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Estimating The Impact of Advanced Dispatching Systems On Terminal Performance

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ABSTRACT

Several advanced dispatching technologies are under investigation by North American railroads. These technologies provide a number of important features, including CRT communications with locomotives, real-time train positioning, and computer assisted dispatching algorithms. Other researchers have shown how successful deployment of such systems should improve line-haul reliability, reduce en route delays, and provide better estimates of train arrival times (ETA's). This paper examines the effects of these line-haul improvements on terminal performance. Interviews with officials at six terminals identifies the types of improvements that can be expected, while analysis of operating data quantifies the extent of such improvements. Basically, more reliable train operations and better ETA's would improve train connection reliability and allow more efficient allocation of yard crews and other terminal resources. Better information on the location of interchange, industry, and local crews will allow more effective supervision of these operations. Overall, a 1-2 hour reduction in average yard times and a 5-10% improvement in the utilization of terminal crews may be achievable. Advanced train dispatching systems therefore do have the potential for improving general freight service over and above the effects on line operations alone. While dramatic improvements in overall service should not be expected, reductions of perhaps 6 to 12 hours in average trip times and substantial improvements in reliability appear to be realistic.

INTRODUCTION

Background

The North American rail industry is undertaking several efforts to implement advanced train dispatching capabilities. The Association of American Railroads and the Railway Association of Canada are jointly investigating Advanced Traffic Control Systems (ATCS), which would provide modular capabilities for various levels of control over train operations (Detmold, 1988). The goal of ATCS is to develop specifications for modular hardware that will, in effect, create a large enough potential market to stimulate and coordinate R&D activities by suppliers (Moore-Ede, 1984; Armstrong, 1986). In a separate effort, the Burlington Northern Railroad is far advanced in the development and testing of ARES, the Advanced Railroad Electronics System (Smith and Resor, 1988). An ARES locomotive control module receives signals from satellites that are relayed via a VHF link to a dispatching center, where they are analyzed to determine the locomotive's current position. With frequent updates of the locomotive's position, the system can also estimate the locomotive's speed. In addition, Guilford Transportation has established a subsidiary to develop accurate positioning capabilities that could be used by railroad, truck companies, or others interested in knowing the current location of their vehicles.

The focus on advanced dispatching systems is driven by several trends. Most important, perhaps, is the continuing need for the railroad industry to explore ways to improve service and productivity. In addition, continuing technological advances in computers and communications provide the potential for achieving better control over line operations, as demonstrated by the computer-assisted dispatching systems implemented in recent years by individual railroads (Petersen et al, 1986). Satellite positioning systems, which only recently have become available for private use, provide for more accurate positioning of locomotives than was possible with the traditional signal block system used by railroads. Similar capabilities are also feasible with transponder based technology, in which a locomotive reads its location from transponders placed at frequent intervals along the track. With better communications, dispatching algorithms, and positioning capabilities, railroads no longer need extensive wayside signal systems that are expensive to install, upgrade, and maintain. Better communications also provides potential benefits in fuel efficiency and safety. An intelligent dispatching system can advise trains to slow down and conserve as they approach meets; in general, such systems should be able to evaluate the tradeoff between fuel economy and line speed (Resor and Smith). With a direct link into the locomotive's controls, the dispatcher can also force reductions in train speed or even stop a train if it exceeds its operating order. In short, advanced train dispatching systems offer significant potential for improvements in line operations, line capacity, fuel economy, and signal maintenance expense. Taken together, such benefits could indeed have a major impact on line-haul productivity.

The Potential for Terminal Benefits

While better service is frequently cited as a benefit of systems like ATCS or ARES, relatively little attention has been given to the exact linkages between the advanced dispatching capabilities and the improvements in rail freight service. For unit trains and intermodal trains that, for the most part, avoid classification yards, line-haul times may be an important component of rail service. For general freight, however, line-haul times are substantially less important than yard times (Martland, 1972). This paper therefore addresses one of the critical linkages between dispatching and overall service, namely the link between advanced dispatching capabilities and terminal performance.

Overall, successful deployment of an advance dispatching system should lead to more reliable train operations, more accurate estimates of train arrivals (ETA's), and more complete terminal information systems. These direct effects will then lead to better terminal performance and ultimately to better service capabilities. There are three basic kinds of improvements that can be anticipated:

1. Better connection reliability: with better dispatching, train performance would improve. If trains arrive earlier, then cars on the trains will have more time to make their connections. If train arrivals are more reliable, then connection performance should also be more consistent.

2. More effective allocation of terminal resources: if trains arrive and depart more nearly on schedule, then it will be possible to allocate fewer resources more rationally on a daily basis. Likewise, if ETA's are more accurate, then it will be possible to make better tactical decisions concerning yard operations.

3. More effective control over terminal resources: terminal managers can use the positioning and communications technologies directly to supervise the switching operations in and around terminals.

Literature Review

Previous studies have addressed the interaction between line-haul and terminal performance. Some of the most relevant studies were conducted by the Federal Railroad Administration and the Freight Car Utilization Program between 1971 and 1981. These studies showed both theoretical and empirical support for the hypothesis that terminal performance will improve if train operations improve. For example, analyses of train connections on Southern Railway showed that average yard times generally improved when trains arrived earlier, which led to the conclusion that "increases in average train speed can have a network impact greater than the reduction in line-haul times alone" (Martland, 1974). Likewise, during the B&M case study, B&M implemented a policy to run trains on time; 1-2 hour improvements in train delays led to 1-4 hour improvements in total trip times (Martland, Messner and Nowicki, 1980). Another way to interpret these results is that, contrary to what is often presented as operating wisdom, there is clear evidence that reductions in line time would not be dissipated in the terminals, but instead would quite possibly lead to additional savings in terminal time.

During the 1970's, the MIT Rail Group also developed a methodology for relating train connection reliability to inbound train performance, yard congestion and other factors (Martland, 1982). This methodology was centered on the use of PMake functions, where PMAKE stands for the probability of making the appropriate connection to an outbound train. Various studies established PMAKE analysis as an effective way to model terminal performance and provided examples of the effect of changes in train operations on yard performance. PMAKE analysis eventually provided the basis for the development of the MIT Service Planning Model (McCarren, 1978; Martland and Van Dyke, 1979), which has been used by most of the major North American railroads for service planning studies. As will be shown below, PMAKE analysis provides an excellent framework for examining the potential service effects of advanced dispatching systems.

Visits to BN Terminals

A qualitative feel for the potential impacts of advanced dispatching systems was obtained by visiting a representative set of major BN terminals. Visits were made to six terminals:

a. Eola Yard, Aurora, IL

b. Murray Yard, Kansas City, MO

c. Northtown Yard, Minneapolis, MN

d. Pasco Yard, Pasco, WA

e. Balmer Yard, Seattle, WA

f. Cherokee Yard, Tulsa, OK

Interviews with terminal managers addressed such topics as the potential impacts of ARES on train service, the impact of train performance on terminal performance, resource allocation within the terminal, work rules that affect crew assignment, and the impact of better information on terminal management. The terminal managers then provided a tour of the terminal and nearby industrial locations in order to provide a better view of local operations and a clearer perception of operating problems where better dispatching systems could have a beneficial effect.

Most of the terminal managers expected significant benefits from ARES. The most important areas were felt to be the following:

a. Better planning of switching operations as a result of more frequent and more accurate ETA's

b. Relief of congestion and train interference within and near major terminals as a result of better dispatching (primarily at locations with extensive local, industrial, and interchange operations)

c. Better control over local, industry, and interchange operations as a result of placing ARES equipment in terminal switch engines

d. Better communications with local, industry, and interchange crews, with attendant benefits in crew productivity and/or clerical productivity

Some, but not all of the managers saw additional benefits in the preparation of reports summarizing crew activities, in training opportunities for terminal personnel, in better control over deadheading (of crews, power, and end-of-train devices), and in reduced radio contact with crews. Terminal managers were also very interested in "Service by Design", which was a BN program aimed at achieving better control of operations. They viewed SBD as more important, and much broader in scope, than simply improving train reliability. At some terminals, however, train operations were so unreliable that the terminal managers said that there was little or no "design" to terminal or outbound train operations. In other words, better control of line operations may be a prerequisite for Service by Design.

Overview of the Research

This paper presents the results of research into the effects of successful deployment of ARES on BN terminal performance. Section 2 analyzes the effects of advanced dispatching capabilities, especially better ETA's and positioning, on resource allocation within terminals. Section 3 addresses the effects of line improvements on terminal queues and processing times. Section 4 uses PMAKE analysis to estimate the overall effects on terminal service.

EFFECTS OF ARES CAPABILITIES UPON YARD EFFICIENCY

Introduction

BN terminal managers identified two broad categories of potential terminal benefits. The first category of potential benefits derives from the improved interface between line-haul and terminal operations. With more reliable train operations and better ETA's, terminal managers would be able to plan terminal operations and crew assignments more effectively. The second category of potential benefits derives from the enhanced capabilities for communications with and supervision of terminal crews. With ARES receivers and communications equipment on switch engines used in and near terminals, managers believed that they would be better able to supervise switching operations and thereby achieve improvements in terminal efficiency. These two categories of benefits are examined more closely in the next two sub-sections.

ETA's and Crew Assignments

The basic crew assignments were quite stable in all of the terminals visited. Furthermore, since changes in assignments generally had to be posted a day in advance, they would not be affected by better (or worse) ETA's, which would only apply to traffic arriving in the next 8-12 hours. However, better ETA's would affect decisions that are made with a shorter lead time, including the following:

a. Calling an extra crew for the next shift (1.5-2 hour lead time)

b. Holding a crew for overtime (0-2 hour lead time)

c. Holding a train for late inbound connections (1-4 hour lead time)

d. Deadheading power, crews, and/or end-of-train devices (1-8 hour lead time)

e. Determining hump sequences and train assembly priorities (0-4 hour lead time)

f. Assigning routes through the terminal to local crews when there are possibilities of conflict between these crews and inbound trains (0-0.5 hour lead time).

As a general rule, the shorter the lead time, the more important ETA's become. To illustrate this effect, consider the following two situations:

a. It is 0600 and a decision must be made whether or not to add a crew for the 0800-1600 shift. Given the current conditions in the yard, the terminal manager is willing to add another crew if 7 or more trains arrive by 1400, since trains arriving after that time will probably be handled by the next shift. In fact, according to the ETA's, 7 trains are due by 1400. The manager knows, however, that the ETA's are not always accurate and would like to know the probability that at least 7 trains arrive (in which case adding an extra crew would be the proper decision).

b. For the same situation as in the previous example, the terminal manager is considering holding a crew for overtime instead of calling an extra crew. He figures that an overtime crew could work with trains that arrive by 1000, but that the extra capacity would be useful only if at least 4 trains arrive in that period. In fact, according to the ETA's, 2 trains are due in by 0800 and 2 more are due in at 1000. Again, given the inaccuracy of ETA's, what is the probability that 4 trains will actually arrive?

This situation was simulated as shown in Exhibit 1. The first 2 columns show the inbound trains and their ETA's. The next seven columns show simulated arrival times, which were determined by sampling from the distribution of arrival delays observed in Tulsa in August 1988. Each column represents one possible scenario for the arrival times of these trains.

This simple simulation was run for 100 days for each of three arrival time distributions corresponding to the qualitative descriptions heard during the terminal interviews. Exhibit 2 describes the three arrival time distributions; the distribution labelled "+/- 0.5 hours" has 20% of trains arriving 1 hour early, 60% arriving on time, and 20% arriving 1 hour late.. The results of the simulations are shown in Exhibit 3. Part A shows the distribution of the number of trains arriving by 1400. On 75-81% of the simulated days, 7 or more trains arrived by 1400 and an extra crew could be utilized effectively; on the other days, only 5 or 6 trains arrived by 1400 and an extra crew would be superfluous. Hence, if an extra crew is added, the chances are roughly 1 in 5 that it will be underutilized. For the decision concerning overtime, shown in Part B, the accuracy of the ETA's is more of a problem. On 59-73% of the simulated days, 4 or more trains will arrive by 1000 and there will be plenty of work for the overtime crew to handle. However, on the other days, there will be no need for overtime. The chances are roughly 1 in 3 that the decision to hold a crew for overtime will be a waste of money. Even with the most accurate ETA's, there was still more than 1 chance in 4 that there would not be enough traffic (4 trains) to justify the overtime. In fact, with the least reliable ETA's, there is a 16% chance that only 1 or 2 trains will arrive, which would make the decision to hold a crew for overtime look quite foolish. In general, as the accuracy of the ETA's declines, the uncertainty grows concerning the workload for the near future. [PB]

The accuracy of ETA's will have the greatest effect on the tactical decisions concerning hump sequencing, train assembly priorities, dead-heading, and routing of crews through terminals. In many of these decisions, the ETA of a single train is of interest. A typical situation might be "If inbound train IB01 arrives within 3 hours, then I should hold outbound train OB02 so cars can make the connection. The latest ETA shows an arrival in 3 hours, but can I believe it?" Referring back to the distributions in Exhibit 2, with the most reliable ETA's, there is only a 20% chance that the train will arrive after its ETA. With the least reliable ETA's, however, the possibility of a late arrival more than doubles. If the terminal is a crew change point, there will be similar problems in deciding when to call the crew. Northtown estimates that better ETA's could save 50% of the costs of initial terminal delays, i.e. about $10,000 per month. In general, tactical planning becomes quite difficult in the absence of reliable ETA's. In such cases, a terminal responds to events and makes less of an effort to maintain a predetermined work plan.

EXHIBIT 1

Simulated Arrival Times for One Week

		Day of the Week						
Train	**Schedule**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**
11	0700	09	07	07	08	07	08	10
12	0800	07	09	09	09	11	09	09
13	1000	10	09	09	10	11	12	09
14	1000	12	13	11	12	12	11	11
15	1100	10	12	13	11	12	11	11
16	1600	13	14	12	11	14	14	13
17	1400	14	15	17	16	16	15	16
18	1500	17	17	17	17	16	18	17
19	1700	18	19	18	19	18	17	18
Number of Trains Arriving by 1000		4	3	3	3	1	2	3
Number of Trains Arriving by 1400		7	6	6	6	6	6	6

EXHIBIT 2

Distributions of Actual Arrivals Minus ETA's (%)

	Actual Arrival Minus ETA						
ETA Distribution	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
+/-0.5 hours			20	60	20		
+/- 1 hour		10	30	30	30	10	
> 1 hour	8.3	16.7	16.7	16.7	16.7	16.7	8.3

Productivity Reports and Crew Supervision

Terminal managers also mentioned the possibility of using advanced dispatching capabilities to improve their supervision of crews under their control. There was general agreement that this capability was of little or no use for yard crews that could be seen from the yard towers. For interchange, industrial, and local crews, however, ARES provides terminal managers information that they do not have. First, they would know the location of the crews without using the radio, and they would therefore be able to provide timely information to customers. Second, clerks could use the ARES communications capabilities to transmit changes in work orders to the crews. Third, and perhaps most important, supervisors would be able to monitor switch crew activities continuously. This would enable management to ensure that switch crew tasks were performed most productively. For example, if a train remained at one place for an extraordinarily lengthy time, the terminal manager would immediately have important productivity information. Finally, the locational information can be translated into productivity reports by recording the time that a switch engine enters and leaves a particular switching location and calculating the length of time that each operation takes. As a result, terminal managers would be better able to estimate switching costs, to identify efficient or inefficient crews, to train new personnel, and, in general, to supervise terminal and local operations.

It is difficult to quantify these benefits. At Tulsa, terminal managers estimated that they could obtain an extra hour of work in the terminal from each local or industrial crew. At Seattle, terminal managers estimated that they could save most of the

EXHIBIT 3

Distributions of Expected Train Arrivals (%)

A. The Percentage of Simulated Days in which the Indicated Number of Trains Arrive by 1400.

ETA Distribution		Number of Trains 5	6	7	8	>6
+/- 0.5 hours			19%	62%	19%	81%
+/- 1 hours			25%	52%	23%	75%
> 1 hour	3%	16%	4%	17%	81%	

B. The Percentage of Simulated Days in which the Indicated Number of Trains Arrive by 1000

ETA Distribution	Number of Trains 1	2	3	4	5	6	>4
+/-0.5 hours		6%	21%	56%	17%		73%
+/- 1 hour		10%	31%	40%	18%	1%	59%
> 1 hour	5%	11%	18%	41%	21%	4%	66%

efforts of 1 or 2 clerks who spend most of their time simply chasing down crews to give them change orders. Several of the managers said that they could supervise crews more efficiently with ARES and therefore devote more time to other terminal problems. Overall, an improvement of perhaps 10% in the switching hours and clerical and supervisory efforts involved in industrial and local operations might be achievable; a similar improvement could result for interchange crews in terminals where congestion is currently a problem.

EFFECTS OF TRAIN RELIABILITY ON YARD PROCESSING TIMES

Introduction

This section examines the extent to which variability in train arrivals affects congestion and the utilization of yard resources. The analysis was done using the "Terminal Queuing Model", which is described in the next sub-section. The model was run repeatedly with a variety of inputs reflecting different levels of variability in line haul performance. The results demonstrate that improvements in line-haul reliability could cause an improvement in terminal processing queues, but that the effect would be modest.

Model Description

The Terminal Queuing Model (TQM) estimates the time spent by cars awaiting classification, taking into account train arrivals and the terminal's processing rate. Inputs fall into two categories:

1. Train characteristics:

   a. Scheduled arrival times for trains in each of three categories of traffic (priority intermodal, priority freight, and other freight)

   b. Train arrival distributions for each category (each distribution shows the percentage of cars arriving anywhere from 6 hours early to 12 hours late)

   c. The average number of cars to be classified, for each category of train

2. Yard characteristics:

   a. Number of crews per shift

b. Processing rate (cars/hour/crew)

The first step in the model is to generate actual arrival times for trains over a 3-day period. For each scheduled arrival, the model chooses the arrival delay from the appropriate distribution. The model then determines how many trains arrive each hour over this 3-day period. The number of cars classified is at most the processing rate per crew multiplied by the number of crews per shift. A queue begins to build when more cars arrive than can be classified. Note that crews cannot be added indiscriminately. At a single track hump, for example, at most 2 crews can work effectively at one time; one switch crew pushes a cut of cars over the hump, while the other crew returns to the receiving yard to hook up to the next cut of cars to be humped.

Statistics are taken only from the second day of operations, allowing a 24-hour warm-up period for the model. Trains scheduled to arrive on either day 1 or day 3 would be included in the statistics if their simulated arrival times were on day 2. The most important statistics are the average queue length and the standard deviation of queue length. Each simulation was repeated 50 times in order to obtain reliable estimates of these performance measures.

General Analyses

The first analysis investigated the effect of train reliability on processing queues at a large terminal. No attempt was made to match train schedules to any particular yard, as the goal was simply to understand more about the effect of train reliability on yard processing times in general. Two sets of schedules were used - peaked and uniform - and a total of 2750 cars were expected to be classified each day. For the base case, the distributions of train arrivals, however, were based upon the actual distributions observed at Cherokee Yard in Tulsa during August 1988 for intermodal, priority freight, and other freight trains.

Exhibit 4 summarizes the queues predicted for a various switching capacities for the situation where scheduled arrivals were relatively uniform throughout the day. As the number of crews per day was cut back, the length of the average queue increased. When the total available switching capacity declined to the same level as the average expected arrivals, the queues increased sharply. In this case, 3.5 crews had the capacity to handle 2800 cars per day, and the queues built up rapidly if fewer than 4.5 crews were used. If train schedules are peaked, the queues are somewhat longer (Exhibit 5).

To show the effect of improved train reliability, the same analysis was repeated using more reliable train arrivals. Intermodal arrivals were assumed to have the distribution of observed intermodal departures at Tulsa during August 1988, while priority and other freight trains were assumed to have the observed reliability of intermodal arrivals. The results (Exhibit 6) show little or no change as long as capacity is adequate, but there is a 7% reduction for the case where switching capacity is most limited (3.5 crews).

Analyses Based Upon Operations at Tulsa

The same analysis was conducted for a situation designed to be much more similar to conditions at Cherokee Yard. For these runs, the actual train schedules were used and the average number of cars to be classified was reduced to 1500, which is a typical daily workload at Tulsa. Based upon the interviews, a single switcher is normally working at the hump. This provides something less than 24 hours per day of hump capacity, depending upon the time taken for lunch breaks, receiving instructions, train interference, and other delays. The situation was therefore modelled assuming 5, 6, 7 and 8 hours available per crew per shift, which is equivalent to model inputs of 1.88, 2.25, 2.63, and 3 crews per day. The results for the two sets of train schedules are shown in Exhibit 7. The benefits of reliable arrivals are on the order of 10 to 20% in this case, which is somewhat greater than in the general case.

Summary

This section has demonstrated that improvements in inbound reliability can result in a reduction in classification queues, especially in situations where the demand approaches capacity. Reductions of up to an hour might be realized in congested yards. The effect is likely to be more pronounced in situations where train schedules are peaked and yard switching capacity is closely tied to the schedules. Furthermore, the simulation results suggest that unreliable train performance will lead to a high degree of variability in terminal queues in congested yards.

EFFECTS ON TRAIN CONNECTION RELIABILITY

Introduction

Train arrival variability and terminal queues alone do not determine the level of service provided by a terminal. Train and terminal performance must be combined with train schedules and blocking plans in order to estimate the time that cars will spend in

EXHIBIT 4

Terminal Queuing Model Results, General Case (Uniform Schedules, Tulsa Arrivals)

Crews/day	Capacity	Cars Switched	Average Queue	Average Time (hrs)
6.0	4800	2713	127	0.63
5.0	4000	2737	151	0.90
4.5	3600	2771	172	1.14
4.0	3200	2771	240	1.80
3.5	2800	2699	407	3.48

EXHIBIT 5

Terminal Queuing Model Results, General Case (Peaked Schedules, Tulsa Arrivals)

Crews/day	Capacity	Cars Switched	Average Queue	Average Time (hrs)
6.0	4800	2851	141	0.71
5.0	4000	2775	180	1.08
4.5	3600	2838	196	1.31
4.0	3200	2742	295	2.22
3.5	2800	2738	452	3.86

EXHIBIT 6

Terminal Queuing Model Results, General Case (Peaked Schedules, Intermodal Arrivals)

Crews/day	Capacity	Cars Switched	Average Queue	Average Time (hrs)
6.0	4800	2705	132	0.61
5.0	4000	2752	176	1.05
4.5	3600	2778	187	1.25
4.0	3200	2750	307	2.31
3.5	2800	2720	417	3.59

EXHIBIT 7

Terminal Queuing Model Results, Tulsa Case

Crews/day	Actual Arrivals Average Queue	Actual Arrivals Average Time (hrs)	Intermodal Arrivals Average Queue	Intermodal Arrivals Average Time (hrs)
3.00	111	1.11	99	0.99
2.63	136	1.55	125	1.42
2.25	188	2.50	159	2.10
1.88	326	5.22	274	4.38

classification yards. This section uses PMAKE analysis as a way to relate train and yard performance to train connection performance. A PMAKE function gives the probability of making a connection as a function of the time available to make that connection (Exhibit 8). If very little time is available, then the connection will almost certainly not be made and cars will be delayed until the next appropriate train. If a great deal of time is available, then cars will usually make the connection. PMAKE functions can be calibrated as a function of train performance and yard efficiency using the "Process PMAKE" approach (Tykulsker, 1981; Martland et al. 1983]. This approach has been implemented in the "Process PMAKE" Model, a spreadsheet that is described in the next section. The "Process PMAKE" model was used to estimate the changes in PMAKE that would result from better train performance or more consistent processing times within the yards. Basic PMAKE analysis was then used to estimate the resulting changes in average yard times and connection reliability.

Model Description

The objective of the "Process PMAKE" Model is to provide a way to estimate a PMAKE function based upon estimates of train and yard performance. A "Process PMAKE" function can be calibrated by first convoluting train arrival distributions and yard processing times and then adjusting for the probability of delays caused by lost paperwork ("no-bills"), repairs ("RIPS"), tonnage constraints ("Tons"), cancelled blocks or trains, and miscellaneous causes. More specifically, the model convolutes the following four processing time distributions:

a. Arrivals: the actual minus the scheduled arrival time (a late arrival decreases the probability of making a connection)

b. Departures: the scheduled minus the actual departure time (an early departure decreases the probability of making a connection)

c. Classification: the time from train arrival until the train is classified.

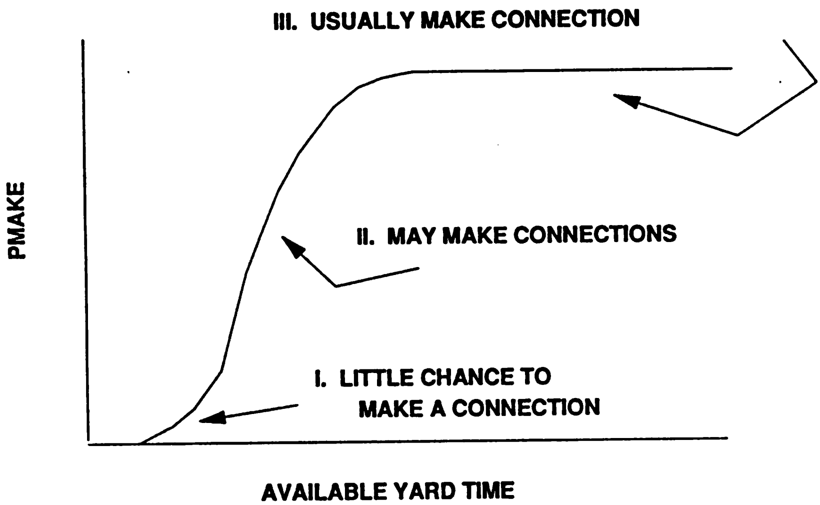
d. Assembly: the time from "making" the train until the train actually departs.

Examples of these distributions are shown in Exhibits 9a to 9d. In each of these figures, the X-axis is processing time (in hours) and the Y-axis is the percentage of cars. The model convolutes these distributions to obtain the distribution of total processing time, as shown in Exhibit 9e. It is then necessary to adjust the cumulative distribution of total processing time for "PMAX", the maximum probability of making a connection. PMAX equals 1 minus the probability of other delays, as suggested by Exhibit 9f. The resulting distribution is shown in 4-2g; the X-axis is now interpreted as the scheduled time available to make the connection and the Y-axis is the percentage of cars that make the connection.

For ease of computation and comprehension, a PMAKE function can be linearized and specified by three parameters (Exhibit 10). PMAX has already been defined. T50 is the available time for which PMAKE is half of PMAX; T50 therefore equals the median of the total processing time distribution. T90 is the additional available yard time required for PMAKE to reach 90% of PMAX; T90 is therefore a measure of the variability in processing times. If train and yard performance were perfectly reliable and if daily yard volumes never varied, then T50 would equal the time required to classify an inbound train plus the time required to assemble an outbound train and T90 would equal 0. If there were no tonnage delays, if cars never had to go to the rip-track, and if

EXHIBIT 8

PMAKE Analysis - The Key to Understanding Reliability



paperwork were always in order, then PMAX would equal 1.0. In such circumstances, the PMAKE function would look exactly like a deterministic cutoff. The power of PMAKE analysis is that it can be used to study yard performance even though such assumptions are seldom, if ever true.

Given the probability of making a connection for a particular available yard time (AVAIL), the expected yard time for a particular train connection is:

MEAN = AVAIL + [1 - PMAKE(AVAIL)] * DELAY (Equation 1)

where DELAY is the delay until the next train departure, e.g. 24 hours for daily train operations. More complicated formulations take into account the possibility that a car may miss more than one connection.

An example may help (Exhibit 11). Consider cars arriving on an inbound train due in at noon that are supposed to connect to an outbound train that departs daily at 2000. The available yard time in this case is 8 hours, and the PMAKE for 8 hours is 0.75. As a result, there is a 0.75 probability that the cars will, on any given day, make the connection with a yard time of about 8 hours. If the cars miss the connection, then they will be delayed until the next day (at least), and spend an extra 24 hours in the yard. The expected average yard time is therefore 8 hours plus the expected delay of 0.25*(24 hours) for a total of 14 hours. This same analysis could be done for a representative set of train connections to estimate average yard times for a particular class of traffic at a classification yard.

Applications of the Process PMAKE Model

The "Process PMAKE" Model was first applied to Cherokee Yard, Tulsa, Oklahoma. This yard was chosen for two reasons. First, its primary function is to perform intermediate classifications and it has relatively little industrial and interchange activity. Second, during the visit to the yard, a copy of a special study of train performance was obtained. The study showed train arrival and departure times for August 1988, which provided the necessary data to obtain train arrival and departure distributions for different classes of trains. Terminal managers also provided estimates of the times required for classification and assembly.

Separate PMAKE functions were calibrated for connections involving intermodal, priority freight, and other freight trains (note that intermodal trains may also carry high

EXHIBIT 9

A PMAKE Function Can Be Calibrated by Convoluting Distributions of Train Arrivals and Yard Processing Times

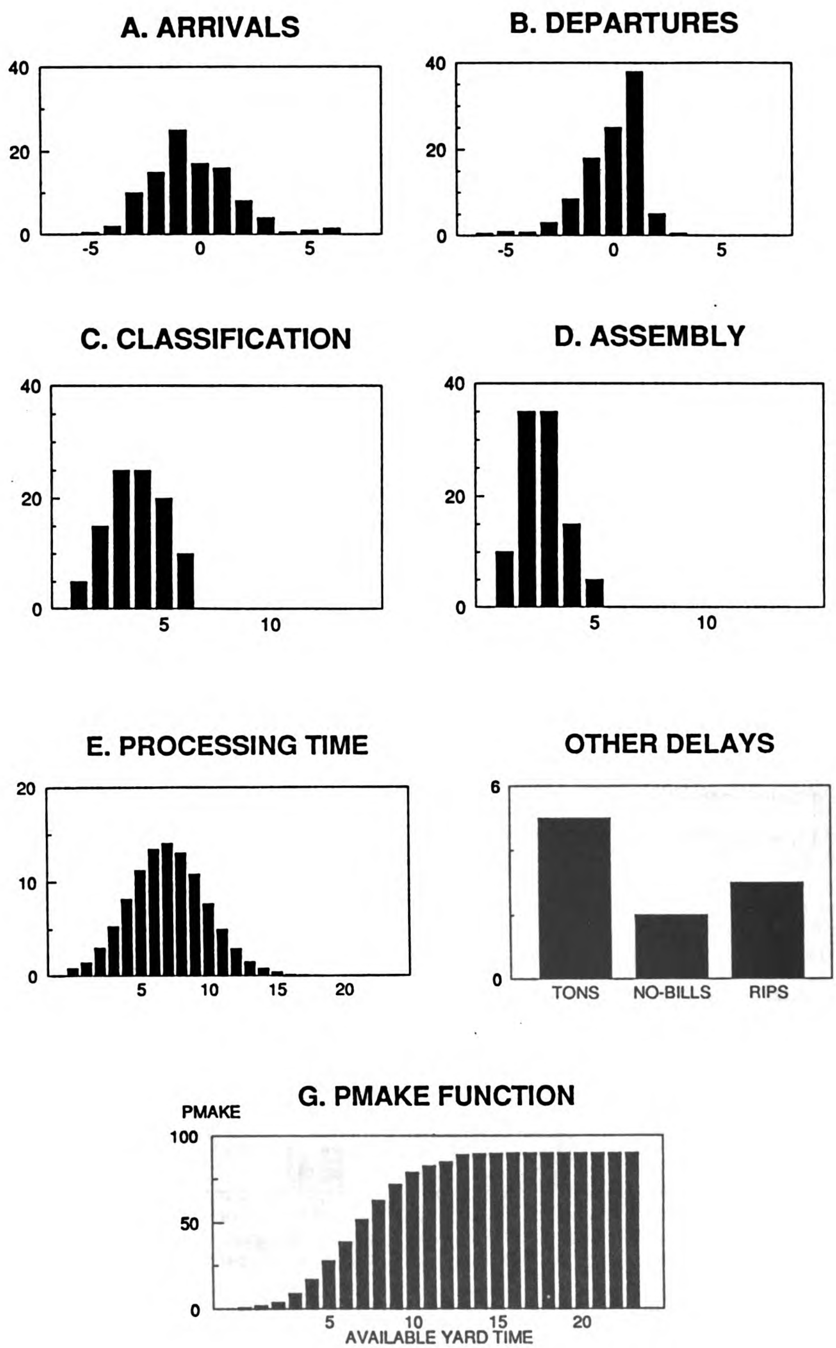


EXHIBIT 10

Linearized PMAKE Parameters

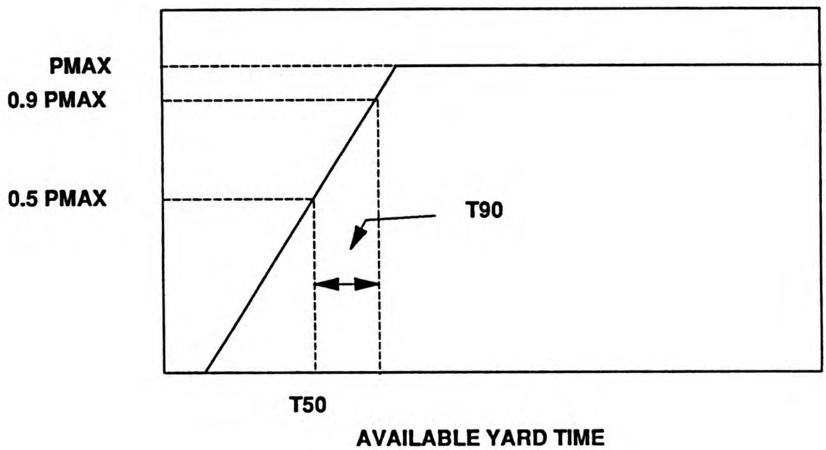
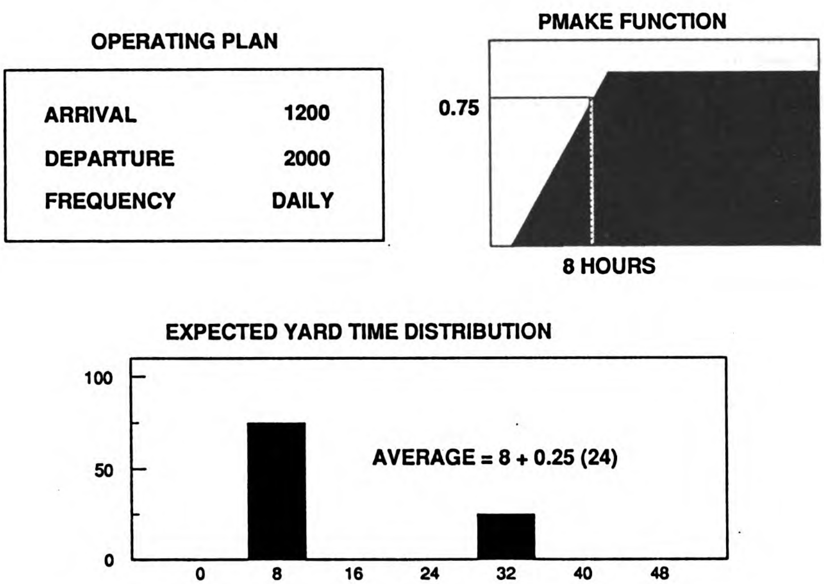


EXHIBIT 11

Predicting Train Connection Performance



priority freight such as auto parts). The actual train arrival and departure distributions were used for each group, while estimates of processing time and PMAX were based upon the discussions with terminal officials. The results were as shown in Exhibit 12. T50 is the lowest for the first row in this table, because relatively little time is required to switch a block of cars from one intermodal train to another. For priority and other freight trains, T50 increases because cars must wait in the hump queue before being humped, as described in Section 3. Since T90 reflects the variability inherent in the various processes, it also increases from intermodal to priority freight to other freight. The last row of the table represents a special case that will be discussed below.

These PMAKE functions were then applied to the 26 train connections that were specified in the BN train briefs for August 1988. If both the inbound and the outbound trains were in the same category, then that PMAKE function was used to estimate the average yard time. If the trains came from different categories, then the average yard time was estimated as the average obtained using the PMAKE functions for those two categories. The overall predicted average yard time was 17.6 hours, which was equal to the actual yard times for train-to-train connections at Tulsa in August.

By changing the distributions assumed for train arrivals and departures, it is possible to estimate the effects of train performance on yard performance. For example, when the performance of intermodal trains is used for "other" trains (instead of their actual performance), the PMAKE (i.e. T50-T90-PMAX) for other trains improves from 7-6-.9 to 6-4-.9 (see the last line of Exhibit 12). The improvement in T50 occurs because the intermodal trains arrived roughly an hour earlier, relative to their schedules, than the "other" trains. The improvement in T90 occurs because intermodal trains were more reliable than the "other" trains. Similar changes were then made in the train arrival distributions used for the intermodal and priority freight trains to reflect the benefits that would be achieved from more reliable train performance. The overall result predicted for Tulsa was a reduction in average yard times from 17.6 hours to 15.8 hours. Similar results (not presented in this paper) were achieved for yards in Kansas City and Memphis.

The effect of improvements in yard efficiency can also be incorporated into PMAKE analysis. The analysis of Sections 2 and 3 suggests that a reduction of perhaps an hour could be achieved in processing times, which was modelled as further reductions in T50 and T90, leading to an additional decline in average yard times from 15.8 to 14.4 hours. Overall, this PMAKE analysis therefore suggests that a reduction from 17.6 to 14.4 hours might be feasible at Tulsa. (Actually, since the trains in this analysis arrived a half hour to an hour early, a portion of the 3.2 hours saved would show up as a savings on the line. The PMAKE methodology used in this section in effect estimates yard times using the scheduled rather than the average arrival times of the inbound trains.)

The impact on reliability would be greater than the impact on average times. Equation 1 indicates that the average yard time equals the average available time plus the average delay. For these connections, the average available time was 11.4 hours, so that the average delay predicted for the base case was 6.2 hours. In rough terms, 25% of the cars would miss their connection and suffer a 24 hour delay. Since no changes were assumed in train schedules, the average available

EXHIBIT 12

PMAKE Functions Calibrated for Tulsa

Arrivals	Departures	Yard Processes	T50	T90	PMAX
Intermodal	Intermodal	Intermodal	3	3	.95
Priority Freight	Priority Freight	Priority Freight	5	5	.90
Other Freight	Other Freight	Other Freight	7	6	.90
Intermodal	Intermodal	Other Freight	5	4	.90

time remained 11.4 hours and the entire savings of 3.2 hours represented a reduction in the average delay. In effect, with more reliable train performance and faster yard processing, only half as many cars (13%) would miss their connections.

Further improvements in yard time would have to come as a result of changes in operating plans or of actions taken to increase PMAX. It is relevant to note that improvements in dispatching and in locomotive assignments could lead to an increase in power availability, which could in turn cause a reduction in tonnage delays and a subsequent increase in PMAX.

Summary

PMAKE functions provide a way to relate train performance and terminal efficiency to train connection reliability and average yard times. Significant improvements in train reliability would reduce the T90 and possibly the T50 parameters, which would in turn lead to more reliable train connections and lower yard times. Based upon the analysis of Tulsa, improvements of approximately one to two hours in average yard times would appear to be within reach as a direct result of improvements in train reliability. At congested yards, an additional hour may be saved as a result of better utilization of terminal resources and earlier returns of industrial, local, and interchange crews. Furthermore, train connection reliability could improve dramatically. At a typical industry average rate of $0.60 per car hour, the benefits of better train connection performance could approach $1 million annually at a yard handling 2,000 cars per day.

SUMMARY AND CONCLUSIONS

Extent of Benefits

Advanced dispatching systems offer real and, to varying extents, measurable benefits for terminal performance. Where measured, train performance was variable enough to allow considerable room for increased reliability. Improving overall train reliability to the level actually achieved for intermodal trains would save on the order of one hour in average yard times for train connections at the yards studied. Average yard times would be most affected at terminals that perform a great deal of intermediate classification.

In addition, a modest improvement in terminal efficiency and further improvements in train connection performance could be achieved through better utilization of terminal crews. Terminal efficiency would get the greatest boost, perhaps 5 to 10%, in terminals where there is a great deal of industrial and interchange activity and switch crews are often out of sight of the tower. Additional improvements in average yard times on the order of one hour appear to be feasible. These improvements in average yard times are above and beyond any savings in trip time that may be achieved through better planning of meets and passes.

Terminal managers who are comfortable with computers and the use of productivity measures would be most apt to take advantage of the increased information provided through advanced dispatching systems. Prior studies have shown that increased supervision can lead to a clear improvement in the utilization of terminal crews (including local, industrial, and interchange crews). Better positioning, communications, and reporting capabilities will, in effect, allow the existing managers to make better use of their time, which would be equivalent to adding supervisory capacity.

Linkages to Other Studies

The BN is conducting a broad investigation of the potential benefits of advanced dispatching systems that goes well beyond the research reported on in this paper. Two studies in particular should be mentioned. Zeta-Tech and the University of Pennsylvania are investigating the effect of advanced dispatching systems on line performance. The results of their studies will include estimates of changes in train reliability that might result from ARES. Such effects could be directly incorporated into the arrival and departure time distributions used to calibrate a Process PMAKE function.

The effect of terminal performance on system performance is being investigated by A&L Associates in a separate study using the Service Planning Model (SPM). The SPM uses PMAKE functions together with traffic flows and an operating plan to predict origin-to-destination trip time distributions. The PMAKE functions calibrated for Tulsa, Kansas City, and Memphis will be used in that study, which will relate the improvements in terminal performance to improvements in origin-to-destination performance for general freight.

Overall Implications

The research in this paper supports some general conclusions about the potential impact of advanced dispatching systems on system service. It has shown that terminal performance could be improved by a small but measurable amount through the introduction of advanced dispatching capabilities. Furthermore, these terminal improvements are expected to carry through to origin-to-destination performance. For a typical freight car moving through several major yards, the benefits would likely be on the order of 1 to 3 hours per yard, which could reduce average trip times by perhaps a quarter of a day. This would be roughly a 5% improvement for a typical trip currently requiring an average of, say, 5 days. In addition, there would be somewhat greater improvements in trip time reliability, since there would be much more consistent performance in the terminals. Service improvements of this magnitude would certainly not revolutionize the railroad industry, but they would help railroads remain competitive in some situations and also provide tangible benefits in terms of car utilization.

For larger improvements in service, railroads need to make substantial changes in blocking, operate more through trains, and increase train frequency. While advanced dispatching systems would not directly affect such decisions, the indirect effects could be substantial. For example, with better control over meets and passes, a railroad in effect increases line capacity, thereby allowing additional trains to operate with no increase in line investments. Also, the ability to operate reliable trains may well be a prerequisite to programs such as "Service by Design" that attempt to instill a concern for reliable performance at all levels of the operation. Advanced dispatching systems, therefore, may be a critical component of a large program aimed at improving rail service.

The decision of whether or not to implement an advanced dispatching system lies with each individual railroad. How much investment is justified depends for the most part upon the extent and condition of the current dispatching and signalling systems and the current level of operating performance. While predictions of dramatic improvements in service should be questioned closely, modest improvements in terminal performance and general freight service can certainly be expected with implementation of such a system.

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ENDNOTES

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