can divide this average yard time into four segments:

(1) the period between the car's arrival and the end of its classification,
(2) the wait between the end of classification and the start of assembly of the next appropriate outbound train for the car,
(3) the possible delay to the car, once classified and ready to leave, in the event that its outbound train is full and the car must therefore wait until the next train, and
(4) the period between the start of the assembly of the car's outbound train and its departure.

We shall refer to the sum of segments 1 and 4 as the car's processing time. Processing time is largely under the control of the yard manager. In addition to mean processing time, however, the average yard time of cars depends on segments 2 and 3. We will call the sum of these latter two yard time segments wait time. Their lengths depend on factors typically beyond the yard manager's control. Segment 2, the average wait in the yard between the end of classification and the start of assembly, depends on the frequency of pickup of each block, which is determined by those managers who set

--the train schedule, and

--the minimum train load factor, which affects the number of cancelled and extra trains.

Segment 3, the delay undergone by cars that are classified and ready to depart, but are left by their outbound train because this train lacks the capacity to take them, is determined

--like Segment 2, by the frequency of pickup of each block,

--by the capacities of the motive power fleet, and

--by the profile of the various line segments.

Clearly, none of these factors are under the control of the yard manager (though he may have some say in deciding on cancelling a train or adding an extra). The yard manager should thus only be held responsible for those parts of a car's stay in the yard during which it was undergoing processing, i.e. the periods between its arrival and the end of its classification, and between the start of its assembly and its departure time. The only problem with this policy is the possibility that trains already assembled may be delayed past the departure time the yard manager had forseen when he began assembly. At yards where such delays were significant, a solution would be to consider the time during the delay to be part of wait time.

2.13. The Impact of Changes in Inbound Volume. At a classification yard, managers deal with queues -- servicing them, finding space for them, predicting them, and preventing them. Queues build up as trains, cars, crews, and paperwork wait to begin the next in their sequence of processes. The cause of the buildup may be

- --random and cyclical fluctuations in volume (in daily, weekly, seasonal, and multi-year cycles),
- --breakdowns of equipment or facilities,
- --unreliable line-haul train operation (both inbound and outbound), and
- --bad weather. [4]

In this thesis, we will focus on the effect of queues of cars created by variations in volume. The role of the local manager is to assure the adequate functioning of the yard in the face of operating conditions over which he has no control, and which vary constantly and somewhat unpredictably. An important measure of these operating conditions is the arrival rate of cars at the yard. This variability results from variations in customer demand, and from labor agreements and economies of scale that prevent some trains, especially the local trains that pick up and set off cars at customer sidings, from operating each day of the week.

We can imagine two possible ways inbound volume can affect average yard time. Each of the two effects acts on one of the two components of yard time: wait time and processing time. First, increases in inbound volume can reduce average yard time by raising outbound train frequency and thus reducing mean wait time. The faster cars for each outbound block accumulate, the less likely is cancellation of scheduled trains due to low tonnage, and the more likely is the adding of extra trains. The greater the frequency of outbound trains and thus the mean frequency of block pickups, the lower will be average yard time. However, the effect of inbound volume on the number of outbound trains is likely to be weak for three reasons:

a) Variation in volume is likely to lead managers to add or cancel a train only when the number of cars is significantly above or below the capacity of a train.

b) Many other factors will determine whether a train is operated on a given day or not, including weather, derailments, power availability, and a requirement or desire to work fewer crews on weekends.

c) Some trains only pick up and set off cars.

Second, increases in inbound volume can affect processing times.

Depending on the goals of the yard manager and the degree of utilization of switchers, higher volume may lead to higher processing time. The capacity of a switcher depends greatly, of course, on the customs, incentives, and personalities of the people involved. Capacity can therefore only be estimated. If the capacity of the current number of switcher-hours is being nearly fully used, the relationship between switcher-hours, mean processing time, and volume is shown in Exhibit 2-1. Depending on the incentives and constraints of the yard manager, he may, as shown in Exhibit 2-1, respond to a higher volume by either

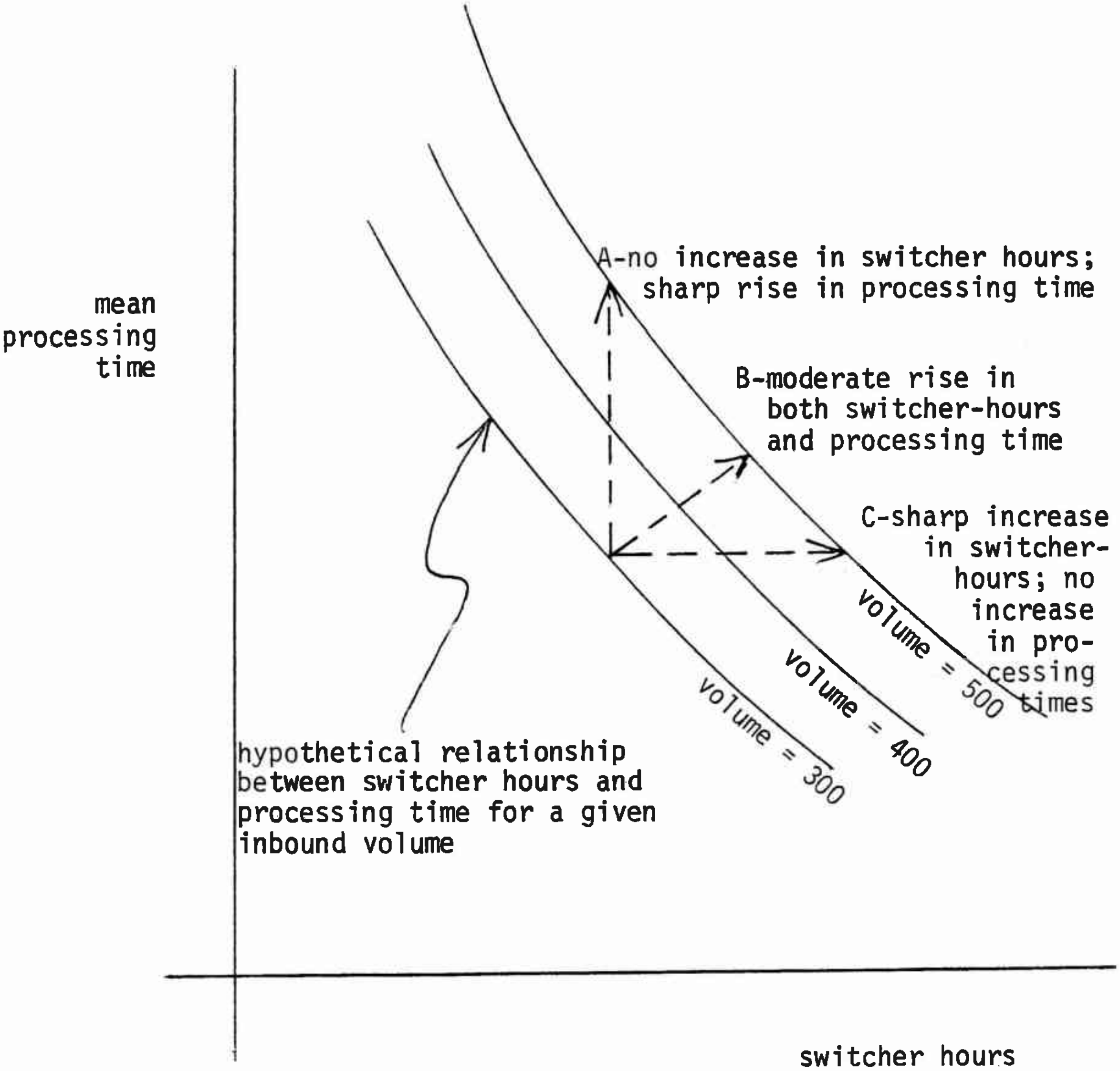
A - keeping switcher-hours constant and letting processing time deteriorate. Because of restrictions in the labor agreement, yard managers may be unable to match the number of crews worked each day to the volume on that day. The result is that cars tend to build up in the yard, and cars arriving on these days have to wait longer before being classified or assembled.

B - increasing switcher-hours somewhat, but permitting a moderate rise in processing time, or

C - increasing switcher-hours in order to keep processing time constant. For example, the yard manager can add a second switcher during part of the day to the hump, so one switcher can be getting a string of cars to classify while another switcher is classifying a

EXHIBIT 2-1

RANGE OF RESPONSES THAT YARD MANAGER MAY MAKE TO INCREASED INBOUND VOLUME



previous string. He can also similarly add a second switcher to the assembly of trains, or dedicate a switcher to the servicing of local customer sidings instead of making one of the switchers take time off to do so.

Let us see how higher volume could possibly lead to higher processing times. Suppose the goal of the yard manager is not to keep a constant mean processing time, but rather to simply keep the yard unplugged. Whether or not a standard exists for processing time, the yard cannot continue to function unless, on average, switchers hump trains as fast as trains arrive, and unless trains are assembled as fast as their cars are humped. The more volume rises without the yard manager adding any switcher hours, the more likely is this arrival rate to begin to exceed the rate at which the yard's switching locomotives can classify cars and assemble outbound trains, and therefore the longer will a given inbound train be likely to wait before being classified, and the further in advance will an outbound train have to be assembled if it is to be ready at the scheduled departure time of its train. If he is trying to maintain a processing time, on the other hand, the yard manager will work more switchers at a low inbound volume so as to be able to hump each train soon after it arrives. We see, then, that to function at all, the yard must assure some level of processing time, but that a level of processing time that is better than the one needed merely to keep the yard fluid can be acheived if the yard manager sees fit to pay for added switcher-hours.

Of course, the hypothesis that one operating condition (inbound volume) and one yard decision (the number of switcher hours worked) determines mean processing time is an over-simplification. The yard is buffeted by unpredictable variations in operating conditions of which total inbound volume is but a summary. The timing of inbound and outbound trains varies somewhat unpredictably over the course of the day, as does the distribution of volume among them. Also affecting yard performance somewhat unpredictably is the weather, and the needs that may arise to expedite, repair, and occasionally re-rail particular cars. Other decisions affecting processing time besides the number of switcher hours include the yard manager's decisions on when to work the hours; where in the yard to deploy the switchers; and the order for humping cuts, assembling trains, and doing other yard tasks such as moving cars to and from repair and cleaning tracks and customer sidings.

2.2. The Purposes of a Performance Standard. A central problem in any large organization is the conflict between delegation of decisions, and coordination. This is exacerbated on the railroad by its complexity, its geographic dispersion, and its changing, somewhat unpredictable traffic flow and environment. Headquarters must give the manager of a classification enough freedom of action to operate according to changing local conditions as he sees fit, but must induce him to balance service quality and the various categories of yard in a way that is consistent with system needs. An appropriate performance standard can help bridge the gap between headquarters and yard and fulfill three roles: as predictor, troubleshooter and motivator.

In the first two roles, a standard serves as a passive indicator of yard performance for use by headquarters. In the third, the role of motivator, the standard becomes a way for headquarters to actively reach out and guide yard performance in line with system needs, while continuing to fully delegate operation of the yard to its local managers.

The upper management of any large railroad faces a dilemma. On one hand, the coordination of such a geographically dispersed plant requires that daily communication among managers be supplemented by operating rules such as train schedules. The system is so complex that coordination requires a rigid procedure. On the other hand, this same dispersion and complexity hinders communication between headquarters and officers at outlying posts about each problem or each change in the railroad's environment. Despite the railroad's need for coordination, much decision-making has been de-centralized because of both the cost of the long-distance communication and the sheer impossibility of headquarter's being able to digest all the data for a complete centralization of decisions. Management must therefore try to find a happy medium between the standard procedures required for coordination and the decentralized decision-making that this complex, geographically-dispersed system needs in order to respond to unpredictable changes in conditions both internal (such as strikes, derailments, and equipment failures) and external (such as weather, the traffic pattern, and the demands of specific shippers). Management must therefore define the duties of outlying managers, including those at the railroad's classification yards, in a way that balances adherence to rules and local decision-making.

A railroad yard is one of the important parts of the railroad that cannot be run from headquarters. It must be managed by people on the spot, but headquarters must have control over the performance of these managers. Headquarters must possess a way to predict the cost and service performance of each yard, to spot trouble, and to motivate yard managers to maintain or improve performance without weakening the power of these managers to make day-to-day decisions at the yard. The performance standards recommended by this thesis can provide headquarters with such tools.

We can look at the yard either of two ways. First, we can see it as a technological system that, given the level of service it is supposed to provide in terms of processing time or other measures, consumes resources at a rate we can predict on the basis of the operating conditions (such as volume) it faces from day to day. Second, we can see it as a group of people. We then see that the rate at which the yard consumes resources is not just a function of the level of service it provides, but also of the incentives that headquarters management provides to yard managers. To each of these points of view corresponds roles for a yard performance standard. When viewing the yard as an inanimate system, we see that a performance standard is useful to headquarters both as

1) as a predictor of performance that helps headquarters management profitably balance cost and service in their decisions, and

2) as a means of troubleshooting, or of providing a "blinking light" [5], because, if the yard generally displays the performance predicted by the standard, the standard provides a means to let headquarters identify those specific areas of the yard's operations where a problem exists and where therefore the headquarters manager should concentrate his efforts to bring about improvements.

Viewing the yard as a human group, central management finds a third use for a performance standard:

3) As an incentive to local managers to maintain and improve performance. The standard's roles as predictor and motivator are related to each other. Part of the predictive power of a standard comes from its ability to motivate yard managers to live up to the prediction.

The incentive is created by the local manager's expectation that headquarters will compare actual and standard performance at the end of each period. The relationship between the measurement of performance and a standard for performance is illuminated by the distinction that Peter F. Drucker makes between "control" and "controls:"

> The synonyms for controls are measurement and information. The synonym for control is direction... Controls deal with facts, that is, with events of the past. Control deals with expectations, that is, with the future. Controls are analytical, concerned with what was and is. Control is normative, and concerned with what ought to be. [6]

If a headquarters manager uses his standard only as a way of predicting a facility's performance or of spotting trouble, the standard is merely an aid to the interpretation of the one-way communication of the situation in the field. On the other hand, when he sets a standard as a goal, he gains control over the management of the outlying facility. Used as a means of motivation, the standard is a means of communication from headquarters to field as well as in the opposite direction. This helps insure that yard managers act in consonance with needs of the system, while system managers have a quantified view of the tradeoff between cost and service at the yard. A good standard therefore lets yard managers make their own decisions, but insures that they will act in consonance with the needs of the system.

Drucker points out that in a social organization like a business, the very fact that an event is measured gives it a value in the organization that will affect the results of the measurement. This is not bad, but is rather the essence of the way in which in which controls "become the personal motivation that leads to control." Therefore, Drucker concludes, "...the basic question is not 'how do we control?' but 'What do we measure in our control system?'" [7] Also, however, the headquarters of the railroad will better be able to predict the performance of each outlying facilities, spot problems there, and motivate its managers if simple measurement of performance is juxtaposed with standards for performance.

2.3 Hypotheses on Standards for Switcher Use and Car Movement.

In order to help headquarters predict, troubleshoot, and motivate, a performance standard requires two general traits: it must respect the constraints of the yard manager, and it must be simple. These desiderata are both complementary and in conflict. They complement each other because a standard that is based on simple calculations and stated in a simple form can be the subject of negotiations in which the yard manager communicates his constraints to headquarters. As the complexity of the computations underlying a standard increases, headquarters and yard managers have a harder time (1) understanding the standard, and accepting the reasoning by which it was created, and (2) negotiating over the degree to which the headquarters manager should raise the standards in his effort to provide a realistic target for better performance. The goal of being able to use the standard as a motivating tool also requires that it be easy to modify to reflect changes in operating conditions with which the standard was not made variable. For example, extra switcher-hours may be needed during maintenance or upgrading work that perturbs yard operations.

The goals of simplicity and respect for constraints will be in conflict, however, whenever respect for a yard manager's constraints requires that one of the standards display a third trait: variability. In this thesis, we will focus on performance standards for two critical measures of yard activity: switcher use and car movement. We shall see that a standard for switcher use that varies with volume may be harder for the yard manager and his superiors to accept and negotiate than a fixed standard. However, [illegible] the yard manager is also constrained by a processing time standard, then a fixed standard for switcher will be ineffective, because it ignores the change in the constraint imposed by rising volume. We shall also examine the yard time standard for cars. Here, a fixed standard has the simplicity we desire, but ignores the effect on yard time of the frequency of block pickups, over which the yard manager has little control. We shall see that in both cases, we have several ways out of this dilemma. We can set a different standard for each day of the week that reflects average operating conditions on each of the seven days. Or we can employ regression analysis to set a standard that varies with actual operating conditions each day. Finally, at least in the case of the car movement standard for the yard, we can seek a disaggregate measure of performance that lets us isolate that part of performance that is not subject to operating conditions beyond the yard manager's control.

In Section 2.13, we saw that if labor agreements or other institutional factors have led the switchers to be under-utilized, the yard can absorb a higher volume with no increase in either switcher use or processing times. Otherwise, however, as we saw in Section 2.13 and particularly in Exhibit 2-1, the yard manager who is faced with rising inbound volume has the choice between raising switcher use or permitting higher processing times. If the headquarters manager seeks standards for both these performance measures, he must recognize that the yard manager faces this tradeoff. To set a fixed standard for both measures would be to fail to recognize the yard managers constraints.

If the switchers are well-utilized, fixed standards for both performance measures can fail to either predict, troubleshoot, or motivate. The standards won't predict well if volume turns out to be significantly higher over the coming quarter or year than predicted, for the yard will have to work more switchers, let processing time slip, or both. Even if volume does not vary much from what was predicted over the next quarter, it will surely vary somewhat from week to week and even more over the days of the week (as we shall see in Section 3.2 in the case of both the yards we are studying). Therefore, a fixed standard for both switcher use and processing time will fail to let these standards serve as troubleshooters, because even if all is well, either processing times or switcher use will always be fluctuating with volume, and headquarters will have trouble discerning days when, in view of the pressures to keep both performance measures down, the yard failed to perform adequately.

Finally, fixed standards for both switcher use and processing time would also fail to motivate the yard manager to maintain and improve performance. Depending on the level at which the twin fixed standards were set, they would either prescribe more switcher-hours than were needed at low volumes, too few switcher volumes at high volumes, or both. No matter what level headquarters chose for the twin fixed standards, the standards would fail to provide pressure for the yard manager to improve his performance except over a narrow range of volumes. At other levels of volume, the standards would be either too high or too low. Conversely, to the extent that the standard varies in a way that approximately reflects the effect of inbound volume, it will more accurately represent the performance the yard manager can achieve in terms of both switcher use and processing time.

In this thesis, we propose to deal with the tradeoff between switcher use and processing time by establishing a fixed standard for processing time, but a standard for switcher use that varies with volume. We do so because inbound volume has a much more significant effect on switcher use than on processing time at the two yards we studied. From this we infer that the managers concerned with both yards seek to vary switcher use in response to changes in inbound volume in a way that lets processing time stay fairly constant. This undoubtedly reflects an implicit consensus within the management of each railroad about the approximate balance they should strike between origin-to-destination service quality (as affected by yard processing time) and system cost (as affected by yard costs). What it almost surely does not reflect is an explicit quantification of the way costs and service vary with each other. Instead, by degrees, the organizations have each arrived at a policy for yard management that, in combination with the policies with which the rest of the railroad has come to be run, achieves an adequate overall relationship between cost and revenue.

The principal desirable features for a performance standard are that

1) it should be simple enough in terms of the way it is calculated and stated to let managers at headquarters and the yard negotiate over how to adjust for (a) variations in unmeasured operating conditions, such as construction activities in the yard, and (b) in line with the desire of headquarters to set goals for future yard performance, and

2) it should respect the constraints of the yard manager, including:

(a) The pressure he may be under to perform in terms of other performance measures. For example, if headquarters hopes to set a standard for switcher use that will predict, help troubleshoot, and motivate, they must somehow take into account whatever pressure they are putting on the yard manager to also keep average yard time down.

(b) The yard manager's lack of full control over the performance measure itself. For instance, if headquarters wants to set a standard average yard time, they must do so in a way that accounts for the fact that the yard manager has no control over the wait portion of yard time.

We therefore want our performance standard to be as simple as possible but also to respect the yard manager's constraints in terms of his limited ability to affect this measure of performance and his need to maintain performance in other areas.

Sections 2.31 and 2.32 present possible standards for switcher use and car movement. In each case, one of the proposed standards varies with operating conditions: these conditions are inbound volume in the case of switcher use and block pickup frequency in the case of average yard time. If its structure is simple enough, managers can adjust the condition-variable standard just as easily as they can the fixed standard to take account of operating conditions not included in the standard, such as construction in the yard. However, the frequency of these adjustments will be lessened to the extent that the condition-variable standard takes into account operating conditions for which the fixed standard must periodically be adjusted. Moreover, if headquarters seeks to elicit better performance, the condition-variable standard will provide a steadier pressure because it will tightly follow the varying pressure of constraints presented by operating conditions.

The accuracy of a standard as a predictor of aggregate performance generally rises with the length of the period over which managers use it to predict performance. By taking into account the pattern of variations in operating conditions from day to day, a condition-variable performance standard reduces, at reasonable cost, the period during which the standard is effective.[1] Moreover, whenever the operating conditions change from what they have been in the past, the condition-variable standard will do a better job of predicting performance over the course of a quarter or a year.

We have seen that in our attempt to set standards that predict, help troubleshoot, and motivate, we are caught in a dilemma between variability and simplicity. The standards for switcher use [illegible] car movement that we will discuss in the next two subsections distinguish themselves, not just by their respective degrees of simplicity and variability, but also by two other criteria relating to the first ones. Whereas simplicity and variability are traits of the standard itself, we may also speak of two characteristics of the way we determine the standard: the aggregateness of the required data, and the complexity of the required computations.

We will discuss standards for three performance measures: (1) a major component of yard cost, switcher use; (2) a major subcomponent

[1] This improves the standard's effectiveness as a troubleshooter.

of switcher cost, fuel use, and (3) and the yard's contribution to the railroad's origin-to-destination service, as embodied in the movement of cars in the yard (measured in terms of either mean processing time or connection reliability). Contrary to what one might think at first, increasing data disaggregateness and increasing computational complexity do not necessarily go hand in hand. We will review a volume-variable standard for switcher use that is based on aggregate measures of yard activity on each day (inbound volume and switcher hours), but that uses a relatively complex analytical tool, linear regression. On the other hand, we will discuss a standard for the mean processing time of cars in which much more disaggregate data on the arrival, classification, assembly, and departure times for trains is simply averaged to arrive at the standard.

All other factors equal, managers prefer standards based on aggregate data and on simple calculations, because both are cheaper in terms of both manpower and data processing needs. Indeed, a tradeoff may be discerned between data aggregateness and computational simplicity: we can measure the effect of different factors either by spending more to measure the factors directly, or by spending more to estimate the effect of the factors using more involved mathematical techniques. We must keep in mind, of course, that while either course of action may lead to a standard that respects the yard manager's constraints, the one based on simpler calculations will more easily be made the subject of negotiation, and more easily be adjusted and accepted. The rest of this section discusses the relative advantages of several kinds of performance standards for switcher use, fuel use, and car movement, and Chapter Three tests the applicability of these standards at two highly dissimilar classification yards. These analyses will illuminate how simplicity, variability, and data aggregateness should be traded off against each other in choosing methods for the development of standards for the key measures of performance at a given classification yard.

The standards we will propose and test are all based on past data. C. D. Martland pointed out that we may not always be able to develop a model of the relationship between a performance measure and its determinants. Sometimes we can measure the performance and therefore have a standard for it, but have no way to relate this total to its determining factors. [8] Even if we are able to establish a relationship between past variations of a performance measure and its determinants, we must be careful to observe how yard performance was affected, not just by operating conditions beyond the yard manager's control, but also by the particular incentives provided by headquarters. We have noted Drucker's observation that what a manager gets as a measurement is affected by the fact he is measuring it. A corrallary to this is that what we cannot see from the past relationship among variables are the standards or other incentives to which the yard manager was subject during the period covered by the data. We saw in Section 2.13, for example, that the kinds of incentives that headquarters provides the yard manager regarding processing time will affect how he strikes the tradeoff between switcher use and the yard time of cars.

In the next two sections, we will be particularly concerned with two categories of standards: those based on aggregate, daily measures of yard activity, and those based on the times at which individual trains were processed. We will bring to light the advantages of each by showing what happens when each is used as the basis of a standard for switcher use and car movement.

The standards based on data concerning yard activity for the day as a whole rely on measures such as total inbound volume and total outbound trains, and on their relationship (1) to total switcher hours in the switcher-use standard and (2) to average yard time for cars in the yard time standard. In contrast, the second category of standard is based on more detailed data that is train-specific rather than day-specific. These latter standards are based on measures of yard activity that refer to a single train, such as when it arrived, underwent classification or assembly, or departed, and all share a concern for the various processes going on in the yard. A standard for total yard performance is then built up from observation of these individual processes. Measurements of how long the classification and assembly of each of a number of trains has taken become the basis for a standard prescribing how long these operations should take in the future.

2.31 Possible Standards for Switcher Use. Having established the need for a volume-variable budget for switcher use, we must now consider the form in which we should state it and how we should develop it. This is the purpose of this subsection. Of course, the choices of statement form and underlying data analysis are related. We shall see that we could state such a standard either as a fixed number of switcher-hours for each day of the week, as so many switcher-hours per car, or as a linear or more complex function of total inbound volume. Our computational techniques can range from division and averaging to linear regression and simulation. And, as we said earlier in this section, the underlying data can be either train-specific, or be an aggregate measure for the whole day.

In deciding how to state the standard, we must consider how we shall measure volume, and how we shall state the relationship volume should bear to switcher hours. We could have stated inbound volume in terms of inbound cars, inbound trains, or both. In this thesis, however, inbound cars is used as the sole measure (1) so as to have a single measure of volume, thus keeping the standard simple, and (2) so as to provide an indicator of the workload of the entire yard, including not just the receiving yard and hump, where the number of inbound trains is also a useful gauge of workload, but also in the assembly area, where these trains continue to impose work on the yard only in the form of the cars they brought.

We could state the relationship between volume and switcher use in several forms. Perhaps the simplest solution, which, as we will see in Section 3.3, is the one implicitly adopted by the French National Railways, is to establish a different fixed standard for each of the seven days of the week. (The standard takes the form of the detailed crew schedule displayed in Exhibit 3-18.) Almost as simple is a ratio: so many switcher-hours per inbound car. Next most simple is the form we will adopt: a linear function with a positive intercept, i.e. a fixed number of switcher-hours plus so many extra switcher-hours per car. More complex, non-linear forms might possibly prove too complex to serve as the subject of negotiations between yard and headquarters management.

The day-of-week standard will be adequate to the extent that, whatever the pattern of variation in volume over the course of the week, this volume is stable from week to week. As we shall see in Section 3.31, the ratio of the variance of volume to mean volume is likely to be smaller at a large yard than at a small one. The hypothesis underlying the ratio standard ignores the significant fixed element in the number of switcher-hours that need to be worked at the yard within a wide range of volumes. This fixed element is present is because

i) on most railroads around the world, the services of the people operating the switcher must be bought in discrete chunks such as the eight-hour shift.

ii) if mean processing time is not to rise significantly as volume drops, and trains continue to arrive and depart around the clock, at least one switcher must be on hand to classify and assemble trains even if it is idle for increasingly longer periods during the eight-hour shifts of each of its crews.

iii) a cut in inbound car volume typically appears much more as a reduced number of cars per train than as a reduced number of trains, and the time a switcher needs to classify or assemble a train does not fall in proportion to a cut in the train's length.

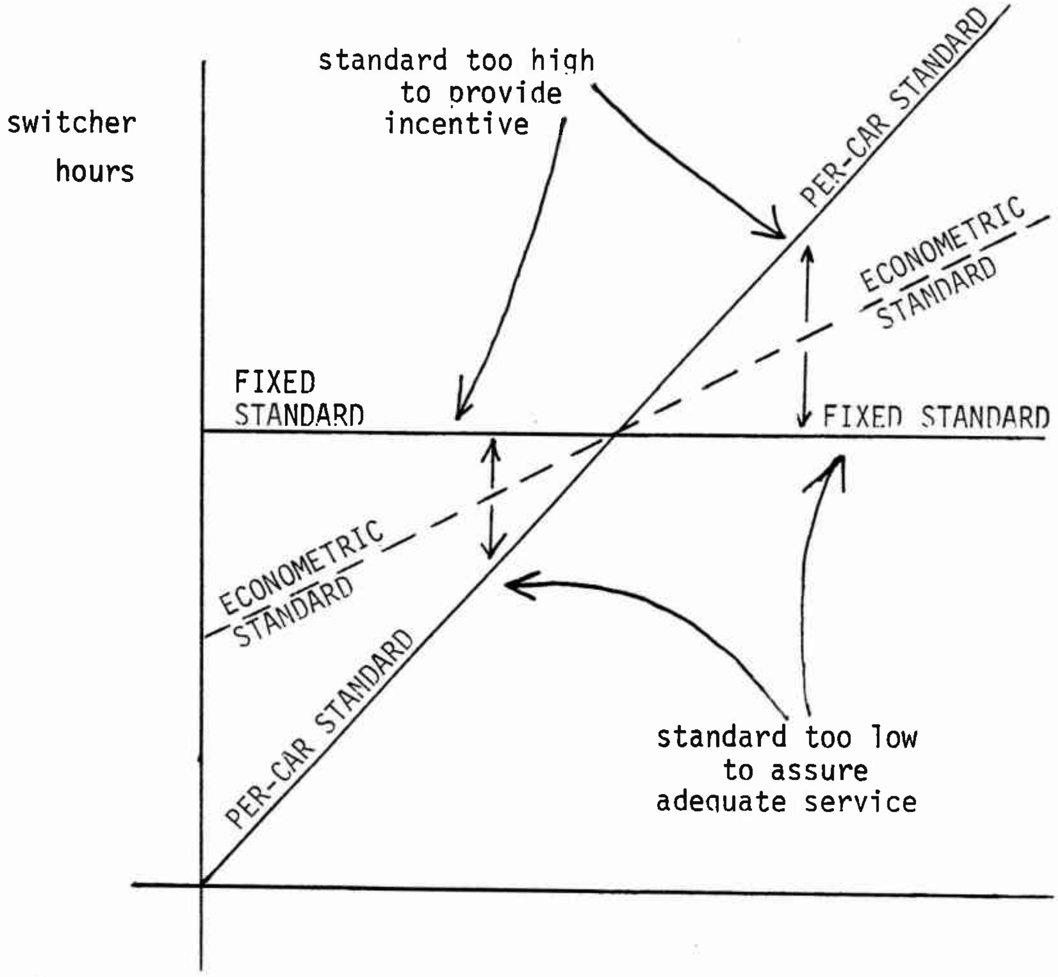
Should volume decline, say, 5 percent, the terminal manager is expected according to the ratio standard to cut his switcher use 5 percent to remain at standard. The presence of this fixed element means that in fact, a 5 percent rise (or fall) in volume can be handled with a less than proportional rise (or cut) in total switcher hours. In contrast to the ratio standard, the linear standard provides a way to constantly prescribe a number of switcher-hours that lets the yard handle the fluctuations in yard volume while avoiding excess in either switcher time or the yard time of cars. It can do so because it can include the fixed element of the variability of switcher use with volume.

The disadvantage of the linear standard for switcher use is that it requires more data and is less transparent than simpler alternatives such as a fixed standard or per-car standard. But either of these standards provides poorer prediction, troubleshooting, and motivation because they fail to take into account the way management will vary switcher use if, in the face of significant volume change, the yard management is to perform adequately in terms of both switcher utilization and mean processing time. Whenever a standard departs too much from what the yard manager can achieve -- by being either too high or too low -- it loses its power as a way to encourage the yard manager to achieve the best performance he can. If a switcher use standard is either overly easy to make or, to cite the more common case, overly optimistic, it is meaningless to everyone concerned. For these reasons, neither a fixed standard for switcher hours, nor a fixed one per car, is likely to be satisfactory because it will at most times either be too high or too low to serve as a realistic target for improved performance. Exhibit 2-2 illustrates this relationship.

On the basis of their respective computational methods, we might guess that fixed or per-car performance standards are somewhat easier for managers at the yard and at headquarters to understand, negotiate over, alter, and accept. The fixed and per-car standards are based on arithmetic, whereas the linear standard is based on the statistical technique of regression. Seeing the effect of adjusting

EXHIBIT 2-2

ADVANTAGE OF ECONOMETRIC STANDARD FOR SWITCHER HOURS OVER FIXED OR PER-CAR STANDARD



the simple standards is also easier. Only one number is involved in the fixed or per-car standard, but at least two appear in the linear standard. However, once everyone involved understands that all that underlies the linear performance standard is the mathematical fitting of a line to a set of plotted points, they are likely to accept the standard more easily.

Having settled on the form for the standard -- switcher hours as a linear function of inbound volume -- we must consider how to develop the standard. One technique might be for the involved managers to meet and simply negotiate a standard. They would do so, however, with at least a general knowledge of how switcher hours have varied with inbound volume at the yard in the past. Another approach is to formally analyze this past relationship, and establish a summary of it that can be the starting point for negotiating the final standard. This is the approach we will recommend here. The analysis will take the form of a linear regression in which the independent variable is inbound volume and the dependent one is switcher hours worked at the two yards. Of course, simpler techniques of fitting a line to a set of plotted data points could also be used to develop a linear standard.

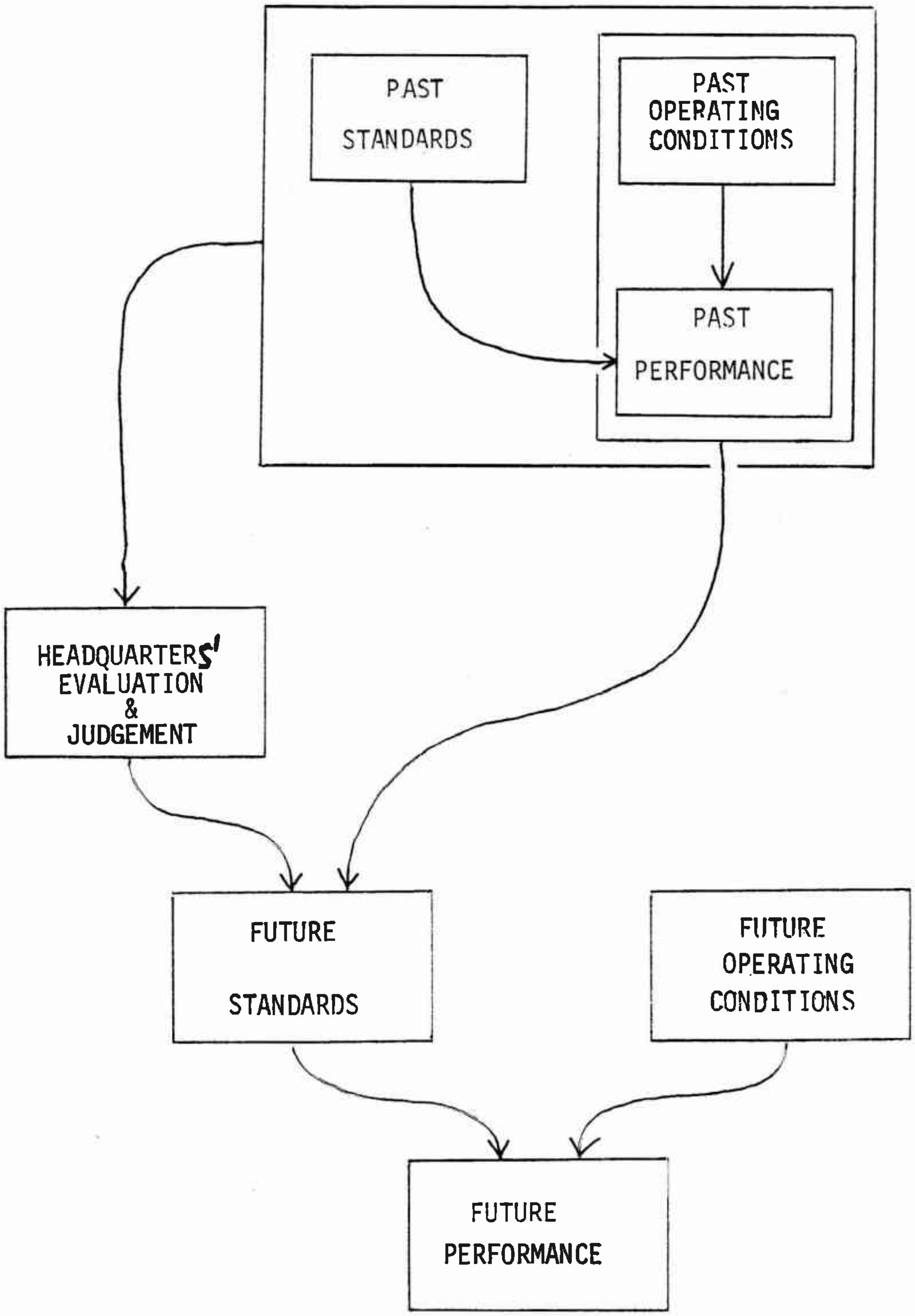
One problem with using past data to establish a future performance standard is that the goals of yard managers may have been different. If we seek to set a standard for switcher hours that varies with volume, we will get a distorted view of how the yard manager should vary switcher hours with volume in the future if we base that prediction on how the yard manager varied crew hours with volume in the past. In the past, the goals of the yard manager, as passed down by headquarters, may have been the maintenance of a lower level of connection reliability. Or it may have been a performance measure other than connection reliability, such as simply keeping the yard fluid.

The linear standard is still simple enough to let headquarters management use their experience and judgement, first, to tighten the standard, and second, to compensate for the fact that the past performance on which they base the linear standard may have been affected by standards or other incentives existing in that past period, and they feel that these incentives (e.g. a preoccupation with operating costs) led other measures of yard performance (such as the yard times of cars) to be unsatisfactory. This relationship is illustrated in Exhibit 2-3.

A final reason the adjustability of the linear standard is useful, paradoxically, is that it fails to take into account all the operating conditions affecting performance. Indeed, it is flexible and clear only because it takes into account one aggregate measure of operating conditions, inbound volume.

EXHIBIT 2-3

RELATIONSHIP AMONG OPERATING CONDITIONS, HEADQUARTERS' JUDGEMENT, STANDARDS, AND PERFORMANCE



In Section 3.2, we review a standard for the number of crews to be worked in which crews is a function not only of inbound volume but also of standard average yard time. Although this standard was based on a regression that had a better statistical fit than a regression in which volume was the only independent variable, this advantage was outweighed by the much greater difficultly in explaining the standard to management. An important element of this explainability is that a standard which varies with just one operating condition can be illustrated graphically.

Other kinds of analysis have been used to establish a volume-variable switcher use standard. For instance, what is often called the "industrial engineering" approach to setting a standard for switcher hours is to go to the yard and measure how long it takes a switcher to perform each of its tasks, including the length of time needed to

--get an inbound cut of cars in position for classification;

--classify each car;

--correct classification errors;

--extract cars needing repair, deliver them to the repair area, and later retrieve them;

--make sure all cars on a classification track are coupled;

--assemble outbound blocks of given lengths into an outbound train.

A range of computational methods can be used to aggregate these timings into a standard relating the number of inbound cars (and perhaps inbound trains, outbound blocks, and outbound trains) to the number of switcher hours. These may range from a simple adding-up of the average durations of each of the components of yard processing, to a simulation model in which a distribution of possible total times is obtained by letting a random number generator come up with hypothetical observations for the durations of each of the components of processing, the observations for the various components having the same joint distribution as that observed in the yard. The standards for switcher use resulting from these analyses can have ratio, linear, or other mathematical forms.

The drawbacks of these methods are the cost of the data collection and computation required, the possibility that switcher crews may alter their behavior during data collection, and the difficultly that management of the yard and headquarters may face in applying their judgement and experience to the modification of the standards. Despite their cost, moreover, even these methods cannot hope to include timings for all the yard activities to which the switchers must attend, including

--derailments,

--rush orders to extract and expedite specific cars,

--switching of customer sidings near the terminal, and

--crew break periods.

Consequently, the creators of these standards are likely to have to add a "fudge factor" if they hope to bring their standards up to the amount of time actually used by the yard during the base period the creators use to calibrate the standards. The use of the linear standard based on regression, on the other hand, assumes that rising volume will increase, to a greater or lesser degree, the time needed for each of a number of yard tasks. It measures the average, cumulative effect of these increases on the total switcher hours that yard managers felt they should work. An regression-based standard is certainly easier than more complex standards for managers to understand, negotiate over, adjust, and accept. Deciding whether the more complex standards predict better in the short run (day or week) and longer run (quarter and year) would require an application of the regression-based method and its more complex alternatives to a yard, and comparison of the results, an undertaking beyond the scope of this study. However, in terms of both the cost of data collection and computations, and of the ease with which management can use the regression-based standard, it is clearly superior.

2.32 Possible Standards for Car Movement. A standard for switcher use is only effective if a standard is also present for the movement of cars through the yard. In this subsection, we will propose two methods of developing a car movement standard. They are roughly analogous to two methods we have described for developing a standard for switcher-hours. In the case of both switcher-hours and yard time, these standards may be distinguished by saying that the approach underlying one relies on regression analysis of aggregate measures of yard activity, whereas the other uses disaggregate measurements of the time needed to perform each of several yard processes. The regression-based car movement standard prescribes average yard time as a function of outbound train frequency, and provides a measurement of mean processing time. In contrast, the second car movement standard starts from disaggregate data on each train, and takes the form of a fixed standard for processing time, and a standard distribution of processing time that headquarters managers can use to predict origin-to-destination trip time and reliability.

Theoretical grounds exist for creating an econometric standard for average yard time that varies with outbound train frequency. One feature of the technique we will describe is that it provides an estimate of mean processing time. We start by noting that average yard time (AYT) = p + w, where p is mean processing time and w is mean wait. If we assume that the arrival pattern of cars on the classification track of each outbound block is random (a reasonable assumption in any yard where classification is occuring at most times of the day and night), then

$$w = 12 / f,$$

where f is the mean frequency with which the block is picked up by outbound trains. We may approximate f by

$$nr / b,$$

where

n = departure rate of trains from the yard per day,

r = average number of blocks picked up per train, and

b = number of blocks made by the yard.

Substituting, we have

$$w = 12b / nr$$

and

$$AYT = p + 12b / nr.$$

Now suppose we determine via linear regression the coefficients b1 and b2 in the following equation:

$$AYT = b1 + b2(1 / n).$$

Then, as shown in Exhibit 2-4, b1 can serve as an estimate of p, the mean processing time, and b2 as an estimate of (12b / r). Again substituting, we can deduce from this the mean frequency of block pickups:

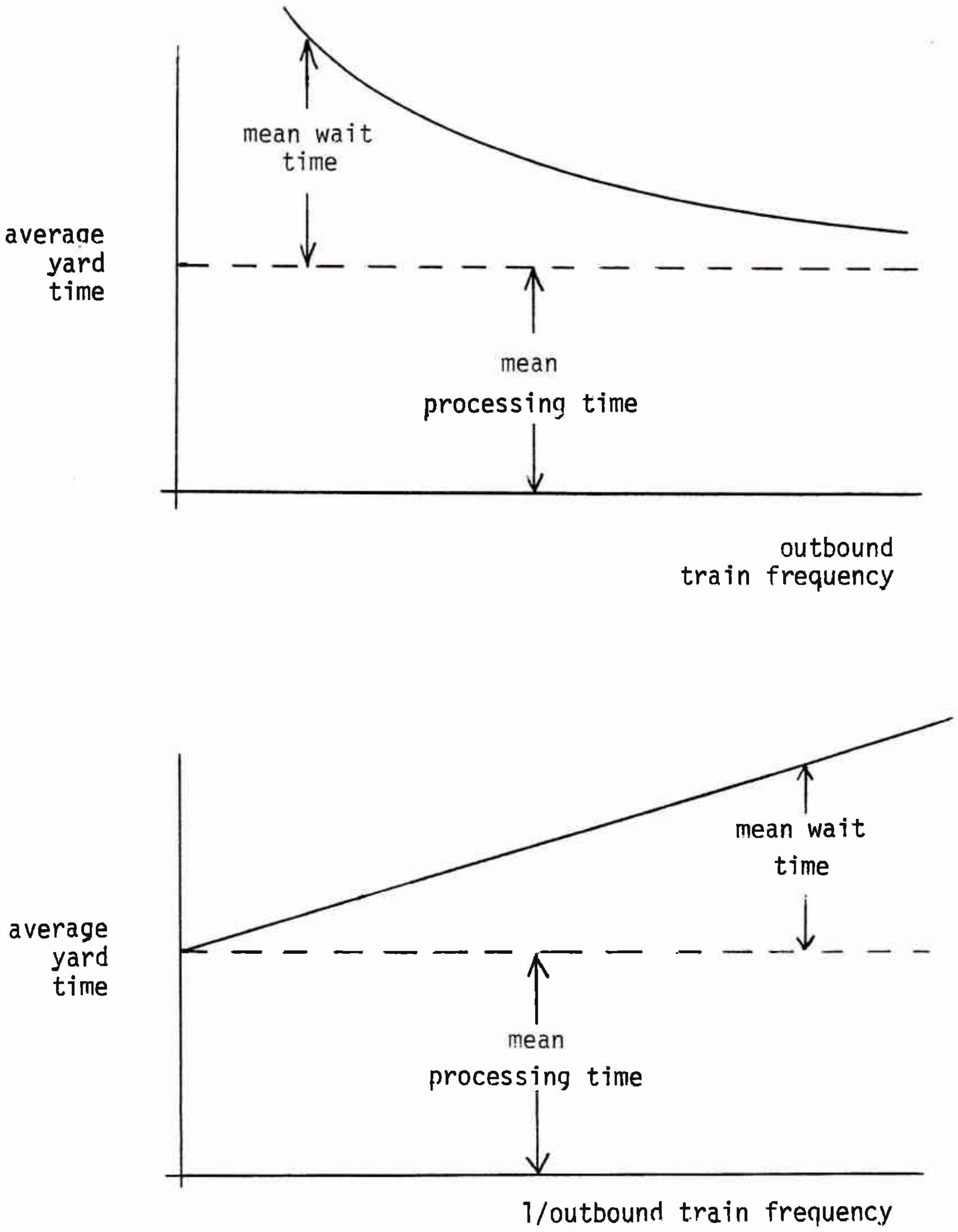
$$b2 = 12b / r$$

$$b2 / 12 = b / r$$

$$f = nr / b$$

EXHIBIT 2-4

RELATIONSHIP BETWEEN OUTBOUND TRAIN FREQUENCY AND AVERAGE YARD TIME



$$f = 12n / b2$$

as well as the size of the wait component of yard time in terms of b2:

$$w = 12 / f$$

$$w = b2 / n$$

The coefficient b2 will be an accurate basis for the calculation of w to the extent that:

1) inbound and outbound trains are evenly spaced throughout the day;
2) inbound and outbound trains each carry the same number of cars;
3) b, the number of blocks made by the yard, is constant; and
4) r, the mean number of blocks picked up per train, is constant.

The first two conditions are never likely to completely fulfilled, but unless there is a period of construction when the yard is closed for many hours at a time, they are likely to be fulfilled to a great enough extent to permit a reasonable estimate of w. As for the last two conditions, every time yard management believes they have changed significantly, they could run a new version of the above regression and obtain a revised value of b2.

Having seen how we might set a regression-based car movement standard, let us turn to an alternative movement standard based on much more disaggregate, train-specific data. A measure of a classification yard's contribution to trip time and reliability is the yard's connection reliability. Given the amount of available time between an inbound and outbound train (AVAIL), the greater the percentage of cars that make the connection, the higher the yard's connection reliability. A complete picture of the yard's connection reliability takes the form of a function, PMAKE, that says what percentage of cars make their connection at the yard for each value of AVAIL. [9] Once the PMAKE function has been estimated using past data, it can serve as a standard for connection relaibility at the yard in the future, though management may first want to alter the summary of past performance so that it reflects their expectations and goals for the future.

Given the train schedule, and the PMAKE function for each of rail system's yards, managers can in principal deduce origin-to-destination trip time and reliability for each traffic flow. [10] A simplified example will show how the trip time and reliability can be deduced for a car travelling from point A to point B via classification yard C. Suppose the yard's PMAKE function shows that if eight hours are available between inbound and outbound trains, the car will, in view of the yard's processing time distributions and delays to cars due to left tonnage and train cancellations, make its connection 60 percent of the time. Suppose further that each day, a train leaves point A at 1 a.m. for arrival at yard C five hours later at 6 a.m. Also suppose that eight hours later, at 2 p.m., a train is scheduled to leave yard C for a nine-hour run to point B, arriving at 11 p.m. Since on average, 60 percent of the cars will make the connection between the two trains, we could state that 60 percent of the cars will have an O-D trip time of 5 + 8 + 9 = 22 hours, and that 40 percent would miss their connection and take 24 hours longer, or 46 hours, to get from A to B.

If the yard manager and his superiors monitor the reliability of the train-to-block connections provided by the yard, they will also know the degree to which the yard contributies to the origin-to-destination transit time and reliability of the cars it handles. As the connection reliability of a yard improves, so too will both origin-to-destination trip time (as cars will tend to leave the yard sooner after arrival), and the reliability of trip time (as fewer cars will miss their connection and have to wait up to 24 hours before the next).

CHAPTER THREE:

DEVELOPMENT OF PERFORMANCE STANDARDS BY MEANS OF ANALYSIS OF DATA FROM TWO YARDS

Having put forward in Chapter Two hypotheses about the possible advantages of several kinds of performance standards for rail classification yards, we turn in this Chapter to a test of these hypotheses that is based on analysis of data from two such yards. We introduce and compare the two yards in Section 3.1. To each of the three subsequent sections corresponds standards of the three kinds we have proposed, which are based on analyses that use increasingly disaggregate data. In the three sections respectively, yard activity measures are stated in terms of averages for each of the seven days of the week during a multi-week period, totals for each day during a period, and values for each train or block during a day. In Section 3.2, we analyze the weekly cycle of operations at each by looking at the average values for each of the seven days of the week of a number of activity measures. In one case, these day-of-week averages will become the standards we will propose for introduction into the management information system in Chapter Four. Section 3.3 presents regression analyses of the two yards that lead to standards for switcher use and for average yard time. We conclude that a regression-based standard for switcher use is appropriate only if volume varies significantly from week to week, and if yard managers have significant latitude in the number of switcher-hours they can work. As for the regression analysis of the determinants of average yard time, we find that it provides a way of measuring the effect of inbound volume and the number of switcher hours worked on average yard time, but that it is not accurate enough as a means of measuring processing time.

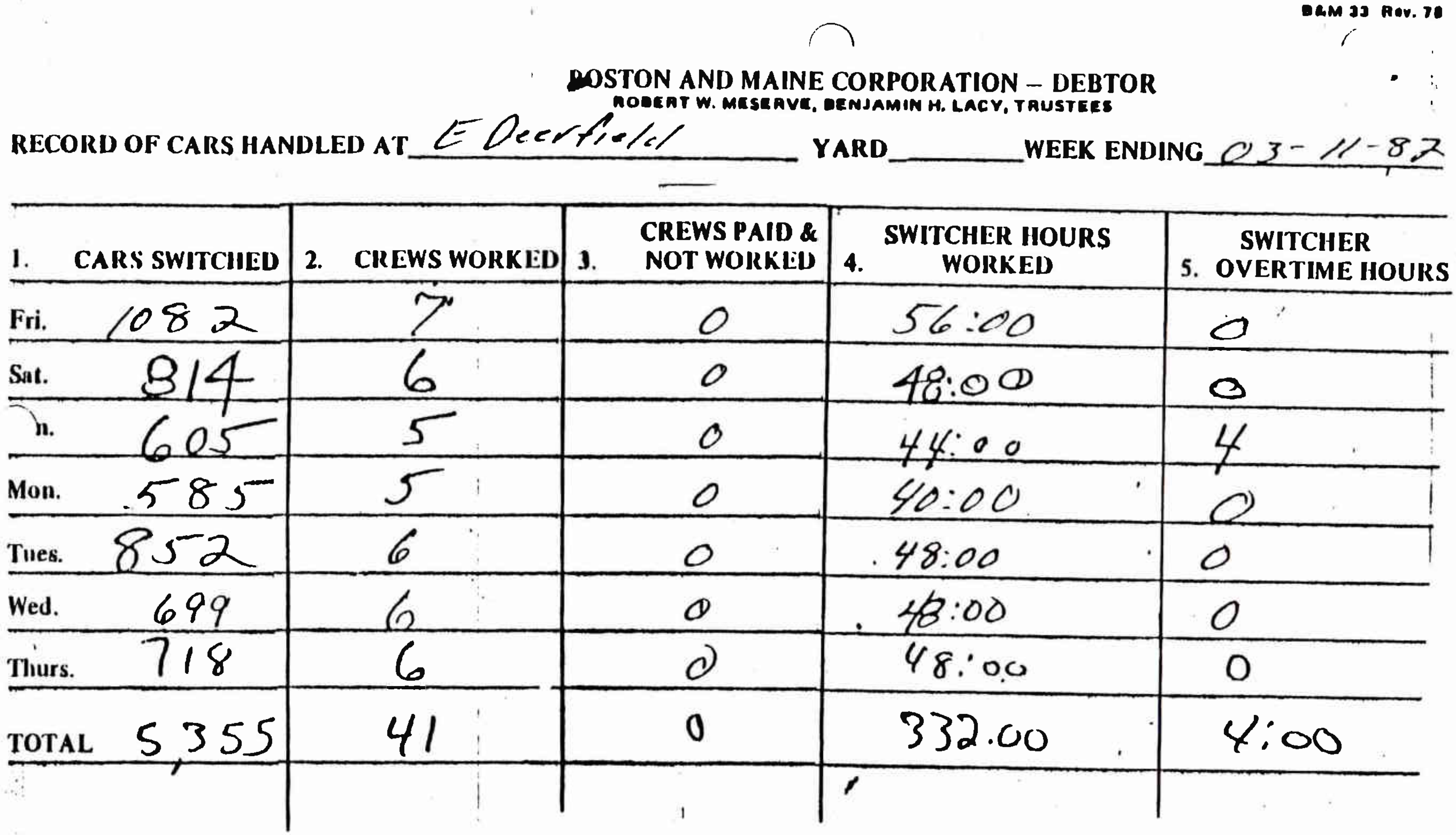
A more satisfactory means of measuring and setting a standard for processing time is one of the subjects of Section 3.4. This method is simply the direct measurement of the time needed to classify and assemble each train. This measurement is supplemented by estimates of mean wait time based on the frequency of block pickups and left tonnage. The accuracy and usefulness of these measurements of processing time and wait time is verified at the close of the section by comparing them to the direct measurement of their sum, average yard time.

3.1. The Classification Yards at East Deerfield and Woippy: A Comparison.

In this section, we will introduce the two yards that are the subject of our study. The two yards we will examine are East Deerfield yard, the principal classification yard of the Boston and Maine Corp. (B&M), and Woippy yard, the largest classification yard of the French National Railways (SNCF). The yards are respectively located in western Massachusetts, U.S.A, and just north of the city of Metz in eastern France. Exhibits 3-A through 3-C show samples of the B&M documents that served as sources for the operating data on East Deerfield that is presented in this chapter; Exhibits 3-1 and 3-2 show corresponding SNCF documents for Woippy yard (the Woippy switcher schedule appears in Exhibit 3-18). Exhibit 3-3 presents some key operating statistics for the two yards.

A critical difference between the two yards is the degree of mechanization of the humping operation. Henry Marcus pointed out that this difference shows the tradeoff that exists between labor and capital at a classification yard. [11] The relative labor intensity of East Deerfield reflects the lower volume of cars handled by the yard, and may also reflect the higher effective cost of capital faced by the railroad of which East Deerfield is a part.

At Woippy, the hump engine (which pushes the cars over a hump, or raised portion of track, from where they roll onto the classification track corresponding to their outbound block), the hump turnouts (devices that direct the wheels of a car onto the right track), and the hump retarders (which brake each car just enough to



B&M 33 Rev. 78

BOSTON AND MAINE CORPORATION – DEBTOR

ROBERT W. MESERVE, BENJAMIN H. LACY, TRUSTEES

RECORD OF CARS HANDLED AT E Deerfield YARD ______ WEEK ENDING 03-11-87

1. CARS SWITCHED		2. CREWS WORKED	3. CREWS PAID & NOT WORKED	4. SWITCHER HOURS WORKED	5. SWITCHER OVERTIME HOURS
Fri.	1082	7	0	56:00	0
Sat.	814	6	0	48:00	0
n.	605	5	0	44:00	4
Mon.	585	5	0	40:00	0
Tues.	852	6	0	48:00	0
Wed.	699	6	0	48:00	0
Thurs.	718	6	0	48:00	0
TOTAL	5,355	41	0	332.00	4:00

EXHIBIT 3-A

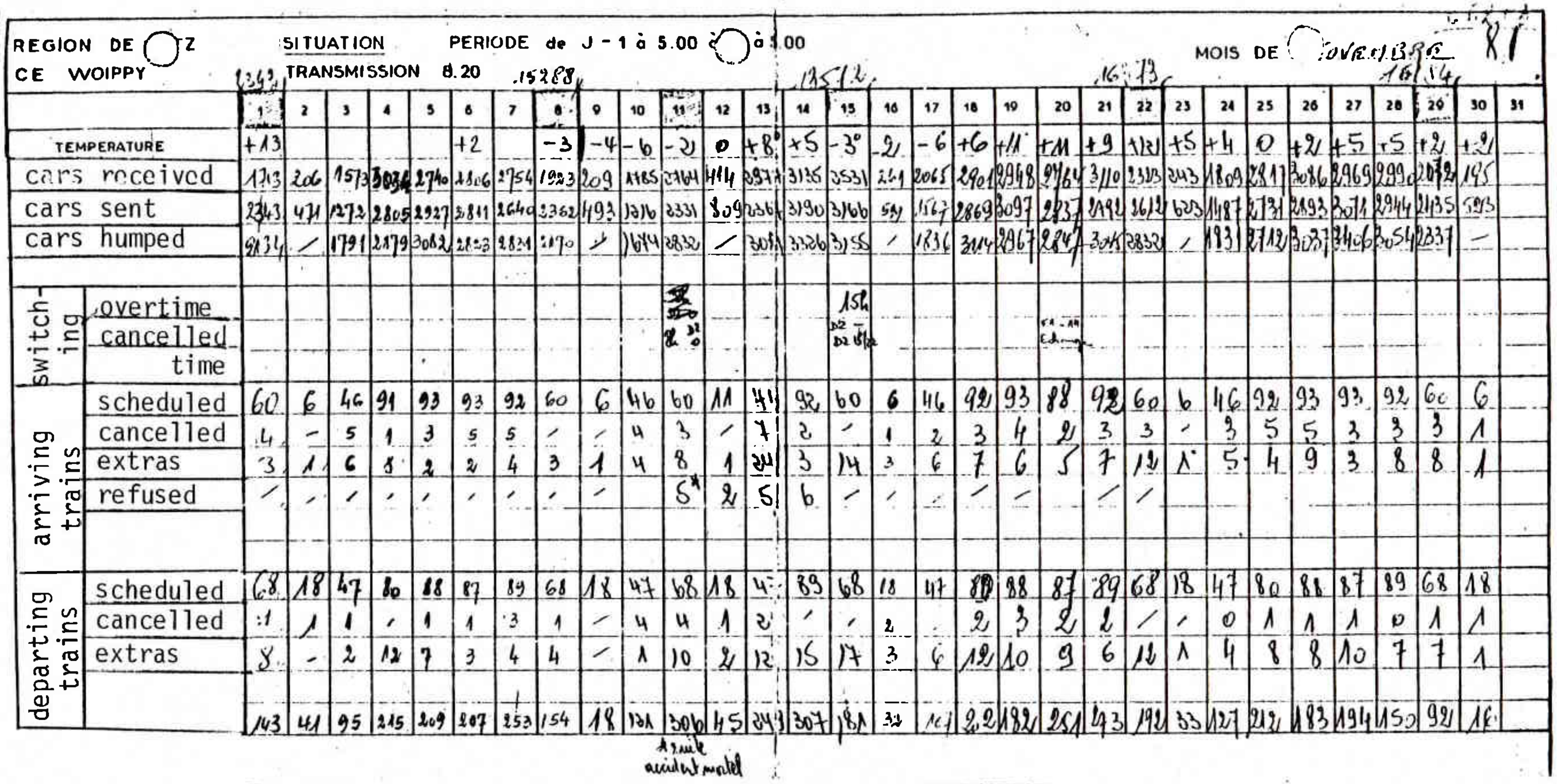
B & M SOURCE REPORT FOR NUMBER OF SWITCHER HOURS WORKED

```
TRC8              TRAIN CONNECTION SUMMARY                        12/14/81

                   DATE     TIME     CARS       TONS      HOURS     AVE. HRS
DEPART   LAME11A   12   11 0635        2          56        72          36

ARRIVE   ED4 09    12   09 1835       10         307       220          22   E DEERFIELD
----------------------------------------------------------------------------------------

                   DATE     TIME     CARS       TONS      HOURS     AVE. HRS
DEPART   LAME10A   12   10 0810        4         111        36           9
DEPART   SPCP10    12   10 1245        2         100        26          13
DEPART   CPSP10    12   10 1739       11        1071       198          18
DEPART   EDSA10    12   10 2340        5         496       120          24
DEPART   EDCO10    12   11 0140        5         438       130          26
DEPART   CVSP10    12   11 0345        7         346       196          28
DEPART   LAME11A   12   11 0635        2          48        62          31

ARRIVE   CVSP09    12   09 2350       36        2610       768          21   E DEERFIELD
----------------------------------------------------------------------------------------

                   DATE     TIME     CARS       TONS      HOURS     AVE. HRS
STATION TOTAL                         425      26086      8029          18

STATION TOTAL                         425      26086      8029          18   E DEERFIELD
```

EXHIBIT 3-B   B & M SOURCE REPORT FOR INBOUND VOLUME AND AVERAGE YARD TIME

```
TRC5                TRAIN CONNECTION SUMMARY                          8/20/81

                       DATE      TIME    CARS      TONS      HOURS     AVE. HRS
ARRIVE   SAED17     08   18 0340       2       226        88         44
ARRIVE   EDI-18     08   18 1650       1        30        31         31
ARRIVE   MELA18     08   18 1820       2       253        58         29
ARRIVE   CGED18     08   19 0130       1        35        22         22
ARRIVE   MEP018B    08   19 0135      12       513       264         22
ARRIVE   MEP019B    08   19 0500       5       446        90         18
ARRIVE   CVSP18     08   19 0630       3       265        51         17
ARRIVE   CPSP19     08   19 0938      13      1448       182         14
ARRIVE   SPCV19     08   19 1905       4       140        16          4

DEPART   EDSA19     08   19 2345      43      3356       802         18   E DEERFIELD

                    DATE      TIME    CARS      TONS      HOURS     AVE. HRS
STATION TOTAL                          376     23809      6863         18

STATION TOTAL                          376     23809      6863         18   E DEERFIELD
```

EXHIBIT 3-C   B & M SOURCE REPORT FOR OUTBOUND TRAIN FREQUENCY



REGION DE ◯Z
CE WOIPPY

SITUATION PERIODE de J - 1 à 5.00 ◯ à 5.00
TRANSMISSION 8.20

MOIS DE NOVEMBRE 81

1343 15288 13512 16373 16154

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TEMPERATURE		+13					+2		-3	-4	-6	-2	0	+8	+5	-3°
cars received		1713	206	1573	3034	2740	2806	2754	1923	209	1185	2764	414	2977	3135	3531
cars sent		2343	471	1272	2805	2927	2811	2640	2362	493	1316	2331	809	2364	3190	3166
cars humped		2134	/	1791	2179	3082	2823	2824	2170	/	1674	2832	/	3071	3326	3155
switching	overtime											[illegible]				15h
	cancelled											[illegible]				D2 — D2 15h
	time															
arriving trains	scheduled	60	6	46	91	93	93	92	60	6	46	60	11	41	92	60
	cancelled	4	–	5	1	3	5	5	/	/	4	3	/	7	2	/
	extras	3	1	6	8	2	2	4	3	1	4	8	1	24	3	14
	refused	/	/	/	/	/	/	/	/	/		5*	2	5	6	/
departing trains	scheduled	68	18	47	80	88	87	89	68	18	47	68	18	4[illegible]	89	68
	cancelled	1	1	1	/	1	1	3	1	/	4	4	1	2	/	/
	extras	8	-	2	12	7	3	4	4	/	1	10	2	12	15	17
		143	41	95	215	209	207	253	154	18	131	306	45	243	307	181

		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
TEMPERATURE		-2	-6	+6	+11	+11	+9	+12	+5	+4	0	+2	+5	+5	+2	+2	
cars received		261	2065	2901	2948	2764	3110	2323	243	1809	2817	3086	2969	2990	2072	195	
cars sent		531	1567	2869	3097	2837	2492	2612	623	1487	2731	2893	3071	2944	2135	593	
cars humped		/	1836	3114	2967	2847	3045	2832	/	1931	2712	3037	3406	3054	2337	—	
switching	overtime					[illegible]											
	cancelled					Echange											
	time																
arriving trains	scheduled	6	46	92	93	88	92	60	6	46	92	93	93	92	60	6	
	cancelled	1	2	3	4	2	3	3	/	3	5	5	3	3	3	1	
	extras	3	6	7	6	5	7	12	1	5	4	9	3	8	8	1	
	refused	/		/	/		/	/									
departing trains	scheduled	18	47	89	88	87	89	68	18	47	80	88	87	89	68	18	
	cancelled	2		2	3	2	2	/	/	0	1	1	1	0	1	1	
	extras	3	6	12	10	9	6	12	1	4	8	8	10	7	7	1	
		32	161	222	182	251	243	192	33	127	212	183	194	150	92	16	

A suite accident mortel

EXHIBIT 3-1

S.N.C.F. REPORT OF YARD ACTIVITY FOR MONTH OF NOVEMBER, 1981

(Figures for each day correspond to 24 hours ended at 5 a.m. that day)

RESEAU EST
REGION METZ
TRIAGE WOIPPY

I ETAT NO 3 I

SEJOUR GLOBAL DES WAGONS

SEMAINE DU V 13 NOVE 1981 AU J 19 NOVL 1981

JOUR	SOMME STOCK		WAGONS EXPEDIES		SEJOUR GLOBAL
1	2	3	4	5	6
V		39469		3136	12,5
S	43383		3380		12,8
D	26003		1124		23,1
L	25295		970		26,0
MA	34845		2700		12,9
MI		30726	8174	3172	9,6
J		26553		2849	10,0
TOTAL ME+J+V	T=	96748	W=	9157 ✓	
SEJOUR GLOBAL MOYEN (ME A VE) :				T/W =	10,7

EXHIBIT 3-2

WOIPPY YARD -- SAMPLE OF SOURCE REPORT FOR TOTAL AVERAGE YARD TIMES

EXHIBIT 3-3

KEY CHARACTERISTICS -- EAST DEERFIELD AND WOIPPY YARDS

	EAST DEERFIELD	WOIPPY
Physical traits		
receiving tracks	8	17
departure tracks		14
classification tracks	18	48
braking of cars rolling off hump	hand brakes on cars	computer-controlled retarders in track
operation of track turnouts	at each turnout	from hump
Operational traits		
average inbound cars per day	413	2179
average switcher hours worked per day	46*	89
inbound cars per switcher hour	9	24
average outbound trains per day	12	70
average yard time for cars (hours)	20.7	13.7
period over which operating statistics calculated	March 5 through June 10, 1982	October 1 through December 23, 1981

---

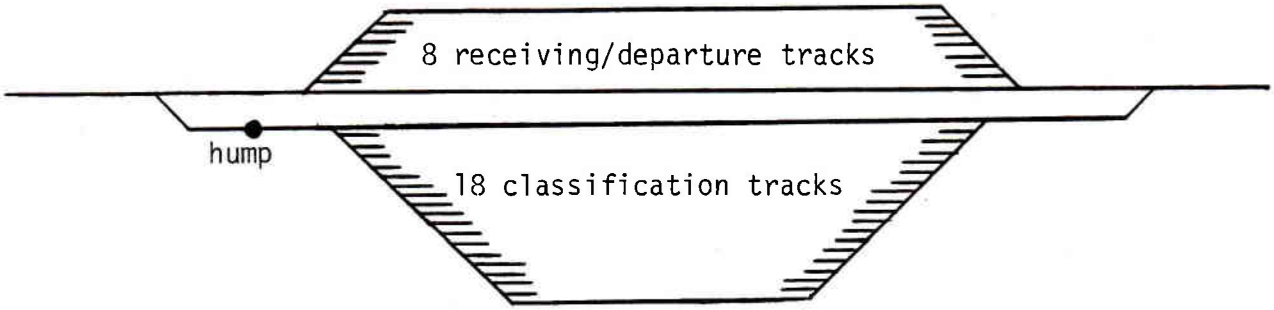
* excludes overtime

prevent it from hitting other cars on its class track too hard, but leave the car with enough momentum to clear the way for following cars) are all remote controlled. An employee at the top of the hump controls the speed of the hump engine via radio, and selects the appropriate classification track according to each car's destination. A computer measures each car's accelleration via electro-magnetic and radar devices, and applies retarders to the car's wheels long enough to slow the car to the right speed. At East Deerfield, in contrast, the humping locomotive is operated by its engineer, who communicates by radio and hand signal with employees who position track turnouts by hand, and set the hand brakes on cars to limit the cars' speed as they roll off the hump.

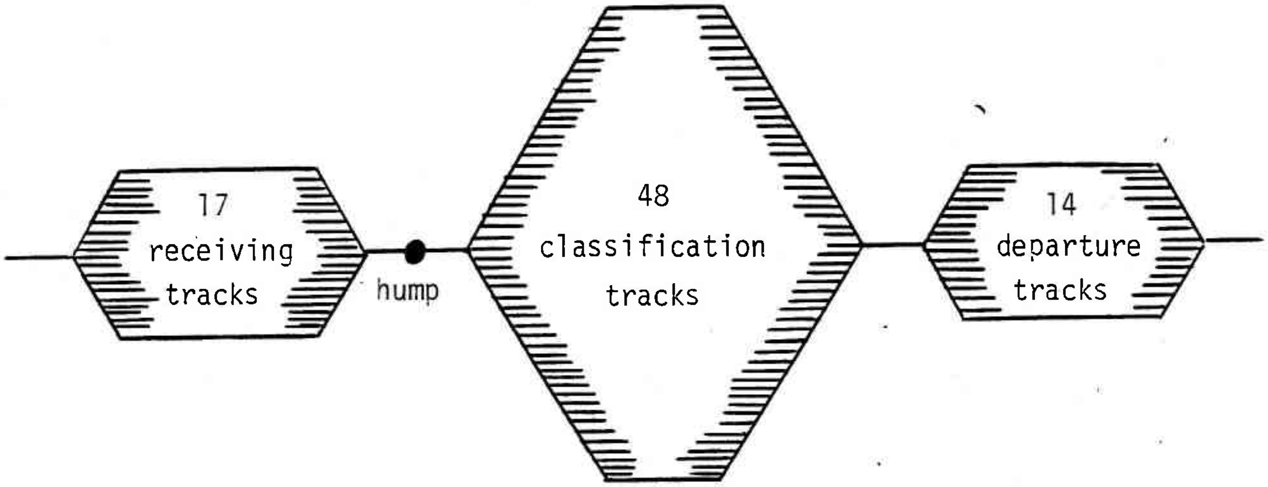
A schematic of the track layouts of the two yards is shown in Exhibit 3-4. The diagrams illustrate Woippy's more efficient layout. At Woippy, inbound cuts are merely pushed from the receiving track over the hump. At East Deerfield, an extra step is needed: the cut must first be pulled out of the receiving track. Some outbound blocks at East Deerfield must also be shifted to another classification track or a departure track, but most depart directly from the classification track.

EXHIBIT 3-4

TRACK LAYOUT SCHEMATICS
OF EAST DEERFIELD AND
WOIPPY YARDS
(not to scale)



EAST DEERFIELD YARD



WOIPPY YARD

3.2. Analysis of the Cycle of Yard Operations over the Seven Days of the Week. In this section, we will both characterize and analyze the two yards by means of the average values for each of the seven days of the week of a number of yard activity measures. The weekly cycle of operations in each yard will be examined. We will discern evidence confirming some of the causal relationships among inbound volume, switcher use, block pickup frequency, and average yard time that we presented in Chapter Two, but find no confirmation of others. The seven average values for one of these measures, the average yard time for East Deerfield, will be included as the standard for yard time performance in the control system we propose in Chapter Four.

Exhibit 3-5 presents the average figures for the key operating measures for each of the seven days of the week. C. D. Martland pointed out that Exhibit 3-5 serves as a summary of yard performance. By arranging the data in this way, and adding columns as needed, yard managers can spot problem areas. They can also use this arrangement of the data as a basic management technique that helps them understand the impact of the weekly traffic cycle on operating performance. [12]

Several of the hypotheses we presented in Chapter Two are confirmed in the data of Exhibit 3-5. These hypotheses concerned the effect of switcher-hours on processing time (Section 2.13), inbound

EXHIBIT 3-5

AVERAGE VALUES OF SELECTED ACTIVITY MEASURES AT EAST DEERFIELD AND WOIPPY FOR EACH DAY OF THE WEEK

EAST DEERFIELD, MARCH 5 THROUGH JUNE 10, 1982

	inbound volume	switcher hours worked (excludes overtime)	inbound cars per switcher hour	outbound trains	average yard time
Friday	509	48.8	10	12.9	21.4
Saturday	488	48.0	10	10.9	23.8
Sunday	283	40.0	7	10.1	20.5
Monday	277	39.2	7	12.0	18.8
Tuesday	449	48.0	9	13.9	19.4
Wednesday	415	48.8	9	12.2	21.0
Thursday	468	48.8	10	13.4	19.0
TOTAL	413	46.4	9	12.2	20.7

WOIPPY, OCTOBER 1 THROUGH DECEMBER 23, 1981

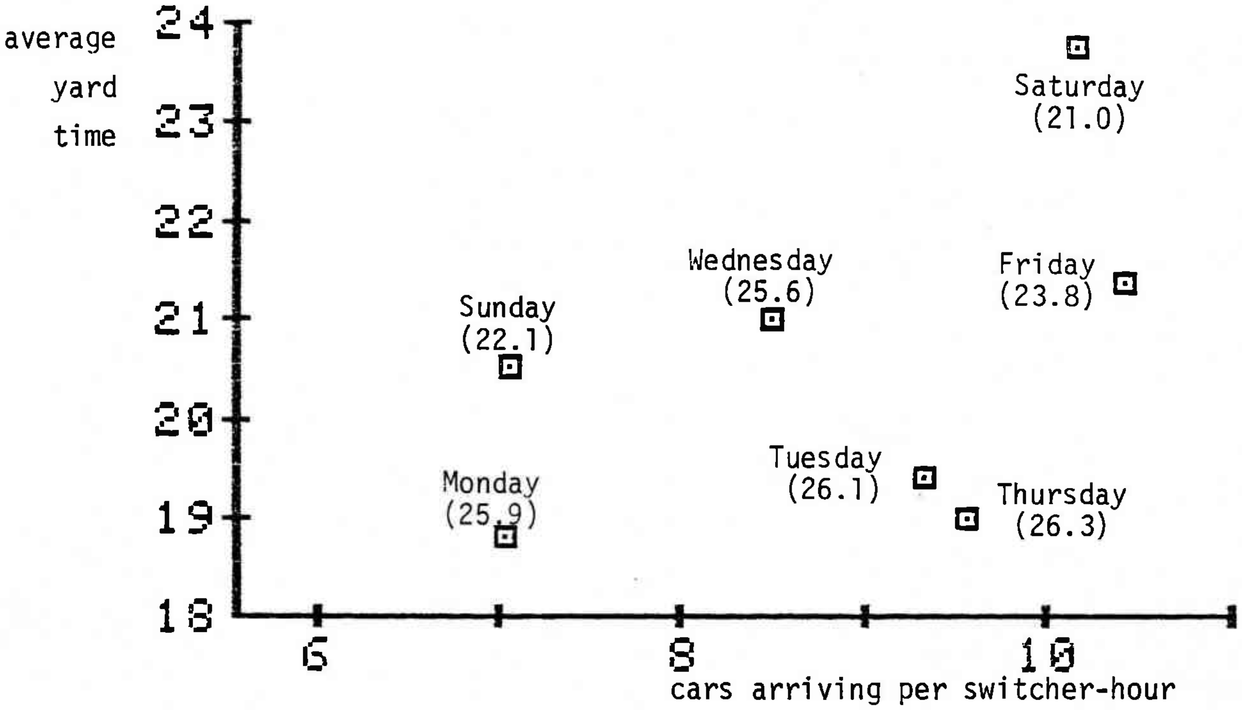
	inbound volume	switcher hours worked	inbound cars per switcher hour	outbound trains	average yard time	average inventory
Friday	2830	113	25	91	11.5	1383
Saturday	2086	104	20	73	13.2	1384
Sunday	219	37	6	19	24.0	1032
Monday	1807	48	38	49	25.3	878
Tuesday	2800	107	26	85	11.9	1263
Wednesday	2621	107	24	87	11.2	1336
Thursday	2888	108	27	88	12.3	1381
TOTAL	2179	89	24	70	13.7	1288

volume on both processing and wait times (Section 2.13), and outbound train frequency on wait time (Section 2.32). In order to show these relationships more clearly, some of the values presented in Exhibit 3-5 are plotted in Exhibits 3-6 and 3-7. Exhibit 3-6 presents the average relationship between cars arriving per switcher hour and average yard time over selected days of the week at the two yards. Section 2.13 described the tradeoff between higher switcher hours and higher processing times that is faced by the yard manager as inbound volume rises. If switchers are already well-utilized, and if the yard manager does not increase switcher hours as volume rises, processing time will rise. One way to measure the degree to which the yard manager responds to to changing inbound volume is in terms of inbound cars per switcher hour. This is the variable on the horizontal axes in Exhibit 3-6. On the vertical axes is average yard time, which, as we saw in Section 2.12, is partly determined by mean processing time. Insofar as the yard manager keeps switcher use steady and lets processing rise with volume, and insofar as total yard time reflects processing time, we would expect average yard time to rise with cars per switcher-hour.

Such an increasing relationship is not obvious in Exhibit 3-6 for either yard. However, in both cases, the relationship between switcher use and inbound volume on one hand and average yard time on the hand is affected, as we predicted it would be in Section 2.32, by the frequency of outbound trains. Note that at East Deerfield, the

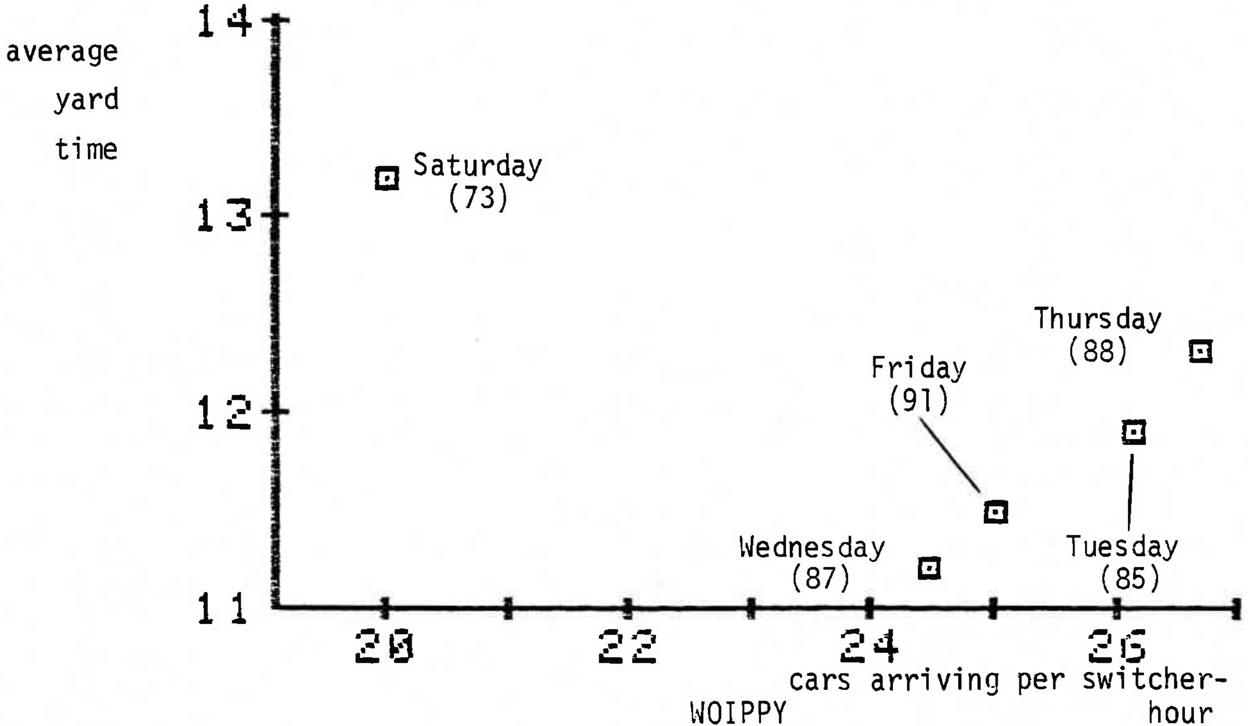
EXHIBIT 3-6

CARS ARRIVING PER SWITCHER HOUR VERSUS AVERAGE YARD TIME FOR AVERAGE VALUES OF SELECTED DAYS OF THE WEEK, EAST DEERFIELD AND WOIPPY YARDS



EAST DEERFIELD

(in parentheses: average outbound trains during this day and the next.)



WOIPPY

(in parentheses: average outbound trains during this day only.)

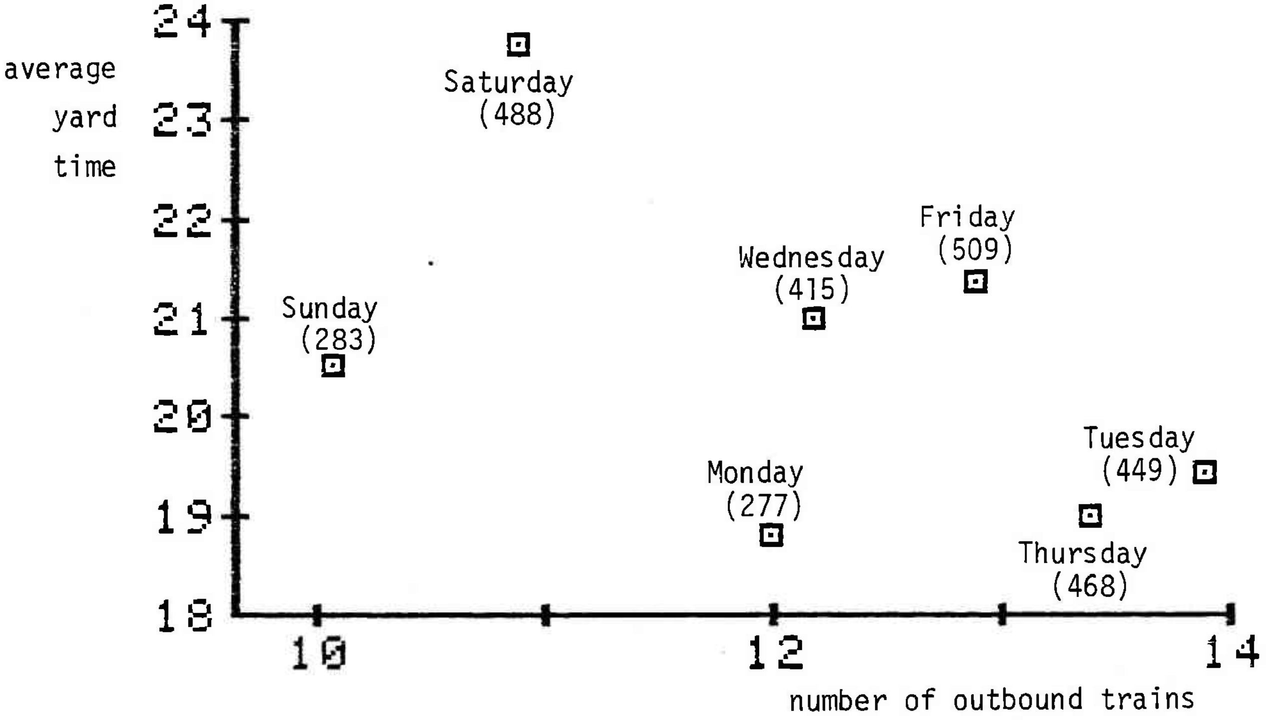
relationship is roughly rising over the seven days of the week except Sunday, when the relevant outbound train frequency is at its lowest (22.1) and thus yard time is high, and Thursday, when this same frequency is high (26.3) and thus yard time is low. As for Woippy, where we have excluded the weekend shutdown days of Sunday and Monday, we see a clean increasing pattern except on Saturday, when outbound train frequency is much lower than for the other four days on the diagram.

A more direct way of examining the effect of inbound volume and outbound train frequency is provided by Exhibit 3-7. Here, for both yards, we see that average yard time is clearly falling with increases in outbound train frequency. Yet average inbound volume seems to have an effect as well, at least at East Deerfield. Note that in the diagram for East Deerfield, the low volume days of Sunday and Monday appear in the southwest part of the diagram, while the highest-volume day, Thursday, appears in the northeast. This may be a combination of two effects. On high-volume days, processing times may be longer, as we saw in Section 2.13, and outbound train frequency may be higher, as we saw in Section 2.32.

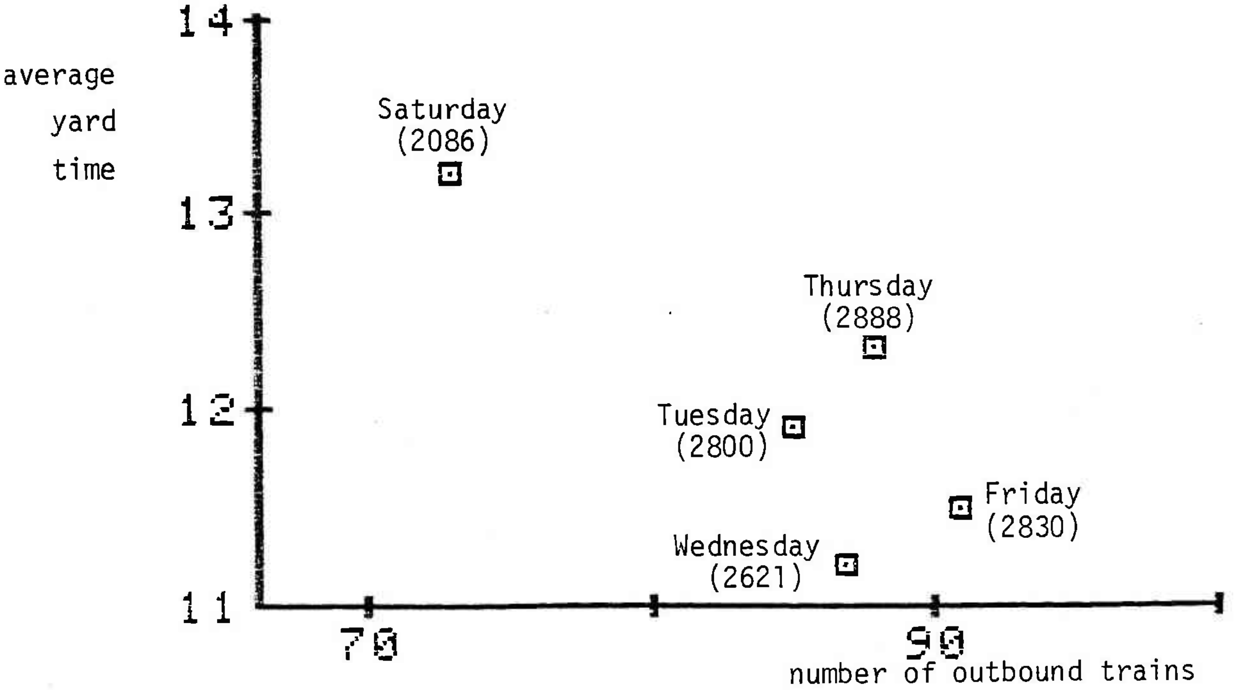
Analyzing average values of yard activity measures for the seven days of the week can form the basis for performance standards. One such standard that was proposed for East Deerfield yard was based on the day-of-week averages for the yard shown in Exhibit 3-8, which

EXHIBIT 3-7

OUTBOUND TRAINS VERSUS AVERAGE YARD TIME FOR AVERAGE VALUES OF SELECTED DAYS OF THE WEEK. (Average inbound volume in parentheses.)



EAST DEERFIELD



WOIPPY

EXHIBIT 3-8

EAST DEERFIELD YARD - AVERAGE INBOUND CARS, CREWS, AND YARD TIME FOR EACH OF THE SEVEN DAYS OF THE WEEK, MARCH 27, 1981 THROUGH AUGUST 18, 1981

	inbound cars, day 1	crews, day 1	inbound cars per crew, day 1	average yard time for cars arriving on day 1	average yard time for cars arriving on days 1 and 2
Friday	368	6.80	54.1	21.0	22.3
Saturday	371	5.86	63.3	23.5	22.0
Sunday	234	5.19	45.1	19.7	19.7
Monday	216	5.21	41.1	19.6	17.8
Tuesday	304	6.46	47.1	16.5	17.8
Wednesday	352	6.60	53.3	18.9	19.4
Thursday	343	6.57	52.2	20.0	20.5

correspond to a period in 1981. Exhibit 3-8 is the first appearance of the term "crew," which is the unit in which the Boston and Maine Corp. customarily measures switcher use. It is equivalent to eight switcher-hours. Appropriately transformed, average yard time and inbound cars per crew displayed the nearly linear relationship shown in Exhibit 3-9. The fitted regression line summarized the past relationship among volume, crews, and yard time. It could have been kept in its linear form, and used as a standard for average yard time as a function of inbound cars per crew:

average yard time, days 1 and 2 =
9.641 + .201 (inbound cars per crew, day 1)

Or it could have been algebraically transformed into a standard for switcher use as a function of inbound volume and standard average yard time:

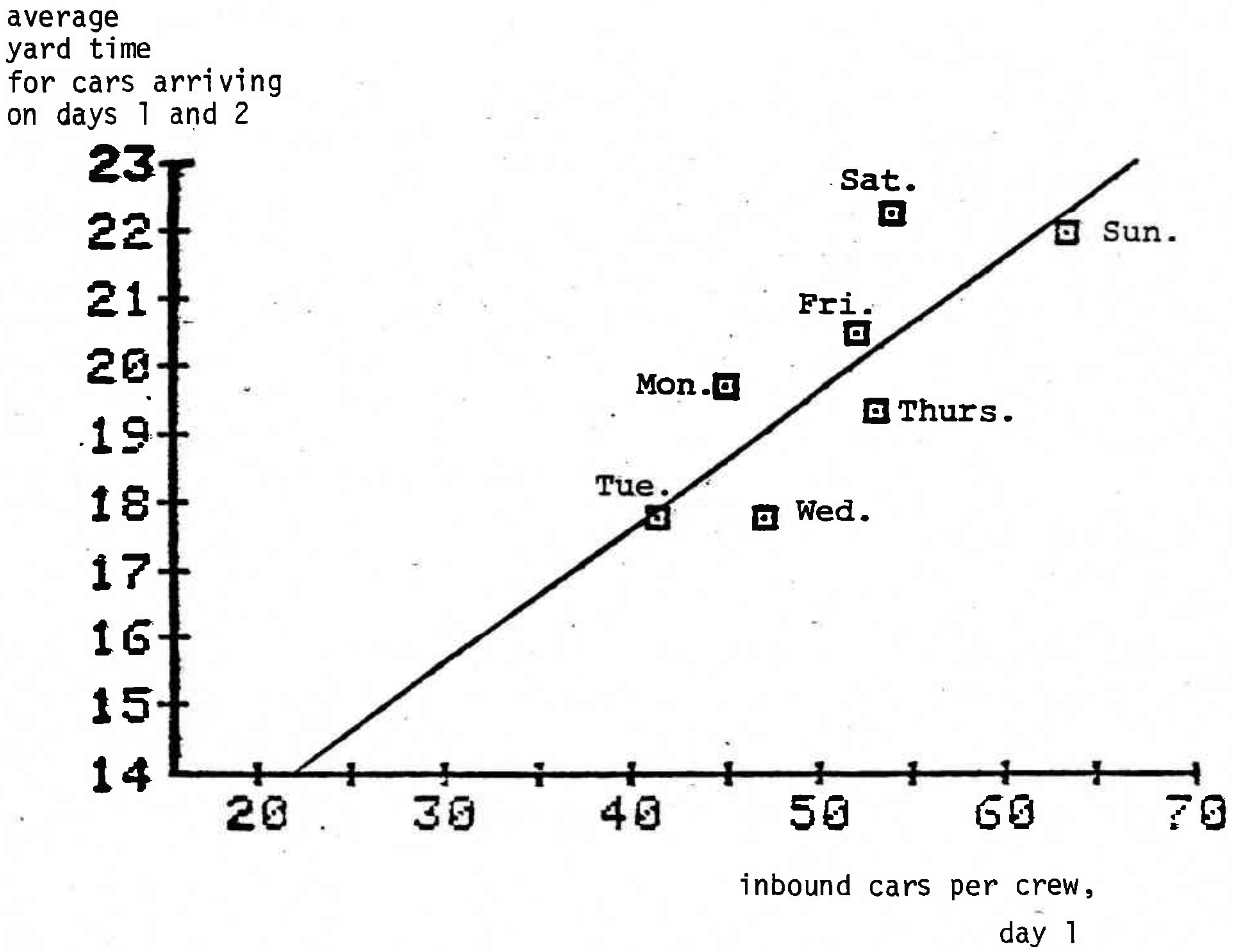
crews to be worked, day 1 =
(.201 (inbound volume, day 1)) /
((average yard time, days 1 and 2) + 9.641)

Ultimately, however, the decision was made not to use this standard at East Deerfield. Because the data on which the regression analysis were averages for each day of the week, and not individual days, using statistical analysis to calculate confidence intervals, as we will do in Section 3.3, was impossible. Therefore, knowing the degree of accuracy of the estimated coefficients (.201 and 9.641) was also impossible. Another general problem with regression analysis of

EXHIBIT 3-9

EAST DEERFIELD YARD -
INBOUND CARS PER CREW VERSUS
AVERAGE YARD TIME

(Shown are averages for each day of the week for available data between March 27 and August 18, 1981, plus fitted regression line.)



day-of-week averages is that because the various measures of yard activity each fluctuate on some weekly cycle, every variable, if transformed with the right running averages or lags, can be shown to be correlated with every other. The standard was also unsatisfactory because it did not take into account the frequency of outbound block pickups. Our discussion in Section 2.32 leads us to expect that this pickup frequency should significantly affect the wait portion of yard time. The data analysis for the two yards shown in Exhibit 3-7 supported this argument, and other analyses that we will summarize in Section 3.3 confirm it.

3.3 Regression Analysis of the Determinants of Switcher Use and the Yard Time of Cars.

Regression analysis of two or more yard activity measures provides a way not just to estimate the average relationship among them, but also to quantify the degree of uncertainty of this estimate. In Section 2.3 , we saw that linear regression could be used to provide standards for switcher use and average yard time. In this section, we will test these techniques. We will also employ regression analysis to estimate the effect of inbound volume and switcher use on average yard time.

In Section 2.31, we hypothesized that a standard for switcher use based on econometric analysis would be more useful as a predictor, troubleshooter, and motivator than either a fixed or per-car standard. In this section, we will estimate such a standard for both East Deerfield and Woippy. Our goal, as already described in Chapter Two, is not to gain the best possible statistical model of the relationships between yard activity measures, but rather to develop a standard that manages not only to respect the constraints of the yard manager, but also to be as simple as possible. We will conclude that such a standard is appropriate at East Deerfield, but not at Woippy, where volume varies less and the latitude of yard managers to alter the number of switcher hours is reduced. We will show, however, that regression analysis of the relationship at Woippy between volume and switcher use serves as a means of evaluating the weekly cycle of switcher use implicit in the crew schedule.

We will also use linear regression to investigate the effect of inbound volume, and the number of switcher hours worked, on average yard time. We will find no basis for stating that variations in average yard time can be traced to inbound volume or switcher use. As proposed in Section 2.32, we will use the relationship between outbound trains and average yard time to estimate the average processing time at each yard. Here, the estimate of variability supplied by the regression analysis will prove valuable, for it will let us determine the degree of uncertainty surrounding the processing time estimates. Finally, we will show how regression analysis of switcher use can be used to evaluate the crew schedule, and in the case of the standard for the fuel use of East Deerfield switchers, how a ratio standard may be as good as a linear one.

3.31. Alternative Regression Models. In order to test our hypotheses about the possible causal relationships among measures of yard activity, two sets of roughly parallel regression models for the yards were estimated. Exhibit 3-10 summarizes the characteristics of the variables used in the models. The data from East Deerfield run from early February through early June, 1982, whereas those from Woippy are from the last quarter of 1981.

Sundays and Mondays were omitted for Woippy because classification and train assembly at the yard ceases for 24 hours starting 1 p.m. each Sunday. Use of data for Sundays and Mondays would lead to overstatement of the correlations among the yard activity measures because switcher use, volume, and train frequency all drop precipitously during this period, while yard time rises sharply.

Average yard time for each day at East Deerfield is the average amount of time that cars arriving in the yard on that day spent in the yard on that day and succeeding ones. The SNCF estimates average yard time for each day at Woippy by taking the average of 24 hourly ~~yard~~ car inventory counts, and dividing the result by the number of cars that left the yard during the day. This is not a fully accurate

EXHIBIT 3-10

Summary of Characteristics of Variables Used in Regression Models

	East Deerfield	Woippy
dates covered	3/5/82 through 6/10/82	10/1/81 through 12/23/81
days of week included	all seven	Tuesdays through Saturdays
number of observations	97	58
measure of average yard time, day 1	actual, for cars arriving on day 1	$\frac{\text{average inventory during day 1}}{\text{outbound volume, day 1}}$
variable used to express effect of frequency of outbound trains	$\frac{1}{\text{outbound trains, day 1 and 2}}$	$\frac{1}{\text{outbound trains, day 1}}$
variable for number of switcher-hours	number of 8-hour shifts (excludes overtime)	number of switcher-hours (all-inclusive)

measure of the average yard time for these cars, for it ignores whatever amount of time they might have spent in the yard on previous days, and includes part of the yard time of cars that will leave on future days. However, it does provide an accurate measure of total car time incurred that day in the yard.

Corresponding to the two distinct methods of calculating yard time for the two yards are two variables we will use in estimating the effect on yard time of outbound train frequency. Recall that in Section 2.32, we proposed to estimate this effect by finding the coefficient of 1/D, where D is the number of departing trains per day, in a linear regression whose dependent variable is average yard time. Since at East Deerfield we are concerned with predicting the yard time for cars arriving today, and yard time averages about 20 hours at the yard, we would expect this yard time to be as much affected by outbound train frequency tommorrow as by today's. Therefore, to measure the effect of outbound train frequency on the average yard time of cars arriving at East Deerfield on day 1, the frequency of outbound trains was measured for days 1 and 2. (A more relevant period over which to measure this frequency might have been for example from 8 p.m. on day 1 until 8 p.m. on day 2, but this would have required taking account of the exact departure time of each train .) On the other hand, for Woippy, only today's outbound trains were included in D. We might expect yesterday's outbound train frequency to have some effect on today's inventory, especially in the early morning, but since average yard time is only 13.7 hours, this effect will be swamped by today's train frequency.

Finally, we should note that whereas the total number of switcher-hours for Woippy each day was used, only those switcher-hours were used at East Deerfield for which crews were paid on a straight-time as opposed to overtime basis. This choice lets the performance standard that results from the regression model fit more easily into existing Boston and Maine management practices. On the B&M, yard managers can increase switcher-hours piecemeal by giving overtime to switcher crews that are already on duty, but try instead to call other crews for additional eight-hour shifts that are paid at the straight-time rate, which is lower than the overtime rate. (We will discuss this pay structure in more detail in section 4.2.) The measure of switcher use on which the B&M therefore concentrates is the number of eight-hour shifts worked.

For each yard, we sought the statistical relationship between average yard time and the three measures we have hypothesized as possible determinants of yard time -- inbound volume, switcher hours, and outbound train frequency. Ideally, we would measure the effect of each of these variables on that portion of yard time we believe they really affect. In other words, we would measure the effect of inbound volume and switcher use on processing time, and the effect of outbound train frequency on wait time. Unfortunately, the resources available to the author prevented him from collecting and processing the neccessary data over a long enough period at either yard. However, a benefit of this limitation is that it led to the development of some less data-intensive methods of setting standards, which are described in this thesis.

As a preliminary step in the statistical analysis, the correlation coefficients among volume, switcher-hours, and outbound trains were found. Exhibit 3-11 shows these coefficients. The mean, range, and standard deviation of these three variables, and of average yard time, are shown in Exhibit 3-12. Note in Exhibit 3-11 that both yards display a similar degree of positive correlation between inbound volume and switcher hours. In contrast to the relationship between volume and switcher-hours, the correlation between inbound volume and the outbound train variable is dramatically different between the two yards. This relationship is insignificant for East Deerfield, but for Woippy we see that days with higher inbound volume also have a strong statistical tendency to have more outbound trains.

The above discussion of the correlations among inbound volume, switcher-hours, and outbound trains serves as a prelude to a series of regression models that were fitted in order to see how these three variables each affected average yard time. The results of these models are summarized in Exhibits 3-13 and 3-13a. Our goal was to

EXHIBIT 3-11

CORRELATION COEFFICIENTS AMONG VOLUME, SWITCHER-HOURS, AND OUTBOUND TRAINS

	EAST DEERFIELD	WOIPPY
inbound volume & switcher hours	.609	.408
inbound volume & outbound trains *	.074	.800
switcher hours & outbound trains *	.019	.389
* outbound trains included	days 1 and 2	day 1

EXHIBIT 3-12

SUMMARY STATISTICS OF VARIABLES

	EAST DEERFIELD	WOIPPY
inbound volume:		
mean	413	2678
maximum	643	3235
minimum	178	1602
standard deviation	116	400
switcher hours:		
mean	46.0	110.1
maximum	56	125
minimum	32	99
standard deviation	4.4	5.8
outbound trains:		
mean	12.2	86.4
maximum	17	104
mimimum	3	56
standard deviation	2.2	9.5
average yard time:		
mean	20.7	11.8
maximum	40	24.9
minimum	12	9.2
standard deviation	3.8	2.1

EXHIBIT 3-13

REGRESSION MODELS FOR AVERAGE YARD TIME. (t-statistics in parentheses).

EAST DEERFIELD

$$\begin{matrix}\text{average yard time,}\\ \text{day 1}\end{matrix} = \underset{(1.5)}{3.5} + \underset{(1.1)}{0.3}\begin{pmatrix}\text{inbound}\\ \text{volume}\\ \text{day 1}\end{pmatrix} + \underset{(8.4)}{383}\left(\frac{1}{\begin{matrix}\text{outbound trains,}\\ \text{days 1 and 2}\end{matrix}}\right)$$

corrected R^2 = .415

$$\begin{matrix}\text{average yard time,}\\ \text{day 1}\end{matrix} = \underset{(-0.7)}{-2.3} + \underset{(2.4)}{10.1}\begin{pmatrix}\text{switcher}\\ \text{hours,}\\ \text{day 1}\end{pmatrix} + \underset{(8.5)}{377}\left(\frac{1}{\begin{matrix}\text{outbound trains,}\\ \text{days 1 and 2}\end{matrix}}\right)$$

corrected R^2 = .442

WOIPPY

$$\begin{matrix}\text{average yard time,}\\ \text{day 1}\end{matrix} = \underset{(0.2)}{.97} - \underset{(-2.6)}{.00182}\begin{pmatrix}\text{inbound}\\ \text{volume,}\\ \text{day 1}\end{pmatrix} + \underset{(2.9)}{0.14}\begin{pmatrix}\text{switcher}\\ \text{hours,}\\ \text{day 1}\end{pmatrix}$$

corrected R^2 = .132

$$\begin{matrix}\text{average yard time,}\\ \text{day 1}\end{matrix} = \underset{(-4.3)}{-19.1} + \underset{(5.0)}{.17}\begin{pmatrix}\text{switcher}\\ \text{hours,}\\ \text{day 1}\end{pmatrix} + \underset{(7.9)}{1038}\left(\frac{1}{\begin{matrix}\text{outbound trains,}\\ \text{day 1}\end{matrix}}\right)$$

corrected R^2 = .543

EXHIBIT 3-13a

REGRESSION MODELS FOR AVERAGE YARD TIME
WITH INBOUND CARS PER SWITCHER HOUR
AS SECOND INDEPENDENT VARIABLE

(t-statistics in parentheses)

EAST DEERFIELD

$$\begin{array}{c}\text{average}\\ \text{yard time,}\\ \text{day 1}\end{array} = \underset{(1.7)}{4.1} + \underset{(0.5)}{.068}\left(\begin{array}{l}\text{inbound cars}\\ \text{per switcher}\\ \text{hour, day 1}\end{array}\right) + \underset{(8.3)}{381}\left(\frac{1}{\begin{array}{c}\text{outbound}\\ \text{trains,}\\ \text{days 1 \& 2}\end{array}}\right)$$

corrected R^2 = .408

WOIPPY

$$\begin{array}{c}\text{average}\\ \text{yard time,}\\ \text{day 1}\end{array} = \underset{(-1.8)}{-7.7} + \underset{(2.4)}{.222}\left(\begin{array}{l}\text{inbound cars}\\ \text{per switcher}\\ \text{hour, day 1}\end{array}\right) + \underset{(5.8)}{1203}\left(\frac{1}{\begin{array}{c}\text{outbound}\\ \text{trains,}\\ \text{day 1}\end{array}}\right)$$

corrected R^2 = .399

find the effect of inbound volume, switcher-hours, and outbound trains on average yard time at each of the yards. At East Deerfield, however, the strong correlation (.609) between inbound volume and switcher hours meant that we could not include both these variables in our regression model. Our goal for East Deerfield was therefore to find out whether inbound volume or switcher hours would be the best second independent variable to stand alongside the outbound train variable in the regression model. Similarly, at Woippy, the strong correlation (.800) between inbound volume and outbound train frequency forced the exclusion of these two variables from the same regression model. Our goal for Woippy was then to find which of these two variables, inbound volume or the outbound train variable, would serve most satisfactorily as a second independent variable to go with switcher hours.

Let us first look at the choice between inbound volume and switcher hours at East Deerfield. Exhibit 3-13 shows that whichever of these two variables is included as the second independent variable, the effect of the outbound train variable on yard time remains extremely strong, as indicated by a t-statistic of over 8 in both cases. In Exhibit 3-13a, we see that outbound train frequency also retains this explanatory power when the second independent variable is inbound cars per switcher hour. The t-statistic of this variable is 0.5, and the corrected R-squared is .409. Returning to Exhibit 3-13, we see that when inbound volume is the second independent variable, its t-statistic is 1.1 and the corrected R-squared of the model is .415. When this second variable is instead switcher-hours, t-statistic and R-squared rise to 2.4 and .442. Our choice for the second independent variable should therefore clearly be switcher-hours.

Now we turn to the choice at Woippy between inbound volume and the outbound train variable as the second independent variable in our preliminary regression model for yard time. The first independent variable is switcher hours, which Exhibit 3-13 shows to have a significant t-statistic regardless of whether the second variable included in the model with it is inbound volume (where the switcher-hour t-statistic is 2.9) or the outbound train variable (where the switcher statistic is 5.0). Here the choice cannot simply be made on the basis of the degree of significance of the two prospective second independent variables, because the t-statistics of both are significant. Instead, we can choose between the models on the basis of the great difference in their overall explanatory power. When inbound volume is the second independent variable, the model's R-squared is only .132, whereas when the outbound train variable is the second, R-squared rises to .532. (Exhibit 3-13a shows that for Woippy, if in a regression where the outbound train variable is the other independent one, switcher-hours is replaced with inbound cars per switcher-hour, the t-statistics for these variables are 5.8 and 2.4 respectively, and the corrected R-squared of the model is .399.)

Through a process analogous to the one we followed for East Deerfield, we arrive for Woippy at the same conclusion as at East Deerfield: on the basis of statistical explanatory power, the best regression model for average yard time is one that includes (1) the outbound train variable and (2) switcher hours. However, for reasons (explained in Section 3.5) relating to the unexpected positive sign of the coefficient for switcher use in both cases, switcher-hours was dropped as a variable from both models. As Exhibit 3-14 shows, this leaves regression models whose t-statistics for the outbound train variable (8.3 for East Deerfield, 5.6 for Woippy) and overall explanatory power (R-squares of .413 for East Deerfield, .349 for Woippy) are reduced but still acceptable. Exhibit 3-15 shows scatter plots of the two sets of data, and the fitted regression lines.

These regression models provide us with estimates of mean processing time at the two yards, as well as with the wherewithall to state the certainty surrounding these estimates. Section 2.32 explained that in a regression of average yard time on outbound train frequency, the intercept coefficient b1 is an estimate the yard's mean processing time. Exhibit 3-14 therefore shows that estimates of the mean processing times at East Deerfield and Woippy are respectively 4.8 hours and 1.9 hours. The certainty of these estimates is given by the confidence interval we can construct around each. Using the method described by Winkler and Hayes [13], if we

EXHIBIT 3-14

REGRESSION MODELS FOR SWITCHER-HOUR USE AS FUNCTION OF INBOUND VOLUME AT EAST DEERFIELD AND WOIPPY YARDS. (t-statistics in parentheses).

EAST DEERFIELD

$$\begin{matrix}\text{switcher-hours,} \\ \text{day 1}\end{matrix} = \underset{(27.4)}{36.4} + \underset{(7.5)}{.02328} \begin{pmatrix}\text{inbound}\\ \text{volume}\\ \text{day 1}\end{pmatrix}$$

corrected R^2 = .364

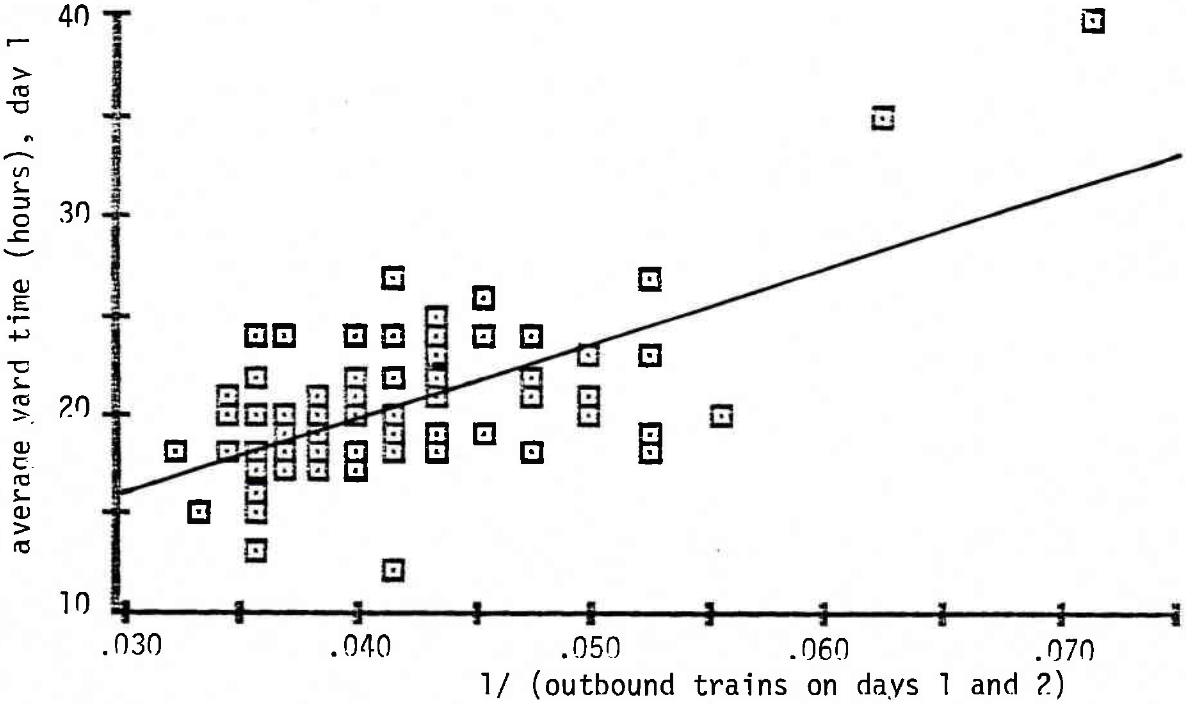
WOIPPY

$$\begin{matrix}\text{switcher-hours,} \\ \text{day 1}\end{matrix} = \underset{(19.8)}{94.3} + \underset{(3.4)}{.00588} \begin{pmatrix}\text{inbound}\\ \text{volume}\\ \text{day 1}\end{pmatrix}$$

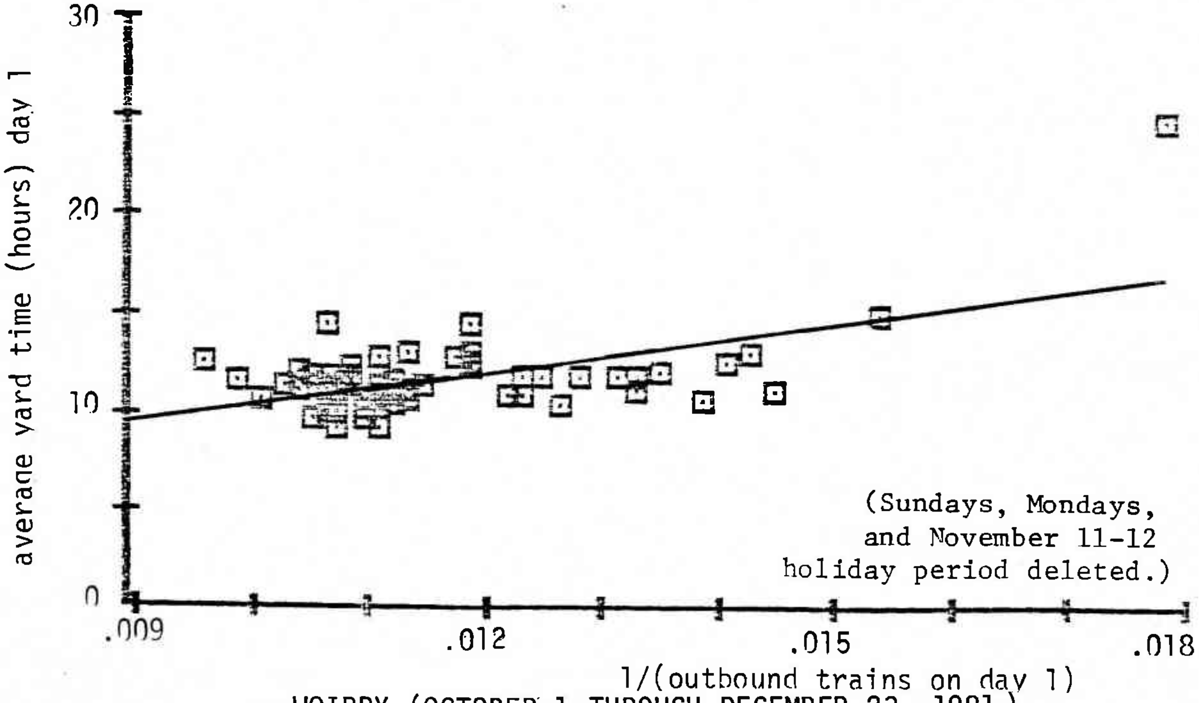
corrected R^2 = .152

EXHIBIT 3-15

OUTBOUND TRAIN VARIABLE VERSUS AVERAGE YARD TIME, PLUS FITTED REGRESSION LINE, EAST DEERFIELD AND WOIPPY YARDS



EAST DEERFIELD (MARCH 5 THROUGH JUNE 10, 1982)



WOIPPY (OCTOBER 1 THROUGH DECEMBER 23, 1981) assume that the random-error terms in the regression are independent, have the same variance for all values of the independent variable, and are normally distributed, we can deduce that the probability is 95 percent that the true mean processing time for East Deerfield lies between 1.0 hours and 8.7 hours, and 80 percent that it lies between 2.3 hours and 7.3 hours. The result for Woippy is still less certain. The estimate of a mean processing time of 1.9 hours at Woippy is so uncertain that, under the above assumptions, the probability is 20 percent that the real mean processing time is greater than 5.8 hours, and 5 percent that it is greater than 7.9 hours.

Having examined the possible statistical evidence of the effect of volume, switcher use, and outbound train frequency on average yard time, let us turn to regression analysis of the effect of inbound volume on switcher hours, which will provide us with the linear, volume-variable standard for switcher use we proposed in Section 2.31. Exhibit 3-16 shows the results of the regression analyses for each yard; Exhibit 3-17 shows the corresponding scatter diagram and fitted lines. Exhibit 3-16 also shows that in both cases, the t-statistic for inbound volume (East Deerfield, 7.5; Woippy, 3.4) is significant when used as the sole independent variable in a regression model in which switcher-hours is the dependent variable. Unfortunately, the explanatory power of this model for Woippy is very low (.152).

EXHIBIT 3-16

REGRESSION MODELS FOR AVERAGE YARD TIME AS FUNCTION OF OUTBOUND TRAIN FREQUENCY, EAST DEERFIELD AND WOIPPY YARDS. (t-statistics in parentheses)

EAST DEERFIELD

$$\text{average yard time, day 1} = \underset{(2.5)}{4.837} + \underset{(8.3)}{379}\left(\frac{1}{\text{outbound trains, days 1 and 2}}\right)$$

corrected $R^2 = .413$

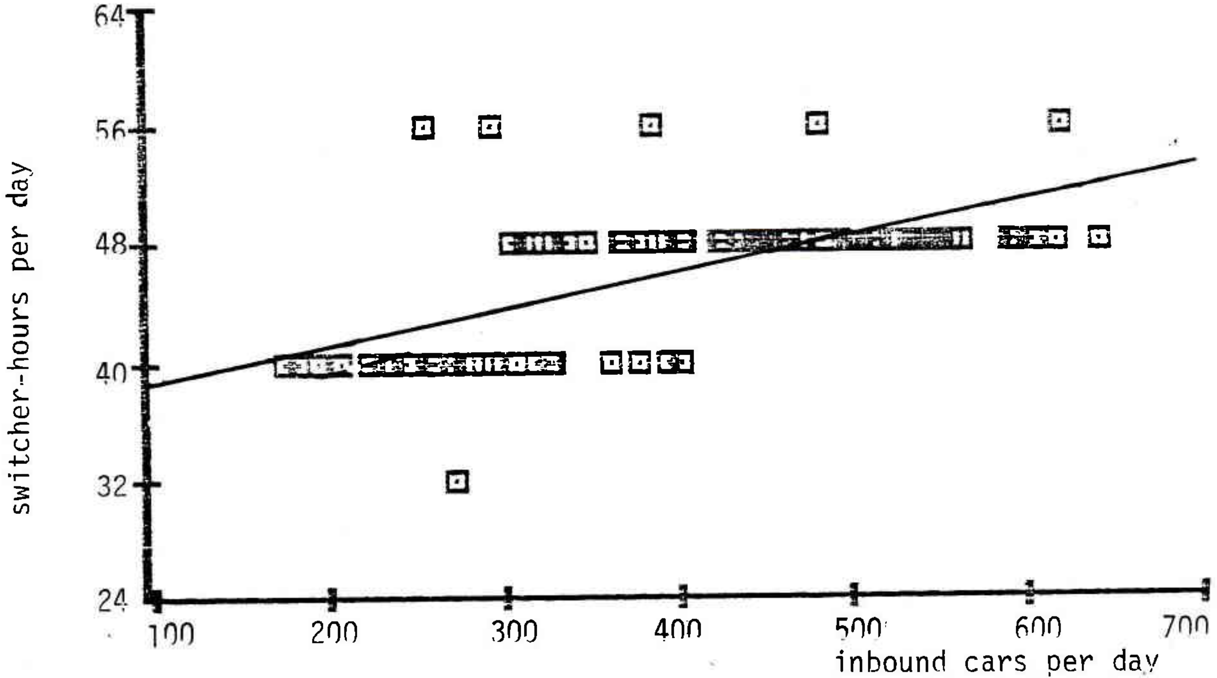
WOIPPY

$$\text{average yard time, day 1} = \underset{(1.1)}{1.892} + \underset{(5.6)}{846}\left(\frac{1}{\text{outbound trains, day 1}}\right)$$

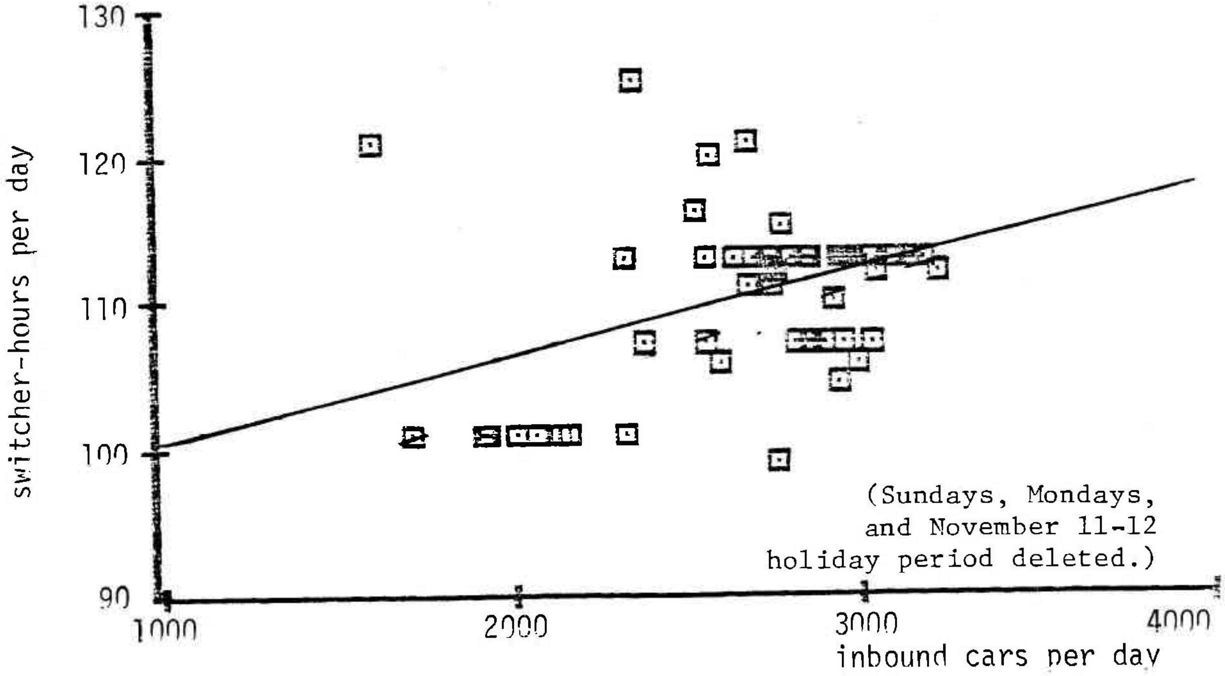
corrected $R^2 = .349$

EXHIBIT 3-17

INBOUND VOLUME VERSUS SWITCHER-HOURS, PLUS FITTED REGRESSION LINE, EAST DEERFIELD AND WOIPPY YARDS



EAST DEERFIELD (MARCH 5 THROUGH JUNE 10, 1982)



(Sundays, Mondays, and November 11-12 holiday period deleted.)

WOIPPY (OCTOBER 1 THROUGH DECEMBER 23, 1981)

3.32. Use of the Switcher-Use Standard to Evaluate the Crew Schedule. Nevertheless, we can employ this summary of the relationship between inbound volume and switcher use at Woippy in an evaluation of (1) the crew schedule that is set at the start of each six-month schedule period, and (2) the modifications that managers at Woippy have made to this schedule in response to the operating conditions they encountered each day. The volume-variability of a switcher standard does not have to be real time. Instead, it may be written into the crew schedule. This is true of the switcher schedule for Woippy, which varies over the seven days of the week. The relationship we have developed between inbound volume and switcher use then points out any day of the week on which, for example, more switcher hours are indeed needed to handle the higher average volume on that day, but not as many hours as are actually scheduled. Where volume-variability is more a result of the crew schedule (as at Woippy) than of the real-time decisions of yard managers (as at East Deerfield), the statistical relationship between volume and switcher use can still be used to evaluate management decisions -- except that now the decisions are those of the managers who set the crew schedules.

Exhibit 3-18 shows the SNCF document summarizing the weekly switcher schedule at Woippy. The implication of this schedule is that 104 switcher-hours are scheduled to work each Saturday, 106 each Tuesday, and 113 each Wednesday, Thursday, and Friday. The bottom half of Exhibit 3-19 relates this scheduled switcher use to the line that was fitted in the regression analysis in Exhibit 3-16. Plotted in this diagram on the bottom of Exhibit 3-19 is scheduled switcher use on each weekday versus average actual volume on that weekday between October 1 and December 23, 1981. The fitted line shows that the scheduled crew use roughly follows the overall pattern of volume, but that indivisibilities in the way that yard managers can adjust switcher use prevent a perfect match of switcher use to volume. The top half of Exhibit 3-19 differs only from the bottom half in that whereas the bottom half showed scheduled switcher use on each of the five days, the top half shows average actual switcher use during October 1 through December 23, 1981. This diagram shows that, if we accept the line fitted in the regression of Exhibit 3-16 as a standard, Fridays at the yard tended to be days when switcher use was above standard. This poorer performance appears compensated to a degree by the low average yard time on Fridays, but in the absence of separate measurement of the processing and wait components of yard time that we will describe in Section 3.4, we cannot judge to what extent this lower yard time is affected by more intensive switcher use as opposed to the frequency of the pickup of outbound blocks.

S.N.C.F.
Région METZ
C.E. de WOIPPY

DT 2/3 TRIAGE de WOIPPY

PROGRAMME D'UTILISATION DES ENGINS MOTEURS DE MANOEUVRES

ET DE LOCOTRACTEURS

Pièce 3.20 (NG TR3 B6 N° 4)
Service au ..27.SEP.1981...
A.03

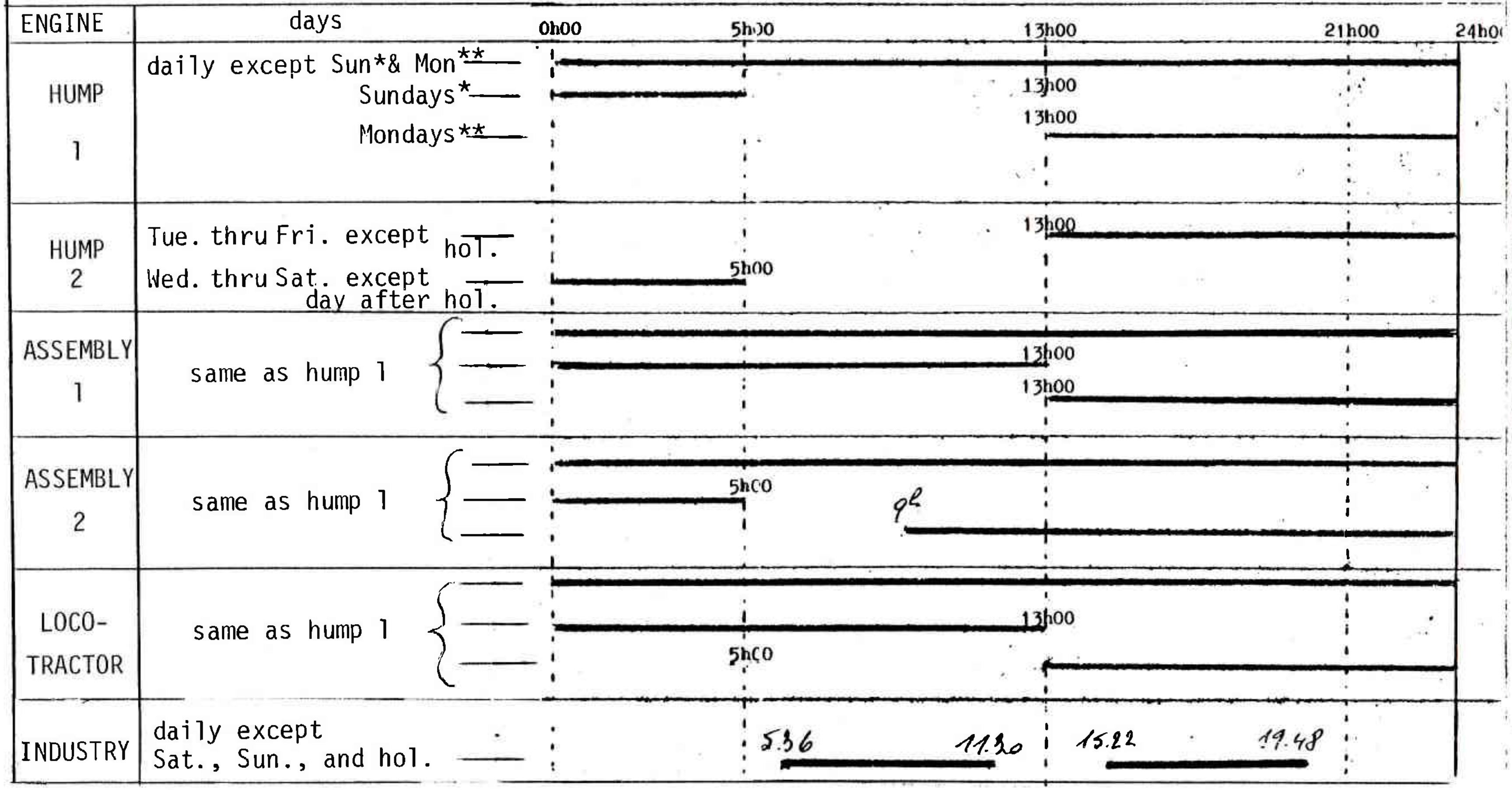
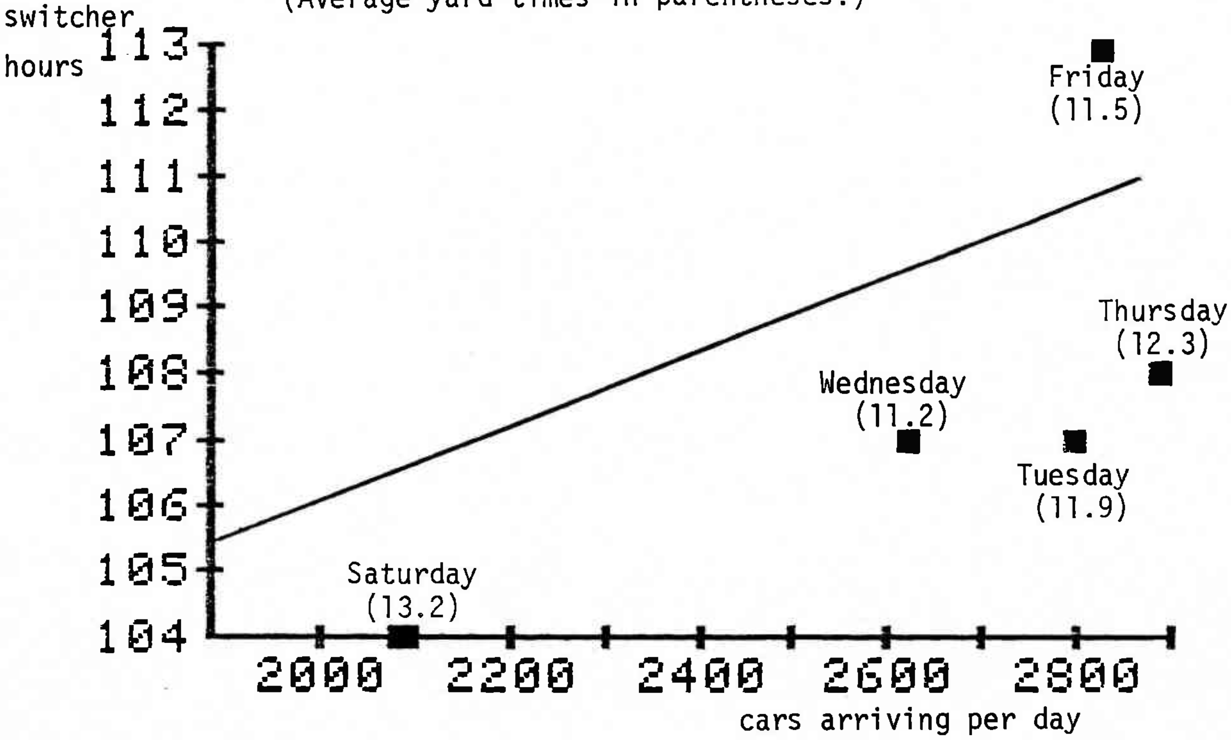


EXHIBIT 3-18
S.N.C.F. DOCUMENT SHOWING SCHEDULE OF SWITCHER USE AT WOIPPY YARD

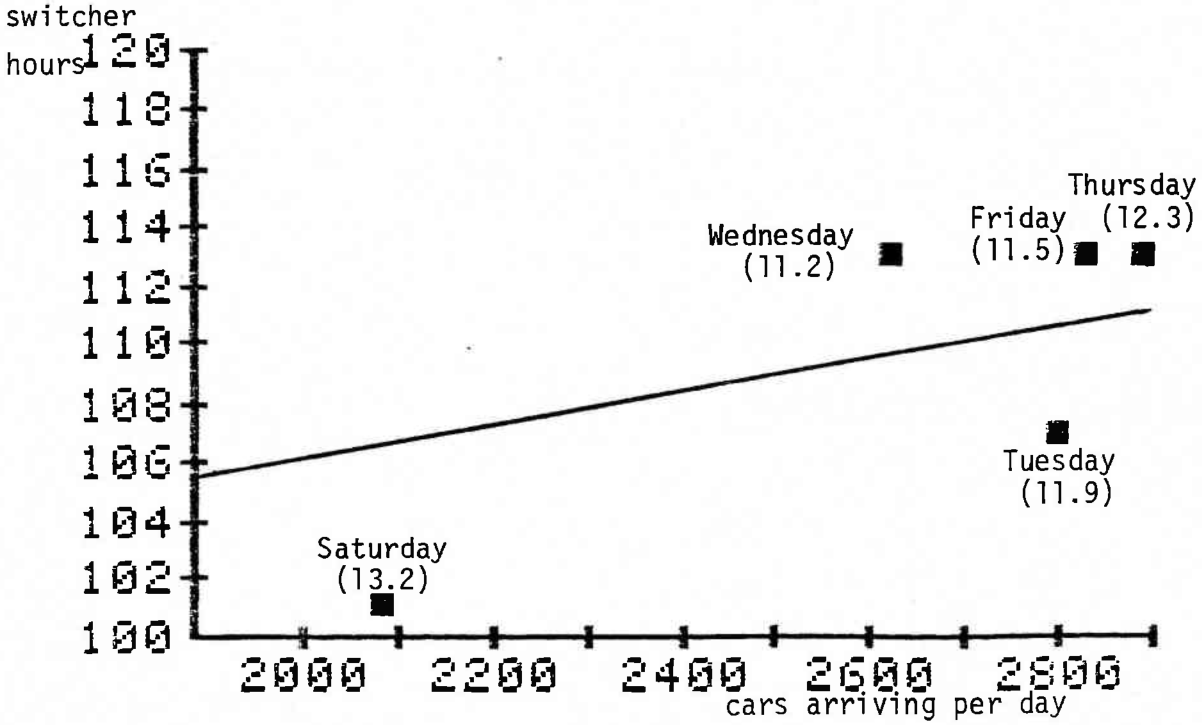
(* and holidays. ** and days after holidays.)

EXHIBIT 3- 19

WOIPPY YARD - VOLUME VERSUS SWITCHER HOURS FOR AVERAGE VALUES OF SELECTED DAYS OF THE WEEK, PLUS LINE REPRESENTING STANDARD (FROM EXHIBIT 3-16).
(Average yard times in parentheses.)



ACTUAL SWITCHER HOURS VERSUS ACTUAL VOLUME



SCHEDULED SWITCHER HOURS VERSUS ACTUAL VOLUME

3.33. The Standard for Fuel Use: Linear or Ratio? In Section 2.31, we described how a linear standard for switcher use could be superior to a standard stated in terms of so many switcher-hours per car. A similar hypothesis can reasonably be made about the best standard for the amount of fuel to be consumed by switching locomotives as a function of the number of switcher hours worked. Just as we hypothesized in Section 2.31, and have in fact seen in the present section, that a significant fixed component should be present in the variability of switcher use with volume, we now might expect a significant fixed component in the variability of fuel consumption with switcher-use. The reason for this expectation is that on the Boston and Maine, switchers are often left running when not in use, especially during cold wheather. Some fuel continues to be consumed whether the locomotives are running or not.

In order to test the hypothesis of a significant fixed component in fuel consumption, and to see whether an econometric standard for fuel was appropriate, a regression model was developed for the relationship between the use of switchers and the fuel they consumed. Summary statistics on the data on which the model was based, and the regression model itself, are shown in Exhibit 3-20, and a scatter diagram of the data and the fitted regression line are shown in Exhibit 3-21. Two facts stand out. First, in the model we developed, the number of switcher-hours worked fails to explain fuel

EXHIBIT 3-20

EAST DEERFIELD YARD - REGRESSION MODEL OF FUEL USE AS A FUNCTION OF CREWS WORKED, FOR FEBRUARY 5 THROUGH APRIL 19, 1982.

(t-statistics in parentheses)

	crews worked, day 1	average gallons of fuel loaded, days 2, 3, and 4
mean	6.03	302
minimum	5	119
maximum	8	573
standard deviation	0.72	98

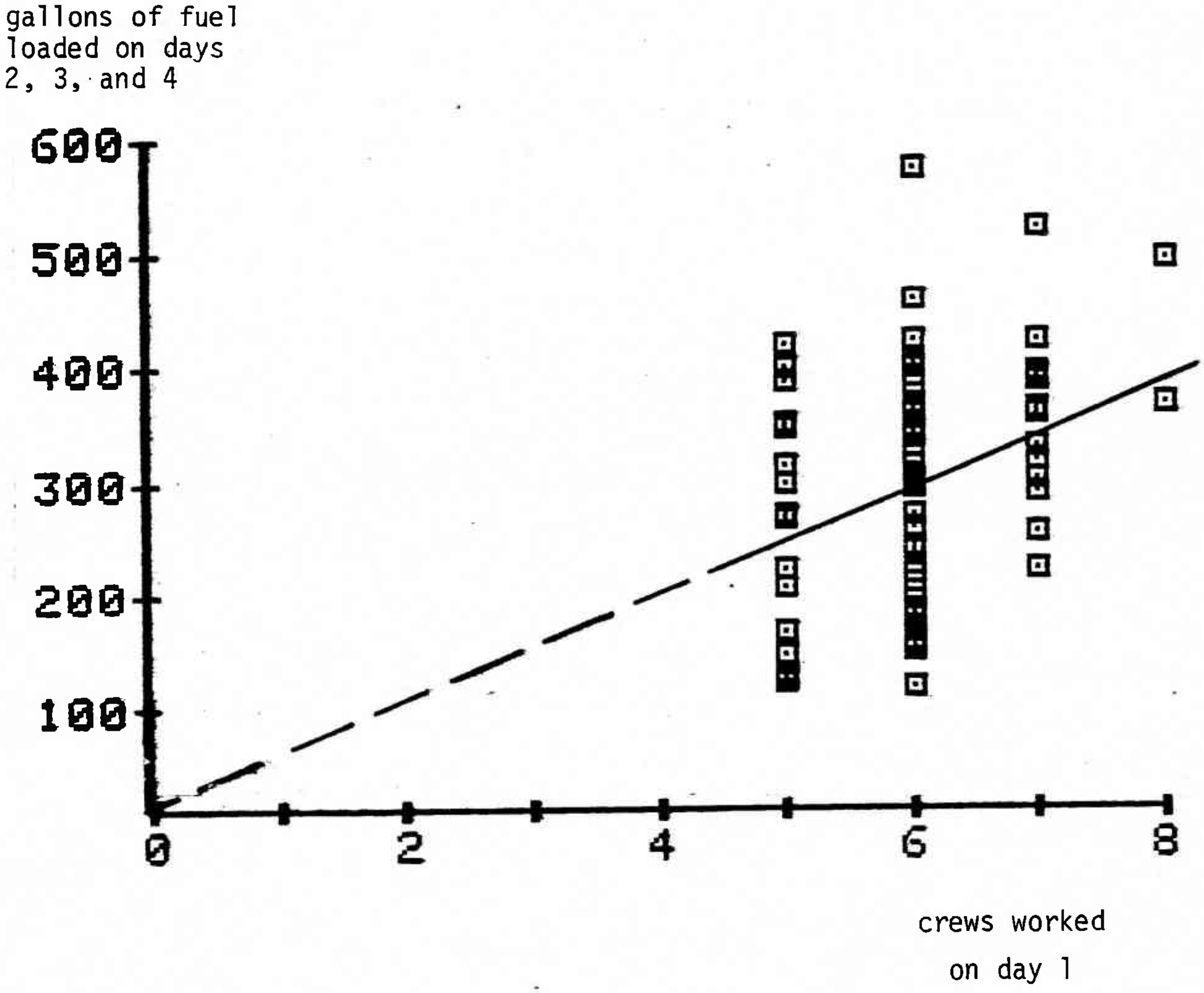
correlation coefficient .351

$$\begin{array}{l}\text{average gallons of}\\ \text{fuel loaded into}\\ \text{yard switchers,}\\ \text{days 2, 3, and 4}\end{array} = \underset{(0.1)}{12.1} + \underset{(3.2)}{48.0}\left(\begin{array}{c}\text{crews worked,}\\ \text{day 1}\end{array}\right)$$

corrected $R^2 = .111$

EXHIBIT 3-21

EAST DEERFIELD YARD - CREWS WORKED VERSUS GALLONS OF FUEL LOADED IN SWITCHERS, FEBRUARY 5 THROUGH APRIL 19, 1982, PLUS FITTED REGRESSION LINE.



consumption adequately. Second, the intercept point of the fitted line that expresses the relationship between these two variables is very uncertain, but our best estimate of it is very close to zero. The average number of gallons of fuel loaded into switchers per day was 302, but our estimate of the fixed portion of this consumption is only 12 gallons. These results lead us to adopt a standard for fuel use that is simply proportional to switcher use, with no fixed component.

3.4. Train-Specific Analysis of Processing Times. Thus far in this chapter, we have examined yard operations and developed standards for yard performance using (1) what might be called "day-of-week" analysis and (2) regression analysis. Both these techniques begin with measures of aggregate yard activity measures for each day, including inbound volume, switcher hours worked, and average yard time. In contrast, the analysis we will perform in this section begins with more disaggregate data, data that is specific not to each day but to each inbound and outbound train and each outbound block. Although because it is more disaggregate, this data is more costly to collect and process, it may in some cases provide a standard that is more satisfactory because the calculations underlying it are simpler. As we have seen, this may let it be more easily accepted and negotiated over than a more complex standard, such as one based on regression. The disaggregate data can be summarized in a way that enhances the control of headquarters over the yard

(1) by isolating that portion of total yard time for which the yard manager is responsible, namely processing time, and

(2) by forming the basis for an estimate of the reliability with which cars will make connections from inbound trains to outbound blocks. This estimate is the PMAKE function described in Section 2.32, and lets headquarters management predict and set standards for origin-to-destination trip times and reliability.

Our accomplishment of both tasks, using a sample week's worth of data from Woippy yard, will rest on the distribution we will obtain of the classification times of inbound trains and the assembly time of outbound trains. For the two yards, we present the distribution of classification and assembly times over about a week. The sum of the means of these distributions will provide an estimate of average processing time. We will validate this estimate of processing time at Woippy by using the frequency of outbound pickups and of left tonnage to estimate wait time, and by comparing the sum of these estimates of mean processing time and wait times with average yard time as measured directly.

To obtain a PMAKE function that expresses the yard's connection reliability, we will convolute these two distributions to obtain a total processing time distribution. In its cumulative form, such a distribution gives, as an increasing function of the available time between an inbound and outbound train, the probability that enough time for both classification and assembly will be available between the two trains, and thus that a car will make the connection (assuming the outbound train is not cancelled or full). To make this distribution more useful for the prediction of origin-to-destination trip times and reliability, we will adjust it for the degree to which actual train arrival and departure times adhere to schedule, and for the likelihood that a given car will be delayed because its outbound train is cancelled or full.

The PMAKE function for a given yard may be determined by a technique developed by Martland [14] and tested by Tykulsker [15]. Called the Process PMAKE function, it is based on the idea first introduced in Section 2.12, which is that the time required for the processing of a car through a classification yard can be split into two segments:

--the time between the car's arrival in an inbound train and the end of the car's classification. For the sake of brevity, we will refer to this entire time in this section as the classification of the car.

--the time between the start of the assembly of a car's outbound train, and the departure of that train. We will call this entire time the car's assembly.

The available time for the accomplishment of these two processes for a given car is given in principle by the difference between the scheduled arrival time of the car's inbound train and the scheduled departure time of the car's outbound train. Should, however, one of the trains operate either early or late on a particular day, the time available on that day to classify and assemble the car will be correspondingly increased or reduced. Let us define

arrival deviation =

(actual arrival time) - (scheduled arrival time)

and

departure deviation =

(actual departure time) - (scheduled departure time).

(Note that in both case, a train arriving or leaving late will have a positive deviation from schedule.) Then the amount of time available for processing may be expressed as

(scheduled departure time + departure deviation)

- (scheduled arrival time + arrival deviation).

We are concerned with the probability that this available time will be greater than the time needed for classification and assembly, i.e. the probability that the car will make the connection between the inbound and outbound trains. Still another way to state this is as the probability that

scheduled departure time - scheduled arrival time

is greater than

total processing time =

arrival deviation

\+ classification time

\+ assembly time

\- departure deviation.

Recall that the PMAKE function states the probability that a car will make its connection as a function of available time between trains. To obtain the basis for a PMAKE function, we must merely determine, for each possible length of time between trains, what is the probability that this length of time will be greater than total processing time.

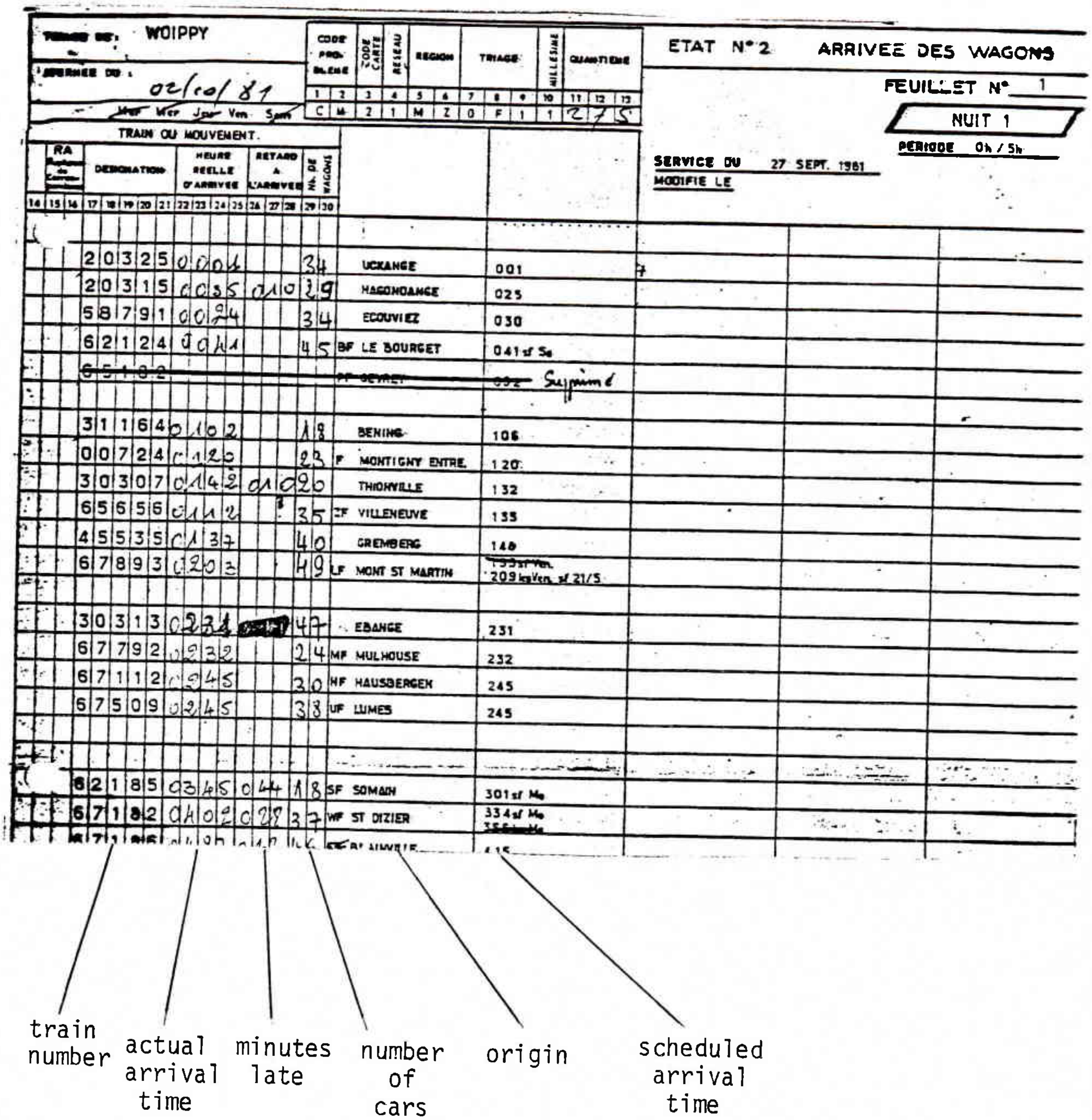
The technique Tykulsker demonstrated for carrying out this task was to examine past data from the yard to obtain discrete distributions for each of these four random variables (arrival deviation, classification time, assembly time, and departure deviation). He then convoluted these to get a discrete distribution of their sum. With a slight adjustment, the cumulative form of this sum distribution then represents a PMAKE function for the yard. As we shall see, the adjustment takes account of the probability that a car will fail to make its connection to a scheduled outbound train because it is full or cancelled.

In this section, we will present distributions of processing times that were obtained by Tykulsker for East Deerfield and by this author for Woippy yard. Samples of the SNCF domuments that were the source of the required processing times for each train at Woippy are shown in Exhibits 3-22 through 3-25. Arrival, classification, assembly, and departure distributions for the two yards are shown in Exhibits 3-26 through 3-29. (Trains that were in mid-process during the weekend shutdown were omitted from these distributions. They are listed in Appendix A. The distributions for East Deerfield were originally presented by Tykulsker, along with corresponding source reports. [16]) Appendix B describes the computer program that this author used to generate and convolute the Woippy distributions.

The convolution process may be described conceptually as follows. Let P(T) equal the probability that total processing time

EXHIBIT 3-22

S.N.C.F. REPORT OF TRAINS ARRIVED



TRIAGE DE: WOIPPY

JOURNEE DU: 02/10/81

Mar Mer Jeu Ven Sam

CODE PROBLEME		CODE CARTE	RESEAU	REGION		TRIAGE			MILLESIME	QUANTIEME		
1	2	3	4	5	6	7	8	9	10	11	12	13
C	M	2	1	M	Z	0	F	1	1	2	7	5

ETAT N°2 ARRIVEE DES WAGONS

FEUILLET N° 1

NUIT 1

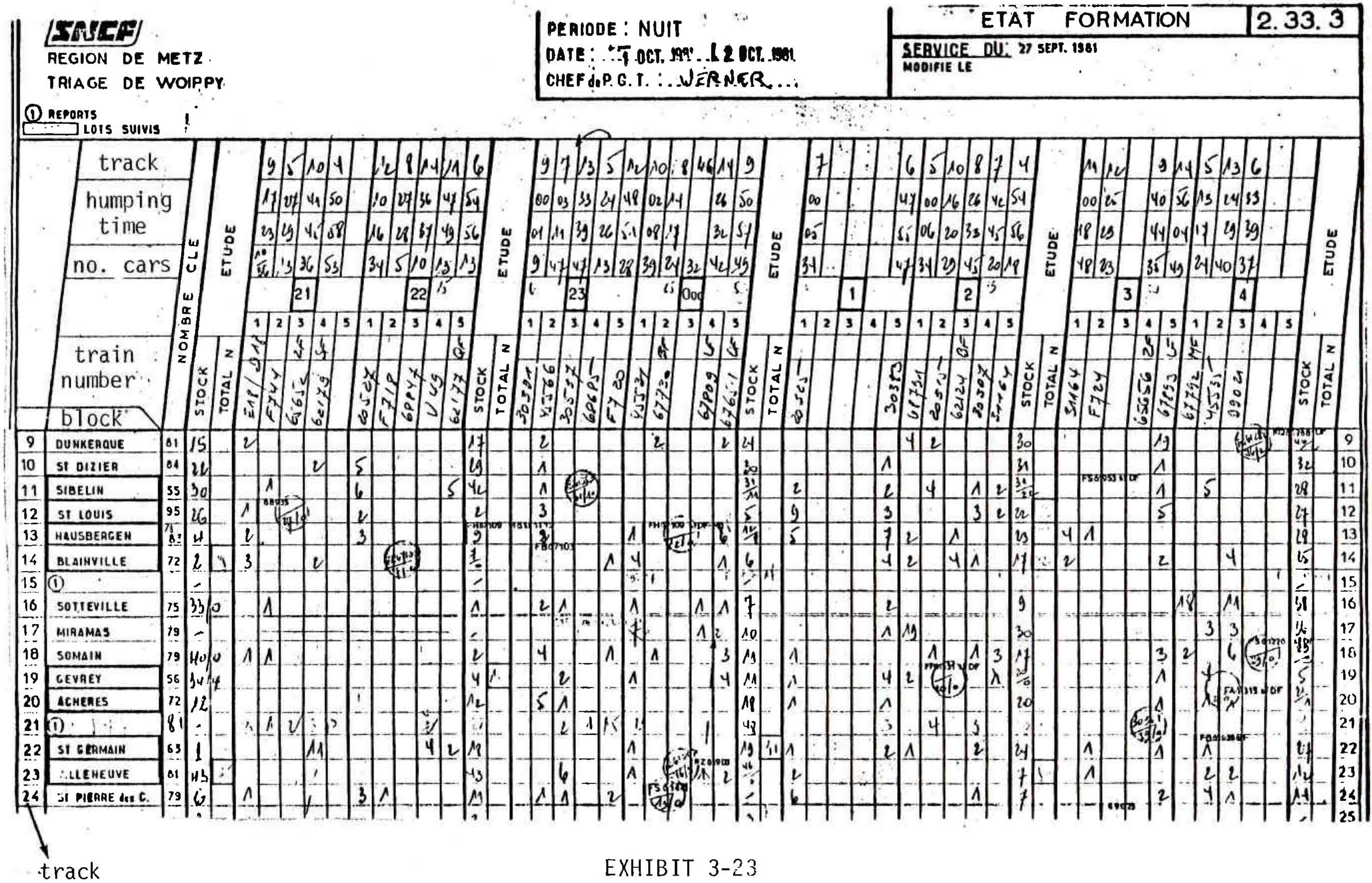
PERIODE 0h / 5h

SERVICE DU 27 SEPT. 1981

MODIFIE LE

TRAIN OU MOUVEMENT.

DESIGNATION	HEURE REELLE D'ARRIVEE	RETARD A L'ARRIVEE	Nb. DE WAGONS		
20325	0004		34	UCKANGE	001
20315	0035	010	29	HAGONDANGE	025
58791	0024		34	ECOUVIEZ	030
62124	0041		45	BF LE BOURGET	041 sf Sa
~~65102~~				~~PF SEVRET~~	~~032~~ Supprimé
31164	0102		18	BENING	106
00724	0120		23	F MONTIGNY ENTRE.	120
30307	0142	010	26	THIONVILLE	132
65656	0142		35	ZF VILLENEUVE	135
45535	0137		40	GREMBERG	148
67893	0203		49	LF MONT ST MARTIN	~~155 sf Ven.~~ 209 ks Ven. sf 21/5
30313	0231	[illegible]	47	EBANGE	231
67792	0232		24	MF MULHOUSE	232
67112	0245		30	HF HAUSBERGEN	245
67509	0245		38	UF LUMES	245
62185	0345	044	18	SF SOMAIN	301 sf Me
67182	0402	028	37	WF ST DIZIER	334 sf Me



SNCF
REGION DE METZ
TRIAGE DE WOIPPY

① REPORTS
☐ LOTS SUIVIS

PERIODE : NUIT
DATE : 1 OCT. 1981 .. 12 OCT. 1981
CHEF de P.G.T. : WERNER

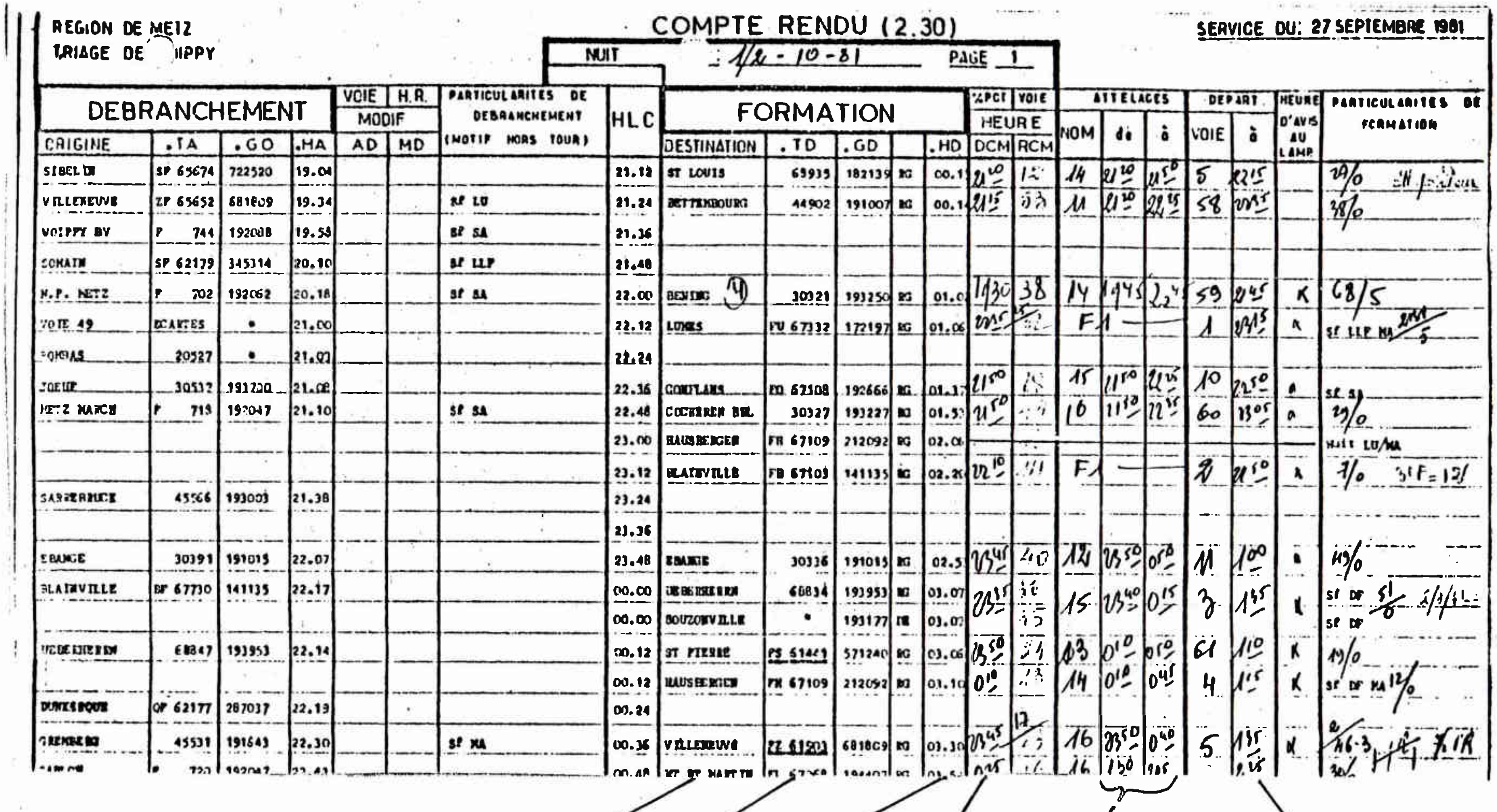
ETAT FORMATION 2.33.3

SERVICE DU: 27 SEPT. 1981
MODIFIE LE

track	block	NOMBRE CLE	STOCK
9	DUNKERQUE	81	15
10	ST DIZIER	84	22
11	SIBELIN	55	30
12	ST LOUIS	95	26
13	HAUSBERGEN	71	4
14	BLAINVILLE	72	2
15	①		-
16	SOTTEVILLE	75	33
17	MIRAMAS	79	-
18	SOMAIN	79	40
19	GEVREY	56	34
20	ACHERES	72	12
21	①	81	-
22	ST GERMAIN	63	1
23	VILLENEUVE	81	45
24	ST PIERRE des C.	79	6

EXHIBIT 3-23

S.N.C.F. REPORT SHOWING TIME AT WHICH EACH TRAIN'S CLASSIFICATION ENDED



REGION DE METZ
TRIAGE DE [illegible]IPPY

COMPTE RENDU (2.30)

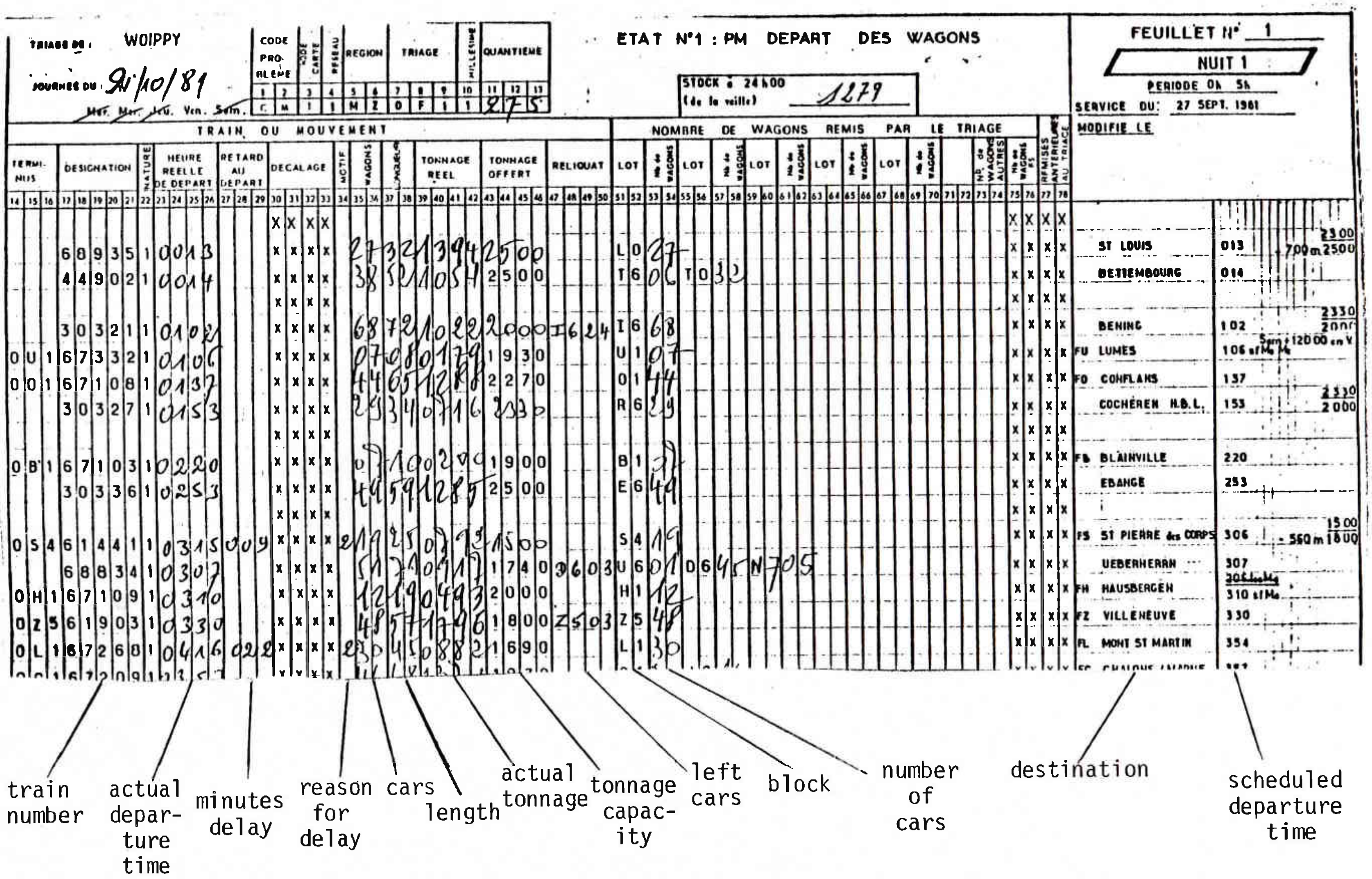
NUIT : 1/2 - 10 - 81 PAGE 1

SERVICE DU: 27 SEPTEMBRE 1981

DEBRANCHEMENT				VOIE	H.R.	PARTICULARITES DE DEBRANCHEMENT (MOTIF HORS TOUR)	HLC	FORMATION					%PCT	VOIE	ATTELAGES			DEPART		HEURE D'AVIS AU LAMP	PARTICULARITES DE FORMATION
				MODIF									HEURE								
ORIGINE	.TA	.GO	.HA	AD	MD			DESTINATION	.TD	.GD		.HD	DCM	RCM	NOM	de	à	VOIE	à		
SIBELIN	SP 65674	722520	19.04				21.12	ST LOUIS	65935	182139	RG	00.1	21^{10}	12	14	21^{20}	21^{50}	5	22^{15}		29/0 [illegible]
VILLENEUVE	ZP 65652	681809	19.34			SP LU	21.24	BETTEMBOURG	44902	191007	RG	00.1	21^{15}	33	11	21^{30}	22^{15}	58	22^{35}		38/0
VOIPPY BV	P 744	192008	19.58			SP SA	21.36														
SOMAIN	SP 62179	345314	20.10			SP LLP	21.40														
M.P. METZ	P 702	192062	20.18			SP SA	22.00	BENING ④	30921	193250	RG	01.0	21^{30}	38	14	21^{45}	22^{45}	59	22^{45}	K	68/5
VOIE 49	ECARTES	•	21.00				22.12	LUMES	FU 67332	172197	RG	01.06	~~22^{15}~~	[illegible]	F1	—	—	1	23^{15}	A	SF LLP MA [illegible]/5
[illegible]OMBAS	20527	•	21.02				22.24														
JOEUF	30532	191220	21.08				22.36	CONFLANS	ED 62108	192666	RG	01.17	21^{50}	[illegible]	15	21^{50}	22^{25}	10	22^{50}	A	SF SA
METZ MARCH	P 719	192047	21.10			SF SA	22.48	COCHEREN BEL	30327	193227	RG	01.5[illegible]	21^{50}	[illegible]	16	21^{30}	22^{35}	60	23^{05}	A	29/0
							23.00	HAUSBERGEN	FR 67109	212092	RG	02.06									HUIT LU/MA
							23.12	BLAINVILLE	FB 67103	141135	RG	02.20	22^{10}	[illegible]	F1	—		2	22^{50}	A	7/0 3^e F = 12/
SARREBRUCK	45566	193003	21.38				23.24														
							23.36														
EBANGE	30391	191015	22.07				23.48	EBANGE	30336	191015	RG	02.5	23^{45}	40	12	23^{50}	0^{50}	11	1^{00}	A	49/0
BLAINVILLE	BF 67730	141135	22.17				00.00	UEBERHERRN	68834	193953	RG	03.07	23^{15}	36	15	23^{40}	0^{15}	3	1^{35}	K	SF DF 51/6 [illegible]
							00.00	BOUZONVILLE	•	193177	IR	03.07		15							SF DF
UEBERHERRN	68847	193953	22.14				00.12	ST PIERRE	PS 61449	571240	RG	03.06	23^{50}	34	13	0^{10}	0^{50}	61	1^{10}	K	19/0
							00.12	HAUSBERGEN	FR 67109	212092	RG	03.10	0^{10}	23	14	0^{10}	0^{45}	4	1^{15}	K	SF DF MA 12/0
DUNKERQUE	OP 62177	287037	22.19				00.24														
GRENBERG	45531	191643	22.30			SF MA	00.36	VILLENEUVE	ZZ 61203	681809	RG	03.30	~~23^{45}~~	17	16	23^{50}	0^{40}	5	1^{35}	K	[illegible]
[illegible]	P 720	192047	22.43				00.48	[illegible] ST MARTIN	FL [illegible]	[illegible]	RG	03.5[illegible]	0^{25}	[illegible]	16	1^{50}	1^{05}		2.15		[illegible]

EXHIBIT 3-24

S.N.C.F. REPORT
OF TRAIN ASSEMBLY TIMES



TRIAGE DE : WOIPPY

JOURNEE DU : 2/10/81 Mer. Mer. Jeu. Ven. Sam.

CODE PROBLEME		CODE CARTE	RESEAU	REGION		TRIAGE			MILLESIME	QUANTIEME		
1	2	3	4	5	6	7	8	9	10	11	12	13
C	M	1	1	M	Z	0	F	1	1	2	7	5

ETAT N°1 : PM DEPART DES WAGONS

STOCK à 24 h00 (de la veille) 1279

FEUILLET N° 1

NUIT 1

PERIODE 0h 5h

SERVICE DU: 27 SEPT. 1981

MODIFIE LE

TRAIN OU MOUVEMENT / NOMBRE DE WAGONS REMIS PAR LE TRIAGE

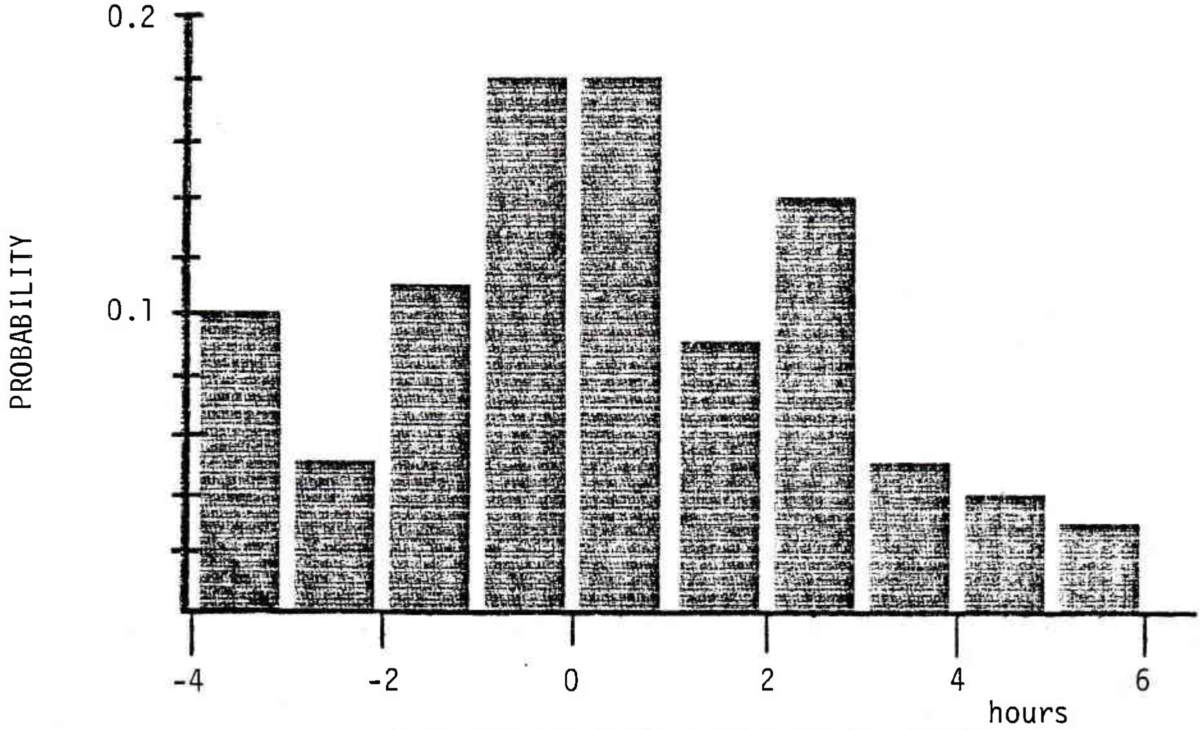
TERMINUS (14-16)	DESIGNATION (17-21)	NATURE (22)	HEURE REELLE DE DEPART (23-26)	RETARD AU DEPART (27-29)	DECALAGE (30-33)	MOTIF (34)	WAGONS (35-36)	LONGUEUR (37-38)	TONNAGE REEL (39-42)	TONNAGE OFFERT (43-46)	RELIQUAT (47-50)	LOT (51-52)	Nb de WAGONS (53-54)	LOT (55-56)	Nb de WAGONS (57-58)	LOT (59-60)	Nb de WAGONS (61-62)	Nb de WAGONS FS (75-76)	REMISES ANTERIEURES AU TRIAGE (77-78)		
					X X X X													X X	X X		
	68935	1	0013		x x x x		27	32	1394	2500		L0	27					x x	x x	ST LOUIS	013 700m 2300/2500
	44902	1	0014		x x x x		38	52	1054	2500		T6	06	T0	32			x x	x x	BETTEMBOURG	014
					x x x x													x x	x x		
	30321	1	0102		x x x x		68	72	1022	2000	I624	I6	68					x x	x x	BENING	102 2330/2000
0U1	67332	1	0106		x x x x		07	08	0179	1930		U1	07					x x	x x	FU LUMES	106 s/Ms 5m+12000 en V
001	67108	1	0137		x x x x		44	65	1288	2270		01	44					x x	x x	FO CONFLANS	137
	30327	1	0153		x x x x		29	34	0716	2330		R6	29					x x	x x	COCHEREN H.B.L.	153 2330/2000
					x x x x													x x	x x		
0B1	67103	1	0220		x x x x		07	10	0290	1900		B1	27					x x	x x	FB BLAINVILLE	220
	30336	1	0253		x x x x		49	59	1285	2500		E6	49					x x	x x	EBANGE	253
					x x x x													x x	x x		
0S4	61441	1	0315	009	x x x x	2	19	25	0719	1500		S4	19					x x	x x	FS ST PIERRE des CORPS	306 - 560m 1500/1800
	68834	1	0307		x x x x		51	71	0117	1740	3603	U6	01	D6	45	N7	05	x x	x x	UEBERHERRN	307 306 ...
0H1	67109	1	0310		x x x x		12	19	0493	2000		H1	12					x x	x x	FH HAUSBERGEN	310 s/Ms
0Z5	61903	1	0330		x x x x		48	57	1796	1800	Z503	Z5	48					x x	x x	FZ VILLENEUVE	330
0L1	67268	1	0416	022	x x x x	2	30	45	0882	1690		L1	30					x x	x x	FL MONT ST MARTIN	354

EXHIBIT 3-25

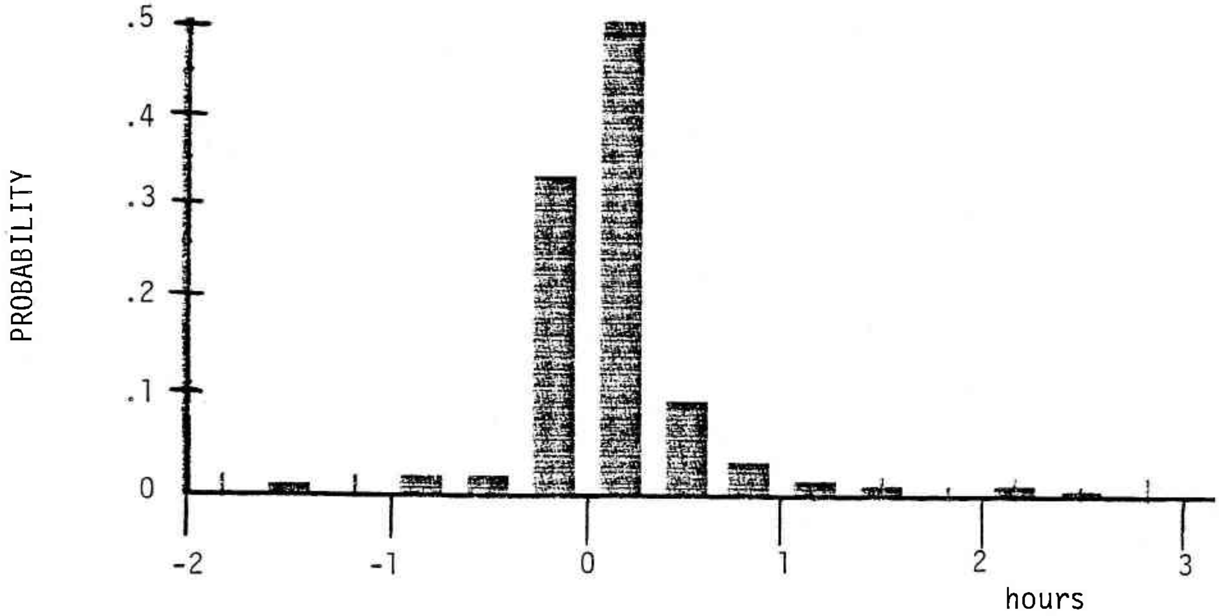
S.N.C.F. REPORT OF TRAINS DEPARTED.

EXHIBIT 3-26

EAST DEERFIELD AND WOIPPY YARDS - DISTRIBUTIONS OF ARRIVAL DEVIATIONS (ACTUAL MINUS SCHEDULED ARRIVAL TIME)



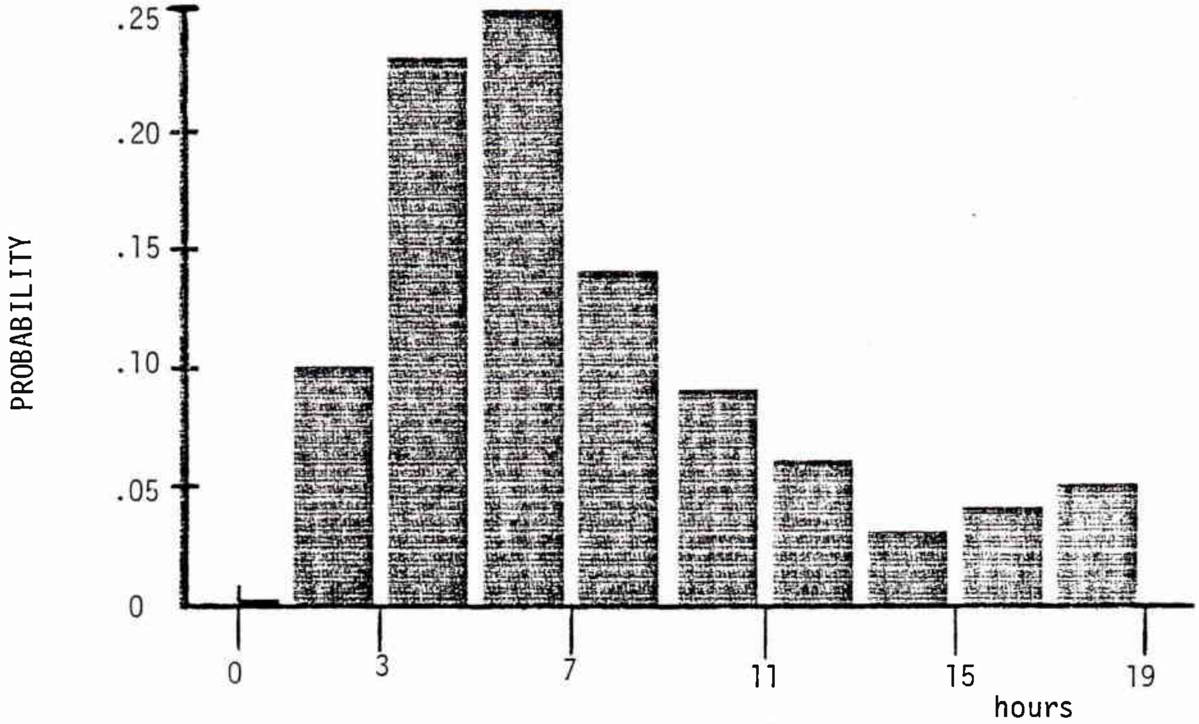
EAST DEERFIELD (NOVEMBER 10-20, 1980)



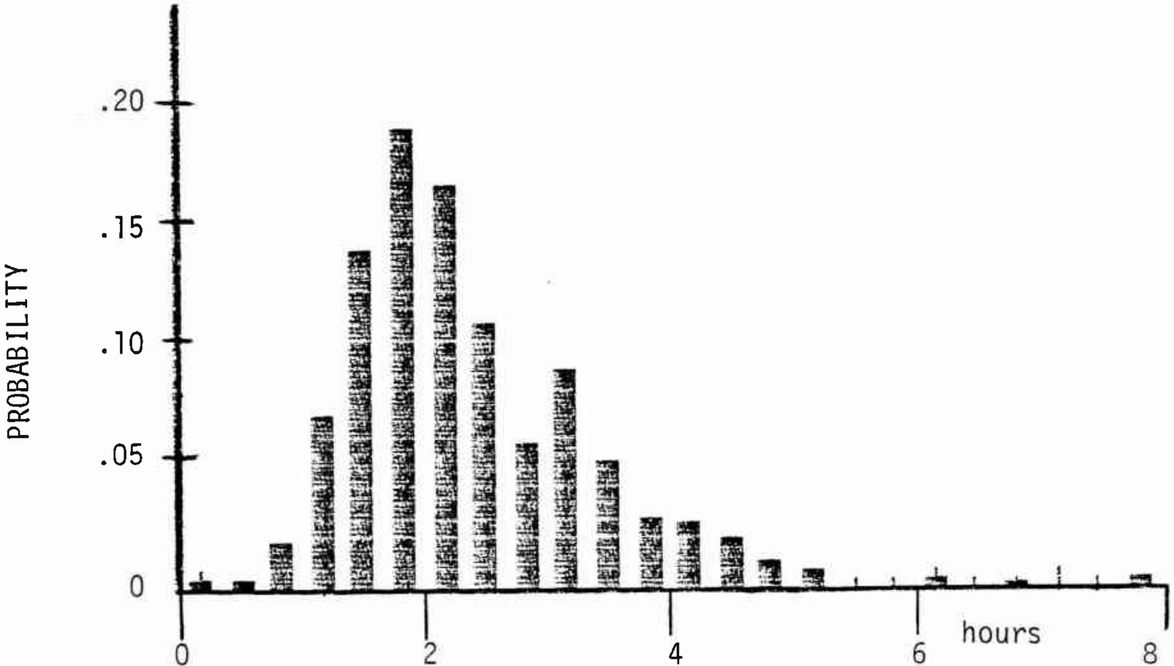
WOIPPY (OCTOBER 1-8, 1981)

EXHIBIT 3-27

EAST DEERFIELD AND WOIPPY YARDS - CLASSIFICATION TIME DISTRIBUTIONS



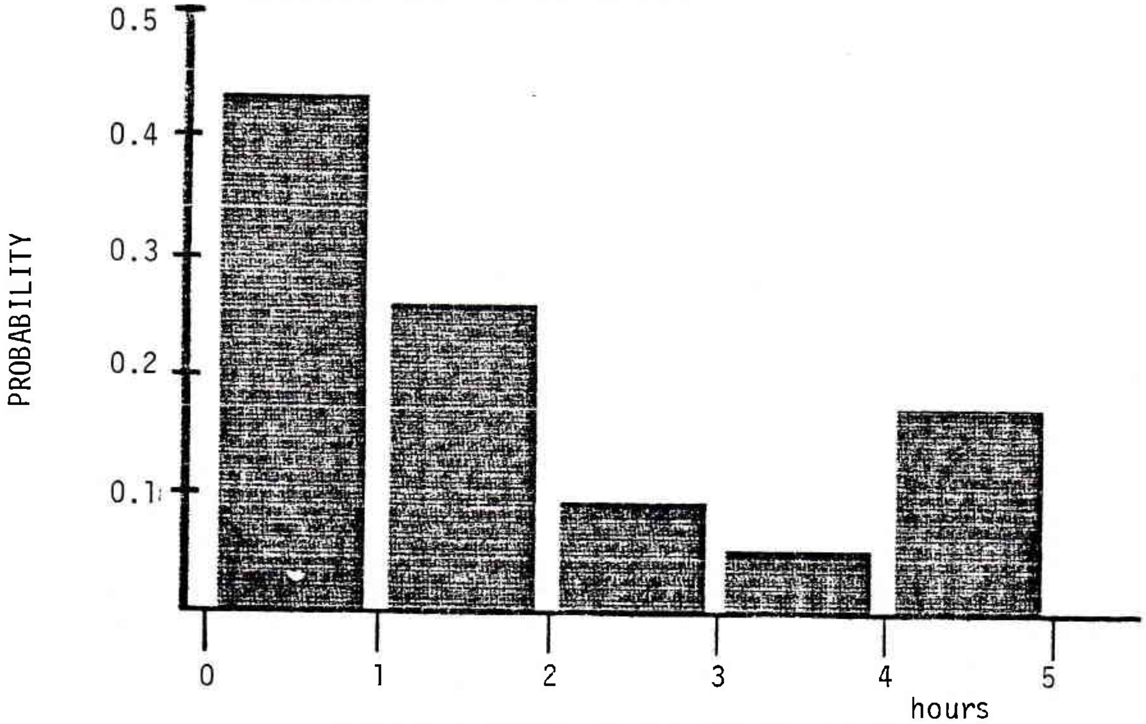
EAST DEERFIELD (NOVEMBER 10-20, 1980)



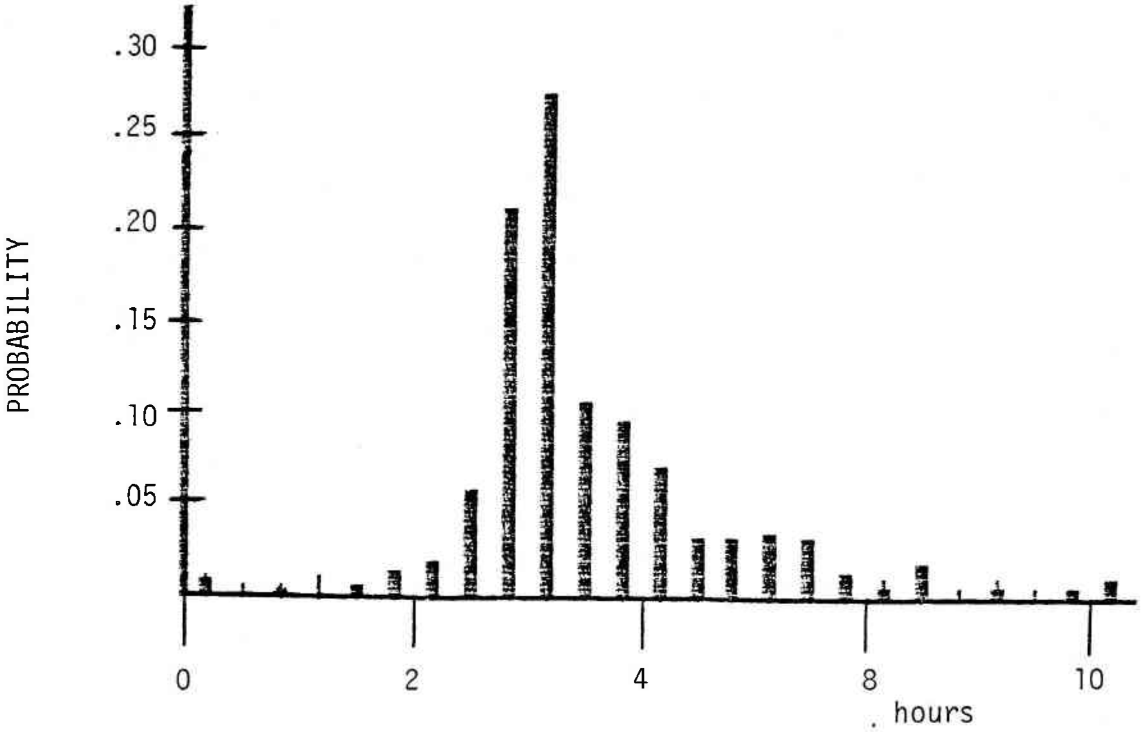
WOIPPY (OCTOBER 1-8, 1981)

EXHIBIT 3-28

EAST DEERFIELD AND WOIPPY YARDS - ASSEMBLY TIME DISTRIBUTIONS



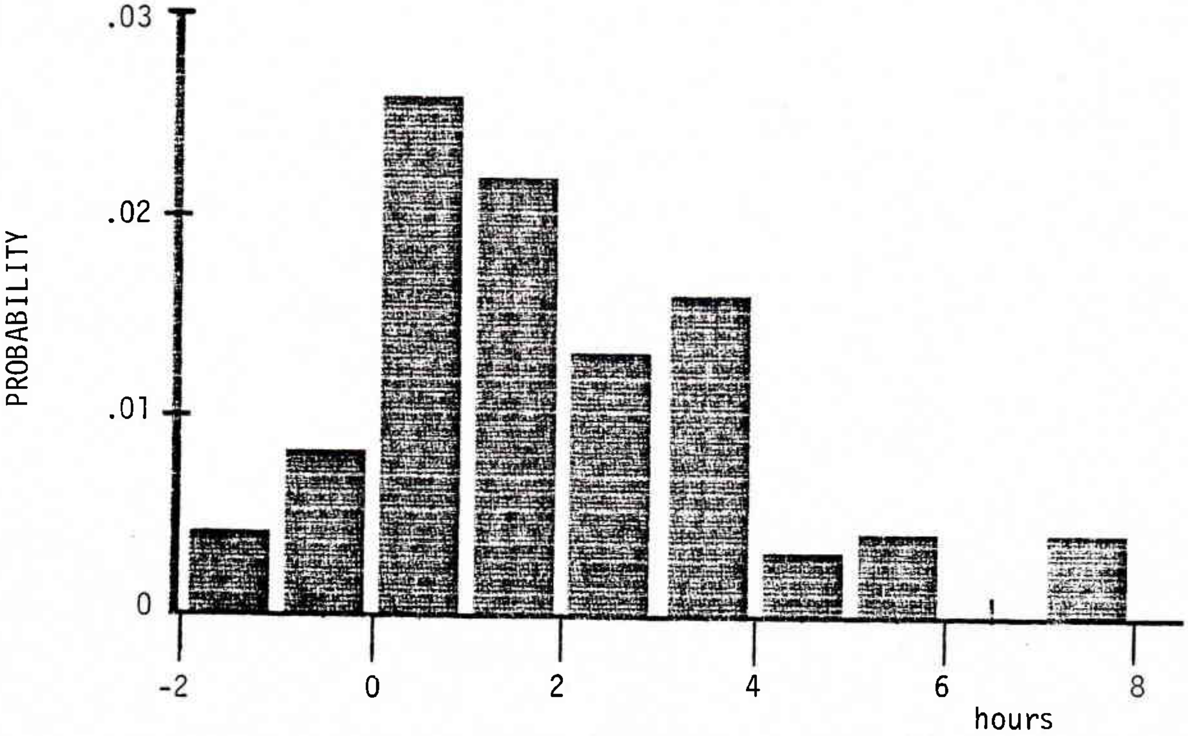
EAST DEERFIELD (NOVEMBER 10-20, 1980)



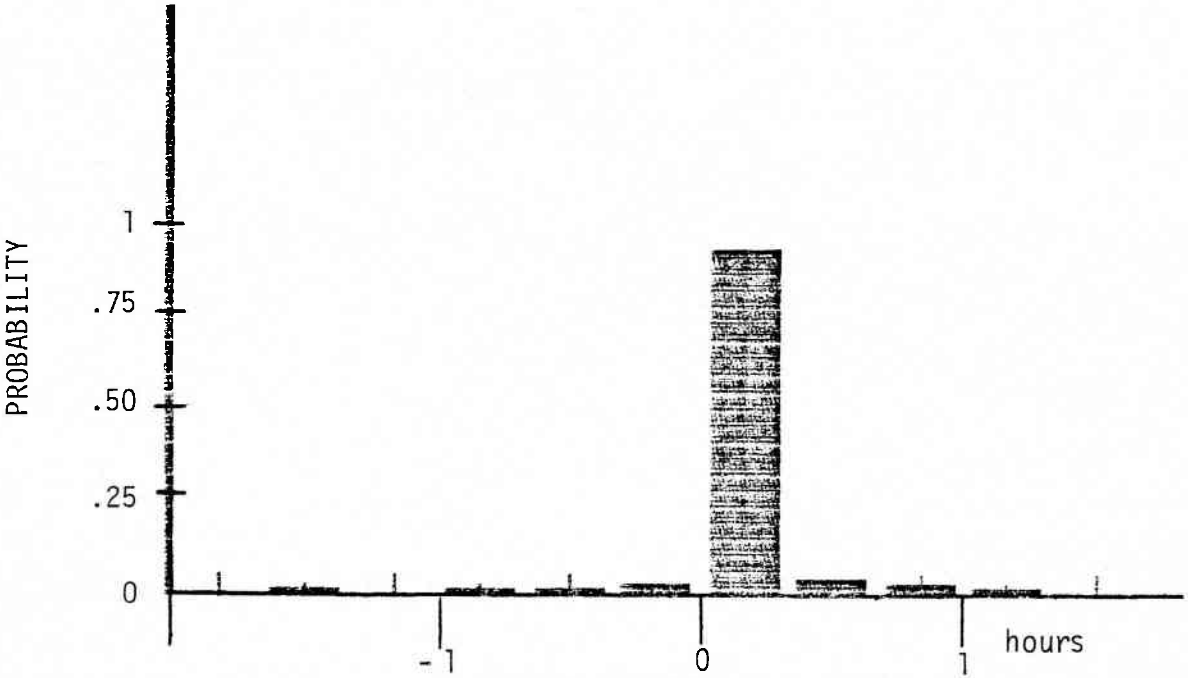
WOIPPY (OCTOBER 1-8, 1980)

EXHIBIT 3-29

EAST DEERFIELD AND WOIPPY YARDS - DISTRIBUTIONS OF DEPARTURE DEVIATIONS (ACTUAL MINUS SCHEDULED DEPARTURE TIME)



EAST DEERFIELD (NOVEMBER 10-20, 1980)



WOIPPY (OCTOBER 1-8, 1981)

equals T. Convolution means finding P(T) for all T to obtain the total processing time distribution. Let a, c, m, and d be possible assembly deviations, classification times, assembly times, and departure deviations respectively. Let

> P(T) = the sum of the quantity (p(a)p(c)p(m)p(d)) over all combinations of a, c, m, and d for which (a + c + m - d) = T.

We can calculate P(T) for all T by defining

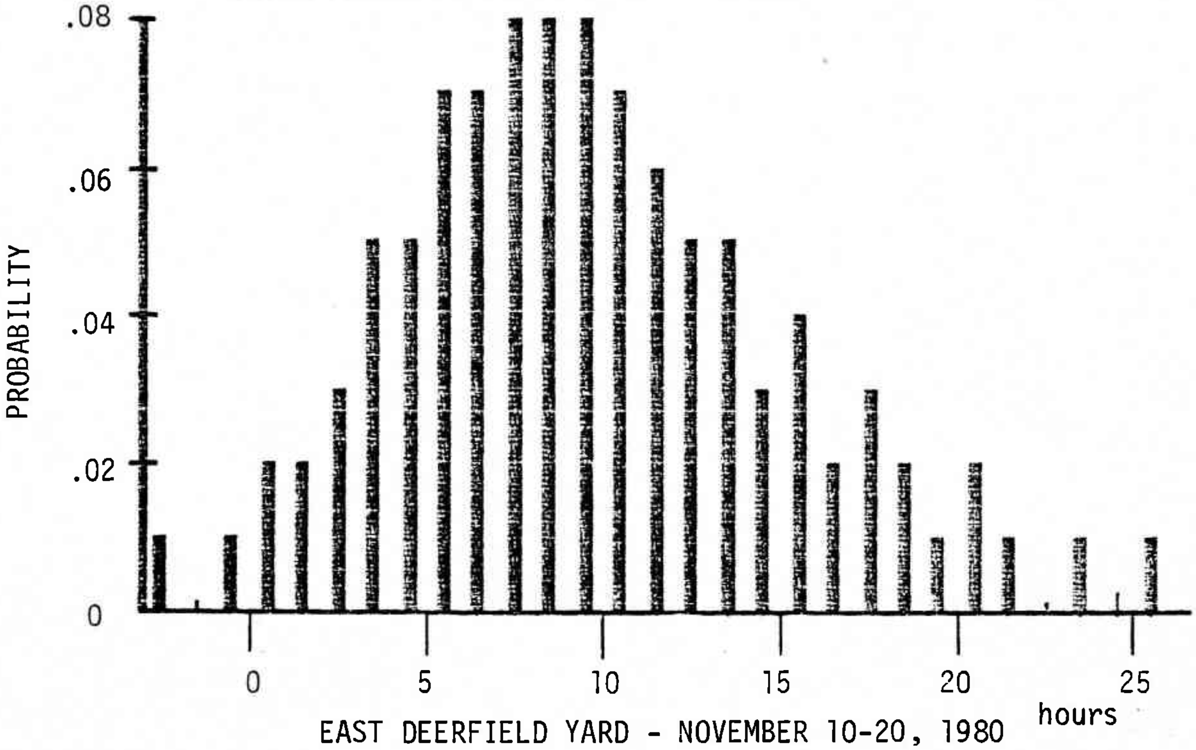
$$P(a,c,m,d) = p(a)p(c)p(m)p(d)$$

as the probability that the four processing times will equal a, c, m, and d. We then calculate P(a,c,m,d) for each possible combination of a, c, m, and d, and after each calculation update the particular P(T) for which T equals (a + c + m - d) by adding P(a,c,m,d) to it.

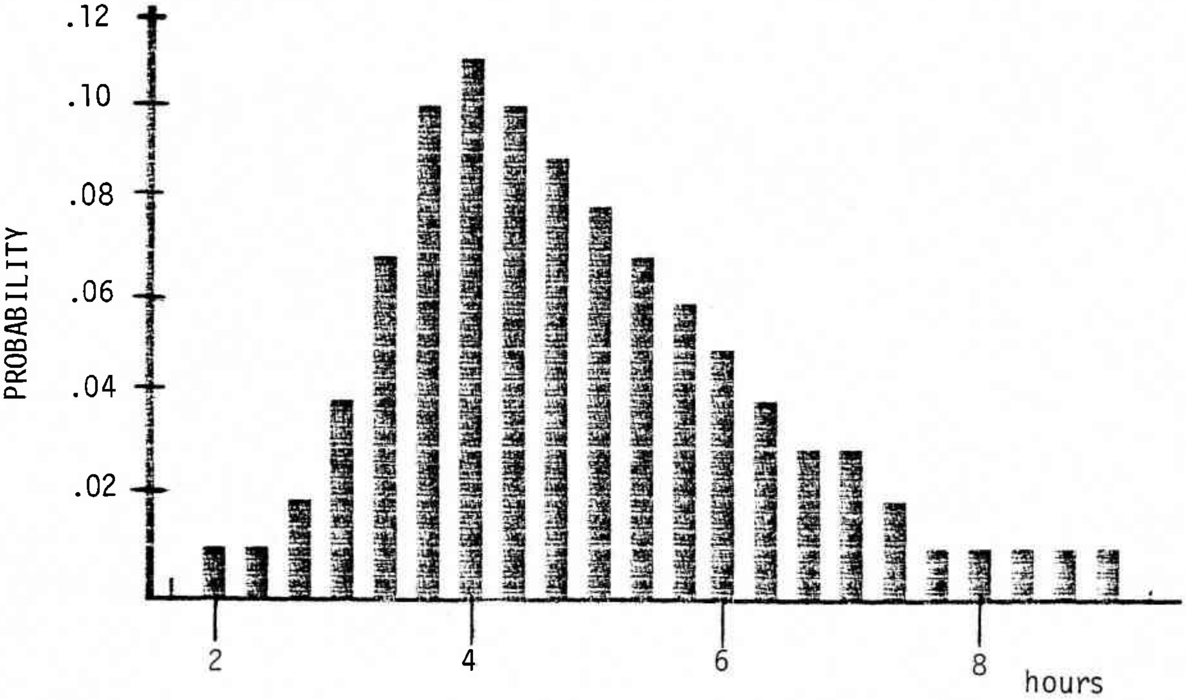
The resulting total processing time distributions for East Deerfield and Woippy yards are shown in Exhibit 3-30. In Exhibit 3-31, the summit midpoints of the histogram bars of the cumulative version of the total processing time distribution for each of the yards has been connected with a line. This line would represent a PMAKE function if there was no possibility that a train could be cancalled due to a low load, or leave some cars behind because it was full. Unfortunately, these events occur in both yards. At Woippy,

EXHIBIT 3-30

EAST DEERFIELD AND WOIPPY YARDS - TOTAL PROCESSING TIME DISTRIBUTIONS



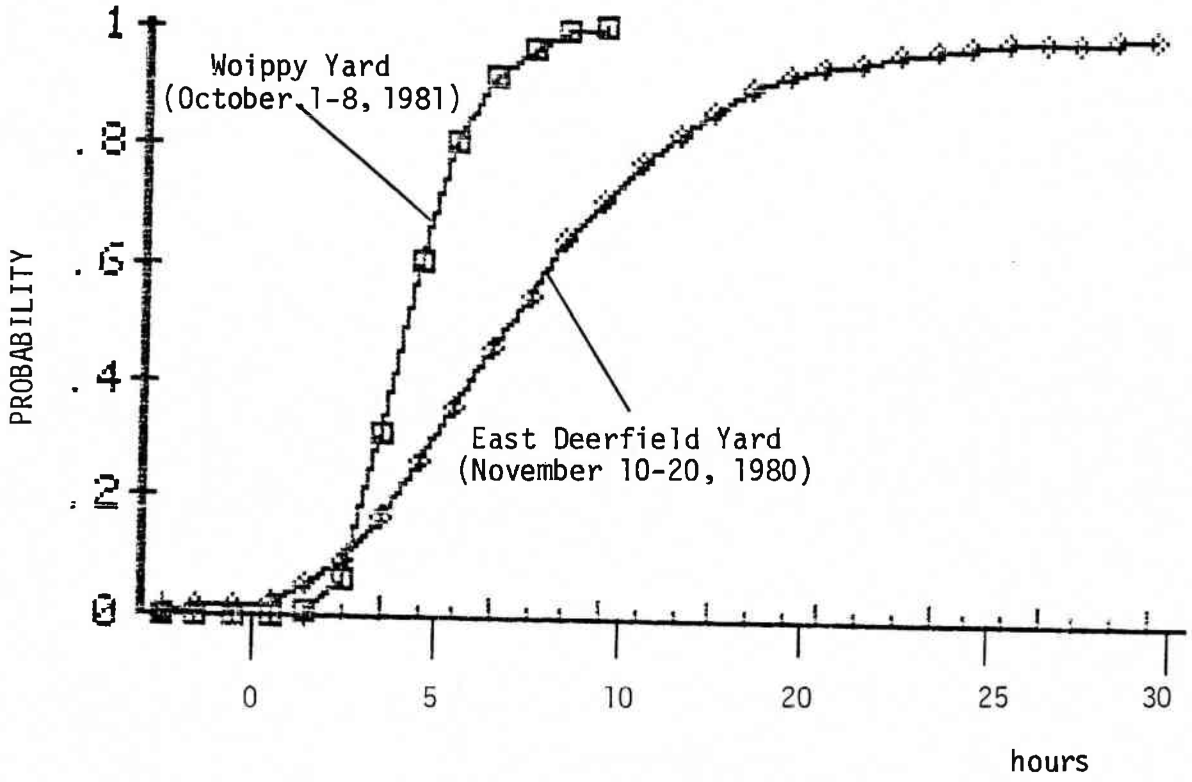
EAST DEERFIELD YARD - NOVEMBER 10-20, 1980



WOIPPY YARD - OCTOBER 1-8, 1981

EXHIBIT 3-31

EAST DEERFIELD AND WOIPPY YARDS - CUMULATIVE TOTAL PROCESSING TIME DISTRIBUTIONS

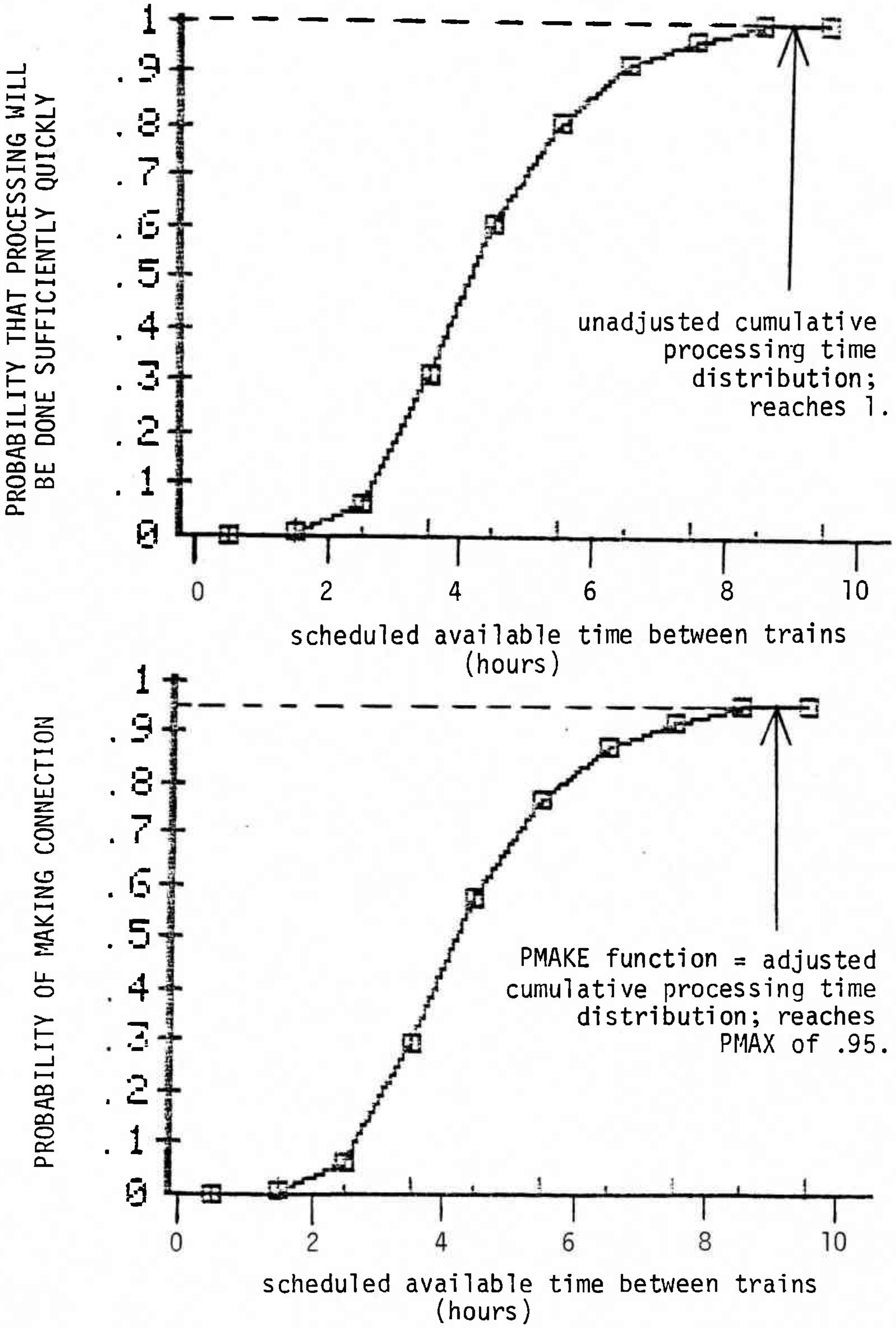


however, cars that fail to depart as scheduled because their train is cancelled are rare. This is because of an SNCF policy of running trains when scheduled, no matter how small the train's load, so that the locomotive and crew of the train will be available at another terminal as scheduled for their next train run. Much more frequent are cars that fail to depart on a scheduled train because it is full and must leave them behind. To say that a train is full is shorthand for saying that its capacity has been reached either in terms of length (it must fit into passing sidings), number of cars (for proper brake operation), or tonnage (a limit determined by the power of the locomotive and the profile of the train's route). Over the period October 1 through 8, 1981, of the 17,311 cars that departed Woippy, 875 or 5.0 percent of the cars were left behind by the first appropriate outbound train to leave the yard after they were classified. We can therefore conclude that whatever the available time between a car's inbound and outbound train, an estimate of the maximum probability that it will make the connection (PMAX) is 95.0 percent. To obtain the PMAKE function for Woippy, therefore, we must multiply the probability given for each level of available time by the cumulative processing time distribution by .95. This adjustment is illustrated in Exhibit 3-32.

In Section 3.31, regression analysis failed to reveal any direct relationship between the number of switcher hours worked and average yard time. The more disaggregate examination we are making in this

EXHIBIT 3-32

ADJUSTMENT OF WOIPPY'S CUMULATIVE PROCESSING TIME DISTRIBUTION USING PMAX TO ARRIVE AT THE PMAKE FUNCTION.



unadjusted cumulative processing time distribution; reaches 1.

PMAKE function = adjusted cumulative processing time distribution; reaches PMAX of .95.

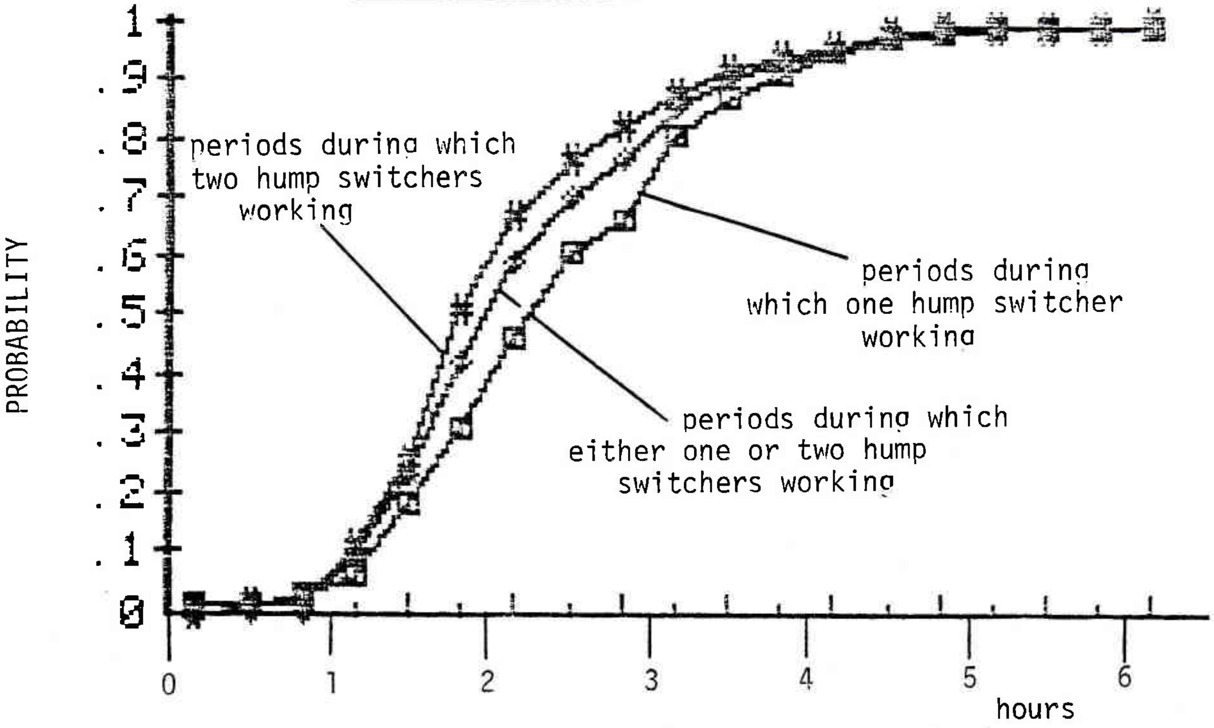
section of the components of processing time, namely classification and assembly times, lets us discern such a relationship. As shown by the switcher schedule for Woippy in Exhibit 3-18, the pattern of operations each weekday is for only one hump switcher to be working between 5 a.m. and 1 p.m., but for two switchers to be working the rest of the day. We would expect processing times to tend to be lower during the period when two switchers are scheduled, and the data confirm this. Exhibit 3-33 shows that during those periods in the weekdays of our sample where two switchers were classifying cars, both mean classification time and mean total processing time were about a half hour shorter than when just one switcher worked.

As in the case of the more aggregate measures of yard activity we examined in Sections 3.2 and 3.3, the classification and assembly distributions for Woippy yard vary over the course of the week. By comparing classification and assembly distributions for different days of the week, we can see how variations in either distribution affect the total processing time distribution and thus the yard's connection reliability. Exhibits 3-34 and 3-35 present the classification, assembly, and total processing distributions for Woippy for October 3 and 8, 1981. Similarly, Exhibits 3-36 and 3-37 show these distributions for October 1, 2, and 8, and Exhibits 3-38 and 3-39 for October 2, 6, and 7.

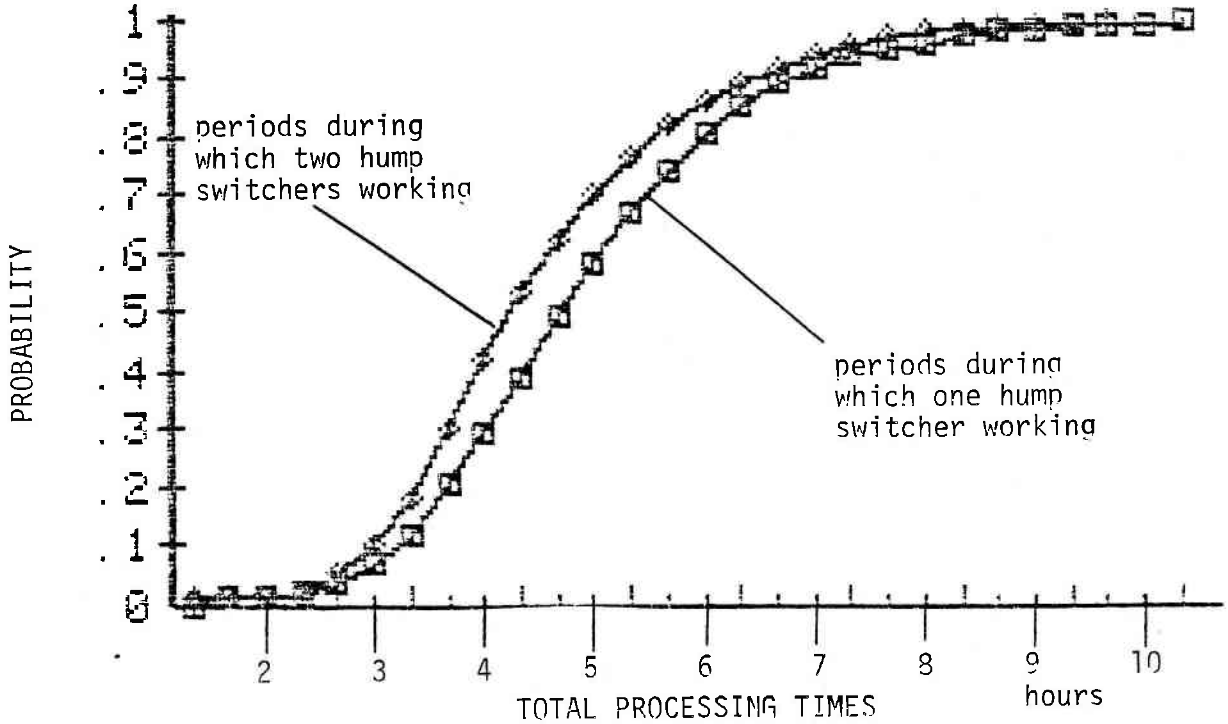
In order to verify the accuracy of the estimate provided by the

EXHIBIT 3-33

WOIPPY YARDS - CUMULATIVE DISTRIBUTIONS OF CLASSIFICATION AND TOTAL PROCESSING TIMES FOR PERIODS WHERE ONE AND TWO HUMP SWITCHERS WORKING, OCTOBER 1-3, 6-8, 1981.



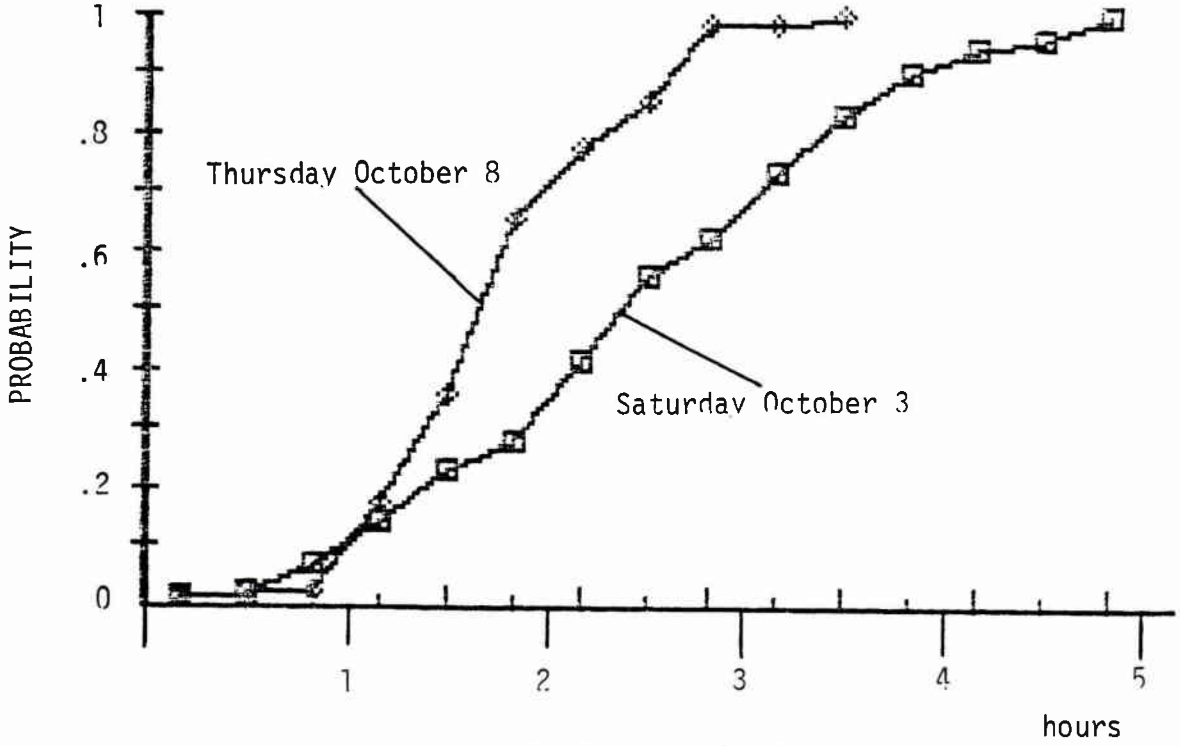
CLASSIFICATION TIMES



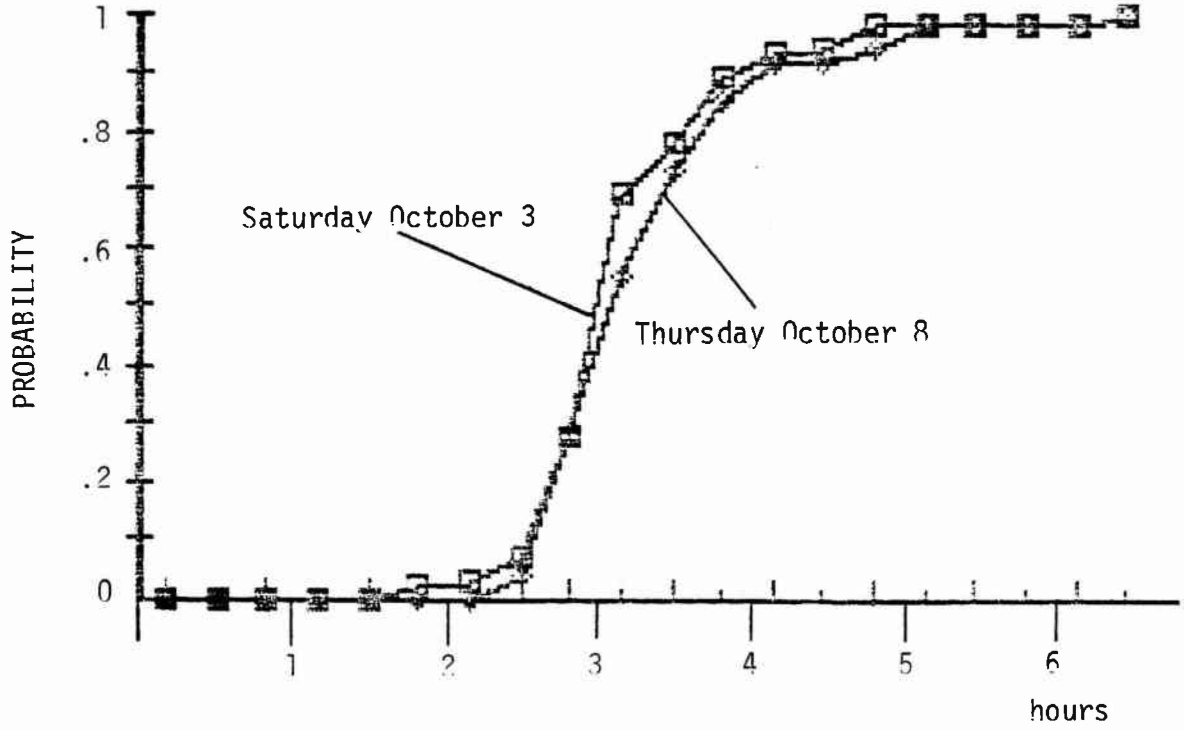
TOTAL PROCESSING TIMES

EXHIBIT 3-34

WOIPPY YARD - CUMULATIVE DISTRIBUTIONS OF CLASSIFICATION AND ASSEMBLY TIMES, OCTOBER 3 AND 8, 1981



CLASSIFICATION TIMES



ASSEMBLY TIMES

EXHIBIT 3-35

WOIPPY YARD - CUMULATIVE DISTRIBUTIONS
OF TOTAL PROCESSING TIMES,
OCTOBER 3 AND 8, 1981

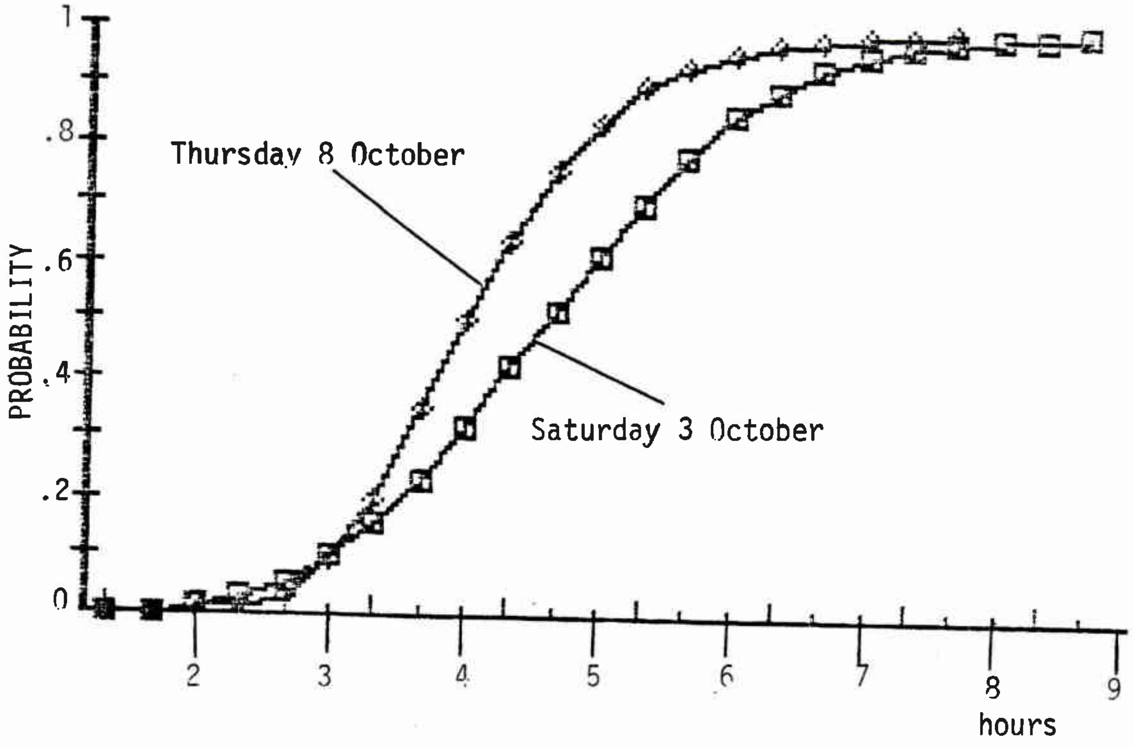
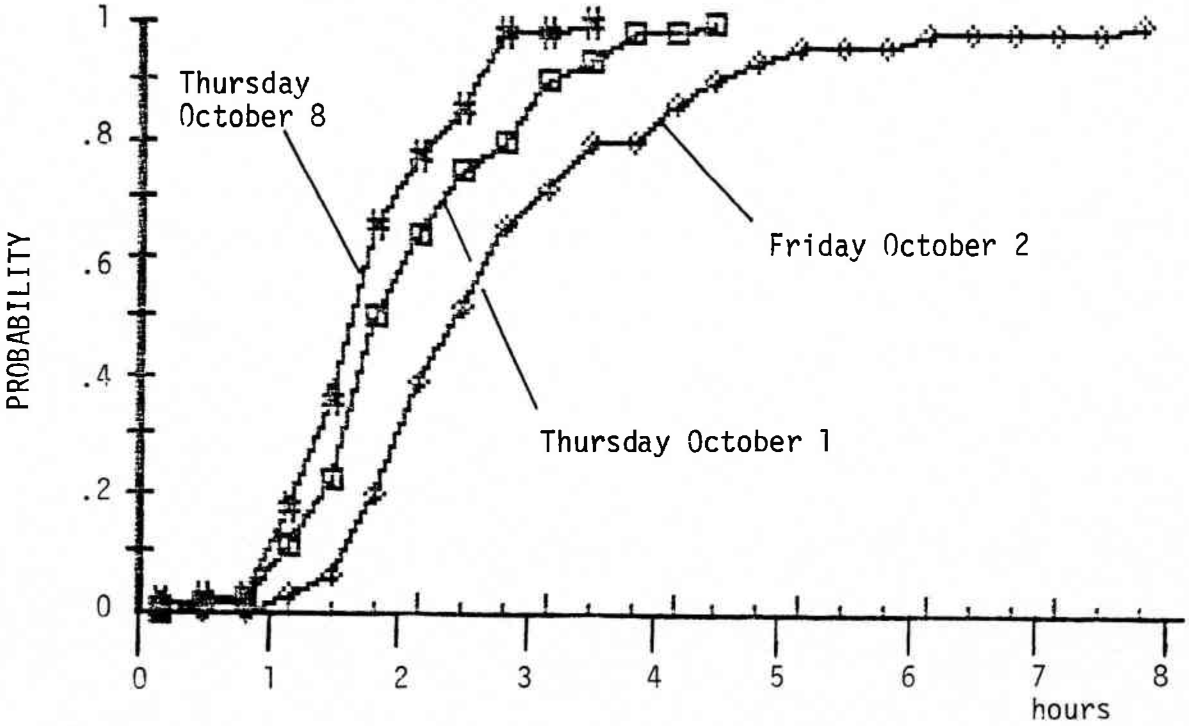
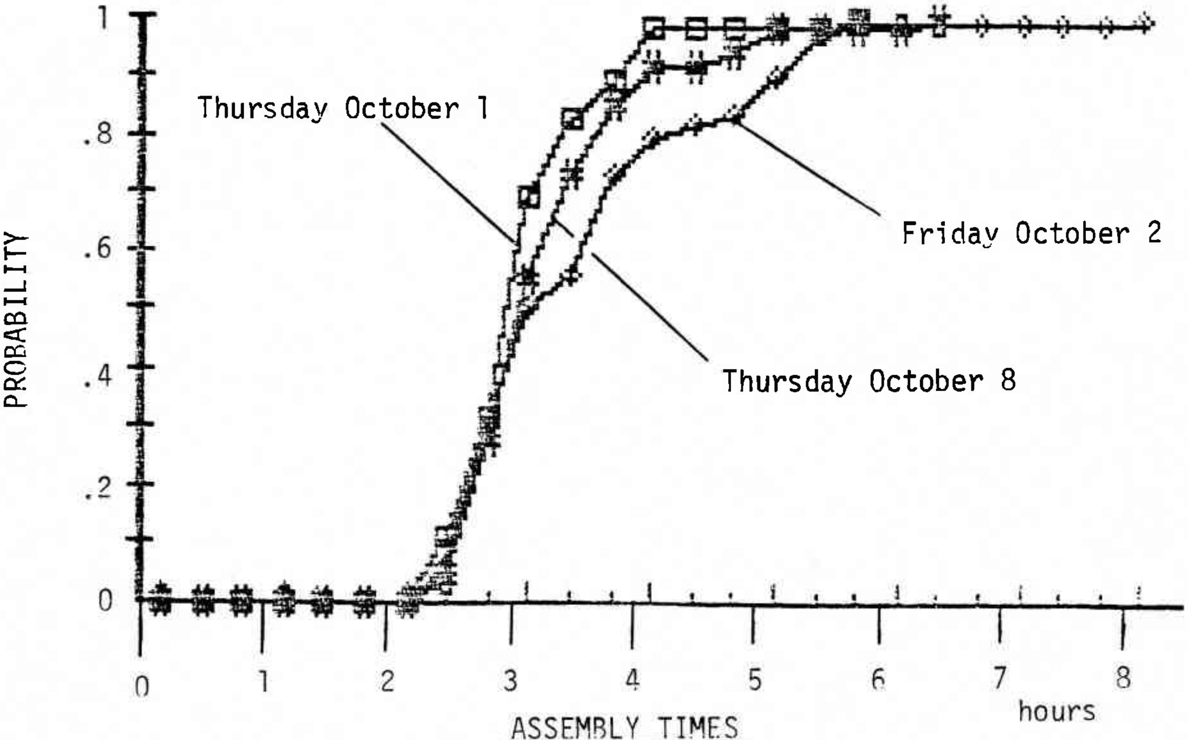


EXHIBIT 3-36

WOIPPY YARD - CUMULATIVE DISTRIBUTIONS OF CLASSIFICATION AND ASSEMBLY TIMES, OCTOBER 1, 2, AND 8, 1981



CLASSIFICATION TIMES



ASSEMBLY TIMES

EXHIBIT 3-37

WOIPPY YARD - CUMULATIVE DISTRIBUTIONS
OF TOTAL PROCESSING TIMES,
OCTOBER 1, 2, AND 8, 1981

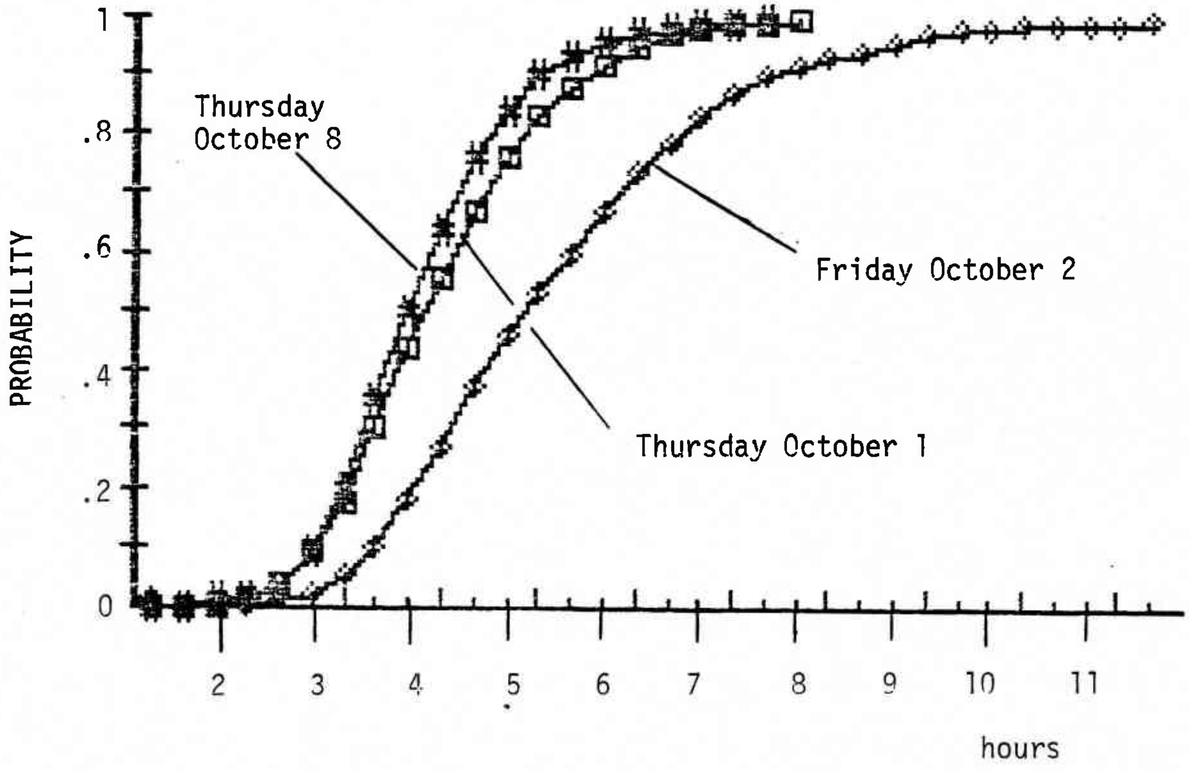
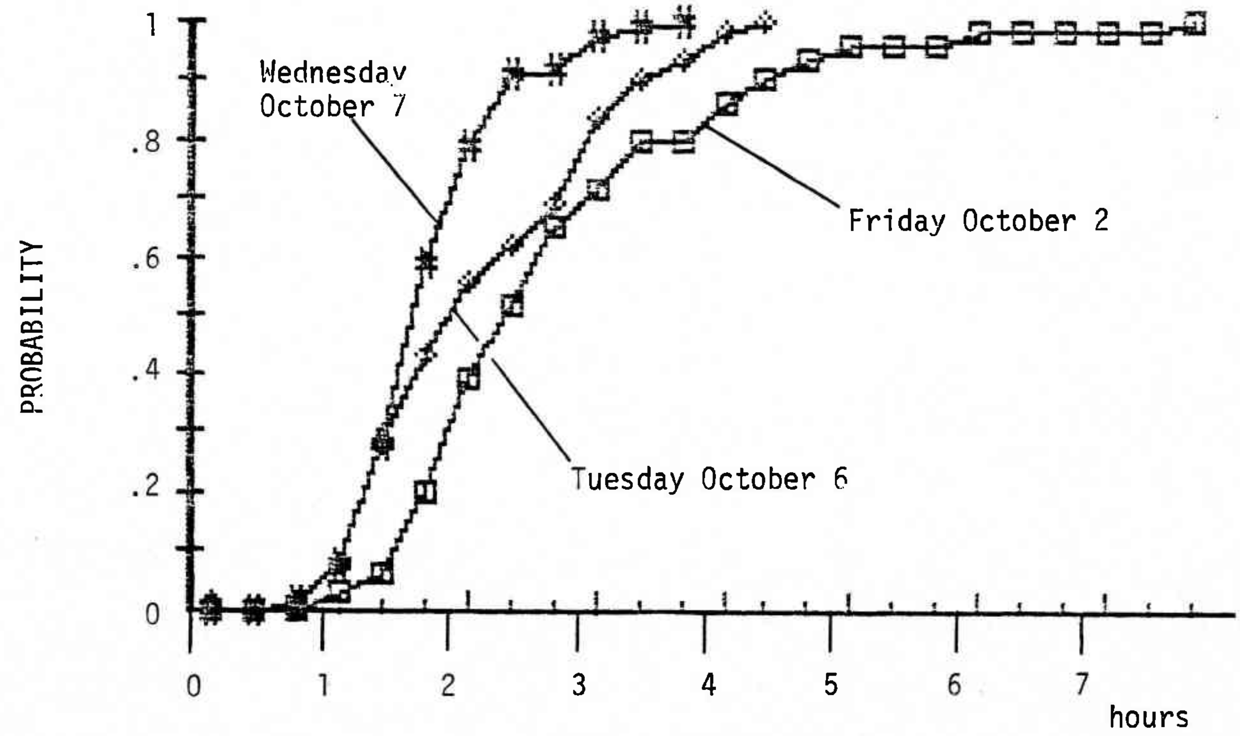
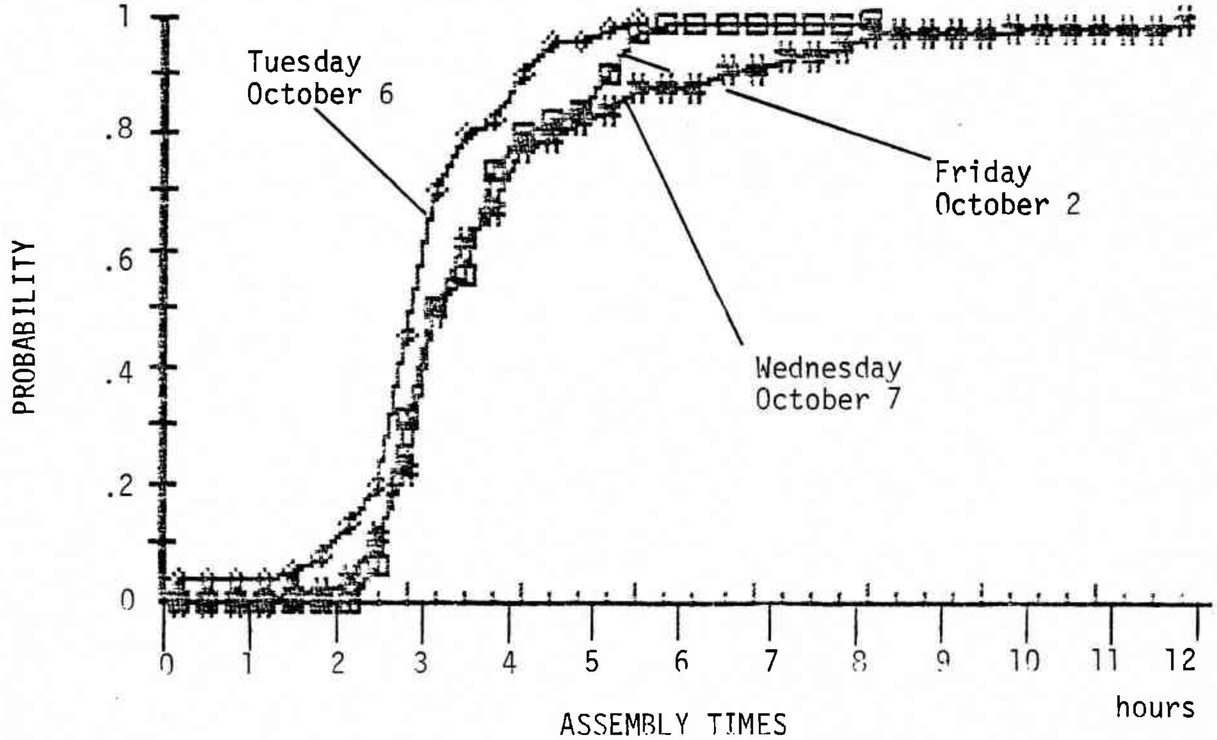


EXHIBIT 3-38

WOIPPY YARD - CUMULATIVE DISTRIBUTIONS OF CLASSIFICATION AND ASSEMBLY TIMES, OCTOBER 2,6, AND 7, 1981



CLASSIFICATION TIMES

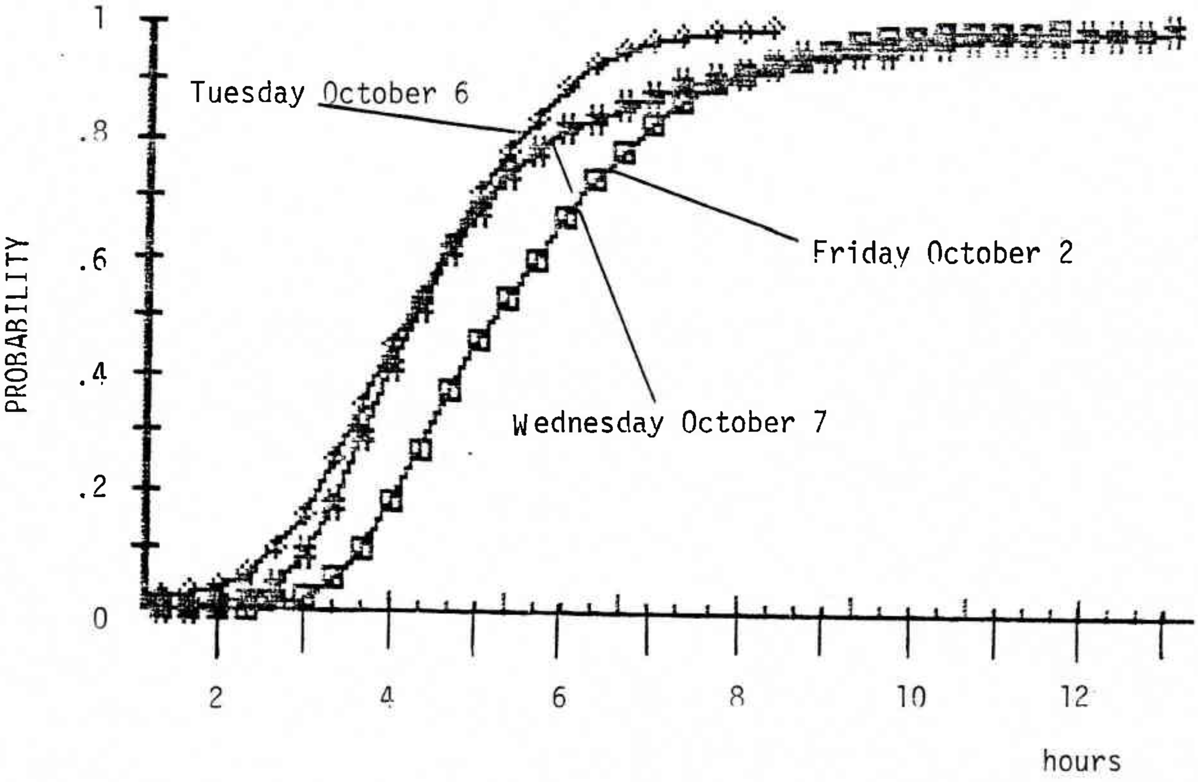


ASSEMBLY TIMES

EXHIBIT 3-39

WOIPPY YARD - CUMULATIVE DISTRIBUTIONS

OF TOTAL PROCESSING TIMES, OCTOBER 2,6, AND 7, 1981



total processing time distribution of mean processing time, we also estimated mean wait time, then compared the sum of these two means to average yard time as measured directly by the SNCF. As explained in Section 2.12, mean wait time is itself composed of two components: the average time a car spends, once classified, waiting for the next pickup of its outbound block, and the average time a car must wait because its outbound train is cancelled or full. The calculation of an estimate of both these components of wait time is shown for Sunday and Monday, October 4 and 5, in Exhibit 3-40. (All the data in this Exhibit came from the SNCF's report of departing trains, of which a sample was shown in Exhibit 3-25.) Sunday and Monday were considered together in this calculation because of the scheduled weekly shutdown of the yard during the 24 hours starting 1 p.m. on Sunday. The number N of pickups of each block is the actual number that occured on Sunday and Monday. The mean wait of the cars in each block is 24/N. The car hours due to the wait is, for each block, the mean wait multiplied by the number of cars picked up. At the bottom of Exhibit 3-40, we see that dividing the 25634 total car hours by the 1764 cars picked up yields a mean wait for pickup of 14.53 hours.

The right-hand part of Exhibit 3-40 shows the calculation of the mean wait due to a car being left by its train. During these two days, the only trains that left some cars were those picking up blocks 01 and T0. The average delay for left cars as a function of the frequency N of block pickups is 48/N. At the bottom right of

EXHIBIT 3-40

WOIPPY YARD - CALCULATION OF MEAN WAIT TIME (INCLUDING PORTIONS DUE TO PICKUP FREQUENCY AND LEFT TONNAGE).

OCTOBER 4 AND 5, 1981

```
WOIPPY CLASSIFICATION YARD
BLOCK PICKUPS AND LEFT TONNAGE

         DATE MONTH   YEAR
   SUN      4    10   1981

AND

   MON      5    10   1981

                                                    CAR
                                   CAR            HOURS
                                 HOURS              DUE
                            CARS   DUE       AVER-   TO
          PICK   MEAN  PICKD     TO   LEFT   AGE   LEFT
BLOCK      UPS   WAIT     UP   WAIT   CARS DELAY   CARS

   A0        1     24     41    984      0    48      0
   A3        1     24     38    912      0    48      0
   B1        3      8     87    696      0    16      0
   C1        2     12     39    468      7    24    168
   D6        3      8     53    424      0    16      0
   E6        2     12     41    492      0    24      0
   F0        1     24     53   1272      8    48    384
   F6        1     24     38    912      0    48      0
   G0        2     12     61    732      0    24      0
   G5        1     24     21    504      0    48      0
   H1        1     24     42   1008      0    48      0
   I6        2     12     71    852      0    24      0
   J6        2     12     22    264      0    24      0
   K6        2     12     24    288      0    24      0
   L0        1     24     45   1080      0    48      0
   L1        1     24     10    240      0    48      0
   M5        1     24     31    744      0    48      0
   N6        1     24     40    960      0    48      0
   N7        2     12     35    420      0    24      0
   O1        4      6    137    822     11    12    132
   P5        3      8     50    400      0    16      0
   Q1        2     12     36    432      0    24      0
   Q2        1     24     38    912      0    48      0
   Q6        1     24     48   1152      0    48      0
   R6        1     24     36    864      0    48      0
   S2        3      8     87    696      0    16      0
   S3        2     12     54    648      0    24      0
   S4        2     12     61    732      0    24      0
   S5        2     12     45    540      0    24      0
   S6        2     12     53    636      0    24      0
   T0        2     12     80    960     16    24    384
   T2        2     12     34    408      0    24      0
   T6        2     12     12    144      0    24      0
   U1        2     12     56    672      0    24      0
   U6        1     24     19    456      0    48      0
   V6        1     24      1     24      0    48      0
   W1        1     24     30    720      0    48      0
   W6        2     12     28    336      0    24      0
   W8        1     24      2     48      0    48      0
   Z5        2     12     65    780      0    24      0

TOTAL                   1764  25634                1068

TOTAL CARS                     1764                1764

AVERAGE HOURS                 14.53               .6054

                                                 END PG
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Exhibit 3-40, we see that the mean wait due to left cars is the total car-hours of the cars that were actually left, 1068, divided again by the total number of cars picked up, 1764, to yield a mean left-car wait of 0.61 hours.

An entirely analogous estimation of the two components of mean wait time for October 7 is shown in Exhibit 3-41. The only difference here is that since the period covered is only 24 hours long instead of 48 hours, as it was above, the mean pickup wait is 12/N, and the mean left-car wait is 24/N.

Comparison of our estimates of mean processing time and mean wait time with total average yard time is the subject of Exhibit 3-42. Note that although, on a given day of the week, the sum of processing and wait times differs by as much as one-and-a-half hours from average yard time as measured directly, the two figures are highly similar for the eight-day period as a whole (12.08 hours versus 12.25 hours).

EXHIBIT 3-41

WOIPPY YARD - CALCULATION OF MEAN WAIT TIME (INCLUDING PORTIONS DUE TO PICKUP FREQUENCY AND LEFT TONNAGE), OCTOBER 7, 1981

```
WOIPPY CLASSIFICATION YARD
BLOCK PICKUPS AND LEFT TONNAGE

        DATE MONTH  YEAR
 WED       7    10  1981

                                                          CAR
                                    CAR                 HOURS
                                  HOURS                   DUE
                             CARS   DUE          AVER-     TO
       PICK  MEAN PICKD      TO   LEFT   AGE   LEFT
BLOCK   UPS  WAIT    UP    WAIT   CARS DELAY   CARS

  A0      3     4   108     432      9     8     72
  A3      2     6    57     342      6    12     72
  B1      5   2.4   177   424.8      3   4.8   14.4
  C1      4     3   141     423     25     6    150
  D6      3     4   106     424      0     8      0
  E6      3     4   107     428      8     8     64
  F0      2     6    76     456     12    12    144
  F6      2     6    38     228      0    12      0
  G0      4     3    78     234      0     6      0
  G5      2     6    63     378      0    12      0
  H1      3     4    60     240      0     8      0
  I6      3     4    74     296      0     8      0
  J6      3     4    25     100      0     8      0
  K6      2     6    54     324      0    12      0
  L1      3     4   128     512      3     8     24
  M5      2     6    67     402      0    12      0
  N6      1    12    33     396      0    24      0
  N7      1    12    12     144      0    24      0
  O1      9 1.333   347   462.7     19 2.667  50.67
  P5      3     4    86     344     23     8    184
  Q1      3     4    80     320      0     8      0
  Q2      2     6    65     390      9    12    108
  Q6      1    12    46     552      0    24      0
  R6      1    12    28     336      0    24      0
  S2      3     4   107     428      0     8      0
  S3      2     6    74     444      0    12      0
  S4      3     4   103     412     42     8    336
  S5      2     6    61     366     11    12    132
  S6      3     4    65     260      0     8      0
  T0      2     6    34     204      0    12      0
  T2      2     6    88     528      1    12     12
  T6      2     6    35     210      0    12      0
  U1      3     4   110     440      6     8     48
  U6      1    12    12     144      0    24      0
  V6      1    12     2      24      0    24      0
  W1      1    12    39     468      8    24    192
  W6      1    12     1      12      0    24      0
  W8      1    12     2      24      0    24      0
  Y6      1    12     1      12      0    24      0
  Z5      2     6    91     546     38    12    456

TOTAL                2881   13110                2059

TOTAL CARS                  2881                 2881

AVERAGE HOURS               4.551               .7147

                                               END PG
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EXHIBIT 3-42

WOIPPY YARD - MEAN CLASSIFICATION TIME, ASSEMBLY TIME, PICKUP WAIT TIME, LEFT TONNAGE WAIT TIME, AND TOTAL YARD TIME, OCTOBER 1 THROUGH 8, 1981

WOIPPY CLASSIFICATION YARD
COMPONENTS OF AVERAGE YARD TIME

	THU 1 10	FRI 2 10	SAT 3 10	SUN 4 10 AND MON 5 10	TUE 6 10	WED 7 10	THU 8 10	AVERAGE
OUTBOUND VOLUME (000 HRS THRU 000 HRS)..	2885	2584	2515	1899	2586	3013	2997	2640
SWITCHER-HOURS..........	113	113	101	82.833	107	113	113	106
AVERAGE CLASSIFICATION TIME.....	2.22	2.96	2.60	2.08	2.39	1.98	1.89	2.29
AVERAGE ASSEMBLY TIME:.........	3.26	3.70	3.32	4.14	3.10	4.04	3.45	3.56
AVERAGE WAIT FOR BLOCK PICKUP........	4.88	4.50	5.05	14.53	5.09	4.55	4.52	5.76
AVERAGE DELAY DUE TO LEFT TONNAGE:........	0.29	0.35	0.41	0.61	0.79	0.71	0.19	0.47
TOTAL AVERAGE YARD TIME:								
ACTUAL (SUM OF ABOVE)...	10.65	11.51	11.39	21.35	11.38	11.29	10.05	12.08
ACTUAL (AS MEASURED DIRECTLY)..	10.84	11.91	13.17	20.01	12.39	10.69	9.54	12.25

END PG

3.5 Summary and Interpretation. Having presented the results of analyses of data from two classification yards, we close this chapter with an interpretation of these results and recommendations about which kinds of performance standards are most appropriate for each yard. In this chapter, we have investigated the relevance of several kinds of standards for switcher use, fuel use, and car movement to each of our classification yards. We analyzed the relationship among averages for each of the seven days of the week of a set of yard activity measures. We estimated regression models for switcher and fuel use, and average yard time. For a sample week, we developed and validated estimates of mean processing time and wait time. Finally, we used discrete distributions of processing times to set a PMAKE function that expresses the connection reliability of the yard.

On the basis of these results, and on each yard's particular circumstances, we recommend for each yard different kinds of standards. Specifically, we recommend a regression-based standard for switcher use at East Deerfield, but a day-of-week standard for switcher use at Woippy; a fuel use standard for East Deerfield having a ratio form; a day-of-week average yard time standard for East Deerfield, and a fixed processing time standard for Woippy; and PMAKE connection reliability standards at both yards.

In Section 3.2, we analyzed the relationship among inbound volume, switcher use, average yard time and outbound train frequency for averages of each of the seven days of the week. We found that inbound volume and inbound volume per switcher hour both had discernable effects on average yard time, but that these effects were swamped by the influence of outbound train frequency of yard time.

The regression analyses presented in Section 3.31 showed that at both yards, inbound volume had no significant statistical effect on yard time, but that it did have a significant effect on switcher hours. Our inability to establish that a significant relationship exists between inbound volume and average yard time lends support to the hypothesis that the managers of both Woippy and East Deerfield adjust switcher-hours so as to maintain roughly constant processing times over a range of volumes.

A standard for switcher-hours that was consistent with this hypothesis should vary solely with volume. In Section 2.31, we hypothesized that a substantial fixed portion existed in the variability of switcher use with volume. This is confirmed by the regression analyses of Subsection 3.31. The yard manager may partially carry out adjustment of switcher-hours to volume ahead of time, as a function of what volume was on each day of the week in previous weeks, and partially as a function of the number of cars that actually arrive on a given day. The correlation between volume and switcher use is lower for Woippy. This indicates either that yard managers have less liberty to tailor the number of crew hours to the workload, or that the usual number of switcher hours is high enough to handle all but the highest volumes without being increased.

In Section 3.32, we used the switcher-use standard we had developed in Section 3.31 for Woippy to evaluate the crew schedule of that yard. As Exhibit 3-19 showed, neither the scheduled switcher-hours nor the average actual switcher-hours was precisely matched to volume on any day of the week. One possible interpretation of this result relates to our earlier hypothesis about why the correlation between volume and switcher use was lower at Woippy than at East Deerfield. More of the variability of switcher-crews is due to the crew schedule at Woippy and less is due to real-time decisions, so Woippy yard managers may find it harder to match switcher-hours to the actual volume on a given day. The fitted line shows that the scheduled crew use roughly follows the overall pattern of volume, but that indivisibilities in the way that yard managers can adjust switcher use prevent a perfect match of switcher use to volume. The regression-based performance standard would also seem less useful at Woippy because volume varies much less from week to week than at East Deerfield. This can be seen in Exhibit 3-12. Over the days of the week on the basis of which we are trying to set a standard, the ratio of mean switcher-hours to the standard deviation of switcher-hours is 10.5 for East Deerfield, but 19.0 for Woippy.

In Section 3.31, we noted the lower correlation between inbound volume and outbound train frequency at East Deerfield than at Woippy. A number of interpretations of this result are possible. One explanation is the much lower number of trains involved at Deerfield. A given train is cancelled or supplemented with an extra train only when the number of cars available for movement on it was either very low or very high. A general rise in volume is much more likely to be cleanly reflected in a yard departing an average of 80 or so trains a day than in one departing about 10 trains. This is especially true because the proportion of the trains beginning their runs at Woippy as opposed to an earlier yard is much greater than the proportion of outbound trains that originate at East Deerfield.

The finding of Section 3.2 that outbound train frequency swamped other factors in its power to determine average yard time was confirmed in the regression analyses of Section 3.31. These analyses also showed, however, that at both East Deerfield and Woippy, the explanatory power of a regression model of average yard time as a function of outbound train frequency was significantly enhanced by the addition of switcher hours as a second explanatory variable. The only trouble was that the resulting coefficient for switcher use was not just significant but positive -- indicating that if the yard manager worked more switcher hours, average yard would be higher. However, both the plot of the "day-of-week" data shown in Exhibit 3-6 and the regression models of Exhibit 3-13a show that as the ratio of inbound volume to switcher-hours worked rises, so does average yard time. This indicates that higher inbound volume has the effect illustrated by arrow B in Exhibit 2-1: it leads to both more switcher-hours and higher processing times.

At this point we are faced with two alternatives in our further development of the similar regression models we have developed for the two yards. The first option would be to retain switcher-hours as a second independent variable along with outbound train frequency. Switcher-hours would then serve as an index of the degree to which yard operations were perturbed by unmeasured operating incidents. This index would then lead us to expect a higher average yard time when operating conditions were apparently such that more switcher-hours were needed. The problem with such an index is the indirectness of the relationship between switcher-hours and average yard time. If we sought to make this relationship the basis of a performance standard, we would find this indirectness has two drawbacks: it makes us uncertain about the future relationship between switcher-hours and average yard time, and it is difficult for us to make it the basis of a standard because it is counter-intuitive and thus will have difficultly gaining acceptance among those whose work will be evaluated by it. Were we to adopt the regression model of average yard time as a basis for a car-movement standard, therefore, we would have to drop switcher-hours from this model.

This would leave us with the outbound train variable as the only independent variable in this model for either yard.

One of our goals has been the establishment of a car movement standard that seperates out wait time, for which the yard manager isn't responsible. Having decided that if the regression-based car movement standard is to be used at all, outbound train frequency must be the only independent variable in the regression-based standard for average yard time, we then examined the accuracy with which this model would let us estimate mean processing time. Clearly, the procedure of estimating mean processing time by means of a regression of average yard time on outbound train frequency yields an estimate whose accuracy is inadequate.

Fortunately, for both yards, two kinds of car-movement standards were available as alternatives to the regression-based one. At Woippy, where the necessary data is already collected on when each train's classification ended or its assembly began, we recommended that this data be used to calculate mean processing time directly. On the basis of this measurement method, a standard for processing time can be set and subsequent actual processing time measured and evaluated. In Section 3.4, we saw that over the course of our sample week, the sum of our estimates of mean processing time and mean wait time at Woippy was nearly identical to the SNCF's direct measurement of total average yard time. This is evidence that the techniques we have described in this section provide estimates of processing time and wait time that are good enough to be made a useful part of the management information system for the yard. Specifically, they provide headquarters with measures of the car movement performance of the yard and of the road movement organization that are more meaningful than total yard time.

At East Deerfield, on the other hand, collection on an ongoing basis of processing times will probably not be undertaken in the near future. The circumstances of the yard make this a costly task, for not all cars are processed in the same way. When an inbound train is humped at East Deerfield, although some cars will be placed immediately on the track corresponding to their outbound block, others will be first classified onto one track, then pulled back up over the hump for reswitching.

Re-switching lets the number of blocks made by the yard exceed the number of classification tracks. What it means, however, is that in order to know the time from train arrival until the end of classification of a reswitched car, yard personnel cannot simply refer to the arrival time of the cut out of which the car is switched onto its final classification track, because a cut being reswtiched may contain cars from several inbound trains. Instead, a fully accurate monitoring of processing time would require that the arrival time of each car be kept track of individually. Of course, some procedure for estimating processing time could be developed, such as measuring actual processing times for cars that aren't reswitched, then increasing the resulting mean time by a multiplier reflecting the estimated increase in mean processing time due to the inclusion of reswitched cars.

Otherwise, recording the time at which each car's classification ended will be more costly at East Deerfield that it now is at Woippy, where the only reswitching is the placing of cars of local trains in station order (an operation not included in our measurement of processing times at Woippy). Because the needed data for a directly-measured mean processing time standard is absent, we recommend for East Deerfield a day-of-week average yard time standard, which takes into account the average effect on each day of the week of operating conditions on yard time without explicity estimating this set of effects.

We showed, finally, how PMAKE functions can be developed for both yards. We recommend that these be used by the headquarters of the respective railroads to predict origin-to-destination trip times and reliability. Although we saw in Exhibit 3-34 through 3-39 that the cumulative processing time distribution displayed significantly different shapes over the eight days of our sample period, statistical analysis over a longer period would be needed to establish how operating conditions such as volume affect the distributions of the processing times. We also saw in Exhibit 3-33 that during six days in our sample, mean total processing time was about a half hour shorter when two hump switchers were at work than when one was. In this author's opinion, however, neither this effect, nor the possible effects of inbound volume, or of what day of the week it is, should be a reason for setting a variable PMAKE function. Instead, one PMAKE function should be established for the yard, and the yard manager held to it under all circumstances. We want to motivate the yard manager to vary his switcher-hours and other resources such that, regardless of the changes in volume or other operating conditions, connection reliability at the yard is as constant as possible. This does not mean that each train's processing time should be the same, but merely that the distribution of processing times, and their mean, should be constant.

CHAPTER FOUR:

INTEGRATION OF THE YARD PERFORMANCE STANDARDS INTO THE RAILROAD'S CONTROL SYSTEM

Thus far, we have explained why we need performance standards, categorized them, presented hypotheses about the relative costs and advantages of each kind, and estimated standards of each kind (fixed, day-of-week, ratio, and linear) for the yard performance measure for which it is most appropriate. In this Chapter, we will show how these standards can be integrated into the management information system of a railroad to enhance the ability of central management to link the yard's cost and service performance to that of the system, and to motivate the yard manager to maintain and improve performance, without compromising his discretion to make the day-to-day decisions needed for the efficient operation of the yard. Section 4.1 will present the rationale for measuring performance, and setting standards for it, in both physical and monetary terms. Measurements of physical performance permit comparison among different periods despite price changes, and, in the form of the PMAKE function, let yard service performance be linked to the service performance of the system. On the other hand, stating performance in terms of costs, including those of switchers, cars, and potentially yard maintenance, is essential if headquarters is to link the yard's cost performance to that of the system.

The succeeding sections of this chapter present examples of documents that management could use to implement these standards. Section 4.2 presents such documents in the form that would be best for a yard like East Deerfield; Section 4.3 presents the documents in a form adapted to a yard like Woippy. The documents fall into two categories: budgets and performance reports. The budgets are to appear periodically, but in each case before the period for which they specify the cost performance that the yard is to acheive. In constrast, performance reports are to appear more often, preferably weekly. They should appear just after the period for which they present standards, and juxtapose these standards with actual performance in terms of such key yard activity measures as switcher-hours worked, switcher cost, processing time, and car cost.

4.1 The Management Information System: General Issues. In this section, we will examine how to implement the standards whose desirable characteristics we explained in Chapter Two, and which we actually calculated in Chapter Three. Two vehicles will be employed to do so. First, the standards, all of which are stated in terms of physical measures of yard activity, will be made the basis of a budget that specifies, for a future period, what the overall cost performance of the yard should be as a function of the somewhat unpredictable level of inbound volume. Second, the degree to which the yard was actually able to actually achieve the levels of physical and cost performance specified in the budget is to be presented in a performance report that juxtaposes actual performance for the preceding week with standards. Recall our triple purpose for a standard -- as predictor, troubleshooter, and motivator. In the budget, a performance standard appears in its role as predictor. In the weekly performance report, it fulfills its function as a troubleshooter. Both the budget and the weekly performance report are vehicles for motivation; the budget informs the yard manager of what he is expected to achieve, and the prospect of the weekly report provides an incentive for him to achieve it.

Different managers at different levels of the organization want data of different degrees of aggregation. The reports we will propose in this chapter can serve as an intermediary between yard and headquarters, because they provide a level of detail that is intermediate between the greater detail sought by the yard manager, and the greater aggregation sought by headquarters. [17].

We must set standards for both the physical measures of yard performance at the yard and the finanical ones. Physical measures are independent of changing price levels, and can be the basis of standards that need not be changed from year to year. Measuring performance in physical terms lets us compare the current value of a given performance measure, or its current relationship with another measure (as expressed, for example, by an equation relating volume to switcher use), with the values or relationships the measure displayed in the past. This aids evaluation of performance. However, in order to link yard performance to system financial performance, physical performance at the yard must be translated into cost, and the standards for this performance into a budget.

In Section 2.2, we said that a good performance standard will bridge the gap between headquarters and the yard by apprising headquarters of the yard manager's constraints, and by motivating the yard manager to run the yard in the way that best contributes to the needs of the system. In comments he meant to be applicable to any business, Drucker finds that the budget

> ...shows how each part relates to the ends and needs of the whole... Properly used,...the budget becomes an important communication and integration device for the manager. It should induce effective upward communication, which brings the manager the point of view, priorities, concerns, and needs of each subordinate unit... And it should...(enable) the manager to convey to the people who work with him an understanding of the needs of the entire business.

The budget, Drucker says, is the best means for making sure that key resources are assigned to priorities and to results. Budgeted costs should be seen as a shorthand for the actual materials, labor, and capital capacity needed. [18] The budget is an important document for yard management, because a number of departments are typically involved. Unfortunately, despite its great influence on how the terminal performs, the budget for a particular operating group at the yard, or even for the whole yard, may ignore whole categories of cost. [19] For example, the budget for the manager that oversees the work of the switchers may not have the fuel of the switchers in his budget if that is the responsibility of the mechanical department. Or the budget for the terminal as a whole may ignore the capital cost of locomotives or cars.

Unfortunately, the physical measure of the yard's contribution to the railroad's service quality and thus its revenue, connection reliability, is harder to put a dollar value on, so yard service performance is best linked to that of the system via its physical measure. Yard performance affects the system's origin-to-destination trip times and reliability, which in turn affect system revenues. We saw in Section 2.32 how the yard's service performance can be summarized by a PMAKE function, and this function used to deduce system service quality.

To show how yard performance in physical terms can be related to the profitability of the railroad as a whole, we must relate the physical standards to the yard budget. To show how this might be done, we have developed samples of reports that could be used for management control at East Deerfield and Woippy. Of course, the railroads of which these yards are a part already have control systems that link physical performance to cost, and already have budgets. The important difference is that the budgets we propose, (1) include car costs as well as operating expenses, (2) are volume-variable, and (3) in the case of Woippy, isolate processing time -- and its associated car cost -- from the total yard time of cars. In the case of the Woippy yard, volume-variability results from the fact that the total car-hours and thus car cost will rise and fall with the volume of cars moving through the yard. This source of cost variability is also present in the budget for East Deerfield, but another source is present as well: the volume-variable standard for switcher use.

Two kinds of reports will be presented: The first puts forward a volume-variable budget. As in conventional budgets, management would set this one at the start of the budget period (i.e. the quarter or the year). However, the budget we propose presents not just one budget figure, but a range of budget figures, each corresponding to a different weekly volume level. The second set of reports would be produced at the end of the week. They present a comparison of actual performance to performance as specified by the standard corresponding to that week's volume.

In Section 2.3, we stressed the need for a performance standard to respect the constraints of the yard manager while staying as simple as possible. The need for simplicity in controls is also emphasized by Drucker. Managers should seek "the smallest number of reports and statistics needed to understand a phenomenon and to be able to anticipate it." The purpose of controls is action, Drucker says, not information. "Complicated controls...misdirect attention away from what is to be controlled, and toward the mechanics and methodology of the control." [20] Simplicity is one of the features of our proposed budgets and reports.

To accomplish the goal of bridging the perspectives of yard and headquarters, we need reports that appear once a week. As pointed out by Rothberg, Ferguson, and their associates, a weekly report on actual and standard performance is most useful because it

--presents information that is at once fresh and substantial enough to serve as the basis for action,

--corresponds to the weekly horizon of the yard manager's planning,

--includes the complete weekly cycle of volume fluctuation that is induced by the train schedule, and

--provides a seven-day sample of current performance that is large enough to let its user detect trends (smoothing out daily fluctuations or isolated operating incidents) but available soon enough to let the yard manager or his superiors take corrective action. In short, it provides the statistical significance that an evaluation of the terminal cannot attain until a week has passed.

Along with operating costs, such as those of labor and fuel, should be considered the cost of car time. Establishing an hourly cost for each car and including it in the yard information system sets the stage for two improvements in the control system. First, car cost can then be traded off against other costs by the yard manager. Second, the cost of delays to cars and trains containing them can be charged to the manager who was responsible for the cars during the delay. This might be the yard manager, the empty car distributor, the train dispatcher, or the manager of the repair area. [21]

A peculiarity of car cost is that it is not, unlike switcher and other operating costs, the direct consequence of the yard manager's decisions. Rather, it is determined on a particular day by both the mean processing time the yard manager achieves, and inbound volume. If processing time is constant, higher volume means a proportional rise in car cost. Also, the added operating cost needed to achieve any given reduction in processing time is mititgated by the resulting savings in car cost. In fact, a yard with a very high processing time might find it can actually achieve a net cost saving by adding switchers and cutting processing times.

Ideally, the hourly car cost a railroad assigned to each of the cars on its system would be continually adjusted to reflect the car's changing opportunity cost. This cost varies chiefly with the car's location on the system (and, specifically, distance from points where cars are currently needed for loading) and its type (box, tank, flat, refrigerator, etc.), which will be in more or less demand depending on the season and the current status of the business cycle.

4.2 Recommendations for Control at East Deerfield. Having shown how we developed performance standards for East Deerfield in Sections 3.2 (for the day-of-week average yard time standard) and 3.3 (for the regression-based switcher-use standard and the ratio fuel standard), we will show how these standards have been applied to the management control of East Deerfield. The volume-variable budget and weekly performance report presented in this section were developed for East Deerfield in cooperation with managers at the yard and at Boston and Maine's headquarters. B&M personel were producing a modified version of the weekly performance report at this writing. The documents that have resulted reflect the complexities of trying to establish a coherent control system in an organization like a railroad, where the heterogeneity in the sources from which data is available and in the forms it takes reflects the division of the railroad into geographical units (such as yards and regional headquarters), and functional units (such as the groups at a yard responsible for operations and for work on rolling stock). Of course, the difficulty of assembling all the information into a one-page budget or performance report confirms that a gap indeed exists between headquarters and the yard, and between functional units at the yard. The documents we will propose are meant to overcome these gaps.

4.21 The Control Documents for East Deerfield. In this section, we will review the volume-variable budget and weekly performance report that this author developed for East Deerfield. Exhibits 4-1 and 4-2 show the volume-variable budget, and Exhibits 4-3 and 4-4 show the weekly performance report. The program whose output is the first page of the volume-variable budget, which is shown in Exhibit 4-1, uses the standard for switcher use developed in Section 3.31 to calculate a budget for each of a number of levels of inbound volume. (Since the standard was stated in Exhibit 3-16 in terms of switcher-hours, these coefficients have been divided by 8 to form a standard for the number of crews to be worked.) The two coefficients of the standard are shown in Exhibit 4-1 as the "starting reference point" and "the change in number of crews to be worked (day 1) per inbound car (day 1)."

The row in Exhibit 4-1 marked "fraction of weekly volume" contains the fraction of a typical week's volume that arrives during each of the seven days. The user could calculate these fractions, as we did, from data for a number of past weeks. These fractions let the program distribute among the seven days whatever weekly volume the user projects.

From this input data, the program calculates the number of crews for each weekly volume level and each day of the week. Although the

EXHIBIT 4-1

VOLUME VARIABLE BUDGET
FOR EAST DEERFIELD,
PAGE 1 OF 2.

```
1982 WEEKLY VOLUME VARIABLE BUDGET
EAST DEERFIELD TERMINAL

(PAGE 1 OF 2)



                              STARTING REFERENCE POINT     4.55

CHANGE IN NUMBER OF CREWS TO BE WORKED (DAY 1) PER:

INBOUND CAR (DAY 1)...................................  .00291

                                MINIMUM CREWS PER DAY        2
                                MAXIMUM CREWS PER DAY        9

                                FRI     SAT     SUN     MON     TUE     WED     THU

FRACTION OF WEEKLY VOLUME      .176    .169    .098    .096    .155    .144    .162


                INBOUND                                                            CREWS
                 VOLUME                                                              FOR
               FOR WEEK                       CREWS TO BE WORKED                    WEEK

                   1600       5       5       5       5       5       5       5       35
                   2000       6       6       5       5       5       5       5       37
                   2400       6       6       5       5       6       6       6       40
                   2800       6       6       5       5       6       6       6       40
                   3200       6       6       5       5       6       6       6       40
                   3600       6       6       6       6       6       6       6       42
                   4000       7       7       6       6       6       6       6       44

                                                                               END PAGE
```

result of the formula for crews can be any positive number, only an integer number of crews can work. So the computer rounds off to the nearest integer. The matrix of crew levels shown at the bottom of Exhibit 4-1 is the result.

The yard manager may be prevented by the labor agreement from matching crew levels precisely to projected volume. He may be obligated, for example, to work crews in a pattern such that each crew member has two consecutive days off per week. Once our standard for switcher use had established the most desirable number of crews to work on each day, at each level of weekly volume, management could fine-tune this matrix so as to be consistent with the constraints presented by the labor agreement.

Based on the crew levels for each day of the week that are the result of the first page of the volume-variable budget that we have been examining in Exhibit 4-1, the program then calculates the labor and fuel cost of switchers, and car cost, and presents them in the second page of the budget, which is shown in Exhibit 4-2. The result of central interest is, for each volume level, the total cost.
In the top half of Exhibit 4-2 are shown budgeted unit costs for crews, utility men (discussed below), fuel, and cars, as well as the variable standard for switcher use whose form we discussed in Section 3.2. Boston and Maine switcher crews are paid at an hourly rate for work during eight-hour shifts. For each such shift, a four-man crew

EXHIBIT 4-2

VOLUME VARIABLE BUDGET
FOR EAST DEERFIELD,
PAGE 2 OF 2.

1982 WEEKLY VOLUME VARIABLE BUDGET
EAST DEERFIELD TERMINAL

(PAGE 2 OF 2)

YARD T&E LABOR COST

STRAIGHT-TIME COST PER FOUR-MAN CREW..................................	349.00
STRAIGHT-TIME COST PER THREE-MAN CREW.................................	265.82
FRACTION OF ABOVE BUDGETED FOR ADDED COST OF YARD T&E	
OVERTIME............................	.04
CONSTRUCTIVE ALLOWANCES.............	.17
COST PER UTILITY MAN PER TRICK..	83.18

FUEL

GALLONS PER CREW	68
COST PER GALLON	1.15
HOURLY CAR COST	.47

FOR WEEK:

INBOUND VOLUME	STANDARD AVERAGE YARD TIME	TOTAL CREWS TO BE WORKED	SHORT CREWS TO BE WORKED	UTILITY MEN TO BE WORKED	YARD T&E LABOR COST	SWITCHER FUEL COST	CAR COST	OTHER WEEKLY LABOR	OTHER EXPENSES	GRAND TOTAL
1600	20.7	35	5	21	16024	2737	15566	19481	7183	60991
2000	20.7	37	5	21	16868	2893	19458	19481	7183	65884
2400	20.7	40	5	21	18135	3128	23350	19481	7183	71277
2800	20.7	40	5	21	18135	3128	27241	19481	7183	75168
3200	20.7	40	5	21	18135	3128	31133	19481	7183	79060
3600	20.7	42	5	21	18980	3284	35024	19481	7183	83953
4000	20.7	44	5	21	19824	3441	38916	19481	7183	88845

END PAGE

is paid what B&M budgeted for 1982 at $349. The current Boston and Maine labor agreement, however, provides for a mixture of four-man and three-man crews. The crew working on the hump classifying cars always consists of four men, including the engineer. The other switchers in the yard may have three or four men in the crew depending on whether someone wants to work as the fourth man on a particular shift. Also working on most shifts is one utility man, who may assist the crews of either one of the yard engines or of a road freight (usually to align track switches for the movement of the road freight within the yard area).

To establish the total labor cost of a switcher per crew, we added to the straight-time pay of each eight-hour shift of a switcher crew an allocation of the cost of overtime, constructive allowances, and switcher fuel. (Constructive allowances are supplemental payments prescribed in the labor agreement for tasks that are not formally part of a crew member's duties.) Making overtime volume-variable is important, because otherwise the yard manager would be at least tempted in the face of a traffic decline to substitute overtime work (whose budget wouldn't decline with volume) in the place of straight-time work (whose budget would decline).

In setting a budget for the overtime and constructive allowances of yard switcher crews, we followed the Boston and Maine practice of stating these budgets in terms of percentages of straight-time expense. B&M managers develop preliminary values for these budgets on the basis of actual spending during the previous year, in this case 1981, but may alter them to reflect what they think constructive allowances and overtime expenses should be, as opposed to what these payments have been in the past. Therefore, to obtain the total labor cost per crew used in Exhibit 4-2, we performed the following arithmatic: We began with the base cost of $349. The additional cost budgeted was 4 percent of the base cost for overtime, and 17 percent for constructive allowances, which raised the total budgeted cost per crew to $422.

In the case of fuel, we adopted a budget that was variable with volume, but only indirectly. The fuel budget varies directly with the number of crews worked. This reflects the regression analysis of fuel use presented in Section 3.33, in which we saw that the fixed portion of fuel use was so small in comparison to the variable portion that we decided to adopt a standard for fuel use that was fully variable with switcher use. Between January 2 and July 30, 1981, 1,394 crews were worked at East Deerfield yard, and switchers consumed 94,843 gallons of fuel. Dividing, we set the standard for fuel consumption at 68 gallons per crew. This standard is inserted in Exhibit 4-2, along with the estimated current average cost per gallon of fuel, $1.15.

Another input to the program that produces the budget is the standard yard time for the week, which is shown in the bottom part of Exhibit 4-2 to be constant over all volume levels at 20.7 hours. To make the budget as up to date as possible, we inserted the average yard time that East Deerfield exhibited over the period March 5 through June 10, 1982. Of course, the standard average yard time that would have appeared at the start of 1982 would have been determined on the basis of performance before 1982 (and then been possibly modified by headquarters to reflect their goals for improved performance).

Other expenses included the budget are those shown in the bottom part of Exhibit 4-2 under "other weekly labor" (labor cost other than that of switcher crews), and "other expenses." These budgets do not vary with volume. Instead, they are fixed. During 1980 and 1981, inbound volume had no measurable effect on the cost of other Transportation Department labor at East Deerfield. These include yardmasters, towermen, crew dispatchers, and clerical workers. This was the result we had generally expected from talking with people at the yard. Inbound volume is one factor determining how many hours will be worked by employees in these categories, but other factors -- including end-of-month paperwork, special projects, derailments, training periods, and absences -- dilute the impact of the inbound car volume to insignificance.

The program combines the crew levels shown in Exhibit 4-1 with the budget and standard yard time data shown in Exhibit 4-2 to produce the weekly total cost levels shown at the bottom of Exhibit 4-2. Car cost for the week is the product of the week's

--average yard time for inbound cars,
--inbound volume, and
--hourly car cost.

Now let us turn to the weekly performance report for East Deerfield, a sample of which is shown in Exhibits 4-3 and 4-4. These reports are analogous in layout to Exhibits 4-1 and 4-2. The major difference is that instead of serving, as did the volume-variable budget of Exhibits 4-1 and 4-2, as a way of stating in advance what performance should be under a number of possible volume levels, the weekly report looks back at the actual volume for the preceeding week and juxtaposes actual performance with what the standards say it should have been, given that volume. In the top half of the first page of the weekly report, which is shown in Exhibit 4-3, appears the same description of the standard for switcher use that appeared in Exhibit 4-1. This is to be inserted into the program at the start of the budget period (a year or possibly shorter period). Also to be inserted at the start of this period are the figures in the bottom of Exhibit 4-3 marked "average yard time, standard." We have inserted here the average yard time that East Deerfield displayed over the period March 5 through June 10, 1982. These figures first appeared

EXHIBIT 4-3

WEEKLY REPORT FOR EAST DEERFIELD
PAGE 1 OF 2

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WEEKLY EXPENSE REPORT
TRANSPORTATION DEPT.
EAST DEERFIELD TERMINAL

SEVEN DAYS ENDED
                           MONTH    DATE    YEAR
              THURSDAY       6       24     1982

(PAGE 1 OF 2)


PRE-SET PERFORMANCE FORMULA:
===========================

                            STARTING REFERENCE POINT............    4.55

CHANGE IN NUMBER OF CREWS TO BE WORKED (DAY 1) PER:

INBOUND CAR (DAY 1).............................................  .00291

                             MINIMUM CREWS PER DAY.............       2
                             MAXIMUM CREWS PER DAY.............       9



                             FRI     SAT     SUN     MON     TUE     WED     THU             WEEK
                               6       6       6       6       6       6       6
                              18      19      20      21      22      23      24


INBOUND VOLUME..........     500     554     306     345     424     444     502             3075

OUTBOUND TRAINS.........      16      10      10      14      14      14      11               89


AVERAGE
YARD TIME:

STANDARD................    21.4    23.8    20.5    18.8    19.4      21      19               21

ACTUAL..................      20    21.9    18.6    15.6    16.3      20    17.8               19


CREWS: BUDGETED.........       6       6       5       6       6       6       6               41

       ACTUAL...........       6       6       5       5       6       6       6               40

                                                                                         END P.1
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EXHIBIT 4-4

WEEKLY REPORT FOR EAST DEERFIELD

PAGE 2 OF 2

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WEEKLY EXPENSE REPORT
TRANSPORTATION DEPT.
EAST DEERFIELD TERMINAL

SEVEN DAYS ENDED
                          MONTH    DATE    YEAR
             THURSDAY         6      24    1982

(PAGE 2 OF 2)

YARD T&E LABOR COST

     STRAIGHT-TIME COST PER FOUR-MAN CREW......................  349.00
     STRAIGHT-TIME COST PER THREE-MAN CREW.....................  265.82

     FRACTION OF ABOVE BUDGETED FOR ADDED COST OF T&E

                           OVERTIME.......................      .04
                           CONSTRUCTIVE ALLOWANCES.........      .17

     COST PER UTILITY MAN PER TRICK............................   83.18

FUEL
     GALLONS PER CREW...........      68
     COST PER GALLON............    1.15

HOURLY CAR COST.................     .47



FROM THIS WEEK'S PAYROLL CONTROL REPORT:
                        TOTAL YARD T&E........    16283
                         TOTAL PAYROLL........    33608

                                                                     YARD
         AVERAGE          TOTAL   4-MAN   3-MAN UTILITY      T&E   OTHER GALLONS
            YARD     CAR  CREWS   CREWS   CREWS     MEN    LABOR   LABOR      OF    FUEL   OTHER   GRAND
            TIME    COST WORKED  WORKED  WORKED  WORKED     COST    COST    FUEL EXPENSE EXPNSES   TOTAL


 BUDGET       21   29954     41      36       5      21    18924   19481    2788    3206    7183   78748

 ACTUAL       19   27328     40      38       2      20    16283   17317    3196    3675    7183   71787

   DIFF       -2   -2626     -1       2      -3      -1    -2641   -2164     408     469       0   -6962

PCT DIFF      -9      -9     -2       6     -60      -5      -14     -11      15      15       0      -9

                                                                                                END P. 2
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in Exhibit 3-5. As we said in Section 3.1, the assumption behind the adoption of these averages as standards is that the determinants of average yard time, principally mean processing time and block pickup frequency, vary in a similar pattern over the course of each week. These standards represent a compromise between setting a fixed standard for each day of the week, which would ignore the variation of these determinants of yard time, and setting a standard based on a formal estimate of the effect of these factors on yard time. In Chapter 3, we saw that such a formal estimate was infeasible for East Deerfield. Data on processing time and block pickup frequency was unavailable, and outbound train frequency proved to be an unsatisfactory proxy for block pickup frequency. Software that may be added to the Boston and Maine's management information system in the near future may produce for each day a more accurate standard yard time, one based on actual train times and connection volumes, and a standard PMAKE function for the yard.

Also appearing the bottom half of the weekly report shown in Exhibit 4-3 are the actual inbound volume, number of outbound trains, average yard time, and crews. A person at the yard inserts these numbers into the program at the end of each week. Outbound trains are shown as a means of providing an at least approximate way of judging the extent to which a rise in yard time is explainable by reference to a drop in the frequency of outbound block pickup as opposed to a rise in mean processing time. On the basis of the parameters of the switcher use standard, and the actual inbound volume for each day, the program calculates the number of crews that should have been worked each day. "Crews, standard" are shown at the bottom of Exhibit 4-3.

Whereas the first page of the weekly report (Exhibit 4-3) shows physical performance for the week, and juxtaposes it with standards, the second page of the report (Exhibit 4-4) shows actual costs for the week and juxtaposes them with the budget. The top half of Exhibit 4-4 is identical to the top half of Exhibit 4-2, which was the second page of the volume-variable budget. Below this section is a report "from this week's Payroll Control Report" of the money paid to switcher crews and to all yard personnel. The Payroll Control Report was developed by Boston and Maine, and is produced weekly by their mainframe computer system. (As mentioned above, the programs for the budget and the weekly expense report were designed by this author for use on a microcomputer.) The bottom section of Exhibit 4-4 summarizes the performance of the yard over the past week in terms of a number measures, and in the case of each also provides a standard with which both the yard manager and his superiors at headquarters can evaluate this performance. The sources of these measures and standards are as follows.

--standard and actual yard time are from the "week" column of page one of the weekly report (Exhibit 4-3).

--car cost is the product of average yard time (standard or actual, as the case may be), the budgeted hourly car cost, and actual inbound volume.

--total crews worked come from the "week" column of Exhibit 4-3.

--4-man crews worked are calculated by the program as the difference between total and 3-man crews.

--in consultation with one of East Deerfield's managers, a standard was set stipulating that the number of 3-man crews worked each week should be five. The actual number of 3-man crews is inserted below the standard at the end of each week.

--the same consultation led to a standard of 21 utility men per week. The actual number is inserted below the standard.

--budgeted yard T&E (train and engine) labor cost is the standard number of crews (which given this week's volume was 41) multiplied by the budgeted cost per crew, whose components appear in the top half of Exhibit 4-4. Actual yard T&E is the same figure given higher up in Exhibit 4-4, "from this week's Payroll Control Report."

--the budget for other labor cost is the 1981 weekly average of these costs, increased by 12 percent to account for inflation. Actual other labor cost is calculated by the program as the difference between yard T&E labor cost and total labor cost for the week.

--standard gallons of fuel is the standard number of crews for this week multiplied by the standard, given higher up on Exhibit 4-4, of 68 gallons per crew. Actual fuel consumption is inserted beneath the standard.

--both budgeted and actual fuel expense are calculated by the program as the product of standard or actual gallons of fuel times the current estimated fuel cost per gallon that appeared higher up on Exhibit 4-4.

--the budget for other expenses was set by raising the average weekly 1981 cost and raising it by 12 percent for inflation. The budget figure is also being inserted as an estimate of actual expenses because these expenses do not currently become available to yard personnel soon enough to permit their timely inclusion in the report.

--grand total cost, in the case of both the budget and the cost for the week, is the sum of car cost, yard T&E labor cost, other labor cost, fuel expense, and other expenses.

4.22 Improvement of Performance Over Two Years At East Deerfield. The econometric analysis of switcher use that we have developed for East Deerfield is helpful not just in the evaluation of performance from week to week, but in determining trends in performance over a much longer period. Over the past two years, while average yard times have remained roughly constant, switcher use has dropped dramatically at East Deerfield. Regression analysis of this use as a function of volume lets us discern the degree to which lower switcher use has resulted merely from the generally downward trend in volume over the two years, and the degree to which, on the contrary, lower switcher use can be traced to other changes at the yard. These changes include the rebuilding of the yard during the summers of 1980 and 1981 so that all switching can be done from a single hump, personnel changes, and enhancements of the control system that have been encouraged by the ongoing discussion of the issues now being examined by this thesis. One purpose of the volume-variable crew standard is to guage inprovement in productivity from other factors besides inbound volume, such as capital improvements that let the yard operate more efficiently.

Regression analysis of the evolution of performance over the two years involved the development of three distinct regression models of switcher use as a function of inbound volume. Each corresponds to a different period. The first is for the spring of 1980; the second for the summer of 1981; and the third, which is the one we already presented in Exhibits 3-16 and 3-17, for the spring of 1982. Key statistics regarding the mean, variability, and correlation of inbound volume and switcher use are presented in Exhibit 4-5. Regression models for the three periods appear in Exhibit 4-6. The explanatory power of the 1980 and 1982 models is adequate (.204 and .364) but that of the 1981 is very low (.065). Exhibit 4-7 shows the corresponding scatter plots and fitted regression lines for the 1980 and 1981 periods. (The analogous plot and line for the 1982 period was shown in Exhibit 3-17.) In order to provide a direct comparison among the effects of volume on switcher use during the three periods, the line fitted in each of the three reg~~g~~ression analyses have been plotted on the same pair of axes in Exhibit 4-8. Although the diagram appears to indicate improvement in performance in terms of switcher use over the three years, this result must be interpreted with caution due to the high uncertainty of the coefficients of the models, especially the 1981 model.

4.3 Recommendations for Control at Woippy. Having described the volume-variable budget and weekly performance report that we developed for East Deerfield, we now turn to a similar set of budget

EXHIBIT 4-5

EAST DEERFIELD YARD - KEY STATISTICS ON INBOUND VOLUME AND CREWS WORKED FOR PERIODS IN 1980, 1981, AND 1982

period covered by data	March 7 through June 12, 1980	April 3 through August 18, 1981 (for available data)	March 5 through June 10, 1982
inbound volume:			
mean	559	315	413
maximum	1127	418	643
minimum	221	175	178
standard deviation	185	57	116
mean/(standard deviation)	3.0	5.5	3.6
crews worked:			
mean	7.21	6.10	5.75
maximum	8	7	7
minimum	1	5	4
standard deviation	1.14	0.73	0.55
mean/(standard deviation)	6.3	8.4	10.5
correlation coefficient between inbound volume on day 1 and crews worked on day 1	.460	.280	.609

EXHIBIT 4-6

EAST DEERFIELD YARD - REGRESSION MODELS OF SWITCHER USE AS A FUNCTION OF INBOUND VOLUME FOR PERIODS IN 1980, 1981, AND 1982

(t-statistics in parentheses)

March 7 through June 12, 1980:

$$\text{crews worked, day 1} = \underset{(17.2)}{5.63} + \underset{(5.1)}{.00283}\ (\text{inbound volume, day 1})$$

corrected R^2 = .204

April 3 through August 18, 1981 (for available data):

$$\text{crews worked, day 1} = \underset{(10.6)}{4.97} + \underset{(2.4)}{.00359}\ (\text{inbound volume, day 1})$$

corrected R^2 = .065

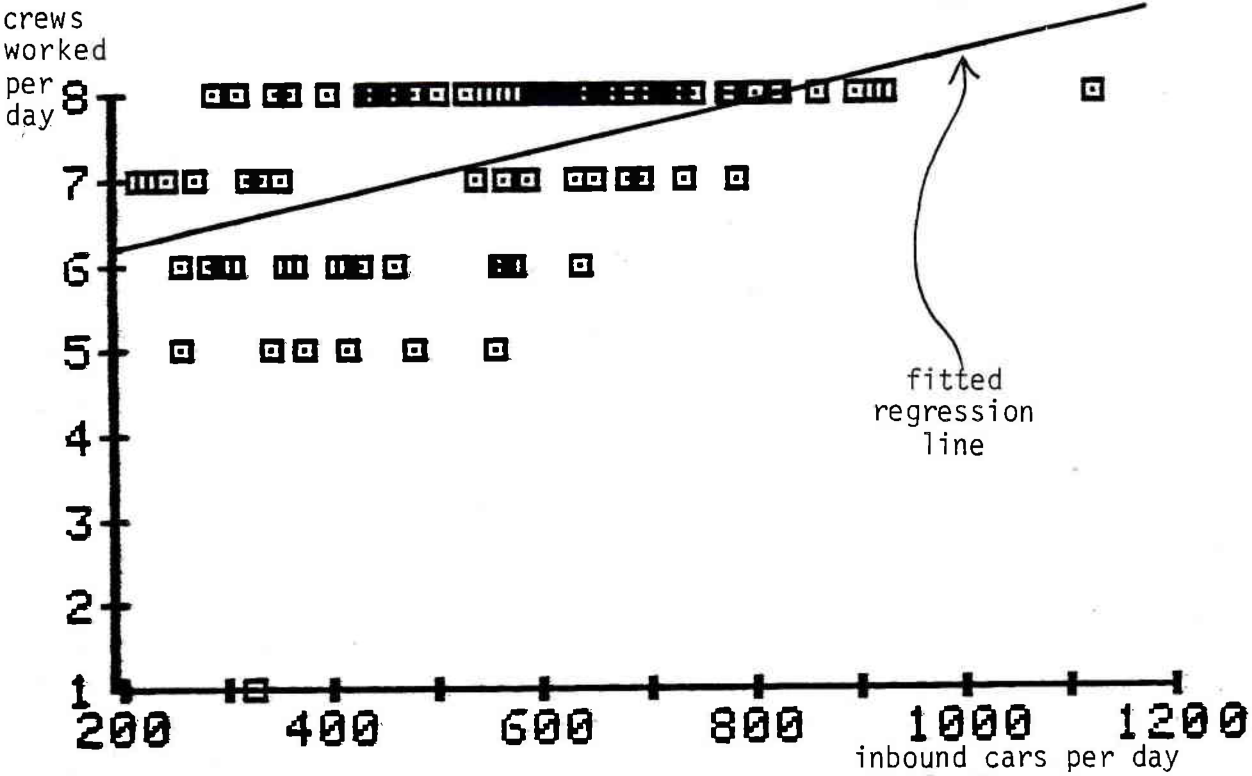
March 5 through June 10, 1982:

$$\text{crews worked, day 1} = \underset{(27.4)}{4.55} + \underset{(7.5)}{.00291}\ (\text{inbound volume, day 1})$$

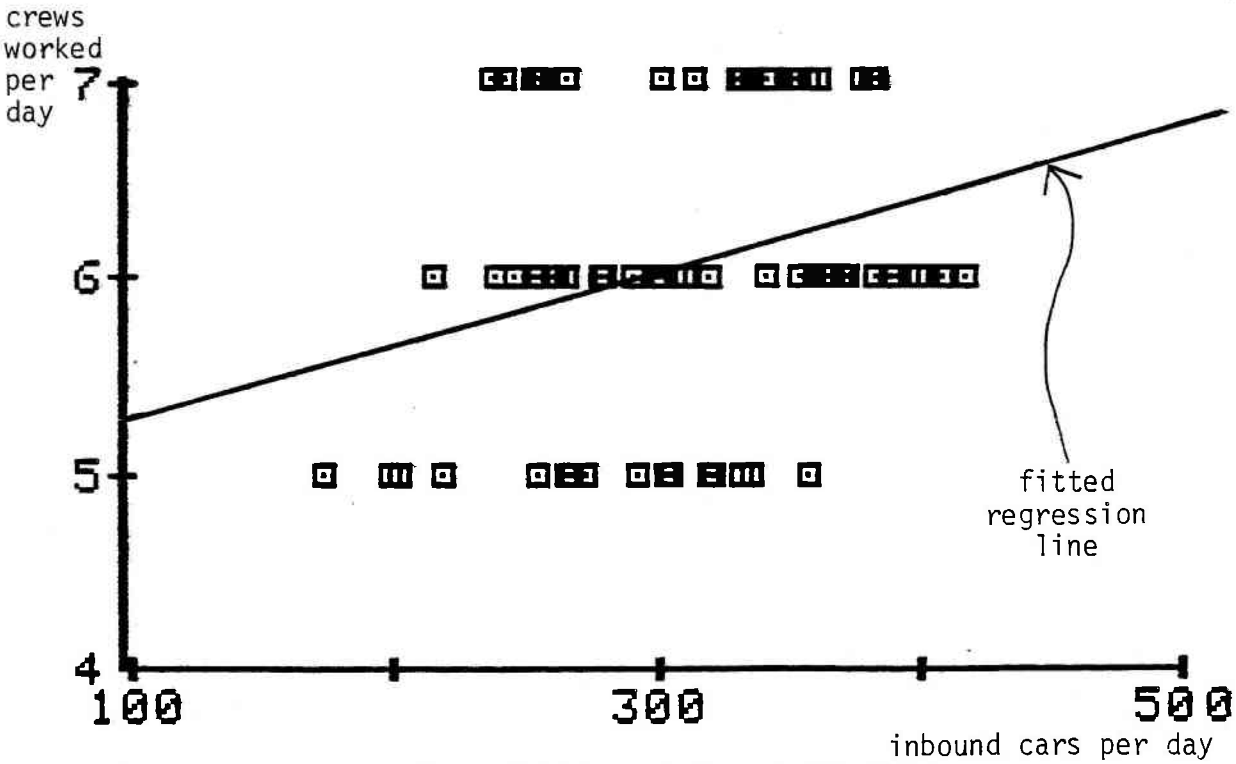
corrected R^2 = .364

EXHIBIT 4-7

EAST DEERFIELD - INBOUND CARS VERSUS CREWS AND FITTED LINE FOR PERIODS IN 1980 AND 1981



March 7 through June 12, 1980



March 27 through August 18, 1981

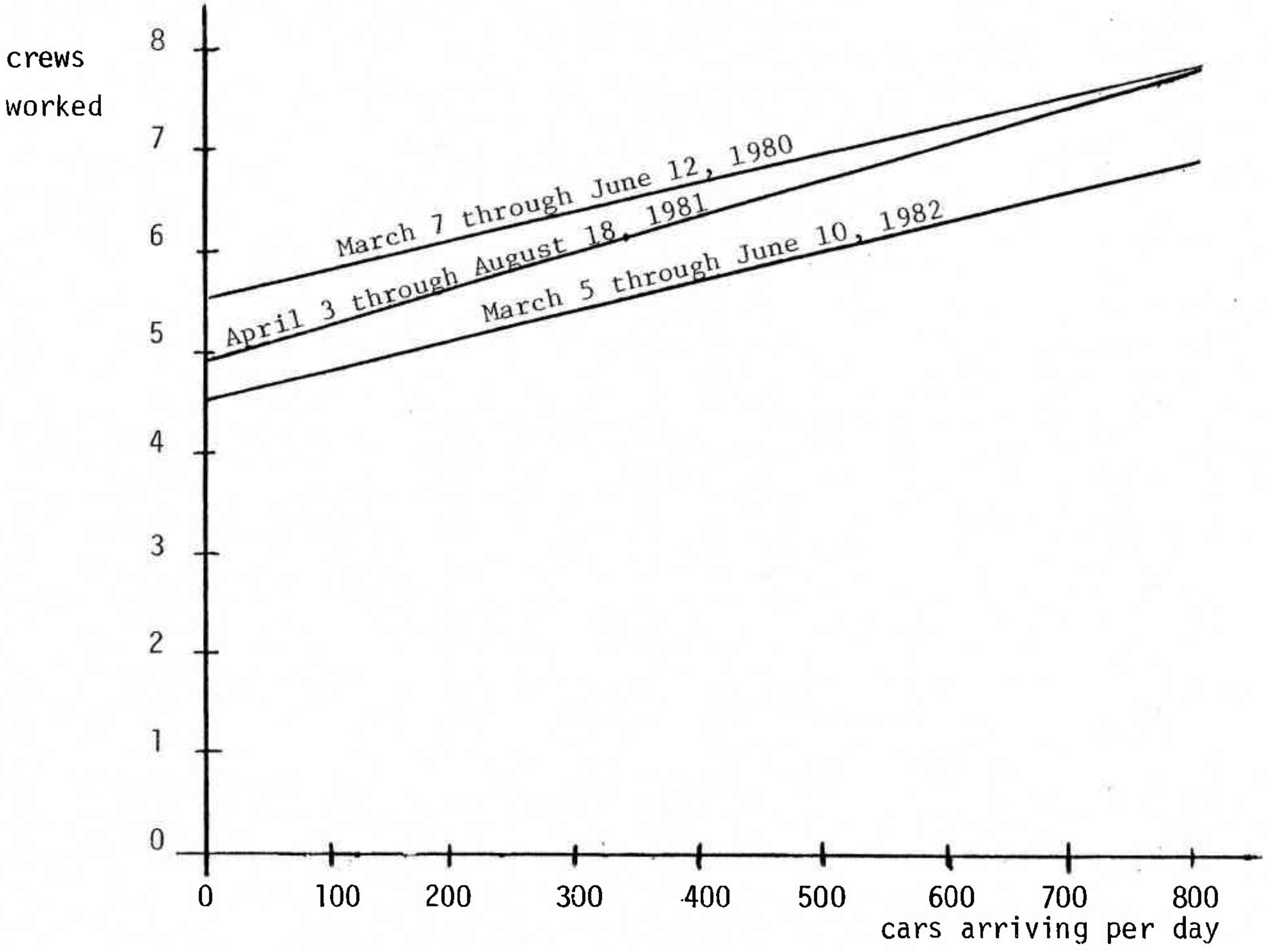


EXHIBIT 4-8 EAST DEERFIELD YARD-FITTED REGRESSION LINES FOR SWITCHER USE AS FUNCTION OF INBOUND VOLUME FOR PERIODS IN 1980, 1981, AND 1982.

and performance reports that could be made part of the existing management information system at Woippy. We will also introduce some reports that could easily be produced at Woippy given the data already collected there, and which we omitted from the East Deerfield control system because that yard does not now collect the needed data. However, were East Deerfield to begin this data collection, and create (as Woippy would also still need to) a means to routinely process the data into the form required by the reports we propose, these reports could usefully be added to the East Deerfield control system as well.

Three differences exist between the suggested control systems for East Deerfield and for Woippy. First, whereas the East Deerfield standard for switcher use is volume-variable, the one for Woippy is fixed, reflecting the relatively low variability of volume and the rigidity of the crew schedule at that yard. Second, a distinct standard for switchers' fuel use exists for East Deerfield, but a standard cost per switcher-hour is used in the budget and in the performance report for Woippy. This unit cost includes labor, fuel, maintenance, and the depreciation of the locomotive. Third, whereas the East Deerfield standard for yard time is a fixed one based on the average yard time for each of the seven days of the week during a period in the spring of 1982, the Woippy standard refers not to average yard time as a whole, but to processing time only. This standard, which is divided into classification and processing time portions, is fixed over the seven days of the week.

A volume-variable budget that could be developed at Woippy is shown in Exhibit 4-9. This budget could be integrated into the budget that the SNCF currently prepares for the yard. It is basically analogous to the budget for East Deerfield that we presented in Exhibits 4-1 and 4-2. The cost per switcher-hour and cost per car-hour were provided to this author by the SNCF. The total number of switcher hours to be worked per week is taken from the switcher schedule that appeared in Exhibit 3-18. We are thus adopting Woippy's switcher schedule as its standard for switcher use. This standard is analogous to the standard for average yard time that we proposed for East Deerfield in Section 4.21: it is volume-variable in the sense that it is set in advance to correspond to the pattern of operations that the yard typically experiences over the course of a week, but once set, does not vary with actual operating conditions. As we said in Section 3.5, a standard for switcher use that varied with actual, as opposed to anticipated, volume would be inappropriate for Woippy because of the great limitation on the ability of the yard manager to modify the pre-set switcher schedule in response to volume variations.

Standard average processing and wait times were chosen by this author on the basis of actual performance at Woippy during the first week of October, 1981, as summarized in Exhibit 3-42. The standard

EXHIBIT 4-9

SAMPLE OF VOLUME-VARIABLE BUDGET,
WOIPPY YARD

1982 WEEKLY VOLUME VARIABLE BUDGET
WOIPPY CLASSIFICATION YARD

COST PER SWITCHER HOUR.....	220.04	FRANCS
SWITCHER HOURS TO BE WORKED	631	HOURS
COST PER CAR HOUR	1.229	FRANCS
STANDARD AVERAGE PROCESSING TIME.........	6	HOURS
STANDARD AVERAGE WAIT TIME...............	6.5	HOURS

FOR WEEK:

OUTBOUND VOLUME	SWITCHER COST (FRANCS)	CAR COST (FRANCS)	TOTAL PROCESS-ING COST (FRANCS)	CAR COST DURING WAIT (FRANCS)
13000	138845	95862	234707	103851
14000	138845	103236	242081	111839
15000	138845	110610	249455	119828
16000	138845	117984	256829	127816
17000	138845	125358	264203	135805
18000	138845	132732	271577	143793
19000	138845	140106	278951	151782

END PAGE

for average yard time must be variable for East Deerfield over the seven days of the week to take into account the variations in the frequency of outbound block pickups. In contrast, yard time standards for Woippy can be in a fixed form because the processing and wait portions of this yard time can be measured seperately. Having a fixed standard for processing time implies that the yard manager should ensure that processing time is affected neither by inbound volume nor by any other operating conditions. The fixed standard for wait time for the week, on the other hand, reflects the overall frequency of block pickups over the course of the week. The mean wait would be expected to vary with the pickup rate over the course of the weekly cycle of operations.

On the basis of these unit costs and standards, the computer program that produces the budget calculates the volume-variable budget for a number of volume levels that is shown in the bottom of Exhibit 4-9. Note that, in contrast to the budget for East Deerfield, only the car cost portion of the budget is volume-variable, not the portion for switcher use. The hourly cost per car and the standard mean processing times are constant over all volumes, but more cars means more car-hours and higher car cost. Also note that the total processing cost for which the yard manager is responsible includes only the cost of cars while they are undergoing processing, not during their wait for pickup. A volume-variable budget for the cost of cars during their wait is shown in the bottom right of Exhibit 4-9. This budget would be the responsibility of the manager would oversees the movement of trains over the main line.

As for the reporting of actual performance at the end of each week and comparison of it with standard, several kinds of reports could be developed that would provide a better summary of the data already collected at Woippy yard. Samples of the current SNCF reports of arriving and departing trains were shown in Exhibits 3-22 through 3-25. Samples of reports that would summarize the current ones are shown in Exhibits 4-10 and 4-11. The Report of Trains Arriving in Exhibit 4-10 would isolate on one sheet of paper some critical data about each train that currently appear in less accessible form on two seperate, more detailed reports (those shown in Exhibits 3-22 and 3-23). This data includes, for each train, its number, scheduled and actual arrival time, number of cars, and time at which classification ended. The computer program generating the report would then calculate and present, as shown in the two righthand columns of Exhibit 4-10, the time between actual arrival and the end of classification, and the number of car minutes incurred during this period. Finally, at the bottom of the Exhibit appears the average duration of the time between arrival and classification for the yard on a whole on, in this example, October 2, 1981. An analogous proposed Report of Trains Departed is shown in Exhibit 4-11. It summarizes key data on each train that appears in the

EXHIBIT 4-10

SAMPLE REPORT OF ARRIVING TRAINS FOR WOIPPY YARD, INCLUDING MEAN CLASSIFICATION TIME

```
WOIPPY CLASSIFICATION YARD

                                          DATE     MONTH      YEAR
REPORT OF TRAINS ARRIVING                    2        10      1981

                                                               TIME
                                                     TIME    NEEDED
            SCHED-                                AT WHICH      FOR
              ULED    ACTUAL    NUMBER    CLASS-    CLASS-
   TRAIN   ARRIVAL   ARRIVAL        OF  FICATION  FICATION       CAR
  NUMBER      TIME      TIME      CARS     ENDED    (MINS.)  MINUTES


   20325         1         1        34       105        64      2176
   20315        25        35        29       220       105      3045
   68791        30        24        34       206       102      3468
   62124        41        41        45       233       112      5040
   31164       106       102        18       256       114      2052
     724       120       120        23       329       129      2967
   30307       132       142        20       245        63      1260
   65656       135       112        35       344       152      5320
   45535       148       137        40       429       172      6880
   67893       153       203        49       404       121      5929
   30313       231       231        47       634       243     11421
   67792       232       232        24       417       105      2520
   67112       245       245        30       524       159      4770
   62185       301       345        18       534       109      1962
   67182       334       402        37       713       191      7067
       .         .         .         .         .         .         .
       .         .         .         .         .         .         .
       .         .         .         .         .         .         .
       .         .         .         .         .         .         .


   TOTAL                          2018                        357840


                              AVERAGE DURATION
                              OF CLASSIFICATION

                              STANDARD                2.50

                              ACTUAL                  2.96

                                                           END PAGE
```

EXHIBIT 4-11

SAMPLE REPORT OF DEPARTING TRAINS FOR WOIPPY YARD, INCLUDING MEAN ASSEMBLY TIME

```
WOIPPY CLASSIFICATION YARD


                                  DATE     MONTH      YEAR
REPORT OF TRAINS DEPARTED            2        10      1981



                SCHED-                                       TIME
                  ULED    ACTUAL                    TIME   NEEDED
               DEPART-   DEPART-    NUMBER  AT WHICH       FOR
     TRAIN         URE       URE        OF  ASSEMBLY  ASSEMBLY        CAR
    NUMBER        TIME      TIME      CARS   STARTED    (MINS.)   MINUTES

     68935          13        13        27      2120       173      4671
     44902          14        14        38      2115       179      6802
     30321         102       102        68      1930       332     22576
     67332         106       106         7      2235       151      1057
     67108         137       137        44      2150       227      9988
     30327         153       153        29      2150       243      7047
     67103         220       220         7      2210       250      1750
     30336         253       253        49      2345       188      9212
     61441         306       315        19      2350       205      3895
     68834         307       307        51      2335       212     10812
     67109         310       310        12        10       180      2160
     61903         330       330        48      2345       225     10800
     67268         354       416        30        25       231      6930
     67209         357       357        46       100       177      8142
     67128         420       420        16        50       210      3360
        .            .         .         .         .         .         .
        .            .         .         .         .         .         .
        .            .         .         .         .         .         .
        .            .         .         .         .         .         .


     TOTAL                            2306                          512400

           AVERAGE DURATION
           OF ASSEMBLY IN HOURS

           STANDARD                                     3.50

           ACTUAL                                       3.70

                                                               END PAGE
```

existing SNCF reports shown in Exhibits 3-24 and 3-25, and states the average time between the start of assembly of a train and its actual departure.

Having explained how mean processing time could be controlled at Woippy on a daily basis, we now turn to the control of wait time. One way to control wait time each day would be to simply define wait time as the difference between mean processing time, as we proposed just above to report it, and average total yard time, as currently reported by the SNCF document shown in Exhibit 3-2. The drawback of this method is that if we want to hold the yard manager responsible for processing time, and the road manager responsible for wait time, we need good measures of the performance of both. But our measure of yard time would, under this method, rely on the SNCF's current approximation of average yard time for each day. As we explained in Section 3.31, this is not a fully accurate measure of the yard time for the cars departing each day, because it excludes the yard time the departing cars incurred on previous days, and includes some of the time incurred by cars that will leave on future days.

A better way to measure wait time is to do so directly, using the estimation procedure described in Section 3.4. In fact, a useful way to present a summary of the wait time incurred at the yard on a given day would be to provide a report whose format would be identical with Exhibits 3-40 and 3-41. These reports state the components of mean wait time for each day, including the wait for block pickup and the wait incurred by left cars. They also show the mean waits for each outbound block. These reports thus complement the proposed reports on arriving and departing trains, which show mean processing time for each train and for the yard as a whole.

The daily reports on processing times and wait times we have just described could be summarized in a weekly performance report having the format shown in Exhibits 4-12 and 4-13. This two-page weekly report for Woippy is basically similar to the one for East Deerfield shown in Exhibits 4-3 and 4-4. The differences parallel those we have already seen in the volume-variable budgets for the two yards: the standard for switcher use is volume-variable for East Deerfield but fixed for each day of the week at Woippy; car movement performance is controlled in terms of mean yard time at East Deerfield, but in terms of mean processing time at Woippy; and East Deerfield's yard time standard is a fixed one, but is different for each day of the week, while Woippy's processing time standard doesn't vary at all. In the first page of the weekly performance report for Woippy, shown in Exhibit 4-12, actual mean classification and assembly times for Woippy from the week ended October 8, 1981, are juxtaposed with proposed standards. These standards are 2.5 hours for the average time from train arrival to the end to classification, and of 3.5 hours for the average time from the start of a train's assembly to its departure, for the total mean processing

EXHIBIT 4-12

SAMPLE WEEKLY REPORT FOR WOIPPY YARD (PAGE 1 OF 2)

```
WEEKLY PERFORMANCE REPORT
WOIPPY CLASSIFICATION YARD

SEVEN DAYS ENDED
                             DATE   MONTH    YEAR
                  THURSDAY     8      10     1981

(PAGE 1 OF 2)

                                             SUN
                                               4
                                              10

                                             AND

                              FRI     SAT     MON     TUE     WED     THU          WEEK
                                2       3       5       6       7       8
                               10      10      10      10      10      10

OUTBOUND VOLUME
(000 HRS THRU 000 HRS)..     2584    2515    1899    2586    3013    2997         15594

SWITCHER-HOURS

PLANNED.................      113     101      84     107     113     113           631

ACTUAL..................      113     101  82.833     107     113     113           630

AVERAGE
CLASSIFICATION TIME:

STANDARD................     2.50    2.50    2.50    2.50    2.50    2.50          2.50

ACTUAL..................     2.96    2.60    2.08    2.39    1.98    1.89          2.31

AVERAGE
ASSEMBLY TIME:

STANDARD................     3.50    3.50    3.50    3.50    3.50    3.50          3.50

ACTUAL..................     3.70    3.32    4.14    3.10    4.04    3.45          3.61

TOTAL PROCESSING TIME:
=====================

STANDARD................     6.00    6.00    6.00    6.00    6.00    6.00          6.00

ACTUAL..................     6.66    5.93    6.21    5.49    6.02    5.34          5.92


AVERAGE WAIT
FOR BLOCK PICKUP........     4.50    5.05   14.53    5.09    4.55    4.52          5.92

AVERAGE DELAY DUE
TO LEFT TONNAGE:........     0.35    0.41    0.61    0.79    0.71    0.19          0.50


TOTAL AVERAGE YARD TIME:
------------------------

ACTUAL (SUM OF ABOVE)...    11.51   11.39   21.35   11.38   11.29   10.05         12.34

ACTUAL (AS MEASURED
              DIRECTLY)..   11.91   13.17   20.01   12.39   10.69    9.64         12.51
```

EXHIBIT 4-13

SAMPLE WEEKLY REPORT FOR WOIPPY YARD (PAGE 2 OF 2)

```
WEEKLY PERFORMANCE REPORT
WOIPPY CLASSIFICATION YARD

SEVEN DAYS ENDED
                                   DATE    MONTH     YEAR
                 THURSDAY             8       10     1981

(PAGE 2 OF 2)


CURRENT AVERAGE COST PER:

CAR-HOUR................     1.229   FRANCS

SWITCHER-HOUR...........    220.04   FRANCS


OUTBOUND VOLUME FOR WEEK     15594


                      CAR
                     COST                    TOTAL                  CAR
          AVERAGE  DURING            SWITCH PROCESS                COST
          PROCESS PROCESS  SWITCH        ER     ING              DURING
              ING     ING      ER      COST    COST     AVERAGE    WAIT
             TIME (FRNCS)   HOURS   (FRNCS) (FRNCS)        WAIT (FRNCS)


   BUDGET    6.00  114990     631    138845  253835

   ACTUAL    5.92  113397     630    138588  251985        6.43  123137

     DIFF       0   -1593      -1      -257   -1850

 PCT DIFF      -1      -1       0         0      -1

                                                              END P. 2
```

time standard of 6.0 hours. Near the bottom of Exhibit 4-12 is a report of the components of mean wait time on each day. Since the frequency of block pickups and left cars varies over the course of the week, no standard has been set for what mean wait time should be for each day. (A mean wait time such as the 6.5 hours we used in Woippy's volume-variable budget could be used to evaluate for the week as a whole the wait-time performance of the manager of mainline train movements.) Finally, at the very bottom of Exhibit 4-12, actual yard time from two sources is reported: the sum of mean processing time and mean wait time as reported in the upper parts of Exhibit 4-12, and average yard time as measured directly by the SNCF and reported as shown in Exhibit 3-2. This serves as a check of the work of the personnel involved in developing the two sets of figures. The two figures do not precisely agree because of the fact that both are estimates. (For the reasons described above, the average yard time as measured directly is likely a less accurate indicator of the yard time of the cars in the yard on each day.)

The second page of the proposed weekly expense report for Woippy is very similar to the volume-variable budget of Exhibit 4-9. The central difference is that now, standard processing time and standard switcher hours, and budgeted switcher and car costs, are juxtaposed with actual volume and performance.

CHAPTER FIVE:

SUMMARY AND CONCLUSIONS

The conflict between delegation and centralization of decision-making that inheres in any large organization is exacerbated on the railroad because of its geographical dispersion, the need for daily coordination of its operations, and its need to respond quickly to traffic fluctuations, weather, accidents, and equipment failures at outlying points. A rail terminal, whose principle function is typically to sort railcars in its classification yard, is an important example of such a outlying point. If the financial performance of the railroad is to be adequate, headquarters management must have some way of ensuring that the performance of the terminal in terms of both cost and car movement is consistent with the system budget and the need to provide origin-to-destination trip time and reliability that attracts sufficient shippers and revenue. However, they cannot run the yard from headquarters. Instead, they must delegate the authority to operate the yard to a manager who is in touch with local conditions. In order to bridge the gap of distance and information between headquarters and yard, headquarters needs to establish a set of performance standards that keep both headquarters and the yard apprised of what yard performance should be if it is to contribute adequately to the needs of the system.

A performance standard for a classification yard, we have seen, should fulfill three roles. Each helps bridge the gap between headquarters and the yard. It should help headquarters predict what yard performance will be, and how it will affect system performance; it should consequently provide a way to distiguish problem spots by showing where performance has been below what was predicted; and finally, it should serve to inform the yard manager of the needs of the system and motivate him to perform as predicted, which may mean performing as he has in the past or somewhat better.

Headquarters will elicit yard performance that is consistent in terms of cost and service with needs of the system to the extent they establish standards for that performance that respect the constraints of the yard managers. If a standard fails to respect the yard manager's constraints, on the other hand, it may fail to fulfill any of its three purposes. Of particular concern are the constraints imposed by standards for performance in other areas (the yard manager who is trying to fulfill a standard for switcher use may also face a potentially conflicting standard for the processing times of cars) and by the yard manager's lack of total control over a particular performance measure (such as average yard time, which depends not just on the rapidity with which the yard processes cars, but on the frequency with which these cars are picked up by mainline trains). The problem is that operating conditions affecting these constraints, such as inbound volume and the frequency of block pickups, vary from day to day. If a standard fails to take into account the yard manager's constraints it will fail to predict, at least whenever it prescribes a better performance than the yard manager can acheive. If it predicts poorly, it will fail to serve as a troubleshooter that highlights problem spots. Finally, if in its failure to take into account the yard manager's constraints, it prescribes performance that is significantly better -- or worse -- than what the yard manager can achieve, it will become meaningless to both he and his superiors at headquarters. The more a standard takes these variations in operating conditions into account, conversely, the more effective will it be as predictor, troubleshooter, and motivator.

We have examined a spectrum of techniques for establishing standards that are reflective of the yard manager's constraints. We did so by means of analysis of data from two very different railroad yards: Woippy yard, on the French National Railways, and East Deerfield yard, on the Boston and Maine, a U.S. railroad. These techniques differentiate themselves in terms of the cost of data collection and processing they require, and the complexity of the computations used to develop a standard from the data. One way to take into account the variations of these operating conditions that is adequate in at least some situations is to establish a different fixed performance standard for each day of the week. These standards might well be based on average performance over some recent past period. In this way, the standard reflects how the average weekly cycle of operations, including average volume, outbound train frequency, and other operating conditions, has been affecting the performance measure of interest. This is the solution we recommend for the establishment of a switcher use standard at Woippy, and a car movement standard at East Deerfield.

Where the variations in this pattern from week to week is wide, however, or where the added cost of collecting and handling the needed data is low, a standard based on either more disaggregate data or more complex computations may be appropriate. This is solution we recommend for the setting of a switcher-use standard at East Deerfield, and a car-movement standard at Woippy. In order to reconcile, in the face of constant fluctuations of volume, the needs to set standards for both the yard's car movement performance and its cost performance, a volume-variable standard is needed for either for cost (particularly that of switcher use) or for car movement. In accordance with the apparent goals of management, we chose to establish volume-variables standards for the one item of cost that the yard manager must, if the switchers are to remain well-utilized, vary significantly in response to changes in volume: switcher use.

First let us examine the standard for switcher-use for East Deerfield, which we recommend be set by means of a computational technique -- linear regression -- that is somewhat more complex than those used by the Boston and Maine Corp. to set performance standards until now. An alternative adopted by many railroads for the setting of a volume-standard for switcher use is to set a standard that expresses the number of switcher-hours that should be worked as a simple proportion of volume. The problem with this technique is that it ignores the substantial fixed portion of switcher use, use that must be maintained no matter what the volume. Indeed, the unit standard for switcher use shares the same set of drawbacks as a fixed standard for switcher use: if the yard manager's goal is to keep processing time steady and switchers well-utilized, then over some ranges of volume, both the fixed and unit stardards will either prescribe more switcher-hours than are needed to do the job, or too few. If a standard is unrealistically optimistic, the yard manager will be unable to attain it and it will fail to predict. If it is either overly optimistic or overly generous to the yard manager, it will serve neither as a means for headquarters to identify problem areas, nor as a way for headquarters to motivate the yard manager to strive for better performance. A standard that is either unrealistically high or low will be ignored.

In contrast to the regression-based switcher-use standard we recommended for East Deerfield, we recommended a day-of-week standard for Woippy that takes the form of the existing switcher schedule. At Woippy, the establishment of a switcher use standard that predicts, helps troubleshoot, and motivates requires that we respect another kind of constraint: the inability of the yard manager to significantly alter the switcher schedule in the face of inbound volume fluctuations. The low explanatory power of inbound volume as a determinant of switcher use at Woippy is evidence of this inflexibility. Another reason for the low effect of volume on switcher use at Woippy is the relatively low variability of volume at Woippy. The ratio of mean inbound volume per day to its standard deviation at East Deerfield is 3.6, whereas over the days of the week when the yard is open, this ratio at Woippy is 6.7. (See Exhibit 3-12.) For these reasons, the detailed Woippy switcher schedule in Exhibit 3-18 constitutes an appropriate standard for switcher use. In deciding to set as Woippy's standard for switcher use the number of switcher hours scheduled for each day of the week, we are respecting the inability of yard managers to significantly alter the switcher schedule that is set at the start of each six-month period.

A standard will also be ineffectual as predictor, troubleshooter, and motivator if it refers to an activity measure over which the yard has no control. The example we have examined is average yard time, whose wait portion is a function of the frequency of block pickups and of left cars, events over which the yard manager has little or no control. A standard for the car movement performance of the yard must be found that respects the fact that the manager's performance in terms of yard time is constrained by pickup and left car frequencies. To control service performance in a way that respects the yard manager's inability to affect car pickup frequencies, the yard must either undertake the separate measurement of the processing and wait portions of yard time, or at least set yard time standards that reflect the weekly pattern of fluctuation in the determinants of yard time.

As we mentioned above, we adopted the former solution for Woippy, and the latter for East Deerfield. In the case of the standard for switcher use, our choice between a volume-variable or day-of-week standard hinged on the relative variability at the two yards of an operating condition that affects the level of performance the yard manager can attain. In contrast, in the case of the car-movement standard, our recommendations for the standards that should be used at the two yards turn on another critical consideration: the cost of the standard itself.At East Deerfield, where the means to collect and process this data would be more costly, we recommend the use of a standard average yard time for each day of the week that corresponds to actual performance during a recent period. The hypothesis underlying this standard is that because of the weekly cycle of volume and train schedules, block pickup frequencies and left tonnage rates also ebb and flow in such a cycle. We recommend the simpler day-of-week car movement standard for East Deerfield, where putting in place the means for the regular collection of the needed data at the yard would entail a significant rise in clerical and data-handling costs. At Woippy, on the other hand, where the neccessary data is already collected, the solution we proposed is to measure processing times and report their average. Since personnel already continually record the needed data, the benefits of having producing reports that state the processing and wait components of average yard time were judged to far outweigh the added expense of the additional data handling.

If a standard is to respect the yard manager's constraints, it must also be simple enough to be able to serve as the subject of negotiation between yard manager and headquarters. The yard's actual performance and the standard should be easily summarized in a few figures that headquarters and the yard manager can monitor and look for trouble spots. However, it should be based on data disaggregate enough to let managers find what exactly is the problem indicated by a more aggregate figure. These features were present in the budgets and weekly performance reports we presented. For instance, the yard manager might notice that processing time on a certain day of the week was above standard. He could then go back to the report for the day and find the particular shift during which processing time may have been too long.

The establishment of appropriate standards may have several desirable effects. The yard manager may begin to take a more system-wide view toward the role of the terminal. The reports juxtaposing standard and actual performance may make communication between yard and headquarters stronger and more two-sided. Headquarters will take a stronger interest in yard performance, and exert more pressure for improvements. This means that less slack will be present in, say, the number of switcher-hours assigned to a given workload, and that therefore the switcher use will vary more with volume. In order to exert control, headquarters must keep in closer touch with the yard and listen to what yard personnel say about how conditions there justified the number of crews worked.

This system is transferable to other railroads. The heart of the system is the set of performance standards we have developed. Another railroad would probably want to begin with the formats we recommend for the budgets and reports, and rewrite them in a new computer program in a way that incorporated the peculiarities of the operations, information system, division of responsibilities, and labor agreements of the particular yard and railroad. However, the following elements of our system of performance standards are applicable to all rail classification yards: standards for the key physical measures of yard performance, including switcher use and car movement; development of budgets for both operating costs and car costs that are based on relationships between physical performance measures such as car-hours and switcher-hours; where appropriate, variability of both physical standards and budgets with volume and other operating conditions; and juxtaposition of total cost (actual and budget) with service performance (actual and standard). Three ingredients are needed for a railroad to implement a system of performance standards of the kind we have developed: it must have the information on cost and service performance measures available in useable form; it must have variability in its operations over the course of the week and from week to week; and it must be able to vary its yard operations in response.

Finally, the concepts concerning performance standards that we have brought to light for the yard will be applicable in other situations, on the railroad and in other industries, where managers at the headquarters of the system must at once (1) delegate the running of outlying facilities to local managers, and (2) ensure that the performance of the outlying facility contributes adequately to the needs of the system.

REFERENCES

1 Carl D. Martland, "PMAKE Analysis: Predicting Yard Time Distributions Using Probabilistic Train Connection Standards," Transportation Science, Vol. 17, No. 1.

2 op. cit.

3 C. D. Martland, "Terminal Operations," unpublished memorandum, June 3, 1982.

4 op. cit.

5 an metaphor suggested in a personal communication by Arsene Felten of the Metz regional headquarters of the French National Railways.

6 Peter F. Drucker, An Introductory View of Management (New York: Harper's College Press, 1977), p. 419.

7 Drucker, p. 421.

8 C. D. Martland, personal communication.

9 Martland, "PMAKE Analysis."

10 This is one of the functions of the Service Planning Model developed by MIT.

11 Henry S. Marcus, personal communication.

12 C. D. Martland, personal communication.

13 Robert L. Winkler and William L. Hays, Statistics: Probability, Inference, and Decision, 2nd. ed. (New York: Holt, Rinehart, and Winston, 1975), pp. 667, 673-75.

14 Martland, "PMAKE Analysis."

15 Robert J. Tykulsker, Railroad Terminals: Operations, Performance, and Control, unpublished master's thesis, Massachusetts Institute of Technology, 1981.

16 op. cit., pp. 49-52, 64-67.

17 C. D. Martland, personal communication.

18 Drucker, pp. 432-33, 438.

19 Martland, "Terminal Operations."

20 Drucker, pp. 424, 428.

21 see Steven C. Rothberg, et. al., The Design of a Management Control System for Railroad Freight Terminals, and William L. Ferguson, Improving Railroad Terminal Control Systems: A Case Study of Southern Railway's Brosnan Yard, volumes 27 and 28, respectively, of MIT Studies in Railroad Operations and Economics. Both dated April 1980.

APPENDIX A

WOIPPY YARD - TRAINS OMITTED FROM ALL PROCESSING TIME DISTRIBUTIONS PRESENTED IN THIS PAPER.

(The processing of these trains spanned the weekly 24-hour shutdown from 1 p.m. Sunday October 4 to 1 p.m. Monday October 5.)

train number	arrival time on Sunday scheduled	actual	number of cars	time classified Monday afternoon
63104	527	517	35	1324
65658	608	600	33	1417
67170	712	712	6	1407
30355	835	827	38	1355
45521	909	900	26	1340
62108	1012	1010	41	1434

train number	number of cars	time assembly started on Sunday	departure time on Monday scheduled	actual
00743	38	515	526	526
00703	6	515	534	534
61531	28	255	538	538
61953	20	515	618	618
61315	32	515	739	739
30351	25	515	800	800
00705	22	515	944	944
00711	29	2320 (Sat.)	1007	1007
67495	30	515	1153	1153
61505	31	515	1237	1237
67464	27	515	1428	1428

APPENDIX B

DESCRIPTION OF COMPUTER PROGRAM DEVELOPED BY AUTHOR FOR CALCULATION OF PMAKE FUNCTION

In the computer program this author wrote to calculate a PMAKE function is written in the Pascal programming language for use on a microcomputer. It works as follows. First it establishes in memory five sets of time intervals, one corresponding to each of the four processing time distributions we have defined (arrival, classification, assembly, and departure), and the fifth corresponding to the total processing time distriubtion whose cumulative version will constitute the basis for our Process PMake function. The program is set to have 60 intervals, each covering 20 minutes, for each of the five distributions.

The program then examines each train arriving during whatever base period the user has selected. (This author used data from Woippy Yard for the first week of October 1981.) For each train, the program calculates the difference in minutes between the train's scheduled arrival time and its actual arrival time. It then finds in memory the corresponding interval of the arrival deviation distribution, and places in that interval the number of cars in the train. For example, if the train contained 45 cars and arrived 36 minutes late, the program would add 45 to the number of cars observed to have arrived between 20 and 39 minutes late. The program actually executes this process by going through each of the 60 pre-established intervals and seeing which trains should be placed in each. The resulting distribution for Woippy yard, for the period October 1 through 8, 1981, was shown in Exhibit 3-26.

At the same time the program is seeing which trains should go in each interval of the arrival distribution, it is also seeing which trains would fit in the correponding interval of the classification time distribution, the classification times having been earlier calculated as the difference between each train's arrival time and the time when its classification ended. (The Woippy classification distribution was shown in Exhibit 3-27.) In an entirely analogous manner, the program processes the data on departing trains to see which trains should be included in each of the 60 intervals of (1) the assembly distribution (Exhibit 3-28), and (2) the departure distribution (Exhibit 3-29).

Finally, the program sets to work convoluting together the four distributions just obtained so as to produce a distribution for total yard processing time. First the arrival distribution is convoluted with the classification time distribution. Convolution was described conceptually in Section 3.4. What convolution means in practical terms in this case is that the program looks in turn at every possible combination of the arrival time intervals and the classification time intervals. This is a total of about 60 times 60 or 3600 combinations. Each of the two intervals in each combination has associated with it a certain percentage of the total number of cars that arrived at the yard during the base period. We can interpret these percentages as estimates of the probability that arrival deviation and classification will have these values for a given train. Assuming that each of the four distributions is independent, the product of the percentages associated with the two intervals equals the probability that a train will have an arrival deviation falling in the range of the arrival interval and a classification time falling in the range of the classification interval. The computer than takes this product and adds it to the total probability that a train will have some arrival deviation and some classification time such that their sum falls in the range equal to the sum of the ranges of the two intervals. A great number of such combinations of arrival deviation and classification time will be present.

An example may help clarify this explanation. Suppose .03 of the arriving cars arrived between 80 and 99 minutes late, and that .08 of all arriving cars were finished being classfied 140 to 159 minutes after their actual arrival. Then the program would calculate that the probability was .0024 that a car would experience exactly this combination of arrival deviation and classification time. The program would also add .0024 to the total probability that the sum of a car's arrival deviation plus its classification time would be between 230 and 249 minutes. Once the program has established in this manner the distribution of the sum of the arrival deviation and the classification time, it convolutes this resulting distribution with the assembly time distribution and the departure deviation distribution using convolution procedures identical to the one just described. The resulting total processing time distribution for Woippy was shown in density form in Exhibit 3-30.