

IMPROVING RAILROAD PERFORMANCE USING
ADVANCED SERVICE DESIGN TECHNIQUES:
ANALYZING THE OPERATING PLAN AT CSX TRANSPORTATION

by

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Abstract

Operating plan design and execution are critical to railroads in both marketing and operational contexts. Trip time and reliability, two dimensions of rail service quality most valued by shippers, depend on the design and execution of the railroad's operating plan. Railroad asset utilization and operating costs also depend on the operating plan.

Through analysis of five alternative operating strategies, this thesis tests the hypothesis that operating plans based on sophisticated strategies for organizing classification activity and train movements can have a major impact on service quality. Unconventional strategies included Local Pre-Blocking, Terminal Complexes, and Tandem Humping. Conventional strategies included ABM-Generated Routing and Improved Yard Performance. Operating plans representing each alternative were created for CSX Transportation's Chicago-Nashville corridor and compared to a base case representing CSXT's November 1993 operating plan. Implementation issues associated with the alternative strategies were considered qualitatively.

The Tandem Humping strategy provided few benefits and was exceedingly complex. The other four strategies were each predicted to lower costs from \$8 to \$24 million per year, subject to implementation considerations. Predicted savings result from reductions in car-hours, car-miles, and car-handlings of traffic targeted by each alternative.

None of the alternatives would require major additional resource expenditures and therefore their relatively modest benefits could justify changes in operations and service design. Implementation of more sophisticated strategies would have to be delayed or altered unless advanced control systems were adopted or more reliable execution of the operating plan was achieved. Where decision support tools are used to generate operating plans, significant benefits could result, but the quality of model input data strongly influences the dimensions of the resulting plan.

Thesis Supervisor: Carl D. Martland
Title: Senior Research Associate

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Many more people deserve credit for this thesis than can be named here. Those who laid the groundwork for this thesis in more indirect ways include America's founding fathers; the countless, unnamed laborers who built the railroads; railroad employees present and past, including several of my ancestors; and current and former rail customers who demand fast and reliable service.

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My girlfriend, Lucy, was constantly with me in my thoughts and occasionally even materially present during the course of my graduate study. Lucy's companionship and charm always lifted my spirits.

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1 Research Motivation and Background

1.1 Goal of the Research

The research presented in this thesis was undertaken with the goal of improving service quality of carload freight movement, focusing on the key dimensions of service quality, trip time and reliability. The research follows recent findings that carload freight movement remains slow and highly variable [Little & Martland, 1993], and that customers weigh trip time and reliability most heavily in choosing carriers and assigning volumes [Vieira, 1992, and AAR-ISM, 1993].

The research addresses the railroad operating plan, which is important not only to customer satisfaction, but also to financial performance. The design and execution of the railroad operating plan jointly determine trip time, reliability, and also asset utilization and operating costs. The research attempts to answer the question: *Is it possible for some or all merchandise traffic to achieve major improvements in trip time and reliability through adoption of a significantly more complex operating plan, which stipulates new roles for some yards and train crews?*

The organizational strategy which underlies the railroad operating plan influences plan elements such as train routes and schedules, car-to-block and block-to-train assignments, and the yard classification plan, which in turn influence both service quality and cost. This research investigates the effects of five alternative strategies on both service quality and operating costs. Three of the alternative strategies incorporate unconventional concepts for organizing classification activity and train movements. The fourth strategy substitutes use of decision support for manual analysis in generation of car routes, while the fifth incorporates improved yard performance. Of the five strategies, four incorporate changes in the design of the operating plan. Only the fifth strategy assumes more effective execution of the base operating plan.

Research into the influence of operating plan design on performance could only be effective if carried out in cooperation with railroad. Opportunities to model strategies as they would be applied to specific operating regions using in-house decision support tools and to confer with service planners about the study region and matters of service planning apparent only to practitioners were considered invaluable factors in securing a credible and relevant result. CSX Transportation assisted the research by providing the network modeling tools and data and the assistance of members of their Operations Research, Technology, and Service Design staffs.

1.2 Prior MIT Research in Service Reliability

The MIT Rail Group has investigated issues in service reliability and operations planning during two multi-year research efforts. The first such research effort lasted from 1970 through 1981, and included participation in Freight Car Utilization Program, funded

by the Federal Railroad Administration and later by the Association of American Railroads. The second period of MIT research in service reliability took place from 1990 through 1994 with funding from the Association of American Railroads.

Both periods of research resulted from the railroads' motivation to improve operating performance in a capital-constrained environment. New techniques for service management, planning, and measurement were developed to improve performance while also improving asset utilization.

During both periods of research, MIT researchers worked extensively with Class I railroads, generating and evaluating data and preparing reports and case studies which documented particularly effective and ineffective operating practices and recommended analytical techniques useful in operations planning and performance measurement. Several of the most in-depth and influential studies performed during these research periods are summarized below.

1.2.1 Research Performed in the 1970s and 1980s

The research performed under the auspices of the FRA/AAR Freight Car Utilization Program and its FRA-funded precursors remain among the most in-depth research into railroad operations and economics ever performed in an academic setting. These projects set precedents in examining operating costs using a holistic analytical framework, illustrating tradeoffs between, for example, labor and car hire costs, train and yard costs, and operating cost and service quality. Close relationships with Class I railroads provided critical data and insights into operating conditions, leading to more effective recommendations than could otherwise have been possible.

The three case studies summarized below provide a good overview of the FCUP-era research. Common elements of the three case studies make them logical precursors to the research described in this thesis. All provide direct methodological precedents for the current research, in that they began with a broad audit of a railroad's existing operations, identified operational changes geared toward performance improvement, and evaluated the potential impacts of those changes using the Service Planning Model and other analytical methods.

- **Southern Railway (1972-1974).** The FRA-funded Southern Railway Case Study noted that improvements in O/D reliability required either improvements in reliability of local pickup and delivery operations and/or train-to-train connections, increased consistency of O/D routing, reductions in car handlings, or reductions in extraordinary delays caused by misroutes or bad-orders. Applying solutions based on those conditions to reliability problems in five lanes, the research achieved improvements in O/D reliability where its recommendations were implemented, saving between \$2,500 and \$15,000 per month. In several instances where actual improvement did not match predictions, mitigating circumstances such as failure to

implement and unanticipated operating changes affected the study region. [Martland, 1974].

- **Boston & Maine (1978-1980).** The Boston & Maine Case Study was the most extensive of the FCUP case studies, dealing with network-wide performance levels and operating changes, and including contributions from both operating and marketing departments, who interacted with MIT researchers through the activities of an interdepartmental service committee. The objective of the case study was to assist B&M in regaining profitability by reducing switching and car-hire expense through a combination of operating plan and car distribution strategy changes. In the first phase of the case study, individual changes to the operating plan were proposed, and their cost and performance impacts estimated using the Service Planning Model. The proposed changes were then reviewed by the operating department and the most attractive and feasible changes implemented. Actual cost and performance impacts of the changes were measured, and unexpected issues which arose in implementation were discussed. The changes were on the whole extremely successful, and resulted in a 15% reduction in total car costs in 1979, a savings of over \$3 million. [Martland, Messner, and Nowicki, 1980]
- **Santa Fe (1980-1981).** The Santa Fe Case Study was more limited in scope than the Boston & Maine Case Study. The final research report contained descriptions of proposed changes to Santa Fe's operating plan for its Northern and Southern divisions, and reported performance changes predicted by the Service Planning Model. Because of its relatively short time frame, the Santa Fe Case Study did not document implementation of recommendations or audit resulting performance changes. The case study did, however, provide an extensive discussion on the benefits and shortcomings of the Service Planning Model and a plan for integrating the SPM into the railroad planning process. [Martland, Clappison, Van Dyke, and Tykulsker, 1981]

1.2.2 Research in Railroad Reliability in the 1990s

Competitive pressure among railroads and from the trucking industry forced the issue of service reliability to the forefront again in the late 1980s. Shippers indicated in surveys and by their carrier choices that service quality was important. Accordingly, the AAR's Research & Test department directed funding to MIT for research in service reliability. Among the major focuses and findings of the research were:

- **Audit of Reliability.** The audit of railroad reliability measured several dimensions of service reliability and operating performance, with the dual goals of demonstrating current performance levels and isolating and ranking root causes of service failures. The audit of reliability was performed in several dimensions, including summarizing the trip times for a group of 93,000 car moves, performing a root cause analysis to determine the causes of service failures, and examining other root cause data supplied by major railroads. A major finding of the audit of

reliability was that more than 80% of all service failures are caused by factors subject to management control, such as power or crew shortages or missed connections in terminals. A related study of double-stack car moves illustrated that cars with the fewest enroute handlings exhibit the best service quality. Even for this group of high-priority cars, however, mechanical problems and holidays explained less than 20% of all shipment delays. [Little and Martland, 1993]

- **Assembly of Terminal Performance Benchmarks.** Throughout the FCUP research of the 1970s and 1980s and through the resumption of service reliability research in the 1990s, a database of yard performance has been assembled. Measures of activity and performance include calibrated PMAKE functions, train arrival and departure distributions, and, in some cases, cars handled per yard crew. The benchmarks showed that the best-performing hump yards have yard times in the 16-20 hour range, average-performing yards have yard times around 24 hours, and poor-performing yards have average yard times at or above 28-30 hours. [Martland, Little, Duffy, and Dong, 1994]
- **In-Depth Study of Terminal Operations.** MIT Researchers participated in a detailed study of CSX Transportation's Radnor Yard in Nashville, TN, in October 1993. The study led to several insights about the relationships between train arrival and departure times, yard staffing levels, cutoff lengths, and performance. The research found that long wait times between processes like inspection, humping, and train assembly contributed to long yard times, and that queues of unprocessed inbound trains formed when many trains arrived when few inspectors and hump crews were scheduled on duty. In addition, Michael Duffy applied SPC techniques and root-cause analysis to missed connections and processing performance at Radnor Yard. [Duffy, 1994 and Dong, 1994:2]
- **Development of Insights in Service Differentiation.** MIT doctoral candidate Oh Kyoung Kwon developed a simulation model which illustrated the effects of three strategies for prioritizing traffic for movement on trains, as could be easily executed in high-demand intermodal operations. The strategies include a strict priority-based assignment, assignment based on the cumulative waiting time in a movement queue, and a hybrid strategy which assigned weights to priority and time in the queue. The model showed that the three strategies resulted in different trip time distributions for high-, middle-, and low-priority traffic. The model also showed that logistics costs experienced by shippers of high-, medium-, and low-value density traffic were significantly influenced by the train makeup rule in effect. These findings imply that through adoption of a particular operating strategy, railroads can choose to provide market segments with better or worse service, and that the choice of operating strategy should be subject to knowledge of market demand for different levels of service quality. [Kwon, 1994]

1.3 Other Significant Research in Railroad Operations

1.3.1 Optimization

Other academic research into design of the railroad operating plan has focused on mathematical optimization of car-to-block assignments, block-to-train assignments, train route and schedule creation, or tactical management problems such as locomotive- or crew-to-train assignment or meet/pass planning. Such models usually minimize costs, subject to coverage and capacity constraints. For compilations of work in optimization of rail problems, see Assad (1980) and Armacost (1995).

One recent example of methodological development is Keaton's (1989) formulation of car-to-block assignment, block-to-train assignment, and train route creation as a single network design problem solved using Lagrangian relaxation and heuristic methods. The formulation's strength was that it combined elements of the operating plan design problem which had previously been solved separately, while adopting assumptions which did not compromise the relevance of the solution. However, solution time was high even for an very small sample network, suggesting that the methods presented could not be used for a network the size of the CSXT merchandise network [see Section 2.3.3].

Acceptance of optimization methods for operating plan design has been limited. Lack of interest in optimization on the part of railroads frustrates basic research, as opportunities for feedback on independent research are limited, and independent research often suffers from a lack of meaningful operating data. The rift between developers of optimization methods and the potential railroad users may be explained by the fact that simplifying assumptions made to reduce the problem of operating plan development to a solvable core are not well accepted by rail service planners. Regardless of the cause, few cases of implementation of optimization methods in operating plan design can be cited.

The outlook for operations research methods in the rail industry is being improved by analysts employed by railroads, and by a small but growing cadre of software development/consulting firms. At least four major railroads maintain operations research staffs, some of which access dedicated programmers [see Section 2.3.2 for a discussion of CSX Transportation's Operations Research Group]. As has happened in the airline and telecommunications industries, new mathematical methods have arisen as by-products of the effort to solve individual corporate problems. Unlike the work of the airline and telecommunications industries, however, most of the methodological advances made at railroads remain unpublished.

Development firms offer software tailored to specific rail problems such as meet/pass planning and locomotive management. Such software promises short-term benefits for railroads, while its sale also funds methodological development. One of the first of such firms, ALK Associates, took over the maintenance and evolution of the ABM, TSS, and SPM, used in this research [see Section 2.3.3], after initial development by MIT and the AAR. Like work by internal operations research staffs, the core algorithms used in this

software are largely unpublished, although software manuals often describe solution procedures conceptually.

1.3.2 Consulting Audit

Management consultants to the railroad industry have performed many detailed analyses of railroad operations. One such report in the public domain documents railroad terminal operating practices and performance in different regions of the country in 1977. The report was produced by Booz, Allen & Hamilton for the FRA in fulfillment of Section 901(2) of the 4R act, in order to "identify potential economies and improvements in performance that result from improvement in local and terminal operations." The report studied four major terminals in different regions of the United States and developed cost factors and work rates for terminal operations. The study then used manual analysis and simulation to identify workload consolidation and service improvement opportunities.

At the time the report was produced, several factors hindered the service design process from giving rise to efficient, high-performance terminal operations. First, detailed car flow information for planning required substantial effort to generate. Second, assignment of crews in yards was often based on historical practice rather than on anticipated workload. Despite these barriers, the report identified major opportunities to reduce car cycle time and yard crew requirements.

A finding relevant to the research presented in this thesis was that the majority of the potential improvement in car cycle times was derived from improvements in execution rather than from changes made to the terminal operating plan. This evidence reminds us that a superior plan will not by itself provide superior performance. Research attempting to improve performance by altering the operating plan, while by no means misguided, should not divert attention from execution of the plan in the field, as execution appears to influence performance most strongly.

1.4 Development of Alternative Operating Strategies

Recent audits of rail service quality [see Section 1.2.2] have identified railroad yards as the chief culprits in causing merchandise service to be slow and unreliable. Therefore, the alternative organizational strategies for railroad operations explored in this thesis attempt to eliminate car handlings in yards, and render remaining yard activity more effective. The alternative strategies would achieve this goal by reorganizing required classification activity across facilities and in time, in an attempt to exploit critical traffic flow densities or unused classification capacity, embodied in both trains and yards.

Three unconventional alternative operating strategies were originally articulated in an October 1993 meeting of MIT Rail Group and Service Design personnel representing CSX Transportation and Burlington Northern. Each alternative operating strategy takes a different approach to meeting the goal of eliminating or improving the efficiency of car handlings. The unconventional strategies examined in this thesis are:

- **Local Pre-Blocking.** Local trains would pre-block originating traffic. Originating traffic would be blockswapped directly to through trains, without requiring any additional processing in the origin terminal. Classification requirements would decrease, allowing yard crew savings. Coordination of through and local train schedules ("schedule sliding") would reduce trip times for originating traffic.
- **Terminal Complexes.** A yard would process a group of trains as at an airline hub. Trains would arrive in a closely spaced group, then be processed on a tight, coordinated schedule. The resulting blocks would be assembled into outbound trains, which would depart in a closely spaced group. This coordinated processing would occur twice per day, using the same bowl tracks.
- **Tandem Humping.** Two yards would operate a large-scale matrix switching operation, building a very large number of small, finely classified blocks, destined for individual local trains and needing no rehandling between the matrix and the terminating local. These blocks would be pulled from the bowl in groups and assembled into trains. Trains would swap groups of blocks repeatedly until the blocks reached their target local trains.

Although the alternative operating strategies represent conceptual advances in the organization of railroad operations, it was decided that the development and evaluation of operating plans based on the new strategies should be facilitated not by developing new network optimization algorithms, but should be facilitated instead by expert use of existing railroad operations planning tools, in this case the ABM/TSS/SPM suite of models [see Section 2.3.3].

Several factors made use of the ABM/TSS/SPM suite of models an obvious choice. The strategies and their representative operating plans would appear more credible to CSXT personnel if rendered using the ABM/TSS/SPM suite of tools. CSXT Operations Reset staff have spent several years refining SPM data and modeling procedures, and used the SPM successfully in an influential project in 1993 [see Section 2.3.4]. Interfaces between CSXT train and traffic data and the models were in place, and expert SPM users were available and interested in the research at both CSXT and MIT. Finally, there were no insurmountable obstacles to representing the alternatives in the ABM/TSS/SPM environment. Although the strategies embodied concepts beyond the scope of the models, manual file maintenance and creation of artificial distinctions between certain types of traffic enabled the strategies to be represented without compromise.

As the research and evaluation of the unconventional alternatives proceeded, a second group of strategies arose. The second group of strategies to be embodied in hypothetical operating plans was examined in order to test the hypothesis that there exist favorable alternatives to existing methods of operations planning and execution which do not depart from traditional railroad operating concepts. One such alternative offered the prospect of improved performance through use of existing decision support tools in the plan development process. The other alternative specifies *a priori* the degree of improvement

in yard operations, then considers the feasibility and cost-effectiveness of attainment of the specified levels of performance. The conventional alternatives to existing operations are:

- **ABM-Generated Routing.** The Automated Blocking Model (ABM) would be used to generate classification tables which determine the blocks in which traffic would move from origin to destination.
- **Improved Hump Yard Performance.** Hump yard performance, represented by PMAKE parameters, would be improved. Two sets of altered PMAKE parameters were tested. "A" parameters represented attainment of benchmark-quality performance, while "B" parameters represented a moderate performance improvement.

1.5 Research Chronology

The research proceeded as follows:

- a. Shortly after the October 1993 meeting, CSX Transportation's Chicago-Nashville corridor [see Section 2.2] was chosen as the network to which the alternative strategies would be applied. A base case operating plan was readily available, and CSXT's suite of operations planning tools could be used to create and evaluate the hypothetical operating plans [see Section 2.3.3].
- b. An initial presentation of the conceptual underpinnings of the Local Pre-Blocking, Terminal Complex, and Tandem Humping strategies was made to CSXT Service Design and Operations Research personnel in March 1994. Subsequent discussion illuminated operating considerations and further refined the strategies.
- c. Beginning in June 1994, hypothetical operating plans representing the Local Pre-Blocking, Terminal Complex, and Tandem Humping strategies were developed. CSXT's current operating plan was used as a launching pad for each alternative plan, but considerable changes were made to the base plan in each case. Operating plans were represented in the ABM/TSS/SPM format so that the SPM could be used to evaluate the service and cost impacts of the changes [see Section 2.3.3]. However, because several of the strategies embodied concepts beyond the scope of the ABM/TSS/SPM suite of tools, additional analysis of traffic flow data was performed as a guide for plan changes. One researcher from MIT and three CSXT Operations Research student interns were assigned to the project full-time, and the research progress was monitored by Operations Research staff.
- d. In July and August 1994, operating plans representing the Local Pre-Blocking and Terminal Complex strategies were completed, simulated using the SPM, and compared to the base case operating plan. Several plans representing the Tandem Humping strategy were also simulated, but scrapped because of problems in the plan development methodology and poor network performance.

- e. In August 1994 the results of the Local Pre-Blocking and Terminal Complex operating plans were presented to Operations Research and Service Design staff and group leaders. Tentative plans were made to implement Local Pre-Blocking, but the Terminal Complex strategy was considered to radical a change to consider in the immediate future.
- f. Research continued in the fall of 1994 on the Tandem Humping, ABM-Generated Routing, and Improved Yard Performance strategies. ABM-Generated Routing and Improved Hump Yard Performance were represented in hypothetical operating plans and compared to the base case in the same manner as were the unconventional alternatives. Because the two conventional alternatives did not depart from traditional railroad operating concepts, the process of developing the representative hypothetical operating plans was much simpler and required little “from-the-ground-up” analysis. For both conventional strategies, the modeled representation of the base case provided a template for the new operating plans which required only minor revisions. Plans representing ABM-Generated Routing and Improved Yard performance were completed and modeled in November 1994.
- g. A new method for developing the Tandem Humping operating plan was identified in January 1995. The new method called for all traffic to be routed using the ABM. Therefore, comparing performance of the Tandem Humping operating plan to CSXT's historical base case would confound effects caused by the Tandem Humping strategy and effects caused by the ABM. When the Tandem Humping operating plan was completed in May 1995, it was compared to the ABM-Generated Routing strategy.

1.6 Outline of the Thesis

This thesis is organized as follows:

- Chapter 2 describes CSX Transportation and its Chicago-Nashville corridor, its companywide service design procedures, Operations Research group, decision support capabilities, and the models used in this analysis.
- Chapter 3 describes the development and evaluation of operating plans representing the three unconventional alternatives to current operations: Local Pre-Blocking, Terminal Complexes, and Tandem Humping.
- Chapter 4 describes development and evaluation of operating plans representing two additional, conventional alternatives to current operations, ABM-Generated Routing and Improved Yard Performance.
- Chapter 5 provides a summary of the thesis, and conclusions and recommendations for further action.

2 CSX Transportation

CSX Transportation provided extensive assistance throughout the research, providing highly detailed traffic flow and operating plan data, analytical and programming support, and expert consultation from the Operations Research and Service Planning Groups. This chapter provides background information about CSX Transportation's rail network, traffic flows, service and financial performance.

2.1 Overview

CSX Transportation was formed in 1986 by a merger of the Seaboard System and Chessie System railroads, which were themselves amalgamations of smaller railroads. Major railroads whose routes eventually became part of the CSX Transportation network included the Chesapeake & Ohio, Baltimore & Ohio, Western Maryland, Pere Marquette, Seaboard Air Line, Atlantic Coast Line, Louisville & Nashville, Monon, Atlanta & West Point, and Georgia Railroads. The series of mergers which created CSX Transportation involved major route rationalization, but the current CSXT network still includes roughly 18,800 route miles and 32,800 track miles in 20 states, the District of Columbia, and Ontario, Canada. Figure 2.1 shows the current CSXT rail network, with merchandise traffic density as of November 1993.

Measured by revenue, CSXT and sister company CSX Intermodal together comprise the largest railroad in the United States, earning a combined \$5.17 billion in 1993. Operating revenue for carload traffic has held between \$4.37 and \$4.49 billion between 1989 and 1993, while intermodal operating revenue has grown steadily, from \$588 million in 1989 to \$793 million in 1993. The operating ratio, or operating cost divided by operating revenue, improved from 86.7% to 82.9% from 1989 to 1993 for merchandise traffic, and from 100% to 93.3% for intermodal traffic, indicating greater efficiency and success of continuing efforts at cost control

CSXT serves a highly diverse customer base. While CSXT is the largest coal hauler in the United States, CSXT also handles dense merchandise traffic throughout its network. Figure 2.2 presents annual traffic flows by commodity for the years 1991-1993.

Figure 2.1: CSX Transportation's Rail Network and November 1993 Merchandise Traffic Density

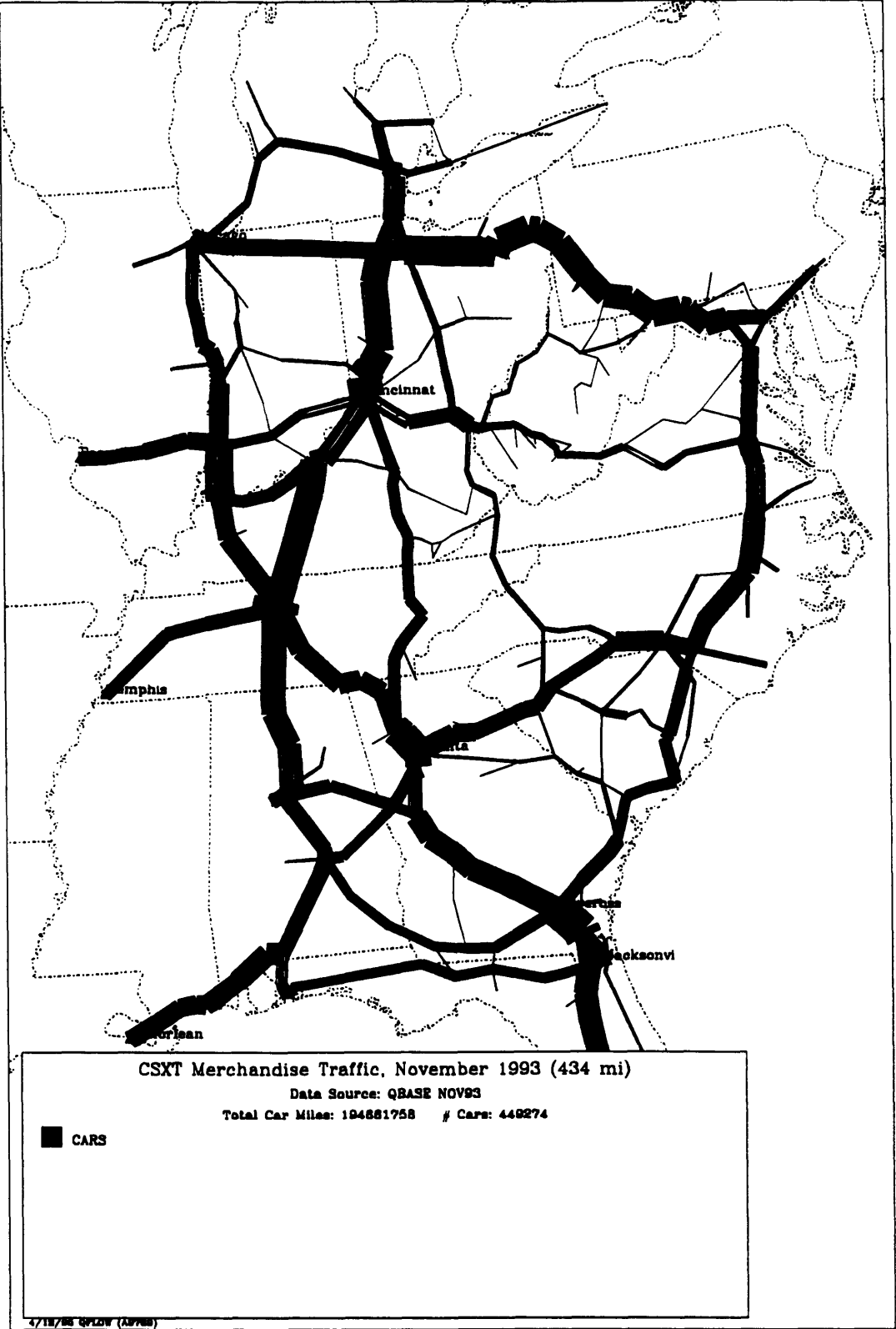


Figure 2.2: CSXT Coal and Merchandise Traffic Flows and Revenue, 1993*

Commodity	1993		1992		1991	
	Carloads (× 1,000)	Avg. Rev. per Car	Carloads (× 1,000)	Avg. Rev. per Car	Carloads (× 1,000)	Avg. Rev. per Car
Automotive	326	\$1,414	288	\$1,434	265	\$1,384
Chemicals	371	\$1,757	356	\$1,739	347	\$1,692
Minerals	374	\$888	345	\$899	327	\$887
Food & Consumer	166	\$1,181	161	\$1,217	164	\$1,226
Agricultural Products	284	\$1,151	264	\$1,125	262	\$1,126
Metals	258	\$941	225	\$973	199	\$1,005
Forest Products	435	\$1,016	441	\$1,016	439	\$968
Phosphate & Fertilizer	423	\$605	457	\$586	475	\$566
Coal	1,566	\$870	1,760	\$889	1,816	\$866
Total	4,203	\$1,016	4,297	\$1,008	4,294	\$979
Intermodal	1,140	\$612	NA	NA	NA	NA

Source: CSX Corporation Annual Report, 1993

2.2 The Chicago-Nashville Corridor

CSXT's Chicago-Nashville corridor experiences heavy traffic in most of CSXT's merchandise commodity groups. Large volumes of grain originate on the corridor, with harvest season providing heaviest volumes, but movements to and from storage occurring throughout the year. Grain-related products such as fertilizer and insecticide terminate in moderate volumes on the corridor. Industrial areas around Evansville and Mt. Vernon, IN, including several rail/barge transloading facilities receive grain, coal, steel, and other high-tonnage commodities.

In addition, the corridor is significant originator and terminator of manufactured products, steel, and chemicals, again from large industrial areas near Evansville and Mt. Vernon, IN, Lafayette and Nucor, IN, and Danville, IL. The corridor also hosts overhead

* Note that revenue per car figures are not indexed by mileage. Contribution per car or per car mile should not be inferred from the information given.

merchandise traffic between the east and southeast and interchanges at Chicago, East St. Louis, and Memphis. In addition to merchandise traffic, three intermodal trains between Chicago and the southeast traverse the corridor each day, and the corridor originates and terminates several unit coal trains each day at local mines and utilities.

Several major yards lie on the Chicago-Nashville corridor. Radnor Yard in Nashville is a 60-track hump yard which processed between 1600 and 2000 cars per day in 1993. Howell Yard in Evansville is a 15-track flat yard which processed between 500 and 700 cars per day in 1993. Much of this traffic was originating or terminating traffic and assembly and breakdown of unit grain trains. Brewer Yard in Danville is an 8-track flat yard which serves as a busy industrial support yard, and is the site of several key blockswaps between Chicago interchange trains to and from Nashville and Waycross, GA. Additional blockswapping between and classification of corridor trains occurs at Barr Yard in Chicago. Additional track space for car storage or blockswapping exists at Vincennes and Terre Haute, IN.

Between the yards, mainline is primarily single track with sidings between 4,500 and 16,000 feet spaced every five to fifteen miles. Double track main line exists for approximately 10 miles north from Nashville to Amqui, and approximately 65 miles south from Chicago to Woodland Junction, IL, owned and operated jointly with the Union Pacific. Total distance from Chicago to Nashville is roughly 415 miles. In addition, distance from Chicago to Lafayette is 95 miles and Lafayette to Terre Haute is 91 miles. Mainline signaling is CTC, while branch lines from Evansville and Danville are controlled by DTC block authority.

Since 1993, CSXT's Chicago-Nashville corridor has been the focus of a major service reliability drive. The vision pursued by CSXT in the service reliability drive was that if operations adhered more closely to the operating plan each day, service reliability would improve and operating costs would decrease. Tactical adjustments to the operating plan were thought to increase costs and degrade service because the downstream effects of tactical changes were not well understood. In addition, the lack of adherence to train schedules was thought to cause inefficient and ineffective yard operations because it forced yard managers to operate each shift without a medium or long-range planning horizon. Section 2.3.4 describes an analysis which provided analytical backing for these views and also provided some methodological and data groundwork for the research presented here.

As part of the service reliability drive, a series of measurements were developed and disseminated company-wide as the Service Reliability Report Card. Figure 2.4 illustrates a Service Reliability Report Card. Numbers have been omitted from the report card to protect confidential information.

Figure 2.3: Service Reliability Report Cards, November 1994 and November 1993

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<<<<<<<< START OF REPTCARD105027 >>>>>>>>
                SERVICE RELIABILITY REPORT CARD
                CHICAGO - NASHVILLE CORRIDOR
                WEEK ENDING: NOV 11, 1994

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MEASUREMENT	THIS WEEK	LAST WEEK	GOAL	4TH Q-T-D	3RD QUARTER
SAFETY:					
PERSONAL INJURY					
DERAILMENTS					
TRAINS PERFORMANCE:					
ON-TIME					
ON-TIME +/- 15 HRS.					
TRAINS RELIEVED H/S					
TERMINAL:					
RIGHT CAR/TRAIN					
RIGHT BLOCK / ORDER					
TERMINAL HOURS					
30 HOUR CARS					
SETBACK HOURS					
CUSTOMER:					
CAR SCHED PERF.					
CUSTOMER COMPLAINTS					
CUSTOMER SWITCHING					
COST:					
TE LABOR/CAR PROCESSED					
CAR EXP/CAR PROCESSED					

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Beginning in January 1994, CSXT began pursuing a major reengineering effort in conjunction with Mercer Management Consulting. Again, the Chicago-Nashville corridor was the test bed for operating changes recommended by the reengineering team, and as a result of the reengineering effort, a team of operating officers was hand-picked to oversee the day-to-day operation of the corridor. Regular root-cause analysis of operating problems was instituted, and all elements of the Chicago-Nashville corridor operating plan were subjected to detailed analysis. Service improvement and cost reduction began slowly but are now reported to be significant. Customer response to changes has been highly favorable, as indicated by Q1/1995 traffic volumes, which exceeded optimistic forecasts.

Because of its heavy originating, terminating, and overhead merchandise traffic, and because of the detailed understanding of operations developed through the service reliability and reengineering efforts, the Chicago-Nashville corridor was a logical choice on which to model alternative strategies aimed at improving the performance of carload merchandise traffic.

2.3 The Service Design Process, Decision Support Tools, and Modeling Conventions

2.3.1 Service Design and Maintenance of the Merchandise Operating Plan

CSXT's Service Design group is responsible for developing and maintaining the elements of the operating plan that concern carload merchandise operations. These include train routes and schedules, car-to-block and block-to-train assignments, yard cutoffs, and customer switching assignments for local trains. Service Design personnel also participate in unit train and intermodal planning and scheduling, but because the alternative operating strategies discussed in this thesis are directed toward the carload network, those functions will not be addressed here.

Train schedules are developed with customer and interchange commitments and yard processing in mind. Service planners do not use an algorithm to determine train routes and schedules, but instead treat each train individually, and attempt to create routes and schedules tailored to confront issues at each yard or activity point.

Most service planners have operating backgrounds, and are responsible for the operating plan in territory that they formerly managed as trainmasters or superintendents. This experience gives them an intimate understanding of the operating characteristics of their particular region, including constraints or advantages that are hard to quantify, such as line congestion or unusual difficulties in yarding trains. However, it is the opinion of some that this knowledge and background leads to a narrow focus on tailoring the operating plan to mitigate individual problems at the expense of larger network efficiencies.

CSXT's data systems for representing the operating plan are highly detailed and the operating plan requires much manual effort to maintain. For instance, at each yard, car-to-block assignment tables must be manually maintained, and at blockswapping locations, a yard system with classification tables must be maintained. If a station is to be added to a train's route, all subsequent stations must be rekeyed, and if arrival or departure times change, all changes must be recalculated and rekeyed manually.

Because changing the operating plan is a complex task, sweeping changes to train schedules and yard activity are rarely made except for trackwork curfews. If major trackwork is required on a subdivision, train arrival and departure times are altered in order to create a work window of sufficient length, usually between six and 12 hours per day. Rerouting traffic from trains affected by the curfew to alternate trains is usually considered only if the traffic is highly service sensitive. For other traffic, service impacts are predicted and communicated along with the plan change.

Routine maintenance of the operating plan is performed in response to fluctuations in traffic volume or in order to correct individual operating or service problems. A typical change to the operating plan and the rationale for the change is shown in Figure 2.5.

Figure 2.4: Sample Notices of Changes to the CSXT Merchandise Operating Plan

Q507	11/20/93	NAS (NASHVILLE) AND NASA (NASHVILLE-AUTO) BLOCKS REPLACE THE LOU (LOUISVILLE) AND LOUA (LOUISVILLE-AUTO) BLOCKS WITH CHANGES IN THE BLOCKING ORDER TO ALLOW THE CARS TO BE SET OFF AT DESHLER. THEY WILL MAKE CONNECTION AT DESHLER WITH R515 AND THEN BY-PASS QUEENSGATE AND OSBORNE HUMPS. SERVICE IMPACT - NONE. REQUESTED BY - SERVICE DESIGN (BRADLEY) (FHD)
Q510	11/20/93	60 (RUSSELL) BLOCK ADDED TO THE REAR END OUT OF LOUISVILLE INTO CINCINNATI. SERVICE IMPACT - NONE. REQUESTED BY - LOUISVILLE DIVISION (JONES) (FHD)
R515	11/20/93	WORK ADDED AT DESHLER TO PICK UP THE NAS (NASHVILLE) NASA (NASHVILLE-AUTO) BLOCKS SET OFF BY Q507. SERVICE IMPACT - NONE. REQUESTED BY - SERVICE DESIGN (BRADLEY) (FHD)
Q520	11/23/93	SETOFF OF "CHE", MONTGOMERY CHESTER YARD, BLOCK MOVED FROM FLOMATON TO MONTGOMERY, AL. SERVICE IMPACT - NONE. WILL MAKE Q612 CONNECTION AT MONTGOMERY IN LIEU OF FLOMATON. REQUESTED BY - MOBILE DIVISION (CROCKETT) (EGY)
R566	11/23/93	DEPARTURE TIME FROM LOUISVILLE CHANGED FROM 1100 TO 1130 TO BETTER SPACE THE TRAFFIC ON THE LOWER MONON. THE 2'10" HAS BEEN ADDED THROUGH-OUT THE SCHEDULE RESULTING IN A 1030 ARRIVAL AND INTERCHANGE TO THE GATEWAY WESTERN. SERVICE IMPACT - NONE, THE GWR SUPERINTENDENT SAYS ALL CONNECTIONS AT EAST ST. LOUIS WILL BE PROTECTED. REQUESTED BY - LOUISVILLE DIVISION (JONES) (FHD)
R592	11/22/93	DEPARTURE FROM NASHVILLE CHANGED FROM 0900 TO 1200 BECAUSE OF THE TRACK WORK AND ASSOCIATED CURFEW MOVING SOUTH ON THE HENDERSON SUB. SERVICE IMPACT - NONE, THIS IS A TEMPORARY CHANGE BECAUSE OF A CURFEW. REQUESTED BY - OPERATIONS CENTER (THIGPEN) (FHD)

Service planners do not have major decision support capability at their disposal. Visualization tools are available through the Princeton Transportation Network Model (PTNM) flow maps, and databases such as the Waybill Movement System (WMS) and QBASE [Kraft, 1992] provide detailed traffic flow data organized by train, yard, origin, destination, car type, and so on. However, these databases contain only raw data, and the data's usefulness depends on the service planners' skill at manipulating and interpreting it. CSXT's Operations Research group [see Section 2.3.2] has built several recommending elements into a series of menus for manipulating QBASE data, including the Blocking

Opportunities Report, which identifies opportunities to build bypass blocks as traffic volumes fluctuate.

When this research began, service planners received no formal training. However, one of the early findings of CSXT's service design reengineering effort was that there was little common understanding of the process of maintaining the operating plan, and that a comprehensive training program would make service planners more proficient and speed the service design process. During the summer of 1994 a formal training program was instituted. Current service planners were encouraged to attend, and new additions to the service design staff would automatically receive the training.

2.3.2 Operations Research

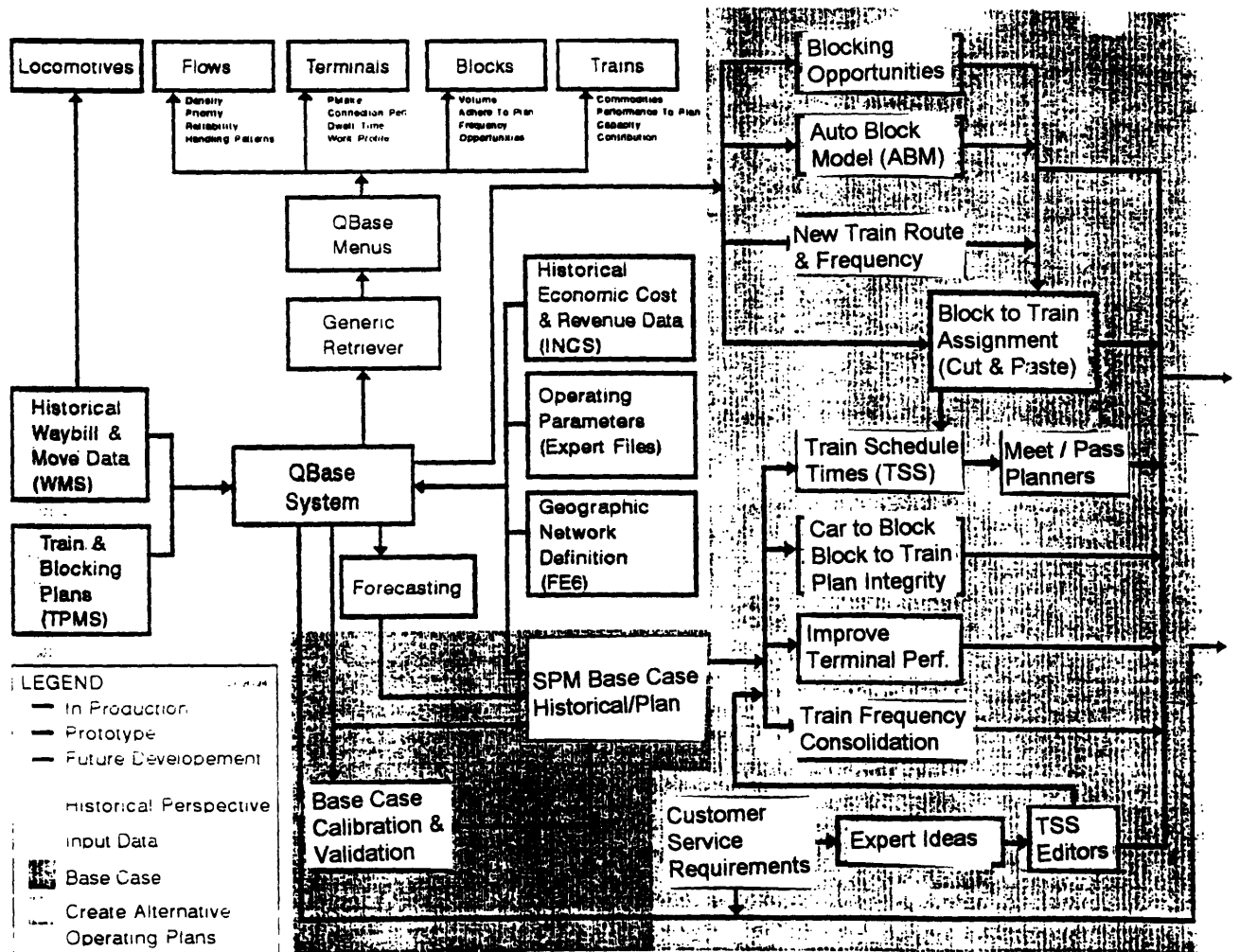
CSXT's Operations Research Group has two primary objectives:

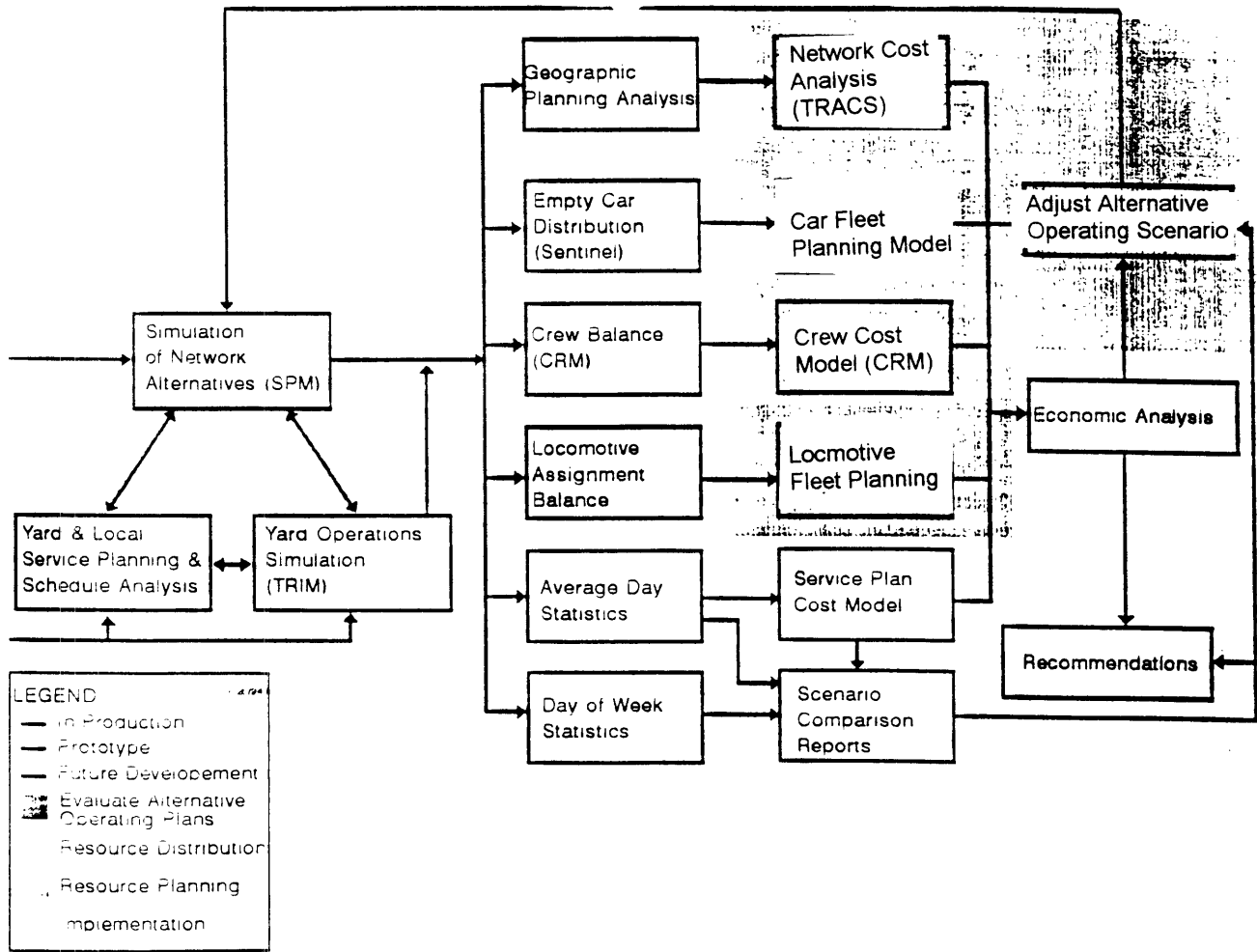
- To provide internal consulting and analytical support for projects in conjunction with many CSXT departments, employing a variety of techniques from straightforward statistical or cost analysis through advanced optimization methods.
- To create a unified framework for planning railroad operations through the development and use of analytical and optimization models which address every facet of railroad operations.

Analysts' time is divided between pursuit of the two objectives in roughly equal proportions. Operations Research staff members work closely with several departments, including locomotive planning, transportation operations planning, finance, marketing, and service design groups. Full-time members of the Operations Research Group include an assistant vice president, senior director, and three directors. They are supported by a manager and eight full-time programmers from CSX Technology, CSX Transportation's information technology affiliate. Operations Research also employs eight to fourteen student interns at any one time, each working a minimum of 20 hours per week.

In order to provide car-move, payroll, and other types of input data from CSXT's mainframe systems to Operations Research models, extensive effort has been devoted to creating front-end data-preparation routines for several models including the ABM and SPM [see Section 2.3.3]. In contrast, efforts to create post-processors which translate model output into the control systems containing the operating plan have been far more limited. This reflects the traditional use of Operations Research models as long-range, broad-brush analytical tools rather than as potential generators of the operating plan. As Operations Research experiences increasing pressure to generate concrete operating recommendations, the development of new models or of interfaces that load model output to real time control systems is increasing.

Figure 2.5: System Architecture of CSXT's Operations Research Models





Members of the Operations Research staff have recently developed several detailed models from scratch, both in an effort to build analytic capability and in support of specific projects. Models include a block-to-train assignment model, used in this research, a locomotive-to-train assignment algorithm, used in development of the Chicago-Nashville corridor operating plan, and several models for simulating and planning yard operations, used in analyses of several major CSXT yards.

2.3.3 The ABM/TSS/SPM Suite of Models for Operating Plan Development

A number of commercially-available decision-support tools reside in the Operations Research Group's modeling framework. Three models among these, the Automated Blocking Model, Train Scheduling System, and Service Planning Model, were central to the research presented in this thesis, as they served as the principal platform for creating and evaluating the hypothetical operating plans representing each alternative strategy.

The models use a standard set of files which contain information about the railroad operating plan. Core files used in defining the network, operating plan, and traffic flows include:

- **Node file:** contains information on each yard in the network, including yard capacity and PMAKE functions for several types of yard operations and traffic types. Nodes which represent agglomerations of customers or junctions instead of yards are assigned system average PMAKE functions. However, neither classification nor blockswapping are explicitly prohibited at those yards.
- **Link file:** contains information on each link in the network, including line speed and mileage, and required HP/ton.
- **Traffic flow file:** contains traffic flow information, including origin and destination node, traffic type or class, average daily volume, and information about the time distribution of traffic origination and termination.
- **Block file:** contains a list of all blocks built in the network, information on which traffic classes each block may carry, traffic destinations assigned to each block, and any trains eligible to carry the block.
- **Blockswap file:** contains information on all blocks swapped between trains, including the block number, swap location, and train(s) which may pick up the block.
- **Train file:** contains information on trains, including arrival, departure, and dwell times for each node in the train's route, the days of operation of each train, and the types of activity performed at each node.

One of the goals of the research was to identify the value of using existing, commercially available decision-support tools for service planning. While the three

models used in this research have existed for years as the result of an industry-wide development effort, and were intended to be used as a suite for developing, maintaining, and evaluating operating plans, few cases are known in which they have been applied and their recommendations used other than in a strategic study capacity. This may be attributable to the difficulties of model calibration and input data generation, leading to unreliable preliminary results, or a general mistrust of abstraction of the railroad on the part of traditional operations planners.

Therefore, rather than attempt to develop a next generation of decision support tools for service planning, the research attempts to make fuller use of the current generation of tools. Over the course of the research, many issues in modeling the railroad network were identified, and discussion of the issues may serve to direct the creation and refinement of the next generation of railroad operations planning decision support tools.

2.3.3.1 The Automated Blocking Model

The Automated Blocking Model (ABM) performs several tasks related to developing and maintaining a railroad blocking plan. These include routing cars from origin to destination using available blocks, and identifying cars for which complete routes cannot be generated.

In this research, the ABM was used to assign cars to new or revised blocks that were created for each alternative operating plan. Application of the ABM ranged from very limited use, in developing the Local Pre-Blocking operating plan, to a complete regeneration of CSXT's car-to-block assignments or classification tables, for the ABM-Generated Routing operating plan. In each application of the ABM, the ABM's Manu-Block module was used to flow cars from origin to destination over their least-cost routes, and complete partial routes for cars whose block assignments changed under an alternative strategy.

The Manu-Block module calculates car routing costs using costs per car mile, car hour, and car handling. Each road or yard link has a time cost generated from the traversal or expected handling time, while road links have an additional mileage cost and yard links have an additional car handling cost. Traversal of this network is with a modified version of Dijkstra's label-setting shortest-path algorithm. Block capacity is limited in cases where traffic may be diverted to alternative routes, but if no alternate route exists for the traffic flows using a block, then the block's capacity is relaxed. The Manu-Block module treats yard capacity in a similar fashion, but yard capacities were not calibrated for this research.

Several of the alternative strategies were envisioned as means of creating more blocks, and thus reducing intermediate handling, and in some cases the creation of new blocks required existing blocks to be eliminated. However, the ABM neither creates nor deletes blocks in order to improve performance or reduce costs. New blocks were created and existing blocks eliminated manually for each alternative plan, often as a result of analysis beyond the ABM's scope. One of the directions for further study identified by this

research is development a model capable of recommending the blocks that should be built at each yard under a variety of operating strategies.

2.3.3.2 The Train Scheduling System

The Train Scheduling System (TSS) is the least used of the three models in the ABM/TSS/ SPM suite. It was originally intended to perform a wide variety of functions involving train route and schedule creation and block-to-train assignment, but its use in this research was limited to sliding train arrival and departure times to minimize excess car dwell time at yards.

The TSS-Times module uses a heuristic procedure to slide train arrival and departure times to minimize excess car dwell time in yards, maintaining existing train dwell times at stations. Given a set of trains, block volumes, and block-to-train assignments, TSS-Times proceeds by fixing the schedules of trains with the highest to lowest connecting volumes. Each successive train is coordinated with the trains whose schedules are already fixed, in each case minimizing the number of car-hours expended in yards. Several iterations of this procedure are executed, and the resulting train arrival and departure times are returned in a revised train schedule file.

While this feature was not used in the research, users may also specify either that existing train dwell times at stations be maintained, or that station dwell times be determined by TSS-Times. TSS-Times generates station dwell times based on user input parameters which reflect fixed and variable time requirements of each station stop. A fixed amount of time is added for each station stop, while a variable increment is added for each block that is to be picked up or set off.

2.3.3.3 The Service Planning Model

The Service Planning Model (SPM) preceded the ABM and TSS in development and does not contain optimizing elements. The SPM distributes the flow of traffic over the railroad network and calculates origin-destination trip times, reliability, and resources used in the movement of traffic.

The SPM introduces variability into the movement of traffic by distributing cars among possible outbound connections at yards according to PMAKE functions calibrated for each yard. PMAKE functions describe the probability that cars will make connections given an amount of time available for classification, and are discussed in more detail in Martland (1982) and in Section 4.2. Because trip time variability is modeled in the yards, routing traffic through better-performing yards, or changing the amount of time available for connections will impact the SPM's representation of O/D performance. The train or block on which traffic is carried does not impact performance unless the user alters multipliers associated with the individual block or train.

2.3.3.4 Current Use of the Models

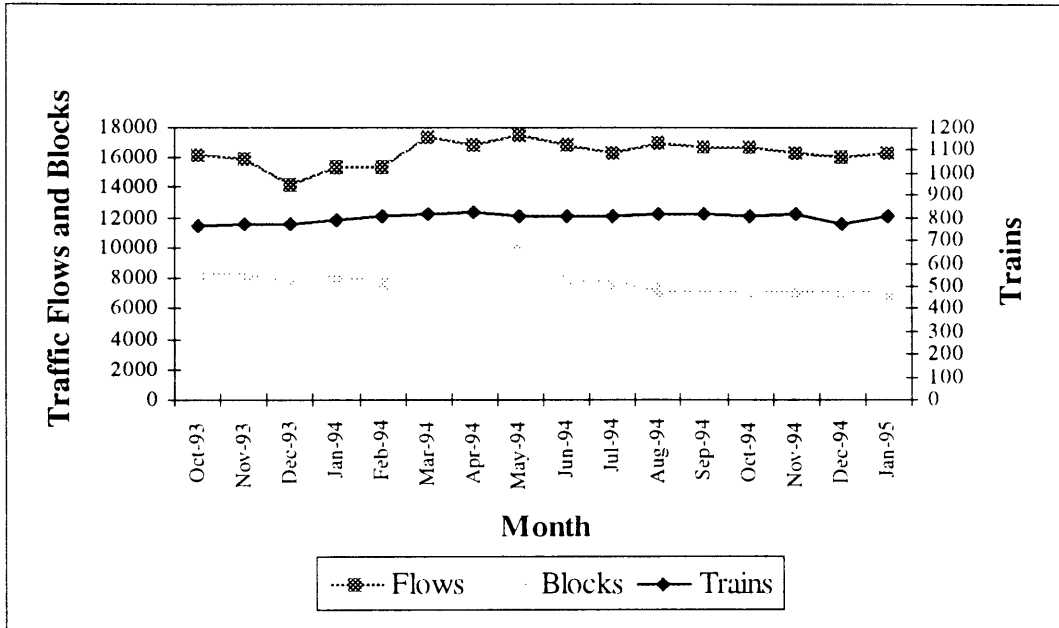
At the end of each month, Operations Research runs the SPM to provide a picture of rail service during the month. The data sources used to generate model input files include QBASE, which provides car move data used to generate traffic flows, car-to-block, and block-to-train assignments, the TRAIN0 file, which provides data on through train routes and schedules for the previous month, and payroll data, which provides similar data for local trains and the few yard switchers included in the model.

Monthly simulation of CSXT's large network yields a tremendous amount of model output and post-processed reports. A single SPM simulation of the CSXT network yields 94 MB of output reports¹. Much of the information contained in SPM output files is routine and is not reviewed on a regular basis. It is not a goal of Operations Research to manage individual O/D pairs using the SPM simulations. Operations Research staff members do not currently monitor the monthly model output as it is generated, or track month-to-month changes in simulated performance. However, model output files are frequently used for reference in relation to "what-if" studies performed by Operations Research.

Each month, input files for the ABM and TSS are generated from QBASE and TRAIN0 data, in a process quite similar to the process which produces SPM input files. However, the ABM and TSS models are not currently run on a monthly basis, being reserved instead for special studies of individual terminals or line segments. Studies performed during 1994 include estimations of the effects of generating the tag table at several CSXT terminals using the ABM, and rescheduling train arrivals and departures at a major terminal to eliminate excess dwell time using the TSS.

As CSXT traffic grows, and as Operations Research improves the data capture process which builds the SPM input files, the size of the SPM simulation of operations increases. The operating plan contains more trains and blocks, and the traffic flow file contains more O/D pairs. Figure 2.6 illustrates the growth of the simulation between October 1993 and January 1995. If data from 1990 through 1992 were still available, the increase in simulation size would be even more apparent. A comparison with the simulations used in the B&M and Santa Fe case studies further emphasizes the large size of the current CSXT simulations.

Figure 2.6: SPM Actual Case Simulation Size, October 1993 to January 1995



Recent simulations of current operations are among the largest railroad simulations ever performed. Periodically, the SPM must be recompiled with larger array bounds in order to model the larger network, a task that sometimes requires considerable effort by a member of the Technology support staff and uses considerable mainframe CPU time. CSX Technology representatives have indicated that some design limits of the SPM have been exceeded several times, and that further expansion of the SPM model size may be infeasible. However, as traffic continues to grow, as the sophistication of the operating plan increases, the effort required to produce the monthly simulations of the network will continue to increase. In addition, if CSX were to merge with another railroad or otherwise increase the size or complexity of its network, the capability of the SPM to simulate the entire system in a single run would be exhausted.

As the network increases in size and complexity, several modeling strategies may be pursued to overcome constraints on the SPM's simulation size. An option that would require only minor changes to current programs is to model intermodal and coal operations separate from grain, automotive, and general merchandise. Considerably more effort would be required to rewrite the SPM to incorporate larger caches or dynamically-allocated memory. If such effort is devoted to creating network modeling and decision support tools, that effort may be more effectively directed to creating a new tool from scratch, which maintains the SPM's strength of simulating system variability but which incorporates advances in computing power and information presentation that have been made since the SPM was developed.

2.3.4 The Base Case and the Plan Integrity Project

In the current research, in order to define the benefits of adopting alternative operating strategies, SPM simulations of each alternative strategy were compared to an SPM simulation of a base case representing the current operating plan. The base case used throughout the analysis represents CSXT operations in November 1993 under the assumption that the railroad ran according to the operating plan. November 1993 was chosen as the base month because of its heavy merchandise traffic, and because November 1993 was a point of particular success in CSXT's Chicago-Nashville service reliability drive.

The original representation of CSXT operations as specified in the operating plan, as well as the means of comparison and assessment of operating plan, were developed during the Plan Integrity Project of 1993, in which this researcher participated extensively. The goal of the Plan Integrity Project was to demonstrate the effects on cost and service that would result if CSXT operated according to plan, and ceased to allow operating managers to make tactical decisions to annul or consolidate trains, run extra trains, or run trains off of their normal schedules.

The Plan Integrity Project engendered a methodological advance in simulating CSXT operations using the SPM that was pivotal to the current research. Before the Plan Integrity Project, Operations Research had used the SPM to simulate operations only as they had occurred in reality during the previous month, without regard to whether operations generally followed or deviated from the plan. Because the intent of the Plan Integrity Project was to compare the operating plan to history, a means had to be devised to simulate execution of the operating plan in a way that would be comparable to the ongoing simulations of history. Likewise, the current research requires a simulation of the operating plan as a basis for comparison of plans representing new operating strategies.

The objective of simulating the operating plan was achieved by substituting data sources in the SPM input file creation process. In order to simulate historical operation, O/D traffic flow and block information was taken from the QBASE file of car move data, while train information was taken from the TRAIN0 file of train movements. PMAKE functions were calibrated from actual yard times. To simulate the operating plan, actual O/D flows were used, but block information was taken from freight car schedules reformatted to the QBASE data format. Train information was taken from a monthly file of train profiles, which included days operated and arrival and departure times for each station. Finally, PMAKE functions were calibrated from the train-to-train connections at each yard specified by the freight car scheduling system, which were read from the freight car schedule file as well.

Once the data gathering process was completed and tested, the comparison of the operating plan to historical operations in moving a common set of traffic flows could be made. Important findings from the Plan Integrity Project included the fact that, while trip time varied little between planned and unplanned operation, traffic moved with considerably greater reliability if the plan was executed than if tactical adjustments were

made. The operating plan called for fewer train starts and fewer train miles than were observed in the historical case, but certain trains in planned operations would be overloaded on a daily basis because CSXT's freight car scheduling system does not have the capability to consider train capacity limits.

The quantitative and qualitative assessment of the operating plan brought about by the Plan Integrity Project was replicated in the current research both for the base case operating plan and for the plans representing alternative operating strategies. While this thesis spares much of the detail found in SPM output, the investigation could be extended to assess the impact of alternative operating strategies, including the Plan Integrity Project's example of planned vs. unplanned operation, on every individual traffic flow, block, and train.

3 Unconventional Alternatives to Current Operations

In October 1993 MIT researchers met with John Orrison, CSXT's AVP-Operations Research, and Gordon Trafton, BN's GM-Network Design, for the purposes of articulating advanced concepts in network and service design, identifying potential benefits of operating plans based on these ideas at a conceptual level, and creating a timetable for in-depth research into the performance impacts of advanced operating plans.

The meeting culminated in the identification of three alternative strategies for organizing and executing operations: Local Pre-Blocking, Terminal Complexes, and Tandem Humping. These strategies were considered unconventional because they entail significant changes in the roles of yards and/or trains and depart from traditional methods and current industry practices for assigning traffic to blocks and trains, for scheduling trains, and for organizing and scheduling yard activities.

Common elements in the three strategies justify expectation of performance improvement. All strategies intend to eliminate car handlings from the system or to improve the speed and efficiency of those handlings that could not be avoided. The alternative strategies also intended to minimize yard dwell time in excess of that required for classification, through blocking changes and sliding of train arrival and departure times.

The established decision support platform of the ABM, TSS, and SPM were used to create operating plans based on the new strategies and compare them to a base case representing CSXT's merchandise operating plan in November 1993. While the ABM, TSS, and SPM were not created with the concepts represented by Local Pre-Blocking, Terminal Complexes, and Tandem Humping in mind, these decision support tools are sufficiently flexible to allow each strategy to be represented in an operating plan.

During the spring of 1994, discussions between Larry Shughart of CSXT Operations Research and MIT identified and refined methods of abstracting and modeling the alternative strategies. In the summer of 1994, modeling proceeded full-time, supported by CSXT Operations Research facilities, data, and personnel. By the end of August, modeling of the Local Pre-Blocking and Terminal Complex strategies was complete. While substantial effort had been devoted to the Tandem Humping strategy, results remained unsatisfactory. A new method for creating and evaluating the Tandem Humping strategy was devised in the fall of 1994 and pursued until May 1995.

The remainder of this chapter describes the Local Pre-Blocking, Terminal Complex, and Tandem Humping strategies in detail, and provides exhibits of anticipated changes in network operations and performance. Sections devoted to each of the three strategies explain the conceptual underpinnings of each strategy, describe the hypothetical operating plan, and discuss modeling issues, results and implementation issues.

3.1 Local Pre-Blocking

3.1.1 Description

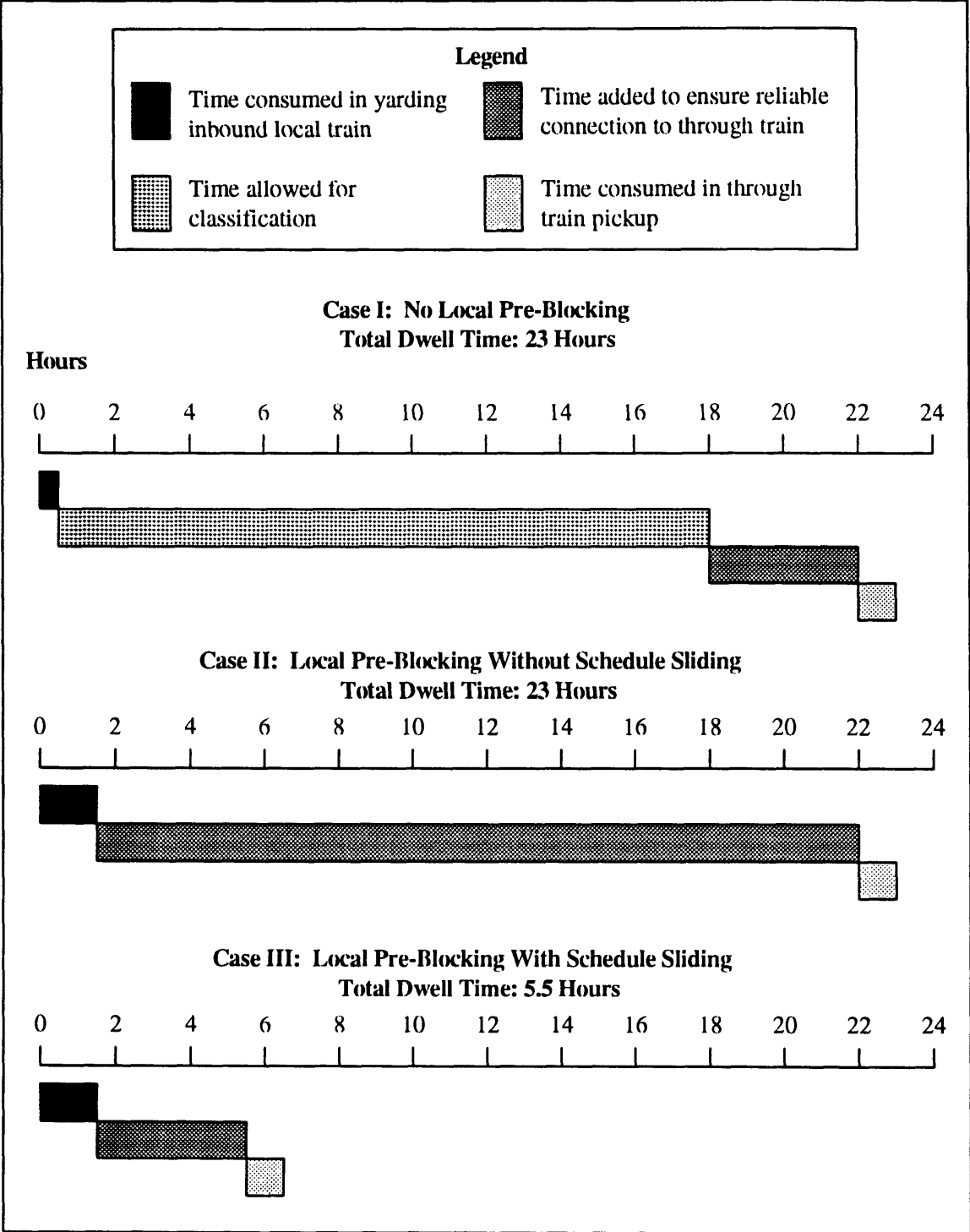
Ordinarily, originating cars are pulled from industries by local trains or yard switchers, then returned to a serving yard, where they are switched into outbound blocks that are picked up by through trains. Traffic typically spends between 15 and 30 hours in the origin serving yard, as a minimum of 10-15 hours is necessary to ensure that switching can be completed before the traffic must depart on a through train.

The Local Pre-Blocking strategy attempts to eliminate dwell time in the origin serving yard by dictating that local trains block cars when pulling them from industries. Cars in blocks built by local trains would be immediately available for pickup by through trains, and would no longer require classification at the serving yard. As a result, switching requirements at the serving yard would decrease, possibly allowing a reduction in yard crews, and car hours would be saved, as originating traffic would be blockswapped from local trains directly to road trains.

When local trains build blocks, the reliability of the connection between local and road trains is improved because originating cars no longer require processing in the origin serving yard. However, if cars are still scheduled for 20-30 hour dwell times at the origin serving yard, regardless of the fact that they are no longer classified there, then O-D trip time will not decrease, and Local Pre-Blocking will only be a means of yard crew reduction. Therefore, in creating the Local Pre-Blocking operating plan we took the additional step of sliding train arrival and departure times in order to reduce the connection times between local trains and their through train connections.

Figure 3.1 presents an example of the potential impact of Local Pre-Blocking on the time required to move a car through the origin serving yard to a connection with a through train. Although the example is a hypothetical one, the times illustrated for the yarding, classification, and pickup processes reflect typical time requirements at serving yards.

Figure 3.1: Dwell Time in the Origin Serving Yard (Best Case Reduction)



3.1.2 Creating the Local Pre-Blocking Operating Plan

In order to create and evaluate a hypothetical operating plan which incorporated local pre-blocking, the following steps were performed:

- a. Pre-block destinations were chosen by tabulating traffic originated by local trains working out of a serving yard by subsequent block, then choosing between three and five of the highest-volume destinations as pre-block destinations [see Figure 3.2]. Each pre-block made by local trains working out of a serving yard corresponded to a block that was already maintained at the serving yard, in order to ensure that track or block-building limitations in the serving yard would not be compromised by pre-blocking.
- b. 35 blocks were added to 22 local trains at nine locations [see Figure 3.3]. Additions were made to the local pre-blocking block and blockswap files to reflect the new pre-blocking arrangements.
- c. Traffic originating at network nodes served by pre-blocking local trains was assigned to new pre-blocks using the ABM.²
- d. Pre-blocks made by local trains were assigned to connecting through trains manually. Often, several local trains working out of a serving yard would make pre-blocks for the same destinations. These blocks were each assigned to the same through train, so that only one train per day would pick up each pre-block. Yard congestion would be minimized because block-swapping activity would be restricted to specified tracks. For example, at Evansville, three local trains each make Chicago, Louisville, and Nashville pre-blocks. Each local train's Chicago pre-block is assigned to the same Chicago-bound train, each local train's Louisville pre-block is assigned to the same Louisville-bound train, and each local train's Nashville pre-block is assigned to the same Nashville-bound train. At Evansville yard, each local train could, for example, set off the Chicago pre-block in track 1, the Louisville pre-block in track 2, and the Nashville pre-block in track 3.
- e. At this point, SPM simulations were performed to demonstrate the benefits of pre-blocking without any schedule alterations. Improvements in this case would be attributable to more reliable connections at the serving yard, including savings of 24 hours for some traffic, and to more efficient routings generated by the ABM. Two simulations were performed. One simulation used a traffic flow file consisting only of the traffic targeted for improvement by local pre-blocking. This included all traffic originating at points served by pre-blocking local trains. The other simulation used an uncut traffic flow file. The purpose of performing two simulations was to demonstrate percentage changes in performance for the subset of traffic targeted for improvement by local pre-blocking, while also capturing any ancillary benefits to traffic not targeted for improvement by the blocking changes.

car dwell time by dictating that all train-to-train connections at yards are scheduled for the least possible dwell time in excess of the time required for classification.

- g. A second pair of SPM simulations were performed to demonstrate additional benefits that would result from sliding of train arrival and departure times to better coordinate pre-blocking local trains with their connecting through trains. Improvements in this case would be attributable to more reliable connections and reduced dwell time in serving yards, as well as more efficient routings generated by the ABM.

3.1.3 Examples

Figure 3.2: Cars Set Off by Local Trains for Switching at Evansville, November 1993*

Block Code Departing Evansville	J724	J731	J734	Total	Pre-Block?	Connection
LOU	30	18	235	283	Y	R561
NAS	32	34	75	141	Y	R591
CHG†	8	2	88	98†	Y†	R592
IHRC†		34	64	98†	N†	
BVL			95	95	N	
DAN	1		64	65	N	
ATL	9	38	1	48	N	
ATK	17		27	44	N	
GUT	6	24		30	N	
SKI	17		4	21	N	
S05			17	17	N	
S04	2		13	15	N	
HFW	1		9	10	N	
WAX		6	1	7	N	
BOI		3	1	4	N	
ANC	1		2	3	N	
WANS	3			3	N	
2 Codes	2 cars each			4	N	
6 Codes	1 car each			6	N	
Total Volume, Pre-Blocked Traffic				522		
Total Volume, Unblocked Traffic				570		

*Source: CSX Transportation WMS Database, November 1993

†Note that IHRC traffic was not pre-blocked because the traffic is delivered to an interchange connection in Evansville, and is not handled by through trains.

Figure 3.2 illustrates a sample form used to determine which pre-blocks would be made by local trains working out of CSXT's Evansville yard. The highest-volume three classifications have been designated pre-blocks, and each has been assigned to a connecting through train.

The data in Figure 3.2 is both encouraging and frustrating from a service design perspective. Some classifications have regular, high volume, and could receive all the benefits of pre-blocking, but many low-volume, less predictable classifications are also present in the data. While such incidental traffic fills trains and brings in revenue, it confounds efforts to improve efficiency and reliability through proactive operating plan design. In this example, less than 50% of the cars listed are subject to pre-blocking. The remainder will still require switching at the serving yard into a wide variety of classifications. Of these additional classifications, few have volume sufficient to provoke service- or efficiency-enhancing tailoring of the operating plan.

Because of concerns about added complexity due to Local Pre-Blocking, several standards were observed in the creation of the Local Pre-Blocking operating plan. In order to ensure that no additional track space would be required in the serving yard, local trains would only build blocks that are already maintained at the yard. For example, all of the block codes listed in the left-hand column in Figure 3.2 are maintained regularly at Evansville Yard. The number of classifications maintained at any yard would not increase due to Local Pre-Blocking. Blocks designated as pre-blocks could be assigned to easy-to-access yard tracks, so that local trains would not cause undue disruption when yarding their trains, even though they would have to switch pre-blocks into several tracks rather than simply tying down the train on a single yard track.

In addition, to simplify the management of pre-blocking local trains and reduce their impact on yard operations, all trains at a serving yard would build the same pre-blocks. This requirement may reduce the number of cars that could avoid classification, because each local train would not necessarily be pre-blocking the highest possible number of cars.

For example, Figure 3.2 illustrates that the top three block destinations for all Evansville local trains combined, LOU, NAS, and CHG, have been chosen as pre-blocks. However, the individual local trains J724, J731, and J734 would have been able to pre-block more traffic if their pre-blocks were determined according to their individual consists. For example, the top block codes for cars originating on J734 are not LOU, NAS, and CHG (398 cars), but instead are LOU, BVL, and CHG (418 cars). Likewise, the top three destinations for cars originating on J731 are not LOU, NAS, and CHG (54 cars), but instead are NAS, IHRC, and ATL (106 cars). However, it was deemed preferable at this stage to pre-block fewer cars in order to simplify operations and management at pre-blocking serving yards.

Figure 3.3 lists all pre-blocking local trains and the blocks assigned to each train. In addition to the pre-blocks listed, each train can return traffic not conforming to the pre-block destinations to the serving yard for classification, as would be done for all traffic in the absence of pre-blocking.

Figure 3.3: Pre-Blocks and Block-to-Train Assignments Added in the Local Pre-Blocking Operating Plan

Serving Yard Location	Local Train ID	Local Train Route and/or Activity	New Pre-Blocks
Bruceton, TN	M791 M792 M793	Bruceton-Jackson turn Br.-New Johnsonville turn Bruceton-Dresden turn	Memphis Memphis-MP Nashville
Danville, IL	J706 J707 J714 R593/R594	Danville switcher Danville-Terre Haute turn Danville-Watseka turn 2-day Danville-Decatur turn	Chicago Decatur (J's only) Evansville Nashville Waycross
Evansville, IN	J724 J730/J731 J732 J734	Evansville-Atkinson turn MTh 2-day Venedy turn Wed. only Evl-Mac. turn Evl.-Mt.Vernon turn	Chicago Louisville Nashville
Flora, IL	J700	Flora/Illinois sub local	Vincennes E. St. Louis (ALS) Cincinnati
Lafayette, IN	J770 J771 R598/R599	Lafayette-Indy turn Laf.-Greencastle turn 2-day Laf.-Chicago turn	Chicago Evansville Nashville Cincinnati
Monon, IN	J773	Monon road switcher	Lafayette Evansville Cincinnati Nashville
Mt. Vernon, IN	J704	Mt. Vernon switcher	Same as Evansville (blocks swapped to J731, J732, J734)
Terre Haute, IN	J708	Terre Haute switcher	Evansville Nashville
Vincennes, IN	J702 J709 J710	Vincennes-Young turn Vincennes-Ft. Branch turn Vin./Illinois sub switcher	Evansville Nashville Cincinnati

3.1.4 Changes in Performance

Performance of traffic handled by pre-blocking local trains was altered in three ways:

- Classification at the origin serving yard was eliminated, as pre-blocked traffic was blockswapped from the originating local to a through train.
- The ABM chose the least-cost routes for traffic moving in the new local pre-blocks, improving some cars whose previous routings were inefficient.
- Changes in train arrival and departure times decreased connection time for some traffic. Although the net effect of changing arrival and departure times was positive, some O-D flows improved while others deteriorated. Furthermore, some excess dwell time was eliminated at points other than at pre-blocking serving yards because through trains whose arrival and departure times were slid were affected over their entire routes, and not only at pre-blocking serving yards.

Figure 3.5: Changes in Trip Time, Reliability, and Activity due to Local Pre-Blocking, With and Without Schedule Sliding

Strategy	Average Dock-Dock Trip Time	% of Cars Arriving Within +/- 24 Hours of Average	Car Handlings Saved Per Day	Car Hours Saved Per Day	Car Miles Saved Per Day
Base Case	94 Hrs.	79%	0	0	0
Pre-Blocking Alone	92 Hrs.	80%	147	864	4020
Pre-Blocking with Schedule Sliding	90 Hrs.	82%	147	1639	4020

Figure 3.5 contains aggregate statistics for 461 cars per day in 514 O-D pairs targeted for improvement by Local Pre-Blocking. Dock-to-dock trip time savings are modest but not inconsequential. While car hour savings due to trip time reduction are extremely small as a percentage of total car hours, the dollar value of those saved car hours is substantial. Saved car hours represent a savings of more than \$230,000 for the targeted O/D pairs, and more than \$4,000,000 when extrapolated to the entire network. Furthermore, per-car savings would likely be larger in reality than reflected in the model, because node aggregation causes changes to be rendered on only a subset of the targeted flows [see End Note 2]. Figure 3.6 illustrates annual cost savings due to car miles, hours, and handlings saved by Local Pre-Blocking.

Figure 3.6: Annual Cost Savings due to Local Pre-Blocking

	Pre-Blocking without Schedule Sliding		Pre-Blocking with Schedule Sliding	
	Targeted Traffic Only	Extrapolation to Entire Network	Targeted Traffic Only	Extrapolation to Entire Network
Annual Value of Saved Car Handlings	\$161 K	\$2.9 M	\$161 K	\$2.9 M
Annual Value of Saved Car Hours	\$237 K	\$4.2 M	\$449 K	\$8.0 M
Annual Value of Saved Car Miles	\$734 K	\$13.0 M	\$734 K	\$13.0 M
Annual Total	\$1.1 M	\$20.0 M	\$1.3 M	\$23.8 M

Figures do not sum due to rounding.

Improvements in O/D reliability for pre-blocked traffic are minor. Improvements in reliability are due to more reliable connections at origin serving yards, caused by the replacement of a classification with a more reliable blockswap. More marked increases in reliability did not materialize because the pre-blocked traffic was typically classified at several more yards before reaching its destination. At each yard, the traffic encountered variability in the classification process that served to erode O/D reliability, improvements at the origin yard notwithstanding.

It is important to note that car mile reductions engendered by the altered operating plan cannot be attributed uniquely to any element of the Local Pre-Blocking strategy. The Local Pre-Blocking strategy does not at its core call for traffic to traverse different routes. Rather, it calls for traffic to be routed via pre-blocks made by local trains where it previously was routed to serving yards to be classified into through blocks. Traffic picked up by pre-blocking local trains was assigned to pre-blocks using the ABM, which routed the traffic from origin to destination, sometimes choosing new routes beyond the initial pre-block which resulted in car mile reductions.

One issue that arises in inspection of the aggregate statistics is that the reduction in car hours is quite small in light of the fact that car handling and car mile reductions should be expected to cause a decrease in car hours. If all of the saved car hours not attributable to schedule sliding were attributable to eliminated classifications, each classification eliminated would contribute a savings of approximately 5.9 hours per car, much less than the average yard times at pre-blocking yards. Likewise, if all saved car hours not attributable to schedule sliding were attributable to saved car miles, then one car hour would be saved for every 4.7 car miles saved.

One explanation for this seemingly paradoxical lack of saved car hours is that in choosing new routes for traffic subject to pre-blocking, the ABM actually traded mileage

savings for car hour savings in a way which actually increased car hours, and in some cases even adding handlings. Another explanation is that replacing classification with swapping of the pre-blocks was not guaranteed to save car hours. Blockswaps are not 100 percent reliable, and are modeled in the ABM/TSS/SPM like classifications using PMAKE functions. Furthermore, due to the length of time allotted for classification, a highly reliable blockswap may replace a highly reliable classification. In the absence of schedule sliding, train-to-train connection times in the plan change only if pre-blocked traffic departs the serving yard on a different through train as a result of pre-blocking.

Figures 3.7a-3.7e demonstrates changes experienced by several representative traffic flows as a result of Local Pre-Blocking. An important question is whether the changes made in incorporating local pre-blocking into the operating plan actually contributed to the measured savings as expected. That is, at the individual O/D pair level, did the substitution of blockswapping for classification demonstrably reduce car hours and improve reliability? Did the sliding of train arrival and departure times demonstrably eliminate excess dwell time in yards? To answer this question, we look to the performance of individual traffic flows targeted for changes in the Local Pre-Blocking operating plan.

Figures 3.7a-3.7e: Examples of Performance Changes Experienced by Individual Traffic Flows due to Local Pre-Blocking[†]

<p>Traffic Flow: Cayuga, IN - Chicago Interchange Roads 0.6 cars/day to BN 0.5 cars/day to CNW 0.5 cars/day to MP 0.7 cars/day to IHB</p> <p>Observations: Pre-Blocking marginally decreased trip time and increased reliability. The only significant effects were to the MP-bound flow, which had an excessive classification time in the base case, possibly due to the origin time distribution. Schedule sliding further reduced trip time by a minor amount, as the gap between local train J706 and connection R592 was closed, but only from 18:45 to 17:15. Presumably, the later pickup of these traffic flows by J706 caused the increase in origin time between the Pre-Blocking and Schedule Sliding cases. The later pickup was reflected in reduced blockswap dwell time at Danville. Although connection time between J706 and R592 decreased with schedule sliding, overall reliability improved marginally for three of the four flows, presumably because the positive effect of longer origin time on reliability outweighed the potentially negative effect of reduced blockswap time. As expected, one classification was eliminated and one blockswap added for each traffic flow.</p>

[†] In this and future presentations of performance of individual traffic flows, L/C/B hours refers to the sum of car hours consumed in linehaul, classification, and blockswapping. O/T hours refers to originating and terminating hours, or the hours between release and pickup plus the hours between arrival at the final node and interchange or delivery. L/C/B is generally considered to denote serving yard-to-serving yard trip time, while the sum of L/C/B and O/T is considered to denote full dock-to-dock trip time. In the ABM/TSS/SPM modeling context, the O/T measure is considered somewhat dubious, because for some originating traffic, shippers determine release time based on expected pickup time. Therefore, trying to craft schedules in response to the distribution of observed release times would not necessarily yield good schedules.

Figure 3.7a, Continued

Blocks		
Base Case	Pre-Blocking Only	Pre-Blocking + Sch. Sliding
Cayuga-Danville Danville-Chicago Chicago-Interchange Roads	Cayuga-Chicago (swap at Danville) Chicago-Interchange Roads	Cayuga-Chicago (swap at Danville) Chicago-Interchange Roads
Schedule		
Base Case	Pre-Blocking Only	Pre-Blocking + Sch. Sliding
J706 1209 DP Cayuga 1430 AR Danville	J706 1209 DP Cayuga 1430 AR Danville	J706 1339 DP Cayuga 1600 AR Danville
R592 0915 DP Danville 1300 AR Chicago	R592 0915 DP Danville 1300 AR Chicago	R592 0915 DP Danville 1300 AR Chicago
Y110 1020 DP Chicago 1130 AR BN	Y110 1020 DP Chicago 1130 AR BN	Y110 1020 DP Chicago 1130 AR BN
Y120 0900 DP Chicago 1300 AR CNW	Y120 0900 DP Chicago 1300 AR CNW	Y120 0900 DP Chicago 1300 AR CNW
Y250 1506 DP Chicago 1524 AR MP 1530 AR IHB	Y250 1506 DP Chicago 1524 AR MP 1530 AR IHB	Y250 1506 DP Chicago 1524 AR MP 1530 AR IHB
O/D Reliability		
Base Case	Pre-Blocking Only	Pre-Blocking + Sch. Sliding
55% (BN) 53% (CNW) 39% (MP) 52% (IHB)	58% (BN) 54% (CNW) 55% (MP) 55% (IHB)	59% (BN) 54% (CNW) 56% (MP) 56% (IHB)
Car Hours, Miles, Handlings		
Base Case	Pre-Blocking Only	Pre-Blocking + Sch. Sliding
L/C/B Hours 59 (BN) 58 (CNW) 112 (MP) 57 (IHB)	L/C/B Hours 55 (BN) 54 (CNW) 52 (MP) 53 (IHB)	L/C/B Hours 54 (BN) 53 (CNW) 51 (MP) 53 (IHB)
O/T Hours 71 (BN) 73 (CNW) 73 (MP) 73 (IHB)	O/T Hours 71 (BN) 73 (CNW) 73 (MP) 73 (IHB)	O/T Hours 72 (BN) 74 (CNW) 74 (MP) 74 (IHB)
Miles 126	Miles 126	Miles 126
Class 2	Class 1	Class 1
Blockswaps 0	Blockswaps 1	Blockswaps 1

Figure 3.7b

<p>Traffic Flow: Mt. Vernon, IN - Chicago 1.7 cars/day to Industry 3.9 cars/day to BN 0.3 cars/day to CNW 1.6 cars/day to SOO</p> <p>Observations: Pre-Blocking and Schedule Sliding each had more substantial effects on the trip time and reliability performance of this traffic. The substitution of connecting train R592 for Q648 had a negative effect on trip time as a result of poorer connection coordination, which was alleviated in part by schedule sliding, except for the flow bound for BN. The extension of pre-blocking to two additional departures per week of train J731 was beneficial to O/D reliability, because the traffic now had more opportunities to meet connections in Evansville. Both adding additional local train departures and schedule sliding of the local trains reduced origin time. One classification was eliminated and one blockswap added for each flow.</p>					
Blocks					
Base Case		Pre-Blocking Only		Pre-Blocking + Sch. Sliding	
Mt.Vernon-Evansville Evansville-Chicago Chicago-Interchange/Local		Mt. Vernon-Chicago (swap at Evansville) Chicago-Interchange/Local		Mt. Vernon-Chicago (swap at Evansville) Chicago-Interchange/Local	
Schedule					
Base Case		Pre-Blocking Only		Pre-Blocking + Sch. Sliding	
<p>J734 1707 DP Mt. Vernon 2230 AR Evansville</p> <p>Q648 0700 DP Evansville 2130 AR Chicago</p> <p>Y110 1020 DP Chicago 1130 AR BN</p> <p>Y120 0900 DP Chicago 1300 AR CNW</p> <p>R508 0530 DP Chicago 0800 AR SOO</p>		<p>J731 J734 1100 1707 DP Mt. Vernon 1930 2230 AR Evansville</p> <p>R592 2145 DP Evansville 1300 AR Chicago</p> <p>Y110 1020 DP Chicago 1130 AR BN</p> <p>Y120 0900 DP Chicago 1300 AR CNW</p> <p>R508 0530 DP Chicago 0800 AR SOO</p>		<p>J731 J734 2000 0007 DP Mt. Vernon 2330 0530 AR Evansville</p> <p>R592 2145 DP Evansville 1300 AR Chicago</p> <p>Y110 1020 DP Chicago 1130 AR BN</p> <p>Y120 0900 DP Chicago 1300 AR CNW</p> <p>R508 0530 DP Chicago 0800 AR SOO</p>	
O/D Reliability					
Base Case		Pre-Blocking Only		Pre-Blocking + Sch. Sliding	
73% (Ind) 69% (BN) 67% (CNW) 68% (SOO)		84% (Ind) 81% (BN) 78% (CNW) 75% (SOO)		95% (Ind) 89% (BN) 86% (CNW) 81% (SOO)	
Car Hours, Miles, Handlings					
Base Case		Pre-Blocking Only		Pre-Blocking + Sch. Sliding	
<p>L/C/B Hours 38 (Ind) 63 (BN) 71 (CNW) 69 (SOO)</p> <p>O/T Hours 33 (Ind) 33 (BN) 37 (CNW) 33 (SOO)</p> <p>Miles 291 Class 2 Blockswaps 0</p>		<p>L/C/B Hours 44 (Ind) 74 (BN) 73 (CNW) 73 (SOO)</p> <p>O/T Hours 30 (Ind) 30 (BN) 35 (CNW) 30 (SOO)</p> <p>Miles 291 Class 1 Blockswaps 1</p>		<p>L/C/B Hours 38 (Ind) 68 (BN) 67 (CNW) 67 (SOO)</p> <p>O/T Hours 28 (Ind) 29 (BN) 28 (CNW) 29 (SOO)</p> <p>Miles 291 Class 1 Blockswaps 1</p>	

Figure 3.7c

Traffic Flow: Mt. Vernon, IN - Bittinger, PA		
1.5 cars/day		
<p>Observations: This flow's trip time and reliability benefit from the combination of Pre-Blocking and Schedule Sliding. Pre-blocking alone causes inexplicable degradation in origin time and reliability which are alleviated with schedule sliding. The more reliable measure of L/C/B time decreases with pre-blocking alone and decreases further due to schedule sliding. Schedule sliding slightly degrades the connection between local trains and R561, but improves the connection at Louisville between R561 and Q376 by eliminating excess dwell time. Overall trip time demonstrated clearly the effects of four classifications. As expected, one classification was eliminated and one blockswap added.</p>		
Blocks		
Base Case	Pre-Blocking Only	Pre-Blocking + Sch. Sliding
Mt.Vernon-Evansville Evansville-Louisville Louisville-Willard Willard-Cumberland Cumberland-Hagerstown Hagerstown-Bittinger	Mt. Vernon-Louisville (swap at Evansville) Louisville-Willard Willard-Cumberland Cumberland-Hagerstown Hagerstown-Bittinger	Mt. Vernon-Louisville (swap at Evansville) Louisville-Willard Willard-Cumberland Cumberland-Hagerstown Hagerstown-Bittinger
Schedule		
Base Case	Pre-Blocking Only	Pre-Blocking + Sch. Sliding
J734 1707 DP Mt. Vernon 2230 AR Evansville R561 1300 DP Evansville 2300 AR Louisville Q376 0500 DP Louisville 0130 AR Willard Q378 0845 DP Willard 2315 AR Cumberland R342 0200 DP Cumberland 0715 AR Hagerstown B738 0410 DP Hagerstown 0413 AR Bittinger	J731 J734 1100 1707 DP Mt. Vernon 1930 2230 AR Evansville R561 1300 DP Evansville 2300 AR Louisville Q376 0500 DP Louisville 0130 AR Willard Q378 0845 DP Willard 2315 AR Cumberland R342 0200 DP Cumberland 0715 AR Hagerstown B738 0410 DP Hagerstown 0413 AR Bittinger	J731 J734 2000 0007 DP Mt. Vernon 2330 0530 AR Evansville R561 1900 DP Evansville 0500 AR Louisville Q376 0500 DP Louisville 0130 AR Willard Q378 0845 DP Willard 2315 AR Cumberland R342 0200 DP Cumberland 0715 AR Hagerstown B738 0410 DP Hagerstown 0413 AR Bittinger
O/D Reliability		
Base Case	Pre-Blocking Only	Pre-Blocking + Sch. Sliding
56%	53%	73%
Car Hours, Miles, Handlings		
Base Case	Pre-Blocking Only	Pre-Blocking + Sch. Sliding
L/C/B Hours 195	L/C/B Hours 192	L/C/B Hours 187
O/T Hours 25	O/T Hours 46	O/T Hours 21
Miles 1048	Miles 1048	Miles 1048
Class 5	Class 4	Class 4
Blockswaps 0	Blockswaps 1	Blockswaps 1

Figure 3.7d

Traffic Flow: Mt. Vernon, IN - Memphis, TN (SSW) 0.2 cars/day		
<p>Observations: The elimination of R557 as a connecting train seems to have mitigated the trip time benefits of local pre-blocking and schedule sliding, although reliability was highest in the local-pre-blocking only case. Schedule sliding reduced the connection time between the two local trains and R591 and between R591 and Q535, noticeably degrading reliability. While schedule sliding decreased the total time consumed in O/D movement, it did so by reducing origin time and increasing classification time. As expected, one classification was eliminated and one blockswap added.</p>		
Blocks		
Base Case Mt. Vernon-Evansville Evansville-Nashville Nashville-Memphis (SSW)	Pre-Blocking Blocks Mt. Vernon-Nashville (swap at Evansville) Nashville-Memphis (SSW)	Pre-Blocking + Sch. Sliding Mt. Vernon-Nashville (swap at Evansville) Nashville-Memphis (SSW)
Schedule		
Base Case J734 1707 DP Mt. Vernon 2230 AR Evansville R591 R557 1600 2300 DP Evansville 0115 0815 AR Nashville Q535 0045 DP Nashville 1530 AR Memphis (SSW)	Pre-Blocking Only J731 J734 1100 1707 DP Mt. Vernon 1930 2230 AR Evansville R591 1600 DP Evansville 0115 AR Nashville Q535 0045 DP Nashville 1530 AR Memphis (SSW)	Pre-Blocking + Sch. Sliding J731 J734 2000 0007 DP Mt. Vernon 2330 0530 AR Evansville R591 0330 DP Evansville 1245 AR Nashville Q535 0045 DP Nashville 1530 AR Memphis (SSW)
O/D Reliability		
Base Case 80%	Pre-Blocking Only 91%	Pre-Blocking + Sch. Sliding 87%
Car Hours, Miles, Handlings		
Base Case L/C/B Hours 71 O/T Hours 23 Miles 403 Class 2 Blockswap 0	Pre-Blocking Only L/C/B Hours 75 O/T Hours 21 Miles 403 Class 1 Blockswaps 1	Pre-Blocking + Sch. Sliding L/C/B Hours 78 O/T Hours 14 Miles 403 Class 1 Blockswaps 1

Figure 3.7e

Traffic Flow: Monon, IN -East St. Louis, IL					
0.5 cars/day (two flows, 0.2 cars/day and 0.3 cars/day)					
<p>Observations: ABM routed traffic into the Monon-Evansville pre-block as expected, then chose mileage-minimizing route, increasing time and handlings and reducing reliability. It is doubtful that the classification called for at Lawrenceville could take place. Schedule sliding again degraded reliability relative to pre-blocking alone by lowering connection time between R599 and R591 from 17:15 to 5:00, connection time between R591 and R590 from 24:45 to 7:15, connection time between R590 and J710 from 19:00 to 10:00. Although a handling was saved by pre-blocking at Lafayette, total handlings increased as handlings were added Vincennes, Lawrenceville, and Flora and removed at Louisville. If the base case route is valid, it calls into question the cost relationships between car miles, hours, and handlings used by the ABM.</p>					
Blocks					
Base Case		Pre-Blocking Only		Pre-blocking + Sch. Sliding	
Monon-Lafayette Lafayette-Evansville Evansville-Louisville Louisville-E. St. Louis		Monon-Evansville (swap at Lafayette) Evansville-Vincennes Vincennes-Lawrenceville Lawrenceville-Flora Flora-East St. Louis		Monon-Evansville (swap at Lafayette) Evansville-Vincennes Vincennes-Lawrenceville Lawrenceville-Flora Flora-East St. Louis	
Schedule					
Base Case		Pre-Blocking Only		Pre-Blocking + Sch. Sliding	
R599 2215 DP Monon 0100 AR Lafayette R591 1830 DP Lafayette 0915 AR Evansville R561 1300 DP Evansville 2300 AR Louisville Q686 2300 DP Louisville 1747 AR East St. Louis		R599 2215 DP Monon 0100 AR Lafayette R591 1830 DP Lafayette 0915 AR Evansville R590 1000 DP Evansville 1400 AR Vincennes J710 0900 DP Vincennes 1244 AR Lawrenceville Q373 2330 DP Lawrenceville 0244 AR Flora Q371 1819 DP Flora 2200 AR East St. Louis		R599 2215 DP Monon 0100 AR Lafayette R591 0600 DP Lafayette 2045 AR Evansville R590 0400 DP Evansville 0700 AR Vincennes J710 1700 DP Vincennes 2044 AR Lawrenceville Q373 1130 DP Lawrenceville 1444 AR Flora Q371 2019 DP Flora 2359 AR East St. Louis	
O/D Reliability					
Base Case		Pre-Blocking Only		Pre-Blocking + Sch. Sliding	
80% 80%		74% 74%		68% 68%	
Car Hours, Miles, Handlings					
Base Case		Pre-Blocking Only		Pre-Blocking + Sch. Sliding	
L/C/B Hours	112 (both fl.)	L/C/B Hours	169 (both fl.)	L/C/B Hours	134 (both fl.)
O/T Hours	14 (both fl.)	O/T Hours	14 (both fl.)	O/T Hours	14 (both fl.)
Miles	661	Miles	430	Miles	430
Class	3	Class	4	Class	4
Blockswaps	0	Blockswaps	1	Blockswaps	1

The O/D pairs in Figure 3.7 suggest that each of the explanations given above for the lack of saved car hours may apply. The Monon to East St. Louis flow was routed by the ABM to save car miles. However, trip time and handlings increased and reliability was degraded by the new routing. For the Mt. Vernon to Chicago flow, adding pre-blocks to trains improved trip time and reliability. However, substituting connecting trains had a noticeable effect on the connection performance at Evansville, and reliability. For the Mt. Vernon to Memphis flow, when schedules were slid, trip time actually increased, presumably because schedules were ultimately driven by heavier traffic flows which ultimately may not have even been targeted by local pre-blocking. All of the examples, however, demonstrate an eliminated handling at the origin serving yard. These examples clearly demonstrate that, while local pre-blocking shows promise in eliminating handlings, network-oriented strategies for minimizing costs can have a wide variety of effects on individual O/D performance.

Figure 3.8 gives an example of the potential of Local Pre-Blocking to reduce switching at larger serving yards. The serving yards shown perform the bulk of through-classification activity at all local pre-blocking serving yards, and also serve as bases for the most extensive local train operations. It is important to note that the reduction in switching suggested by Figure 3.8 represents only traffic originating at outlying network nodes and first classified at a serving yard whose network node is different from the origin node [see End Note 2]. Traffic originating within serving yard nodes may be eligible for pre-blocking as well, but classification savings achieved for this traffic are not measured by the SPM because all activity within the origin node is consolidated. Figure 3.8 demonstrates that a high percentage of through-classification at serving yards may be eliminated by local pre-blocking.

Figure 3.8: Reduction in Classification at Selected Serving Yards due to Local Pre-Blocking

Serving Yard Location	Through-Classified Volume, Base Case	Through-Classified Volume, Local Pre-Blocking	Percentage Change
Danville, IL	76.1 cars/day	50.8 cars/day	-34%
Lafayette, IN	90.1 cars/day	50.0 cars/day	-44%
Evansville, IN	167.7 cars/day	98.2 cars/day	-41%

3.1.5 Implementation Issues

3.1.5.1 Designing and Implementing a Local Pre-Blocking Operating Plan

The Local Pre-Blocking strategy faces few barriers to implementation and successful execution. This is due to the fact that the strategy may be implemented incrementally, rather than as a one-time wholesale change to the operating plan. A railroad could choose to implement local pre-blocking for a single block on a single train, then expand the program based on the original demonstration. An incremental implementation plan would smooth the demands on service planners responsible for creating new blocks in real-time control systems and routing traffic onto those blocks.

As pre-blocks would be added gradually under an incremental implementation scheme, the benefits to traffic and yard operations would accrue gradually as well. As smaller initial traffic volumes would avoid classification, yard crew requirements would be reduced more slowly. If not enough traffic is pre-blocked by local trains in the early phases of an incremental implementation, eliminating or reassigning yard crews may not be justified. For example, pre-blocking a single local train at a terminal might reduce a yard crew's work from eight hours to five hours per day. However, until all of that yard crew's classification was reassigned or eliminated as more trains and traffic are pre-blocked, no yard crew savings would be realized.

While incremental implementation may be an advantage of local pre-blocking, schedule sliding to eliminate excess dwell time for pre-blocked traffic poses different implementation issues. Because new train schedules determined by a model such as TSS-Times are generated as a group, rather than singly, incremental implementation may ultimately increase the demands on service planners relative to batch implementation. New train schedules require much service planning effort in implementation, including creation of new locomotive, crew, and meet/pass plans, as well as the coding of the actual changes into real-time control systems. Locomotive, crew, and meet/pass analysis would only have to be performed once if slid schedules were implemented in a batch, whereas such analyses would be required continually if slid schedules were implemented incrementally. In less capacity-constrained corridors than Chicago-Nashville, meet/pass management could be left to dispatchers.

3.1.5.2 Customer Cooperation in Local Pre-Blocking

Customer cooperation in loading cars in order will play an important role in reducing the impact on local train duty time and switching requirements. When customers load cars in block order, a local train can make a pickup in block without increasing the number of times the train is broken or the number of times the siding must be entered. It is crucial that the customer be made aware of the pre-blocking arrangement, so that cars are loaded and waybills prepared in the proper order.

The order in which cars should be spotted and loaded to facilitate pre-blocking could be determined by a simple expert system which used data on each train's block order and customer siding direction. If the cars were of the same type, then they would be spotted as always. However, if cars in different pre-blocks are of several types, spotting instructions for the empties could be generated at the time the cars were ordered. In both cases, the customer would receive information on the order in which cars were to be loaded at the time empties were ordered.

Customers unwilling or unable to cooperate in local pre-blocking could be handled several ways. If there was a physical reason such as plant layout preventing cars from being spotted and loaded in order, then this circumstance could dictate reordering the pre-blocks on a train. If not, then the customer's cars could simply not be pre-blocked, being pulled into the "all other" block on each local train and classified in the origin yard as was done before pre-blocking. As the failure to pre-block a customer's cars would add cost relative to pre-blocking, the customer could be charged a penalty or denied any discount passed on to customers as a result of local pre-blocking savings, although punitive action should not be considered a desirable means of resolving the situation.

3.1.5.3 Operational Contingency Planning

If a local train cannot make its designated pre-blocks within the scheduled time, because of a surge in the train's volume that day or because heavy overhead traffic prohibits the train from performing necessary switching, several options are available to operating managers:

- If locomotives, a crew, and track time are available, the train could be called and dispatched early, and pre-block its cars at the expense of some overtime and additional locomotive usage.
- If a change in schedule is not feasible, the local train could run on its original schedule and pre-block less traffic or no traffic. Local trains could be directed to make only the largest of several pre-blocks, only the most time-sensitive of the pre-blocks (the block with the least connection time before pickup by a road train), or only the pre-blocks which could be made without interfering with through trains on the line. The local train could also make all pre-blocks, but put only priority traffic into the pre-blocks, gathering everything else by the quickest means possible, to be switched at the serving yard. Yard switchers would switch additional cars not pre-blocked by the local train, at the expense of some disruption at the serving yard, and/or missed connections for the pre-blocked traffic with the tightest connection times.
- Time-constrained local trains pull only loads from customer sidings, putting off empty car gathering until it can be done without putting undue time pressure on pre-blocking.

While the contingency plans discussed here may place some traffic at risk of missing first connections to through trains, disruption to local pre-blocking activity, and also disruption caused by local pre-blocking activity, is local in nature and minor in scope. The impacts on yards caused by heavy traffic or delayed local trains are little different under pre-blocking than under conventional operations, with the exception that yard switchers will sometimes be called upon to switch traffic that arrives at the serving yard pre-blocked on good days.

3.1.6 Conclusions for the Local Pre-Blocking Strategy

Local Pre-Blocking provides modest benefits to O/D trip time by eliminating excess dwell time and switching at serving yards. Local Pre-Blocking may require additional local train starts, in order to balance workload between trains, and it may require individual trains runs to be lengthened. However, these potential costs are balanced by cost reduction opportunities in the serving yard. Because switching requirements are reduced, yard switchers may be eliminated or reassigned to other duties.

In addition, the potential exists for many carload customers to assist the railroad in executing Local Pre-Blocking by following simple loading instructions and communicating shipment destinations in advance of release. Such cooperation on the part of customers could eliminate many of the operating problems imposed on local trains.

Local Pre-Blocking by itself does not significantly impact dock-to-dock reliability. Because Local Pre-Blocking effects a process change only at the origin yard, it is often the case that Local Pre-Blocking strategy cannot eradicate more than one-third or one-fourth of the total variability imposed by yards on an O/D traffic flow. For this reason, Local Pre-Blocking may be viewed as a necessary but not sufficient condition for the achievement of high levels of network reliability. Paired with other operating innovations, Local Pre-Blocking could be instrumental in contributing to a highly reliable service.

Local Pre-Blocking faces few barriers to implementation, as incremental implementation moderates service planner workloads and the required operating plan maintenance is relatively minor. Schedule sliding, while providing additional benefits to targeted traffic and eliminating excess dwell time in yards, is less amenable to incremental implementation and should probably be delayed until the majority of planned pre-blocking activity has been instituted. In the event that local train schedules cannot be slid because of committed switching times at customers, schedule sliding can still be performed with the local train schedules fixed. It is likely that the benefits of schedule sliding would be diminished but not eliminated if local train schedules remained fixed.

All in all, the benefits of Local Pre-Blocking and the lack of significant barriers to implementation make the Local Pre-Blocking strategy worthy of immediate implementation.

3.2 Terminal Complexes

3.2.1 Description

Hump yards generally operate as continuous, FIFO processing facilities. Queues of unprocessed inbound trains exist, and average yard time is inflated by time spent waiting between processes such as inbound inspection, humping, assembly, outbound inspection, and the outbound brake test. The Terminal Complex strategy attempts to circumvent queues before and between processes by identifying a group of inbound and outbound trains which may be processed separately in a scheduled, expedited fashion.

The goal of the Terminal Complex strategy is to drive down the average yard time and increase reliability for a large portion of traffic at a hump yard by scheduling processing, as well as arrivals and departures, for a group of inbound trains and outbound trains which exchange a large volume of traffic. Reliable train-to-train connections would take place in as little as eight hours, with average yard times for traffic processed in the complex dropping to 11-12 hours.

Twice a day, a group of trains would arrive at the yard at one-hour intervals. The trains would be inspected and humped on schedule, resulting in a set of blocks in the bowl. The blocks would then be assembled into outbound trains and inspected, and would depart, again on an expedited schedule.

The Terminal Complex strategy offers several other advantages. Because of expedited processing, blocks built in a complex remain in the bowl between 9 and 12 hours at a time. If a complex is operated in two directions each day, for northbound and southbound trains, for example, both sets of blocks could be built on the same bowl tracks. The use of a large number of bowl tracks to build two blocks per day frees other bowl tracks for new blocks, significantly increasing the yard's ability to build blocks.

The Terminal Complex strategy has two major pitfalls:

- Tolerance for poor execution is very low. Over-the-hump connections are scheduled for as little as eight hours, and complex blocks exist on bowl tracks for only 12 hours at a time. The adverse effects of a late-train arrival or behind-schedule processing could cascade for several days.
- Because most complex blocks occupy bowl tracks during a 12-hour window, they can only receive traffic which arrives on inbound complex trains. Therefore, traffic which otherwise would have been classified into complex blocks but entered Nashville on ineligible trains must be redirected. Some traffic is directed onto inbound complex trains, some utilizes alternate outbound blocks, and other traffic avoids Nashville entirely. If the previous routes for this traffic were highly efficient, then rerouting cars around the terminal complex may increase car hours, car miles, and/or car handlings, and neutralize many of the system-level benefits achieved by the complex.

3.2.2 Creating the Terminal Complex Operating Plan

In order to create an operating plan representing operation of northbound and southbound complexes at Nashville, these steps were performed:

- a. The maximum possible number of trains that could be processed in the complex was determined using process times for inspection, humping, and assembly measured during the Nashville yard study [Duffy 1994]. The complex could feasibly process four inbound trains and four outbound trains, each carrying an average of four blocks, twice a day [see Figure 3.9]. Appendix 1 presents a detailed description of the methods used to arrive at the size of the complex.
- b. Trains [see Figures 3.11 and 3.12] and blocks [see Figure 3.10] to be processed in each complex were chosen by selecting the set of *inbound trains* and *outbound blocks* which maximized the number of cars processed in the complex. *Inbound blocks* were simply those blocks carried by the inbound complex trains, and in almost all cases were simply blocks destined for Nashville. *Outbound trains* were those trains which carried the most complex outbound blocks. Some reassignment had to be performed to ensure that all outbound blocks were carried on the four outbound complex trains in each direction, and that those trains were not overloaded. Several high-volume blocks were chosen in both the northbound and southbound complexes. Appendix 1 presents a detailed description of the methods used to choose the complex inbound trains and outbound blocks.
- c. Arrival and departure times for inbound and outbound complex trains were slid to create northbound and southbound complexes [see Figures 3.11 and 3.12]. Schedules were slid to minimize the difference between the complex schedules and the previous schedules, but no algorithm was used.
- d. Because 22 of the complex blocks would be built on 11 bowl tracks, 11 bowl tracks were freed for additional blocks. 11 new blocks destined to hump yards and large flat yards were created [see Figure 3.14]. Destinations for new blocks were chosen by reviewing a list of CSXT's yards and building blocks to the busiest carload traffic (non-coal, non-phosphate) yards which did not have direct service from Nashville.
- e. Before running the ABM to redirect traffic, the complex blocks were altered to reflect the complex's faster processing. PMAKE multipliers were attached to each complex block which resulted in a complex-block-specific PMAKE function of $T_{50} = 7$, $T_{90} = 1$, $P_{MAX} = 100$, ensuring that traffic departing on the outbound complex blocks would connect reliably in Nashville due to coordinated processing in the complex, even with connection times as short as eight hours. Section 4.2 and Martland (1982) contain expanded discussions of PMAKE functions.
- f. The ABM was used to redirect cars which otherwise would have been classified into complex blocks, but entered Nashville on ineligible trains. Some cars were

directed onto inbound complex trains, others utilized alternate outbound blocks, and still others avoided the Nashville terminal entirely.

- g. To ensure that benefits to trip time achieved in the complex were not eroded by downstream dwell time increases, schedules of local and through trains connecting to complex trains were slid using TSS.
- h. The SPM was used to simulate operation of the northbound and southbound complexes at Nashville.

3.2.3 Examples

Figure 3.9 illustrates the processing schedule conceived for the terminal complex at Nashville. The northbound and southbound complexes would be processed one after the other on a continuing basis. Process times used to create the processing schedule include two hours for inbound inspection, one hour for humping, two hours, 45 minutes for assembly, one hour 30 minutes for outbound inspection. Varying amounts of time were allotted for the brake test in order to space departures, with a minimum allotment of 30 minutes. An important issues for the terminal complex is the constraint that certain activities may not overlap. Only one train at a time may be humped, and only two trains at a time may be assembled. If the bowl is not cleared by the previous complex before the next complex begins humping, humping could be disrupted as tracks are closed out and the earlier complex' cars removed. Assembly would also be delayed as each track would contain traffic in two complexes which would have to be cut, possibly causing additional congestion in the pullout area.

Figure 3.9: Processing Schedule for the Northbound and Southbound Complexes at Nashville

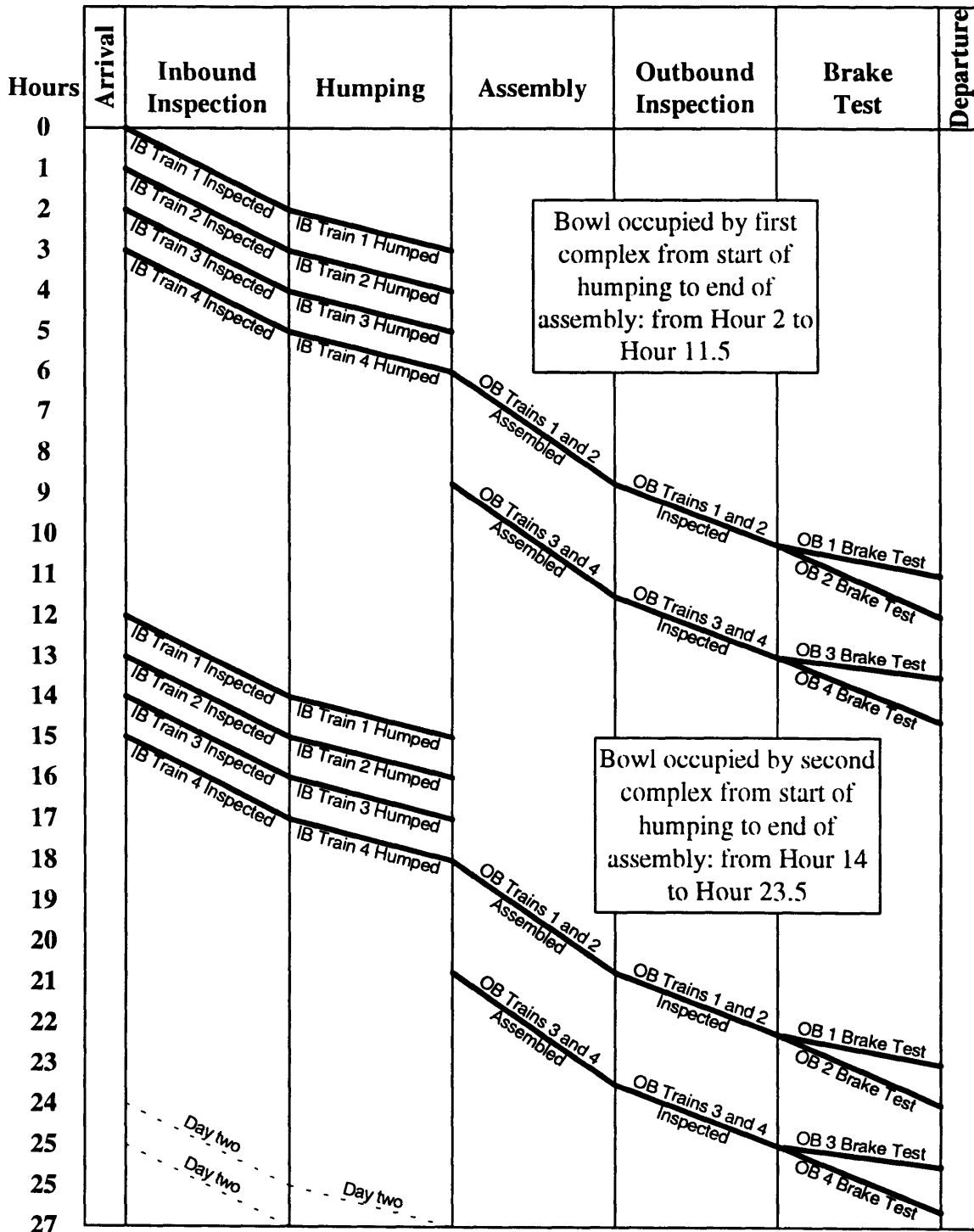


Figure 3.10: Blocks Built in the Terminal Complex at Nashville

Yard Track	Block Destination	Terminal Complex Direction	Block-to-Track Assignment for Terminal Complex	Block Categories Under Terminal Complex
1	Birmingham	Southbound	AM: Birmingham PM: Chicago	AM: South Complex PM: North Complex
2	Atlanta	Southbound	AM: Atlanta PM: Peavey	AM: South Complex PM: North Complex
3	Chattanooga	Southbound	AM: Chattanooga PM: Evansville	AM: South Complex PM: North Complex
4	Pensacola	Southbound	AM: Pensacola PM: Danville	AM: South Complex PM: North Complex
5	Decatur, AL	Southbound	AM: Decatur, AL PM: Lafayette	AM: South Complex PM: North Complex
6	Bruceton/KW	Southbound	AM: Bruceton/KW PM: Camden	AM: South Complex PM: North Complex
7	Hamlet	Southbound	AM: Hamlet PM: Decatur, IL	AM: South Complex PM: North Complex
8	Milan	Southbound	AM: Milan PM: Chicago/SOO	AM: South Complex PM: North Complex
9	Bruceton	Southbound	AM: Bruceton PM: CEI Grain	AM: South Complex PM: North Complex
10	Waycross	Southbound	AM: Waycross PM: Bowling Green	AM: South Complex PM: North Complex
11	Cincinnati	Southbound	AM: Cincinnati PM: New Johnsonville	AM: South Complex PM: North Complex
12	Louisville	Built in Each Direction	Louisville	North and South Complexes
13	Memphis	Built in Each Direction	Memphis	North and South Complexes
14	Memphis/IC	Built in Each Direction	Memphis/IC	North and South Complexes
15	Memphis/SP	Built in Each Direction	Memphis/SP	North and South Complexes
16	Memphis/MP	Built in Each Direction	Memphis/MP	North and South Complexes
17	Chicago	Northbound	Available for New Block	
18	Peavey	Northbound	Available for New Block	
19	Evansville	Northbound	Available for New Block	
20	Danville	Northbound	Available for New Block	
21	Lafayette	Northbound	Available for New Block	
22	Decatur, IL	Northbound	Available for New Block	
23	Chicago/SOO	Northbound	Available for New Block	
24	CEI Grain	Northbound	Available for New Block	
25	Bowling Green	Northbound	Available for New Block	
26	N. Johnsonville	Northbound	Available for New Block	
27	Camden	Northbound	Available for New Block	
28-60	Unchanged - Tracks Not Affected by Complex			

Figure 3.10 shows complex block destinations and the alteration of block-to-track assignments that would accompany implementation of the terminal complex in order to free space for new blocks. Bowl tracks 1 through 11 hold two blocks per day, one each in the northbound and southbound complexes. Because the blocks on tracks 1 through 11 reside there for only 12 hours at a time, access to these blocks is restricted. The only traffic that may be scheduled to these blocks is that which arrives at Nashville on the four

inbound trains in each complex. Bowl tracks 12 through 16 hold the five high-volume blocks that are dispatched twice per day, from both the northbound and southbound complexes. These blocks reside on their bowl tracks continuously, and thus can receive traffic from any train classified at Nashville. The blocks that originally occupied tracks 17 through 27 were designated complex blocks and paired with the blocks on tracks 1 through 11. Tracks 17 through 27 are now available for reassignment of new blocks.

The block-to-track assignments shown do not reflect actual block-to-track assignments. Complex blocks would probably be assigned to the longest bowl tracks to avoid disruptive class track overruns, regardless of whether those tracks were previously occupied by northbound or southbound blocks. In addition, assembly of complex trains would be assisted if complex blocks were distributed among several trim leads to reduce the delays caused by several yard switchers waiting for the same trim lead.

Figures 3.11-3.13 illustrate train schedule and blocking changes made in creating the terminal complex at Nashville. While almost all outbound complex trains carry more blocks when the complex is in operation, blocks built in each complex are smaller because they contain only traffic which entered Nashville on the complex inbound trains. Traffic originally assigned to complex blocks which entered Nashville on complex trains was altered in one of three ways: diverted onto a complex train and processed in the complex, diverted to a non-complex block at Nashville, or diverted to a route which does not include classification in Nashville.

Figure 3.11: Original and Revised Schedules and Blocking of Trains Processed in the Northbound Terminal Complex at Nashville

Inbound Trains				
Train Symbol	R673/R675	Q684	R582	Q520
Route	Hamlet-Nashville	Waycross-Nashville	Atlanta-Nashville	Pensacola-Nashville
Original Schedule	DP Ham 1930 AR Nas 0215	DP Way 1800 AR Nas 0330	DP Atl 1800 AR Nas 0730	DP Pen 2300 AR Nas 0830
Revised Schedule	DP Ham 1915 AR Nas 0200	DP Way 1730 AR Nas 0300	DP Atl 1430 AR Nas 0400	DP Pen 1930 AR Nas 0500
Outbound Trains				
Train Symbol	Q526	R533	Q648	R590
Route	Nashville-Louisville	Nashville-Memphis	Nashville-Chicago	Nashville-Lafayette
Original Schedule	DP Nas 0400 AR Lou 1300	DP Nas 0930 AR Mem 0330	DP Nas 2000 AR Chi 2130	DP Nas 1600 AR Laf 2359
Revised Schedule	DP Nas 1300 AR Lou 2200	DP Nas 1400 AR Mem 0815	DP Nas 1500 AR Chi 1700	DP Nas 1600 AR Laf 2359
Original Blocks	Louisville	Camden Memphis N. Johnsonville	No Pickups at Nashville (carries Wax-Chicago)	Lafayette Terre Haute
Revised Blocks	Louisville Bowling Green	Memphis Memphis/MP Memphis/SP Memphis/IC N. Johnsonville Camden	Chicago Chicago/SOO Danville Decatur, IL	Lafayette Terre Haute Peavey CEI Grain Evansville Mt. Vernon

Figure 3.12: Original and Revised Schedules and Blocking of Trains Processed in the Southbound Terminal Complex at Nashville

Inbound Trains				
Train Symbol	R573	Q595	R532	R591
Route	Cincinnati-Nashville	Chicago-Nashville	Memphis-Nashville	Lafayette-Nashville
Original Schedule	DP Cin 1330 AR Nas 0600	DP Chi 0330 AR Nas 0430	DP Mem 0700 AR Nas 1930	DP Laf 1830 AR Nas 0115
Revised Schedule	DP Cin 2130 AR Nas 1400	DP Chi 1400 AR Nas 1500	DP Mem 0400 AR Nas 1600	DP Laf 1015 AR Nas 1700
Outbound Trains				
Train Symbol	R674	R534	R521	Q531
Route	Nashville-Hamlet	Nashville-Louisville	Nashville-Pensacola	Nashville-Memphis
Original Schedule	DP Nas 0130 AR Ham 1145	DP Nas 1200 AR Lou 2100	DP Nas 0300 AR Pen 1100	DP Nas 0400 AR Mem 1900
Revised Schedule	DP Nas 0100 AR Ham 1115	DP Nas 0200 AR Lou 1100	DP Nas 0300 AR Pen 1100	DP Nas 0400 AR Mem 1900
Original Blocks	Chattanooga Bridgeport	Bowling Green Louisville	Pensacola	Memphis/MP
Revised Blocks	Chattanooga Atlanta Hamlet	Louisville Cincinnati	Decatur, AL Birmingham Pensacola Waycross Jacksonville	Memphis Memphis/MP Memphis/SP Memphis/IC Milan Bruceton Bruceton/KW

Figure 3.13: Schematic Representation of Terminal Complex Schedule Changes

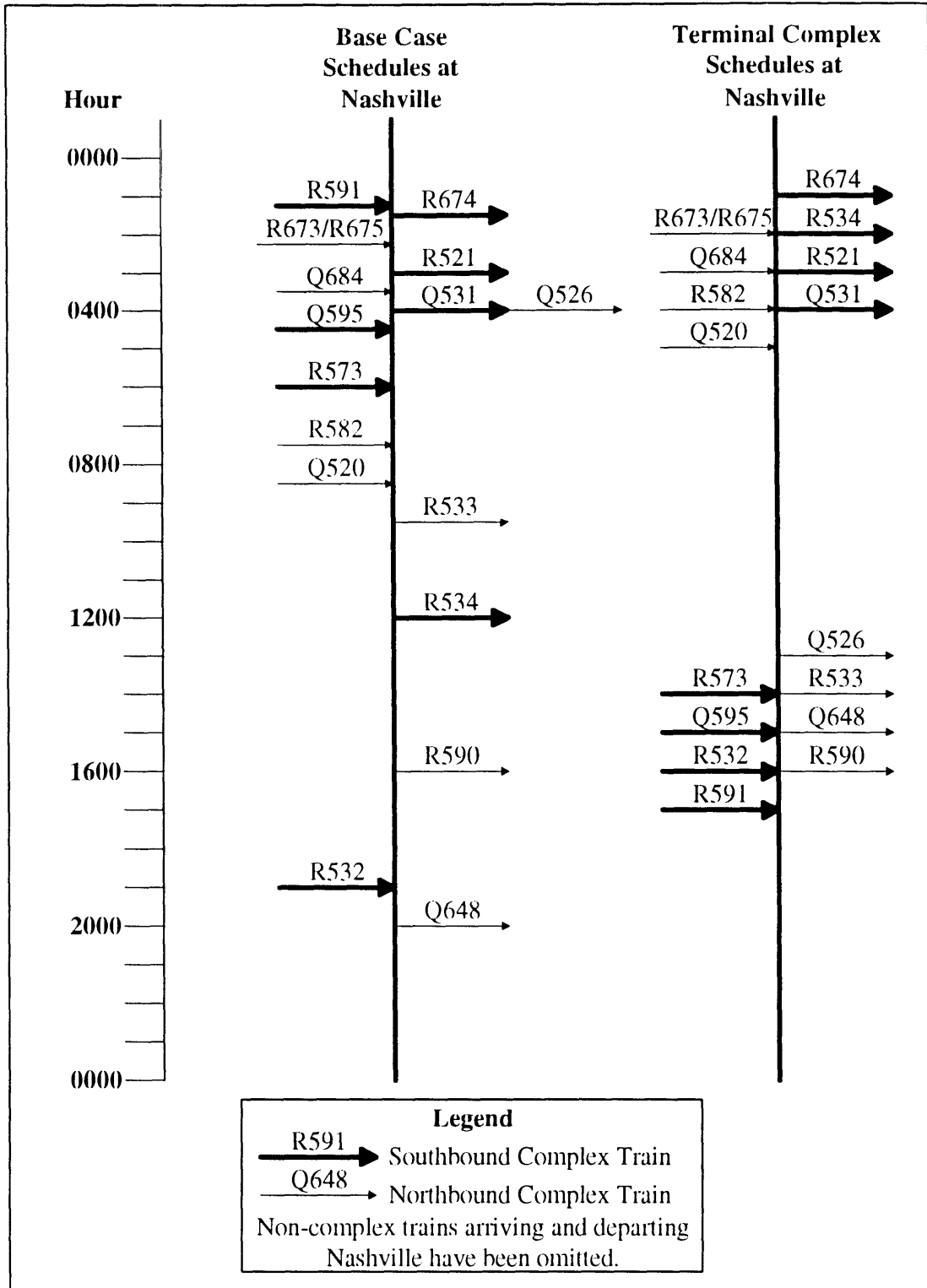


Figure 3.14 lists new blocks created at Nashville on hump tracks freed by the complex. New block destinations were chosen by reviewing major CSXT yards which did not receive direct blocks from Nashville. Blocks to other hump yards were chosen first, followed by blocks to large flat yards and blocks to medium flat yards. Not all of the new blocks chosen were appropriate to the traffic flows through Nashville, as the low volumes of some blocks attest. If CSXT were to create a terminal complex operating plan for implementation, a more substantial analysis would illustrate block destinations which would receive more volume.

Figure 3.14: New Blocks Built on Class Tracks Freed by the Terminal Complex

Block Destination	Yard Type	Daily Volume Using Block per ABM
Cayce	Medium Flat	2 cars/day
Cumberland	Hump	2 cars/day
Dayton	Medium Flat	10 cars/day
Detroit	Large Flat	3 cars/day
Florence	Large Flat	3 cars/day
Jacksonville	Large Flat	10 cars/day
Monroe	Medium Flat	2 cars/day
Montgomery	Large Flat	25 cars/day
Rocky Mount	Large Flat	9 cars/day
Tampa	Large Flat	2 cars/day
Willard	Hump	6 cars/day

Bob Coppinger of CSXT Service Design pointed out that certain newly created blocks might be successful as complex blocks, as they are highly oriented to either northbound or southbound traffic flows (blocks from Nashville to Dayton and Jacksonville, for example). If new blocks such as Dayton and Jacksonville were included in the complex, some destinations would be bumped out of the original set of complex block destinations. Blocks bumped out of the complex would be able to occupy hump tracks continuously, and less traffic would have to be rerouted away from those blocks. Traffic volume processed in the complex might decline, as the original set of complex block destinations were chosen in order to maximize the amount of traffic processed in the complex [see Appendix 1]. However, the original complex blocks were chosen from blocks already built at Nashville, and the effect of new block destinations on the choice of complex blocks was not considered.

3.2.4 Changes in Performance

The following types of performance changes were noted as a result of the Terminal Complex strategy:

- Traffic on the complex trains experienced large decreases in yard time as a result of expedited, reliable processing in the complex.
- A moderate amount of traffic took advantage of the 11 new blocks built on freed bowl tracks at Nashville. This traffic improved by using a bypass block to avoid one or several downstream handlings. While railroads prefer that blocks maintained at a yard have a minimum of 10-15 cars per day, not all newly created blocks reached the minimum level, as the ABM did not select them as superior to current routes. This suggests that better destination choices for new blocks may allow further exploitation of the additional block-building capacity provided by the complex.
- Because the ABM was given considerable latitude to reroute cars which were ineligible for the complex, some of these cars also experienced performance improvements. Some were rerouted onto complex trains, but others traversed equivalent or superior routes which did not include Nashville. Overall, traffic classified at Nashville decreased 24% as a result of rerouting around the complex.
- The Terminal Complex strategy strongly improved performance of the yard at Nashville, as average yard time dropped from 30 hours to 17 hours.

Aggregate statistics for 1422 cars per day in 2109 O/D pairs targeted for improvement by the Terminal Complex are shown in Figure 3.15. Car hours decreased by 4% for the targeted traffic, which includes both traffic processed in the complex and traffic diverted from it. Figure 3.16 shows the annual dollar value of car hour, mile, and handling savings generated by the Terminal Complex strategy. At more than \$12 million annually for the network, saved car hours represent the largest single source of savings, as expected. Although distributed differently, the savings generated by the Terminal Complex strategy are of the same magnitude as those generated by the Local Pre-Blocking strategy.

Figure 3.15: Changes in Trip Time, Reliability, and Activity due to the Terminal Complex at Nashville

Strategy	Average Dock-to-Dock Trip Time	% of Cars Arriving Within +/- 24 Hours of Average	Car Handlings Saved Per Day	Car Hours Saved Per Day	Car Miles Saved Per Day
Base Case	123	80%	0	0	0
Terminal Complex	118	82%	204	7977	7730

Figure 3.16: Annual Cost Savings due to the Terminal Complex

	Targeted Traffic Only	Extrapolation to Entire Network
Value of Saved Car Handlings	\$0.2 M	\$1.2 M
Value of Saved Car Hours	\$2.1 M	\$12.5 M
Value of Saved Car Miles	\$1.4 M	\$8.1 M
Annual Total	\$3.8 M	\$21.9 M

Figures do not sum due to rounding.

Like the Local Pre-Blocking strategy, the Terminal Complex strategy offered only marginal gains in O/D reliability, presumably for similar reasons. The Terminal Complex strategy instituted more reliable processing at a single facility, leaving even traffic processed in the complex vulnerable to disruption at other system points. At the individual flow level, however, improvements were often quite significant. The network-wide effects on reliability of new blocks built on freed bowl tracks were modest because relatively little traffic took advantage of the new blocks, and the prospect of eliminated handlings that they offered. Furthermore, as one of the example flows in Figure 3.17 will show, even when the new blocks do serve to eliminate handlings, the impact on reliability can be negative, contrary to expectations.

The impact of using the ABM to find alternate routes for traffic diverted out of the complex cannot be overemphasized, and is demonstrated by the highly unexpected result that car miles decreased significantly even though large volumes of traffic received new routes. If diverted traffic passed through Nashville as part of its shortest or least-cost route, this traffic would be expected to perform more poorly when rerouted around the complex. However, both at the system level and at the individual flow level, the wide variety of routing options within the same physical corridor made the addition of mileage unlikely. The least-cost alternatives chosen by the ABM for traffic rerouted around the complex were in most cases as good as previous routes in terms of trip time and reliability. In fact, some "rerouting" of cars around Nashville was performed not because a car was ineligible for processing in the complex, but instead because an alternate route was superior even to processing in the complex.

Figures 3.17a-3.17g: Examples of Performance and Routing Changes to Individual Traffic Flows due to the Terminal Complex Strategy

Traffic Flow: Chicago - Gallatin, TN 0.2 cars/day			
Observations: This flow was classified at Nashville into a non-complex block. Although the flow did not take advantage of the expedited processing of the complex, it experienced an ancillary benefit, a reduction in average classification time of 11 hours. This was the result of sliding the schedule of Q595 to fit the southbound complex, and reassigning the Nashville-Gallatin block to Q526. The combination of these actions replaced the 31.5-hour connection time at Nashville with a 19-hour connection time. The difference, largely excess, was eliminated from O/D trip time.			
Blocks			
Base Case		Terminal Complex	
Chicago-Nashville Nashville-Gallatin		Chicago-Nashville Nashville-Gallatin	
Schedule			
Base Case		Terminal Complex	
Q595 0330 DP Chicago 0430 AR Nashville		Q595 1700 DP Chicago 1800 AR Nashville	
R534 1200 DP Nashville 1715 AR Gallatin		Q526 1300 DP Nashville 1700 AR Gallatin	
O/D Reliability			
Base Case		Terminal Complex	
79%		79%	
Car Hours, Miles, Handlings			
Base Case		Terminal Complex	
L/C/B Hours	60	L/C/B Hours	49
O/T Hours	45	O/T Hours	45
Miles	449	Miles	449
Class	1	Class	1
Blockswaps	0	Blockswaps	0

Figure 3.17b

<p>Traffic Flow: Cantonment, FL - East St. Louis 0.9 cars/day</p> <p>Observations: One would have expected this flow to be routed through the northbound complex and placed in the Louisville block, given the superior processing performance of the northbound complex. However, the ABM's choice of classification at Montgomery over complex classification at Nashville is explained by Montgomery's PMAKE function of T50 = 0, T90 = 20, PMAX = 100. Average yard time is largely determined by T50, and Montgomery's T50 is less than 7, the complex T50. Montgomery is a relatively low-volume flat yard which classifies primarily local traffic. Although its PMAKE function is not entirely unreasonable in this context, such processing performance could not necessarily be expected for newly added through-classification. This routing artifact suggests that a set of PMAKE functions representing expected or desired yard performance instead of the performance embodied in car schedules may be useful for studies such as this.</p> <p>Although the new route improves on the base case performance, its improvement stems largely from factors not considered by the ABM in the routing process. For example, the ABM does not consider train routes and schedules when routing cars. Therefore, the routing process considered neither the Montgomery-Louisville block's time-consuming blockswap at Birmingham, nor the fact that in the base case the flow was required to wait 14 hours at Birmingham for Q520's reclassification.</p>	
Blocks	
<p>Base Case</p> <p>Cantonment-Nashville Nashville-Louisville Louisville-East St. Louis</p>	<p>Terminal Complex</p> <p>Cantonment-Montgomery Montgomery-Louisville (swap at Birmingham) Louisville-East St. Louis</p>
Schedule	
<p>Base Case</p> <p>Q520 0030 DP Cantonment 0830 AR Nashville</p> <p>Q526 0400 DP Nashville 1300 AR Louisville</p> <p>Q686 2300 DP Louisville 1800 AR East St. Louis</p>	<p>Terminal Complex</p> <p>Q520 2030 DP Cantonment 0530 AR Montgomery</p> <p>R658 1800 DP Montgomery 0100 AR Birmingham</p> <p>Q572 1000 DP Birmingham 0130 AR Louisville</p> <p>Q686 2300 DP Louisville 1800 AR East St. Louis</p>
O/D Reliability	
<p>Base Case</p> <p>88%</p>	<p>Terminal Complex</p> <p>97%</p>
Car Hours, Miles, Handlings	
<p>Base Case</p> <p>L/C/B Hours 118</p> <p>O/T Hours 16</p> <p>Miles 906</p> <p>Class 2</p> <p>Blockswaps 0</p>	<p>Terminal Complex</p> <p>L/C/B Hours 101</p> <p>O/T Hours 12</p> <p>Miles 906</p> <p>Class 2</p> <p>Blockswaps 1</p>

Figure 3.17c

<p>Traffic Flow: Chicago - Montgomery, AL 0.2 cars/day</p>			
<p>Observations: This flow utilized the new Nashville-Montgomery block. By doing so, it gained 23 hours in trip time, 10 percentage points in reliability, and skipped a handling at Birmingham.</p>			
<p>Blocks</p>			
<p>Base Case</p> <p>Chicago-Nashville Nashville-Birmingham Birmingham-Montgomery</p>		<p>Terminal Complex</p> <p>Chicago-Nashville Nashville-Montgomery</p>	
<p>Schedule</p>			
<p>Base Case</p> <p>Q595 0330 DP Chicago 0430 AR Nashville</p> <p>R527 2030 DP Nashville 0545 AR Birmingham</p> <p>Q579 1400 DP Birmingham 1900 AR Montgomery</p>		<p>Terminal Complex</p> <p>Q595 1700 DP Chicago 1800 AR Nashville</p> <p>Q649 1500 DP Nashville 0700 AR Montgomery</p>	
<p>O/D Reliability</p>			
<p>Base Case</p> <p>63%</p>		<p>Terminal Complex</p> <p>73%</p>	
<p>Car Hours, Miles, Handlings</p>			
<p>Base Case</p> <p>L/C/B Hours 92</p> <p>O/T Hours 61</p> <p>Miles 728</p> <p>Class 2</p> <p>Blockswaps 0</p>		<p>Terminal Complex</p> <p>L/C/B Hours 69</p> <p>O/T Hours 61</p> <p>Miles 728</p> <p>Class 1</p> <p>Blockswaps 0</p>	

Figure 3.17d

Traffic Flow: Chicago - Augusta, GA 0.3 cars/day			
Observations: This traffic flow was rerouted by the ABM to replace handlings at Nashville and Waycross with handlings at Atlanta and Greenwood, effecting large decreases in time and mileage but avoiding the complex. It is not clear why the flow did not take this route in the base case. While classification into the Waycross complex block at Nashville may have been faster and more reliable than classification at Atlanta, mileage considerations outweighed the processing advantage of the complex.			
Blocks			
Base Case		Terminal Complex	
Chicago-Nashville Nashville-Waycross Waycross-Augusta		Chicago-Atlanta Atlanta-Greenwood Greenwood-Augusta	
Schedule			
Base Case		Terminal Complex	
Q595 0330 DP Chicago 0430 AR Nashville		Q647 0700 DP Chicago 0215 AR Atlanta	
Q649 R685 0500 1930 DP Nashville 1530 2330 AR Waycross		R662 0800 DP Atlanta 1530 AR Greenwood	
Q690 1400 DP Waycross 0300 AR Augusta		Q691 0001 DP Greenwood 0345 AR Augusta	
O/D Reliability			
Base Case		Terminal Complex	
62%		68%	
Car Hours, Miles, Handlings			
Base Case		Terminal Complex	
L/C/B Hours	153	L/C/B Hours	109
O/T Hours	50	O/T Hours	50
Miles	1214	Miles	928
Class	2	Class	2
Blockswaps	0	Blockswaps	0

Figure 3.17e

Traffic Flow: Memphis - Dayton, OH 3.2 cars/day			
<p>Observations: This flow utilized the new Nashville-Dayton block, saving handlings at Louisville and Cincinnati and 36 hours of trip time. The tight, 4-hour blockswap connection at Cincinnati is a likely contributor to the decrease in reliability between the base case and the terminal complex routing. What is more surprising about the decrease in reliability, though, is that the base case reliability is 89% even with three classifications. This may be traced in part to the originating time distribution, but also to the available times for classification at Nashville and Cincinnati in the base case. At both of these yards, traffic moves on only one connection, rather than being spread over several connections, because the time available for classification, 32.5 hours in Nashville and 18 hours in Cincinnati is greater than T50 + T90 at each yard.</p>			
Blocks			
Base Case		Terminal Complex	
Memphis-Nashville Nashville-Louisville Louisville-Cincinnati Cincinnati-Dayton		Memphis-Nashville Nashville-Dayton (swap at Cincinnati)	
Schedule			
Base Case		Terminal Complex	
R532 0800 DP Memphis 1930 AR Nashville		R532 0730 DP Memphis 1900 AR Nashville	
Q526 0400 DP Nashville 1300 AR Louisville		R270 1345 DP Nashville 1045 AR Cincinnati	
R518 0730 DP Louisville 1700 AR Cincinnati		Q376 1445 DP Cincinnati 1745 AR Dayton	
R506 1100 DP Cincinnati 1400 AR Dayton			
O/D Reliability			
Base Case		Terminal Complex	
89%		76%	
Car Hours, Miles, Handlings			
Base Case		Terminal Complex	
L/C/B Hours	108	L/C/B Hours	72
O/T Hours	45	O/T Hours	45
Miles	607	Miles	607
Class	3	Class	2
Blockswaps	0	Blockswaps	1

Figure 3.17f

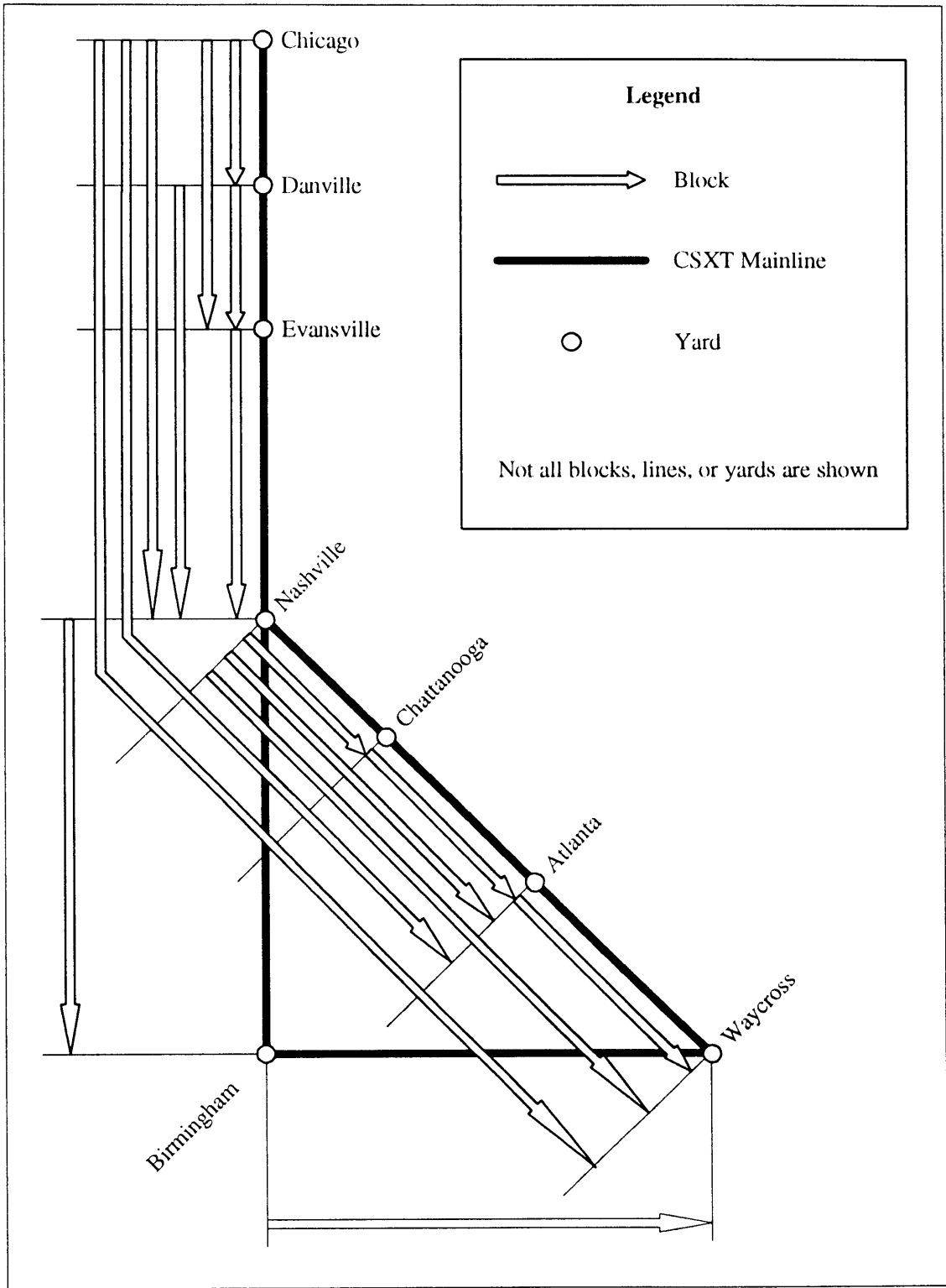
Traffic Flow: Mt. Vernon, IN - Memphis, (SSW) 0.2 cars/day	
Observations: This flow was processed in the complex. Reliability increased by 13 percentage points and trip time decreased by 20 hours. The impact of the complex on this traffic flow may be even greater than reflected by the O/D improvement, because the connection times between J734 and R591 and R557 cause the creation of excess dwell time at Evansville, counterbalancing the positive effects of the complex.	
Blocks	
Base Case	Terminal Complex
Mt. Vernon - Evansville Evansville-Nashville Nashville-Memphis (SSW)	Mt. Vernon - Evansville Evansville-Nashville Nashville-Memphis (SSW)
Schedule[‡]	
Base Case	Terminal Complex
J734 1707 DP Mt. Vernon 2230 AR Evansville	J734 0107 DP Mt. Vernon 0630 AR Evansville
R591 R557 1600 2300 DP Evansville 0115 0815 AR Nashville	R591 R557 1045 1630 DP Evansville 2000 0145 AR Nashville
Q535 0045 DP Nashville 1530 AR Memphis (SSW)	Q531 R533 0400 1400 DP Nashville 1900 0815 AR Memphis (SSW)
O/D Reliability	
Base Case	Terminal Complex
80%	93%
Car Hours, Miles, Handlings	
Base Case	Terminal Complex
L/C/B Hours 71	L/C/B Hours 53
O/T Hours 23	O/T Hours 17
Miles 403	Miles 403
Class 2	Class 2
Blockswaps 0	Blockswaps 0

[‡] It is worth noting that the schedule information for this traffic flow reflects a fundamental mistake in the design of the terminal complex operating plan. Train R591 is a complex train and train R557 is not. Therefore, they cannot both carry the Evansville-Nashville block. Allowing traffic in the Evansville-Nashville block to have access to southbound complex blocks is predicated on the requirement that the Evansville-Nashville block arrives at Nashville on a complex train. If R591 carries the block, fine—traffic is processed in the complex. If R557 carries it, fine too—but the only complex blocks that traffic may access are the Louisville and Memphis blocks. Restricting the block to one train or another represents an error of omission, although it does not affect the performance of this traffic flow because it is classified into a Memphis block at Nashville.

Example O/D pairs shown in Figure 3.17 include both northbound and southbound traffic flows through the complex, as well as traffic rerouted around the complex. Some rerouted traffic remained on existing lines, with no increase in mileage, due to multiple available blocks traversing the same physical mainlines. As an example, figure 3.18 illustrates selected multiple routes through the Chicago-Nashville corridor. Other rerouted traffic was flowed by the ABM at minimum cost, with the same varying results as in the Local Pre-Blocking strategy. In all examples, which represented a wide variety of routing changes and scheduling considerations, the routing changes decreased trip time markedly, and in all but one case, reliability increased significantly. In fact, finding a traffic flow which deteriorated in any way proved surprisingly difficult.

Route mileage, processing performance at alternate yards, and the sheer number of required handlings influenced the ABM's routing decisions for traffic removed from Nashville. Given routes with equivalent mileage and handlings, the ABM routed traffic through the yards which would process the traffic fastest. In the base case, flat yards on CSX's Chicago-Nashville corridor perform little through classification, and traffic classified in flat yards experiences relatively short dwell time. Hump yards are generally much more highly capacitated, and the resulting queues serve to lengthen cutoff times and increase PMAKE parameters.

Figure 3.18: Multiple Routes from Chicago to Waycross, GA via the Chicago-Nashville Corridor



Traffic diversion to selected alternate yards is shown in Figure 3.19. The data shown in Figure 3.19 indicate that the original hypothesis that traffic excluded from processing in the complex would be diverted to flat yards on the Chicago-Nashville corridor is false. It is true that yards gaining classification volume are generally smaller flat yards which previously processed little or no through traffic. However, most such yards lie southeast of the corridor. The concern that ABM-generated routing through small flat yards could be problematic if flat yards become overloaded with through-classification activity remains valid.

Five of the last seven yards which increase in classification are yards which receive a new direct block from Nashville built on a freed complex bowl track. This indicates that many of the traffic flows utilizing the new blocks do not terminate locally, but instead are through-classified, with the new direct block constituting part of a new minimum-cost route. While the volumes of the direct blocks were disappointingly low, the effects on individual long-distance flows were exactly as intended.

The only corridor yards represented are Vincennes, IN and Lawrenceville, IL whose volume increases may be traced to the ABM's mileage minimizing actions, first noted in the Local Pre-Blocking example flows in Figure 3.7.

Interestingly, the yard with the greatest increase in classification volume, Bruceton, TN on the Nashville-Memphis line, acts as a staging area for trains bound for the complex. Of the three daily Memphis-Nashville trains, only R532 is processed in the complex. The other two trains, R530 and Q536 carry Bruceton as well as Nashville blocks. Previously, the Bruceton blocks contained only locally terminating traffic, but when the complex was created, the ABM routed complex-bound traffic into these blocks, intending for it to be classified, picked up by R532 and processed in the complex. Unfortunately, in exchange for expedited processing in the complex, this traffic must undergo an extra handling upstream from the complex.

Nashville experienced the largest increase in blockswap volume. This effect has two causes. First, in order to ensure that inbound complex trains carried traffic intended for processing in the complex, blocks bypassing Nashville were reassigned from complex to non-complex trains, leaving the complex trains to carry as much complex-bound traffic as volume limits would allow. As a result of these changes, high-volume bypass blocks such as the Waycross to Chicago block were swapped at Nashville, while in the base case, they moved on direct trains. Thus the roster of blocks swapped at Nashville grew, but the volume in those blocks also grew, from 72 cars per day in the base case to 105 cars per day in terminal complex operation. This increase was comprised of traffic rerouted around the complex, and also traffic which was classified at Nashville but should not have been, as it had failed to take advantage of existing bypass blocks. While the increase in blockswapping and decrease in classification at Nashville would appear to correspond, and tell the story that much traffic was not taking advantage of existing bypass blocks, there is in fact relatively little direct correspondence.

Figure 3.19: Traffic Diversion due to the Terminal Complex Strategy

Node	City/State	Base Cars/Day	Complex Cars/Day	Difference
Yards with Classification Volume Increases Greater than 5 Cars per Day				
612	Bruceston TN	0	24.2	24.2
495	Erwin TN	1.8	20.8	19
780	Augusta GA	0	18.3	18.3
746	Bridgeport AL	0.2	17.5	17.3
782	Greenwood SC	12.4	25.3	12.9
400	Cincinnati OH	69.2	78.5	9.3
950	Baldwin FL	32.7	42	9.3
663	Dothan AL	3.2	12.4	9.2
174	Vincennes IN	6	14.7	8.7
216	Lima OH	5.9	13.9	8.0
650	Montgomery AL	58.9	66.3	7.4
214	Dayton OH	0.7	7.6	6.9
173	Lawrenceville IL	1.5	7.6	6.1
493	Kingsport TN	0	5.9	5.9
920	Jacksonville FL	0.3	5.8	5.5
833	Cayce SC	1.2	6.4	5.2
Yards with Classification Volume Decreases Greater than 10 Cars per Day				
615	Nashville TN	702.6	567.1	-135.5
902	Waycross GA	310.9	223.7	-87.2
440	Louisville KY	287.7	214.4	-73.3
100	Chicago IL	157.8	131.9	-25.9
640	Birmingham AL	128.0	104.8	-23.2
845	Hamlet NC	35.8	14.8	-21
Yards with Blockswap Volume Increases Greater than 5 Cars per Day				
615	Nashville TN	7.9	105.3	97.4
902	Waycross GA	2.1	42.4	40.3
640	Birmingham AL	4.2	41.2	37
440	Louisville KY	1.2	31.7	30.5
100	Chicago IL	1.5	25.7	24.2
400	Cincinnati OH	20.3	42.2	21.9
152	Danville IL	2.4	21.8	19.4
782	Greenwood SC	8.7	26.2	17.5
168	Evansville IN	0.9	13.1	12.2
700	Atlanta GA	4.5	16.1	11.6

At other yards such as Louisville with apparently corresponding increases in blockswap volume and decreases in classification, the number of blocks swapped there also increased as a result of the addition of the new bypass blocks built at Nashville on freed complex bowl tracks, although this fact explains relatively little of the correspondence.

More of the correspondence is likely due to traffic utilizing existing bypass blocks as a result of ABM routing. However, data problems which were individually addressed in and around the Chicago-Nashville corridor but subjected to less scrutiny elsewhere in the

network may have caused spurious bypass blocks to appear in the base case. To the extent that this is true, reductions in classification due to reroutings made for the terminal complex operating plan are overstated. The degree of error is minor relative to the sum of the savings from all terminal complex changes, especially for the target traffic, which typically traversed the corridor where errors had been eliminated. The error is difficult to estimate without checking the validity of every block and the flows it carries, yet will have to be addressed before operating plans developed using this modeling framework are directly implemented.

3.2.5 Implementation Issues

3.2.5.1 Designing the Terminal Complex Operating Plan

In developing a Terminal Complex operating plan, use of decision support tools cannot be avoided. The sheer number of O/D flows which must be rerouted calls for automation of the process and algorithmic accuracy.

Several of the example O/D flows discussed in Section 3.2.4 illustrated modeling data idiosyncrasies which affected the dimensions of the operating plan. In addition, because of the difficulties of translating car move data to the modeling environment, not all traffic flows were modeled, and it is unclear whether traffic classified in the complex represented proportionately more or less than would be seen if all traffic flows were modeled. These circumstances confirm the fact that the Terminal Complex operating plan created in this analysis is not implementation-ready.

In order to create a new Terminal Complex operating plan, service planners and model users must first collaborate in the calibration of the ABM/TSS/SPM suite of models, reaching general agreement that models represent costs, constraints, and the operating plan in a sufficiently realistic way. Although the scope of plan changes makes use of decision support tools unavoidable, the bright sides of this circumstance are that ongoing verification of model accuracy would require much less effort than the initial calibration effort, and that once calibrated, such tools could speed operating plan development considerably.

With a calibrated ABM, TSS, and SPM, it would be possible to create an implementation-ready Terminal Complex operating plan. However, the task of loading an operating plan created using the ABM/TSS/SPM platform into real-time control systems would be quite significant, given the volume of changes to train schedules and car routes called for by the new operating plan. Automated translation of ABM/TSS/SPM car routes, blocks, and trains to real-time control systems appears to be a prerequisite to implementation of a Terminal Complex operating plan at a major yard.

Creation of additional elements of the operating plan such as locomotive- and crew-to-train assignments and meet/pass plans would also require major effort. Although these elements of the operating plan have traditionally been left to locomotive and crew planners

and dispatchers to be solved "on the fly", the many schedule changes called for in the Terminal Complex operating plan could produce operational chaos if activated without sufficient warning and guidance.

Additional planning methods will probably have to be generated in order to address the issue of control of complex block volumes. In the operating plan evaluated here, only one inbound and one outbound train had unacceptably large average volumes.³ The problem of trains being overloaded all the time can be dealt with easily by culling O/D pairs whose performance suffers the least when rerouted out of the complex. However, the weekly cyclicity of carload volumes could cause many trains bound for the complex to leave traffic behind on heavy days. This is to some degree unavoidable, as the constraint that the complex can process no more than four trains in each direction is firm. The issue becomes one of differentiation of traffic within, for example, the Waycross-Nashville or any other complex block. Several questions demand consideration: Would it be operationally feasible to maintain both complex and non-complex versions of the Waycross-Nashville block? How would traffic be segregated by the car scheduling system? Do certain O/D flows move only on heavy days, exacerbating the cyclicity problem, and can these be handled outside of the complex?

3.2.5.2 Phased Implementation for the Terminal Complex

The Terminal Complex strategy, again unlike the Local Pre-Blocking strategy, cannot be implemented one block at a time, but it is possible to reduce the workload associated with designing the plan and the disruption of implementation. A terminal complex may be implemented in two phases.

The first phase would involve designation of the complex trains and blocks, schedule sliding to create the complex, and creation of a yard operating plan for the complex. During the first phase, no bowl tracks would be doubled, and no new bypass blocks would be built at the complex terminal. This would minimize or eliminate the disruption of many initial implementation problems, such as trains arriving off schedule, complex processing taking longer than planned, and tonnage blowups on complex trains for the simple reason that the requirement that the bowl turn over once every twelve hours does not exist until bowl tracks are doubled.

During the first phase, execution can proceed as it did before the complex. The hump yard can act as a continuous process facility, with bowl tracks holding mid-process queues of cars waiting for outbound trains, with the knowledge that schedules of certain inbound and outbound trains have been coordinated due to the large amount of volume transferred between them. Along those lines, while the makeup of the complex blocks is being refined, schedules could be slid into the complex arrangement in steps, gradually closing the interval between arrival of the inbound trains and departure of the outbound trains. As mentioned in Section 3.1.5, however, sliding schedules periodically over time may create much more analytical work for service planners than would sliding schedules all at once.

During the second phase, performance data would be reviewed, and schedules, car-to-block assignments, and block-to-train assignments adjusted as necessary to maximize connection reliability and consistent volume. As performance becomes more regular, individual class tracks could be doubled. At each doubling, a new bypass block could be built, and its effects on the composition of traffic in the complex reviewed. Finally, when all possible bowl tracks host two complex blocks in a 24-hour period, the complex will be fully implemented.

3.2.5.3 Operational Contingency Planning

Once the phased implementation of a terminal complex has demonstrated initial success, the move to tighten connection times and double blocks on bowl tracks will be inevitable. The complex will then be operating at its full design potential, and in this mode will be most vulnerable to disruption by schedule and volume irregularities. In such cases, varied options remain available to operating managers.

3.2.5.3.1 Complex Trains Off Schedule

If a complex train arrives early, it may simply be held in the receiving yard until its scheduled hump time. However, if one or several complex trains arrive late, several contingencies are available to help cars recover:

- Yard managers could choose to hump a late train immediately upon its arrival, with or without skipping the inbound inspection process. Humping a train without inspecting it raises the likelihood that bad-order cars will have to be switched out of the train before departure. However, if skipping the inbound inspection process would allow many cars to be included in blocks which would otherwise have been pulled from the bowl by the time the train was humped, then skipping the inbound inspection may be a favorable option.
- If several trains are delayed moderately, the assembly and inspection schedule for the connecting outbound trains in the complex could be extended to accommodate the delayed trains. Same-day train-to-train connections in the complex would be maintained, although that day's complex outbound trains would depart late. To delay assembly of a complex's outbound trains would not necessarily impact the processing of the next complex. As designed, each complex's processing schedule requires 9.5 hours between the time the first train is humped and the last block is pulled from the bowl [see Figure 3.9]. Thus, a 2.5-hour buffer exists between the time the last bowl track is scheduled to be pulled and the time the first train of the following complex is scheduled to be humped.
- A single train which arrives far behind schedule, during the wrong 12-hour window, could be humped as if it were a non-complex train. Cars for the Louisville and Memphis blocks would experience no blocking changes, but would be 12 hours behind the original schedule for each missed block departure. Cars for

other complex destinations could be rescheduled to different outbound blocks, or humped to a designated rehump track, and rehumped during the proper window, 24 hours behind the original schedule. In order to avoid disrupting the scheduled complex operation, rehumping could be performed during the 2.5-hour buffer between complexes.

3.2.5.3.2 Heavy Traffic on Complex Trains and Blocks

Heavier than expected traffic can interfere with the routine execution of complex processing in two ways: by causing class track overruns, and by causing complex trains to exceed maximum tonnage. Both of these problems can be predicted well in advance using existing information systems, and that advance knowledge can be used by yard management to plan modifications to complex processing necessary to maintain yard fluidity and connection performance.

Except for those blocks built in both complexes, complex blocks are less subject to short-notice volume changes than are other yard blocks, because they receive cars only from the inbound complex trains. As the complex trains originate, initial volume information would be available to the yard, and adjusted as complex trains pick up at intermediate stations enroute to Nashville.

Isolated class track overruns should cause at most minor disruption to complex processing. If a complex block is expected to overrun its class track, then humping of complex trains may be halted for a short period, during which the cars already on the track could be pulled from the bowl to the departure yard, in effect beginning the assembly process early as a result of heavy volume in a particular block. Of course, this contingency presumes an available departure track and a yard switcher on call in advance of the regular start of assembly. If these are not available, complex cars could be temporarily humped into a free bowl track. Assigning complex cars to a spare bowl track is relatively safe, as the cars will be in the track for no more than a few hours before being pulled to the receiving yard. If no bowl tracks are free, and if humping is nearly complete, then it may be possible to include overrun cars in a track whose block will not receive any more cars. Several relatively low-volume complex blocks in each direction receive most of their cars from two or three inbound trains, and could provide useful additional space to counter class track overruns.

If an outbound complex train exceeds tonnage limits, serious problems could arise. Excess traffic often is not sufficient to warrant an extra, but will cause congestion if left in the yard. Traffic in most complex blocks cannot be left in the bowl because the class tracks holding the blocks must be reassigned every 12 hours. Leaving excess complex traffic in the departure yard may compromise the fluidity of assembly operations for both complex and non-complex trains. Options available for flushing excess complex traffic from the yard include:

- Placing excess traffic from a complex block on a non-complex train which traverses the same route as the heavy complex train. The non-complex train obviously must have capacity available for the excess traffic, but if capacity is available, the only operational changes necessary are a setoff of the excess traffic at block destination or at an appropriate blockswap point. The traffic may or may not be delayed as a result of this action, but yard fluidity will be maintained.
- Reassigning complex traffic to other complex or non-complex blocks, not necessarily traversing the exact route as the original target train. Reassigned traffic might incur delays or expenses in the form of added mileage or handlings, even if reassigned to another complex block. However, clearing the bowl tracks after processing of each complex is crucial for continuing operation. Rather than simply cascading into future periods, leftover cars in the bowl negate the possibility of processing the next group of complex trains and blocks.

3.2.6 Terminal Complex Strategy

To "dive right in" with a full implementation of a plan similar to the plan evaluated in this section would be unwise on several grounds. Decision support tools crucial to the development of the plan have not been reviewed in detail by service planners, and may not reflect real-world conditions important to operating plan development but less relevant to the models' previous strategic study roles. Even if the decision support tools were ready to go, links between the tools and real-time control systems are still in the development stages. Finally, even if a plan could be generated and loaded to real-time control systems immediately, execution breakdowns at the train and yard level and the inability to predict and address volume fluctuations would quickly break down the complex processing schedule.

Nevertheless, the nature of the performance changes generated by implementation of the terminal complex is extremely promising. Average yard time at Nashville dropped by 41%, and the improvement to individual traffic flows as a result of expedited processing was often substantial. While traffic diverted from the complex was expected to experience wholesale performance declines, those expectations were not substantiated by individual flow data, although yard volumes must be reviewed further to ensure that rerouted traffic is classified at appropriate points. Several of the bypass blocks built at Nashville were highly successful in diverting traffic and reducing handlings. Overall, the Terminal Complex strategy provided performance improvements to targeted traffic which were in line with expectations, while decreasing performance of other traffic far less than expected.

Extrapolation of cost savings to the entire network implies creation of complexes at other CSXT yards. This is justified by the fact that traffic at many yards, both major and minor, lends itself to complex-style coordinated processing. In fact, smaller yards at the midpoint of a single trunk line may support even more efficient operations. Less traffic would have to be diverted, as the match between inbound and outbound trains would be cleaner than at Nashville, where traffic has many directional choices.

The prospect of phased implementation provides a major safety net to implementation of terminal complex schedules and coordinated processing. The schedule adherence required when bowl tracks are turned twice per day can be learned, rather than adopted or abandoned in a trial by fire. Given this safety net, the benefits demonstrated in this evaluation dictate that implementation of the terminal complex strategy at a geographically advantageous yard should proceed, accompanied by refinement of the planning tools and creation of links between tools and real-time control systems crucial to the plan development process.

3.3 Tandem Humping

3.3.1 Description

Presently, most traffic is classified between three and five times over the course of a trip. Each yard can build only a limited number of blocks, and therefore cannot guarantee that a particular car will be blocked directly to its destination with no further rehandling.

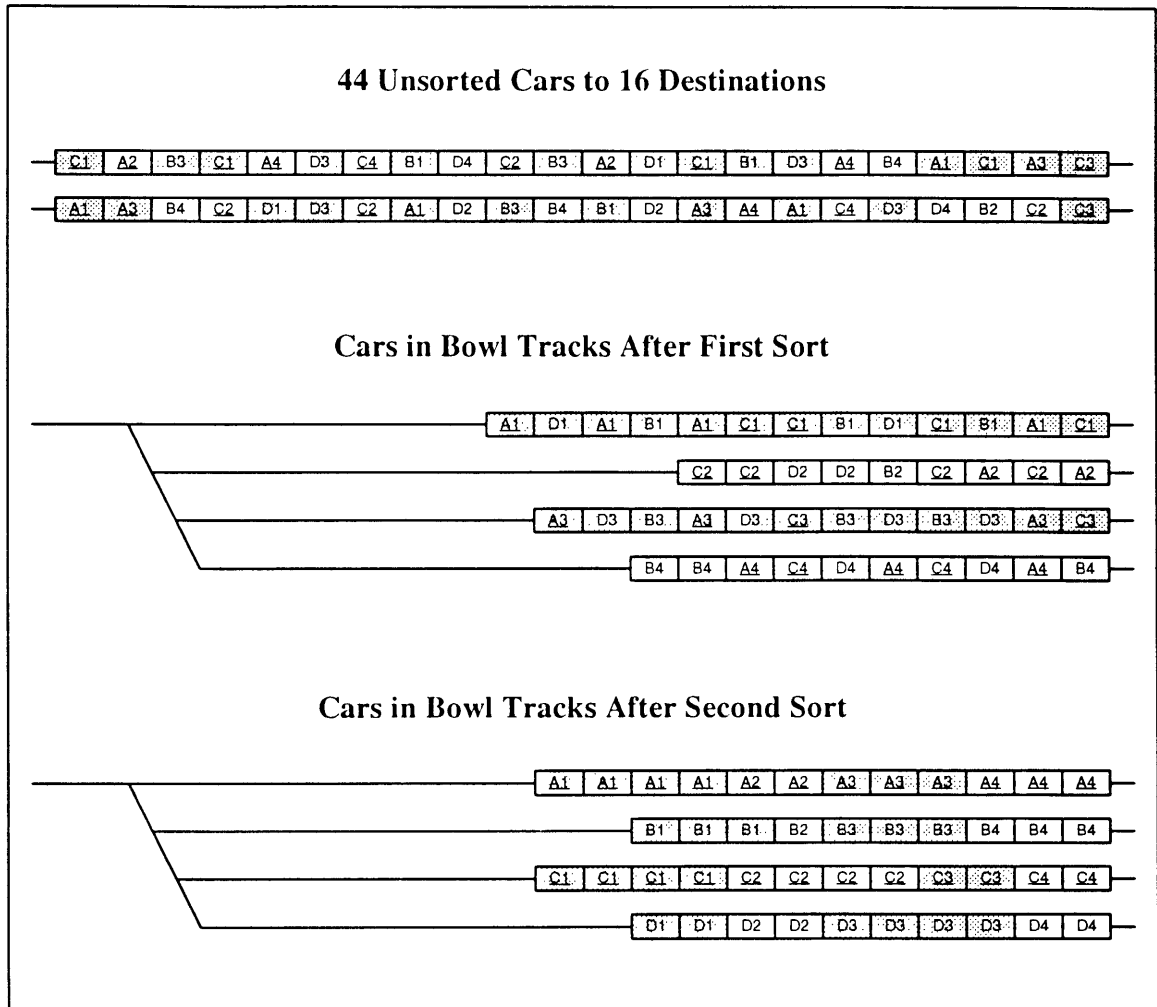
One means of increasing the number of blocks that can be built at a yard is matrix switching. Matrix switching involves humping cars to a group of tracks, then pulling each track back and rehumping, resulting in finer blocks on each track. If three tracks are matrix-switched at a yard, nine blocks can be built, with four tracks enabling 16 blocks, and so on.

Figure 3.20 illustrates the two sorts performed in matrix switching. In the illustration, the two cuts of unsorted cars would be humped into four tracks, upper track first, sorted by only the number of the letter/number destination code. After the first hump, the four resulting cuts are pulled back over the hump, with the topmost track at left, bottom track at right, and so on. Next, the cuts are humped again, sorted by the letter of the letter/number destination code. The first sort guarantees that the cars are also in numerical order, resulting in sixteen blocks on four tracks.

Matrix switching has not enjoyed wide acceptance at North American hump yards because it poses several problems that conventional hump operations avoid. Matrix switching requires cuts of cars to be dragged back over the hump between the two sorting stages, thus occupying the hump and hump engine in seemingly non-productive activity and increasing the hump's exposure to potential mishaps. Routes from the bowl to the receiving yard which avoid the hump can be used, but such movement often disrupts other yard activities and is very time consuming.

In response to these problems, the Tandem Humping strategy was conceived. Rehumping at a single facility would be avoided, as a large-scale matrix switching operation would be created involving two hump yards. The goal of the strategy is to create direct blocks to as many destinations as possible, so that cars processed in the matrix would move in blocks destined directly to their terminating local trains without further classification. Traffic flows moving in matrix blocks would save between one and three handlings per trip, saving yard resources and time.

Figure 3.20: Matrix Switching



The Tandem Humping strategy differs from previous implementations of matrix switching in two important ways:

- The two passes over the hump occur at different yards, rather than a single yard. Traffic entering the first yard is humped onto matrix tracks. Several times a day, cuts on those tracks are assembled into trains and moved to the next facility, at which they are humped a second time onto another set of matrix tracks, creating finely-classified matrix blocks.
- The size of the matrix envisioned in the Tandem Humping strategy is much larger than would be feasible if matrix switching were performed at a single facility. At a single facility, cuts must be pulled back over the hump between the two passes over the hump, a practice that could disrupt hump operations. Whereas a large single-yard matrix might involve four tracks, the Tandem Humping strategy does

not require cuts to be pulled back over the hump, and could support matrices as large as 10 tracks by 10 tracks.

The two matrices envisioned in the Tandem Humping strategy would be operated northbound and southbound at CSX's Louisville and Nashville hump yards, which are approximately 190 miles apart and connected by a high-density route for merchandise and automobile traffic.

Traffic in the northbound matrix would be humped at Nashville, move to Louisville, and be humped a second time. At this point, it would be in one of up to 100 fine blocks destined directly for a local train. Traffic in the southbound matrix would travel the reverse route, being humped first at Louisville, then at Nashville. Traffic *must* pass through both yards to be included in the matrix blocks.

At each yard, up to 20 bowl tracks would be devoted to the matrix, up to 10 for a northbound matrix and 10 for a southbound matrix. This requirement would cause certain blocks to be eliminated at each yard, although some blocks could be replaced by equivalent blocks processed in the matrices.

Each matrix would result in up to 10 tracks holding up to 100 finely classified blocks. If class-track overruns are to be avoided, the size of each block must be sharply limited, to an average of 2.5 to 3 cars per day. The Tandem Humping strategy stretches the conventional definition of a block, as standard yard blocks whose average volume falls below 15 cars per day are viewed by CSXT as candidates for elimination.

If the very small matrix blocks were handled as individual blocks, the amount of additional handling that would be required would negate the positive effects of fine classification in the matrix. Therefore, handling clusters of matrix blocks as if each cluster were a single, standard yard block is pivotal to the success of the strategy.

Matrix blocks would be assigned to yard tracks based on geographic proximity of destinations. Bowl tracks containing matrix blocks would be pulled and the cars assembled into outbound trains as if the tracks contained standard yard blocks. A train leaving a matrix yard might have several clusters of matrix blocks, 5 to 20 blocks in all, pulled from one or two bowl tracks. In order to reach their destinations, clusters of blocks would undergo standard blockswapping.

As an example, Train A might leave Louisville with 20 matrix blocks pulled from two tracks. At Cincinnati, Train A would swap 6 blocks to Train B, which would distribute the blocks to several serving yards. At Dayton, Train A would set off three blocks at the serving yard. At Lima, Train A would set off four blocks at the serving yard. At Fostoria, Train A would swap the remaining seven blocks to Train C, which would distribute them to several serving yards.

Such frequent blockswapping might seem to require additional resources, but swapping of standard blocks takes place with similar frequency. Tandem Humping

changes operations in that cars leaving matrix yards on matrix blocks need no additional classification, only blockswapping, in order to reach their terminating local train. Matrix blocks which arrive at serving yards may be placed on local trains without further rehandling.

The principal drawbacks of the Tandem Humping strategy include:

- Elimination of yard blocks at Louisville and Nashville may force large amounts of traffic to less efficient routings. Traffic which passes through one of the two yards and whose block is eliminated may be classified into a different block, may move out of route to the other yard in order to be processed in the matrix, or may avoid both yards.
- While blocks processed in the matrix may have average volumes near 3 cars per day, there is no guarantee that this volume appears regularly. For this reason, any cluster of matrix blocks may overflow its bowl track with little advance warning. While block order can be maintained easily during bowl track overflows if an empty track is available, without examining every traffic flow, anticipation and reaction to volume fluctuations would be difficult.
- If a matrix is to produce 100 blocks in the proper order in the bowl, cuts must be humped in a strict order in the second stage of the matrix, eliminating some flexibility at the second-stage yard.
- Local trains would generally not receive all traffic via matrix blocks. Therefore, the local train might have to take time to cut non-matrix traffic into its matrix blocks.

3.3.2 Creating the Tandem Humping Operating Plan

The process of creating a Tandem Humping operating plan is complex. Matrix blocks must be geographically proximate in order to facilitate blockswapping, and must also have appropriate volume. In addition, the choices of blocks to eliminate at matrix yards, trains carrying clusters of matrix blocks, and cluster blockswapping points are also challenging problems for which few methodological precedents exist.

In the absence of quick, proven methods for creating such an operating plan, many decisions were made manually using situation-specific criteria. In order to create an operating plan representing tandem humping at Louisville and Nashville, these steps were performed:

- a. In order to represent the tandem humping matrices in modeled form, blocking networks were modified. To reflect the northbound matrix, blocks were added between Louisville and all CSXT network nodes, to reflect the possibility of a matrix block from Louisville to any destination. At the same time, all blocks *destined to* Louisville were eliminated except for the block from Nashville. The

effect of these changes was that any traffic flow utilizing a northbound matrix block at Louisville would have to pass through Nashville before passing through Louisville. At Nashville, the traffic would be classified in the first stage of the matrix and at Louisville classified in the second stage of the matrix.

- b. A separate block file was modified to reflect the southbound matrix. Blocks were added between Nashville and all CSXT network nodes, to reflect the possibility of a matrix block from Nashville to any destination. At the same time, all blocks *destined to* Nashville were eliminated except for the block from Louisville. Thus, in order to utilize a southbound matrix block at Nashville, traffic would have to pass through Louisville first. At Louisville, traffic would be classified in the first stage of the matrix and at Nashville classified in the second stage of the matrix.
- c. Traffic was flowed over the two modified block files separately using the ABM. If routing a traffic flow through the matrix was less costly than requiring that flow to avoid the second-stage yard, then the ABM routed that flow via the northbound or southbound matrix. Northbound flows were routed to Nashville, then Louisville, then on a matrix block to the flow destination. Southbound flows were routed to Louisville, then Nashville, then on a matrix block to the flow destination. If no traffic destined for a particular node would benefit from processing in the matrix, then no traffic would be assigned to the matrix block destined for that node. The ABM routed traffic to 63 northbound matrix blocks, of which 15 already were built at Louisville, and 26 southbound matrix blocks, of which 14 already were built at Nashville [see Figures 3.21-3.26].
- d. Traffic processed in the northbound and southbound matrices was identified using ABM output reports and differentiated from non-matrix traffic through creation of additional traffic classes representing northbound and southbound matrix traffic.
- e. Matrix blocks which received no traffic were eliminated from the block files, leaving only active matrix blocks.
- f. Existing destinations receiving matrix traffic were eliminated from the matrix, leaving a northbound matrix containing 48 new block destinations and a southbound matrix containing 12 new block destinations. The decision to process only new block destinations in the matrix was made for several reasons. If processed in the matrix, blocks to existing destinations would not save any downstream classifications, but would require all traffic on the blocks to pass through both matrix yards, at the expense of considerable additional mileage for some traffic. In addition, volumes on some matrix blocks to existing destinations such as the Louisville-East St. Louis block were large enough to disrupt matrix processing by threatening regular class track overruns at both matrix yards.
- g. Matrix blocks chosen by the ABM were assigned to trains. Initially, the CSXT Operations Research Block-to-Train Assignment Model was run, and the output was modified to ensure that through trains departed Nashville and Louisville with

groups of matrix blocks, and blockswapped matrix blocks to terminating local trains at a single point [see Figures 3.27 and 3.28].

- h. In order to make room for the matrix, other, non-matrix blocks were eliminated at Louisville and Nashville. The northbound and southbound matrices chosen by the ABM required only 10 tracks at Louisville and 11 tracks at Nashville rather than the 20 tracks envisioned for two 10×10 matrices. Furthermore, not all merchandise blocks at Nashville and Louisville were represented in the block file because of node aggregation. Therefore, rather than eliminating 20 or even 11 blocks at each yard, blocks were eliminated according to the proportion of block destinations represented in the block file at each yard. Seven of 31 base case blocks were eliminated at Nashville. Two of the six blocks were reinserted into the matrix. Eight of 37 base case blocks were eliminated at Louisville. Blocks were chosen for removal manually, and were chosen in a way that minimized out-of-route mileage and additional classification that displaced traffic would experience [see Figure 3.29].
- i. The ABM was used to create alternate routes for non-matrix traffic at Louisville and Nashville whose original blocks had been deleted to make room for the matrix.
- j. Blocks and traffic flows representing the matrices were combined with the non-matrix operating plan and flows and evaluated in the SPM.

3.3.3 Examples

Figure 3.21 lists blocks chosen by the ABM for inclusion in the northbound and southbound matrices. Blocks built at Louisville or Nashville in the base case are identified as existing, while blocks added to the file to create the Tandem Humping operating plan are identified as new blocks. To transfer base case blocks to the matrices does not save car handlings, as no new, direct block is added. Building base case blocks in the matrix offers the advantage of allowing several blocks to be built on one bowl track, but creates the disadvantage of requiring all traffic using those blocks to be routed through both matrix yards, even where this is highly inefficient.

Figure 3.22 summarizes classifications saved by matrix blocks between the second matrix yard (Louisville northbound and Nashville southbound) and the destination. "New Routing" refers to situations where no traffic moved to the matrix block destination via the second stage yard in the base case. Note that this information does not represent the net decrease in handlings for traffic flows which move the matrix blocks, because some traffic flows using the matrix blocks must undergo additional classification in order to reach the first matrix yard, negating handling savings achieved downstream from the matrix.

Figure 3.21: Matrix Block Destinations Chosen by the ABM

Northbound Matrix		Southbound Matrix	
Existing Destinations	New Destinations	Existing Destinations	New Destinations
New Albany, IN	Washington, IN	Memphis, TN	Blue Creek, AL
Mitchell, IN	Dayton, OH	Memphis/MP	Bainbridge, GA
East St. Louis, IL	Lima, OH	Memphis/SSW	Pace, FL
Willard, OH	Defiance, OH	Memphis/BN	Hybart, AL
Walbridge, OH	Fostoria, OH	Bruceton, TN	Gaston, AL
Wixom, MI	Tiffin, OH	N. Johnsonville	Elizabeth, GA
Saginaw, MI	Lester, OH	Spring Hill, TN	Calhoun, GA
Baltimore, MD	Parma, OH	Oakworth, AL	Savannah, GA
Ravenswood, WV	Cleveland, OH	Cullman, AL	Live Oak, FL
Cincinnati, OH	Warwick, OH	Stilesboro, GA	Chattahoochee, FL
Cincinnati/ CR	Akron, OH	Wauhatchie, TN	Green Bay, FL
O'Bannon, KY	New Castle, PA	Bridgeport, AL	Agrock, FL
Riverport, KY	Detroit, MI	Murfreesboro, TN	
Lexington, KY	Plymouth, MI	Smyrna, TN	
Patio, KY	Midland, MI		
	Port Huron, MI		
	Fargo, ON		
	Sarnia, ON		
	Philadelphia, PA		
	Wilmington, DE		
	Jessup, MD		
	Brunswick, MD		
	Hancock, WV		
	Emory Grove, MD		
	Bittinger, PA		
	Demmler, PA		
	Washington, WV		
	Apple Grove, WV		
	Hamilton, OH		
	Middletown, OH		
	Mauzy, IN		
	Indianapolis/CR		
	Louisville/SOO		
	Frankfort, KY		
	Berea, KY		
	E. Burnstadt, KY		
	Corbin, KY		
	Gatliff, KY		
	Columbus, OH		
	Taylor, OH		
	Carey, OH		
	Wash. Ct. Hse, OH		
	Vauces, OH		
	Huntington, WV		
	Russell, KY		
	Shelby, KY		
	Williamsburg, VA		
	Richmond, VA		

Figure 3.22: Classification Savings due to Routing via Matrix Blocks

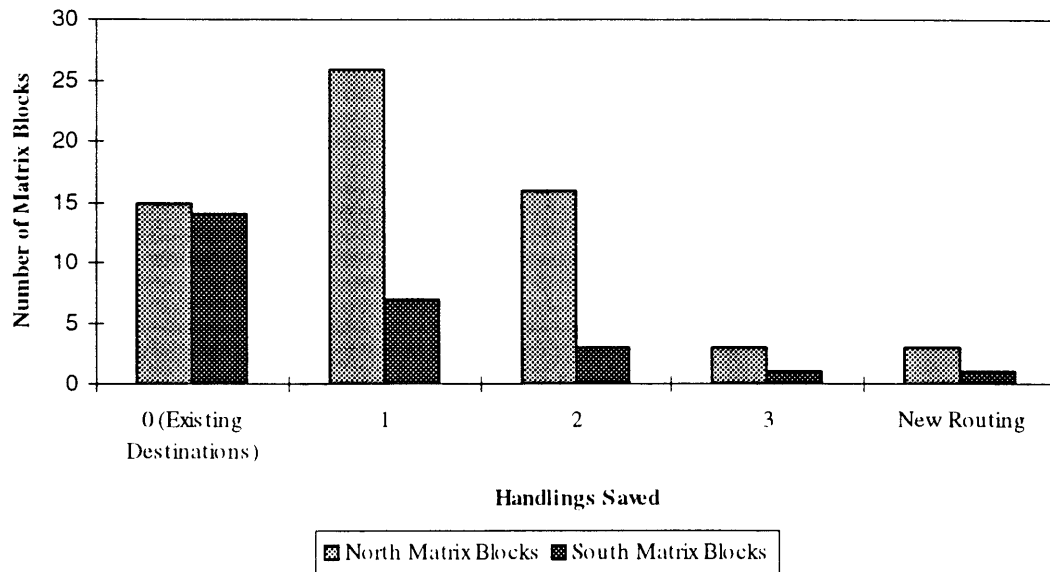


Figure 3.23-3.26 summarize volumes assigned to matrix blocks. Figures 3.23 and 3.24 show existing and new block volumes in the northbound matrix, and Figures 3.25 and 3.26 show existing and new block volumes in the southbound matrix. In both directions, existing blocks are much larger than new blocks, and contain a higher percentage of traffic terminating at their respective nodes.

Figures 3.27 and 3.28 list block-to-train assignments for matrix blocks. Original assignments were generated with a mileage- and capacity-based block-to-train assignment model developed by Yen Shan and James Rinker of CSXT Operations Research. In one of its first major trials, the model performed extremely well in assigning groups of matrix blocks to relatively few trains from Nashville and Louisville, and in minimizing block mileage. However, some revisions were made to lessen the number of setouts made by trains carrying matrix blocks.

Figure 3.23: Volume of Existing Blocks in the Northbound Matrix

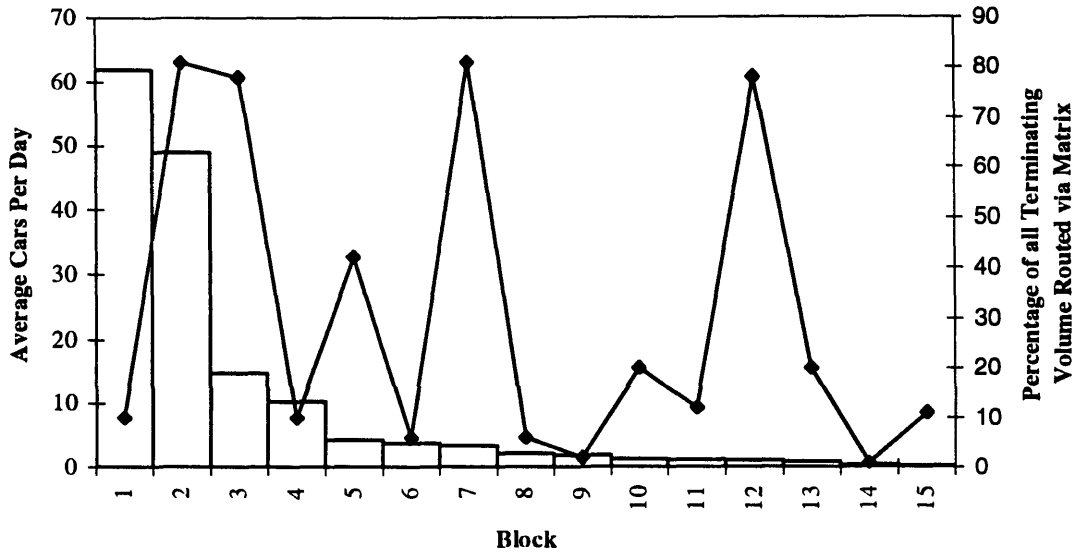


Figure 3.24: Volume of New Blocks in the Northbound Matrix

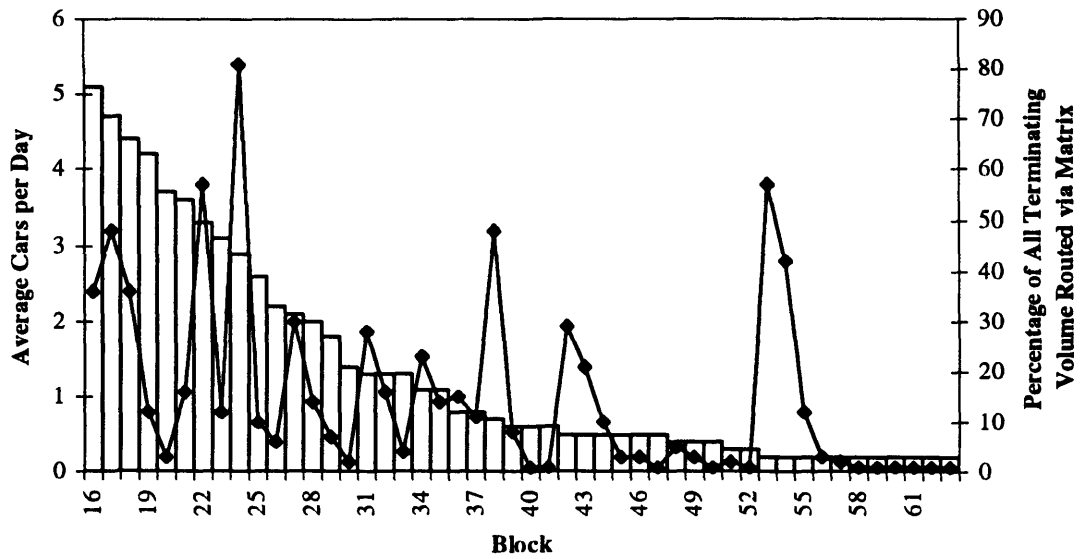


Figure 3.25: Volume of Existing Blocks in the Southbound Matrix

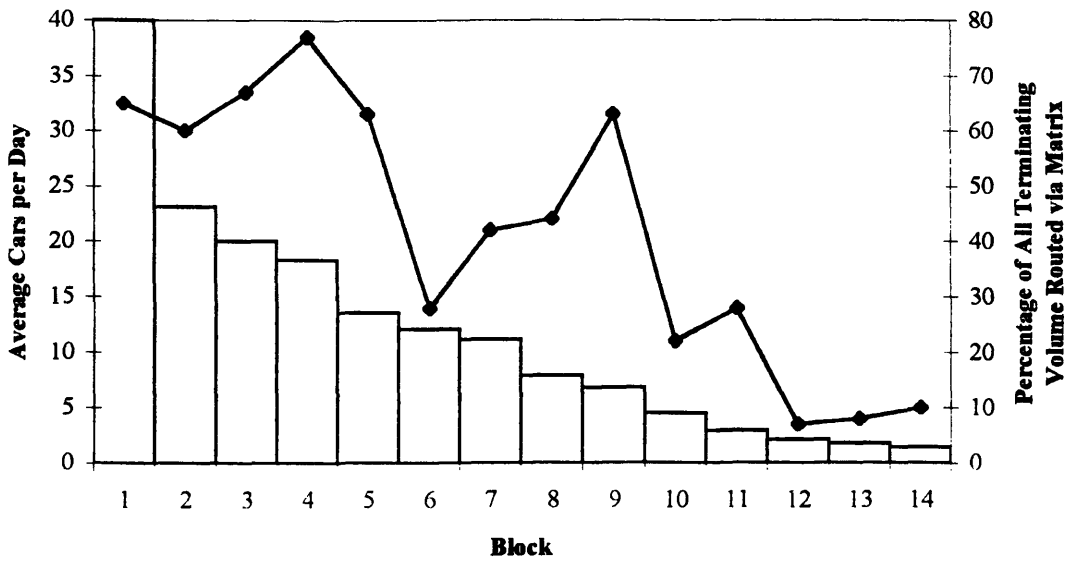


Figure 3.26: Volume of New Blocks in the Southbound Matrix

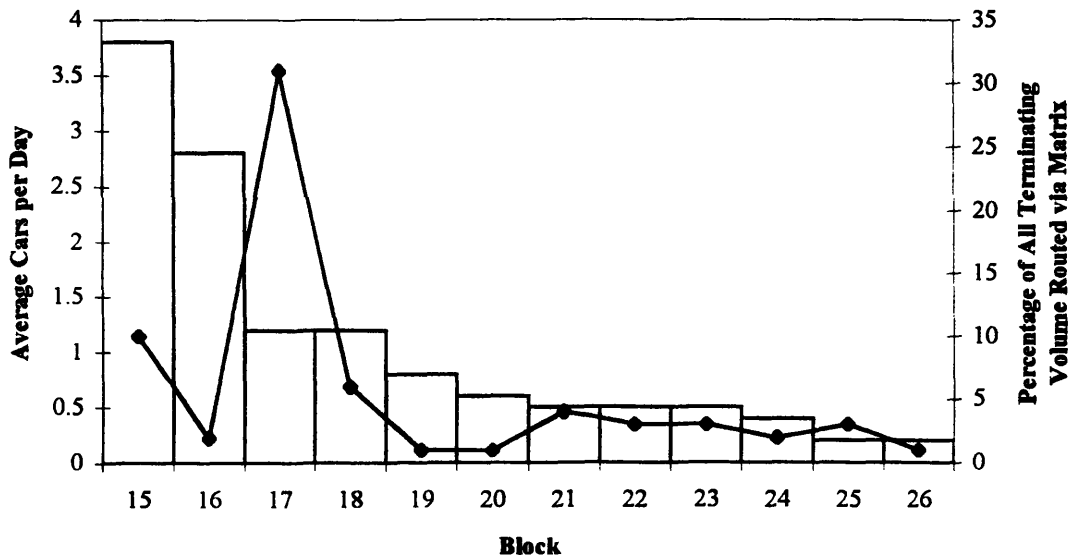


Figure 3.27: Original and Revised Train Assignments for Northbound Matrix Blocks

Destination	Model-Generated Train Assignment	Revised Train Assignment
Louisville/SOO	Q375	Y336
Tiffin, OH	Q376	Q376 (to Willard/R635)
Warwick, OH	Q376	Q376 (to Willard/D712)
Akron, OH	Q376	Q376 (to Willard/D712)
New Castle, PA	Q376	N/C
Wilmington, DE	Q376	Q376 (to Willard/Q396)
Jessup, MD	Q376	Q376 (to Cumberland/R346)
Brunswick, MD	Q376	Q376 (to Cumberland/R346)
Hancock, WV	Q376	Q376 (to Cumberland/R342)
Demmler, PA	Q376	Q376 (to New Castle/B712)
Hamilton, OH	Q376	Q376 (to Middletown/D744)
Middletown, OH	Q376	N/C
Emory Grove, MD	Q376 (to Baltimore/B739)	N/C
Richmond, VA	Q376 (to Jessup/Q405)	Q376 (to Baltimore/Q405)
Williamsburg, VA	Q376 (to Jessup/Q405) (to Richmond/H770)	Q376 (to Baltimore/Q405) (to Richmond/H770)
Bittinger, PA	Q376 (to Martinsburg/R342) (to Hagerstown/B738)	Q376 (to Cumberland/R342) (to Hagerstown/B738)
Lester, OH	Q376 (to Sterling/R354)	Q376 (to Willard/R354)
Parma, OH	Q376 (to Sterling/R354)	Q376 (to Willard/R354)
Cleveland, OH	Q376 (to Sterling/R354)	Q376 (to Willard/R354)
Philadelphia, PA	Q376 (to Wilmington/Q396)	Q376 (to Willard/Q396)
Russell, KY	Q512 (to Cincinnati/H788)	N/C
Huntington, WV	Q512 (to Cincinnati/Q316)	N/C
Washington, WV	Q512 (to Cincinnati/Q316)	N/C
Apple Grove, WV	Q512 (to Cincinnati/Q316)	N/C
Shelby, KY	Q512 (to Cincinnati/Q691)	N/C
Columbus, OH	Q512 (to Cincinnati/R314)	N/C
Washington Ct Hs, OH	Q512 (to Cincinnati/R314)	N/C
Taylor, OH	Q512 (to Cincinnati/R314) (to Columbus/H783)	N/C
Mauzy, IN	Q512 (to Cincinnati/R361)	N/C
Indianapolis/CR	Q512 (to Cincinnati/R361)	N/C
Washington, IN	Q686	N/C
Dayton, OH	R514	N/C
Lima, OH	R514	N/C
Defiance, OH	R514	R514 (to Lima/R516)
Fostoria, OH	R514	N/C
Plymouth, MI	R514	R514 (to Lima/R516)
Port Huron, MI	R514 (to Flint/R330)	N/C
Sarnia, ON	R514 (to Flint/R330)	N/C
Vaues, OH	R514 (to Fostoria/R635)	N/C
Carey, OH	R514 (to Fostoria/R637)	N/C
Detroit, MI	R514 (to Plymouth/R516)	R514 (to Lima/R516)
Fargo, ON	R514 (to Plymouth/R514) (to Detroit/R320)	R514 (to Lima/R516) (to Detroit/R320)
Midland, MI	R514 (to Saginaw/R331)	R514 (to Flint/R331)
Frankfort, KY	R547	N/C
Berea, KY	R547 (to Patio/R549)	N/C
E. Burnstadt, KY	R547 (to Patio/R549)	N/C
Corbin, KY	R547 (to Patio/R549)	N/C
Gatliff, KY	R547 (to Patio/R549)	N/C

Figure 3.28: Original and Revised Block-to-Train Assignments for Southbound Matrix Blocks

Destination	Model-Generated Train Assignment	Revised Train Assignment
Bainbridge, GA	Q543	N/C
Live Oak, FL	Q647 (to Waycross/Q605)	N/C
Green Bay, FL	Q647 (to Waycross/R441)	N/C
Agrock, FL	Q647 (to Waycross/R453)	N/C
Savannah, GA	Q676 (to Greenwood/Q691)	R674 (to Greenwood/Q691)
Hybart, AL	R521 (to Brewton/M730)	N/C
Pace, FL	R521 (to Goulding/M736)	N/C
Chattahoochee, FL	R521 (to Goulding/M736)	N/C
Stilesboro, GA	Added to matrix, manually routed	R674
Elizabeth, GA	R583	R674
Calhoun, GA	R674	N/C
Cullman, AL	Added to matrix, manually routed	R685
Blue Creek, AL	R685	N/C
Gaston, AL	R685	N/C

The data in Figures 3.27 and 3.28 make it appear as though final delivery of matrix blocks is performed by through trains, inefficiently duplicating work performed by local trains and lengthening through train schedules. For example, because train Q376 is the last train to handle the New Castle, PA matrix block, one might assume that train Q376 distributes the block's cars to customers. This situation would not occur in reality, and is tolerated in the modeling environment because of node and train aggregation in the CSXT network. Many local trains work in areas aggregated into a single ABM/TSS/SPM node, and therefore do not appear in the model. In reality, local trains D746, D747, and D763 serve New Castle-area customers⁴, and would pick up the matrix block in the New Castle yard and distribute its cars after it was set out by Q376.

In order to make room for the matrices in the Louisville and Nashville bowls, blocks were eliminated at both yards. Figure 3.29 lists blocks changed at each yard. Fewer blocks were eliminated than the matrix requires because not all blocks are represented in the files because of node consolidation and abstraction.⁵ Decisions on blocking changes were tailored to minimize the negative impacts of the matrices on the set of modeled traffic flows. Selecting blocks for elimination forces the researcher to confront a dilemma caused by the inaccuracy of abstraction of the rail network in to the modeling environment. The choice was between eliminating blocks which would have an unrealistically minor impact on performance because the model fails to illustrate real-world conditions, or failing to design an operating plan demonstrating the best possible network performance of the Tandem Humping strategy.

In designing the Tandem Humping operating plan, the researcher chose the former option. Note that all blocking changes at Louisville and half of the blocking changes at Nashville listed in Figure 3.29 are "non-events" in that they cause no negative impact to any *modeled* traffic. This does not reflect real-world conditions, but instead only reflects the failure of the model to represent real-world conditions. For example, CSXT typically interchanges more than 20 cars per day with Illinois Central in Memphis. However, because of idiosyncrasies in the conversion of waybill records to QBASE records to an

SPM flow file, these flows terminate at node 600 (Memphis local) rather than 604 (Memphis/IC), leaving the 615-604 block (Nashville-Memphis/IC) empty, and a good candidate for deletion.

While this may seem to be poor analysis, the alternative is equally poor. The same factors that make some vital blocks empty in the model also make other blocks unrealistically large, or cause other blocks and traffic flows to not be represented. Therefore, eliminating blocks to make room for the matrix based on the criterion of a close match between the model and reality has the effect of overemphasizing the negative impacts of to diversion.

Figure 3.29: Blocking Alterations to Create Space for Matrices at Louisville and Nashville

Location	Block Destination	Description of Change	Comment
Louisville	Nashville	Moved into Matrix	All cars on the Lou-Nas block can be classified in the first stage of the matrix
Louisville	East St. Louis/MP	Eliminated	Zero volume in the base case
Louisville	Brooklyn Jct, WV	Eliminated	Zero volume in the base case
Louisville	Mauzy, IN	Eliminated	Zero volume in the base case
Louisville	Bardstown Jct, KY	Eliminated	Zero volume in the base case
Louisville	Paris, KY	Eliminated	Zero volume in the base case
Louisville	Goulding, FL	Eliminated	Zero volume in the base case
Louisville	Wauhatchie, TN	Eliminated	Zero volume in the base case
Nashville	Louisville	Moved into Matrix	All cars on the Nas-Lou block can be classified in the first stage of the matrix
Nashville	Memphis/IC	Eliminated	Zero volume in base case
Nashville	Edgemoor, TN	Eliminated	Zero volume in base case
Nashville	Natco, TN	Eliminated	Zero volume in base case
Nashville	Etowah, TN	Eliminated	1.7 cars/day in base case; traffic diverted to Atlanta
Nashville	Cullman, AL	Moved into Matrix	3.6 cars/day in base case; traffic not moving via matrix diverted to Birmingham or classified north of Nashville
Nashville	Stilesboro, GA	Moved into Matrix	6.3 cars/day in base case; traffic not moving via matrix diverted to Calhoun or Wauhatchie

While not necessary to model the performance of the Tandem Humping strategy, block-to-bowl track assignments are an important aspect of the Tandem Humping operating plan, as the efficiency of train assembly and swapping of matrix blocks depends highly on the order of matrix blocks in the bowl.

Figure 3.30 illustrates potential bowl track assignments for the northbound matrix blocks at Louisville, the second stage yard. Blocks departing on the same outbound train are grouped on the same track to the greatest extent possible. However, blocks departing on train R514 were assigned to three tracks rather than two because no more than seven blocks can be assigned to a single track.

Within a track, blocks are ordered according to the assumed sequence in which they will be set out. As no yard layout diagrams were available when the northbound matrix bowl track assignments were created, it was assumed that all trains departed with engines toward the right side of the figure, in the same direction as the pullout, both at Louisville and at subsequent yards at which blocks are swapped between trains. A train's departure direction determines the order of blocks in each bowl track because blocks should be ordered with the first block(s) to be set off closest to the engines. If actual train directions were opposite those assumed here, the order of blocks carried by each train would be reversed on each track.

Figure 3.30: Block-to-Track Assignments for Northbound Matrix Blocks

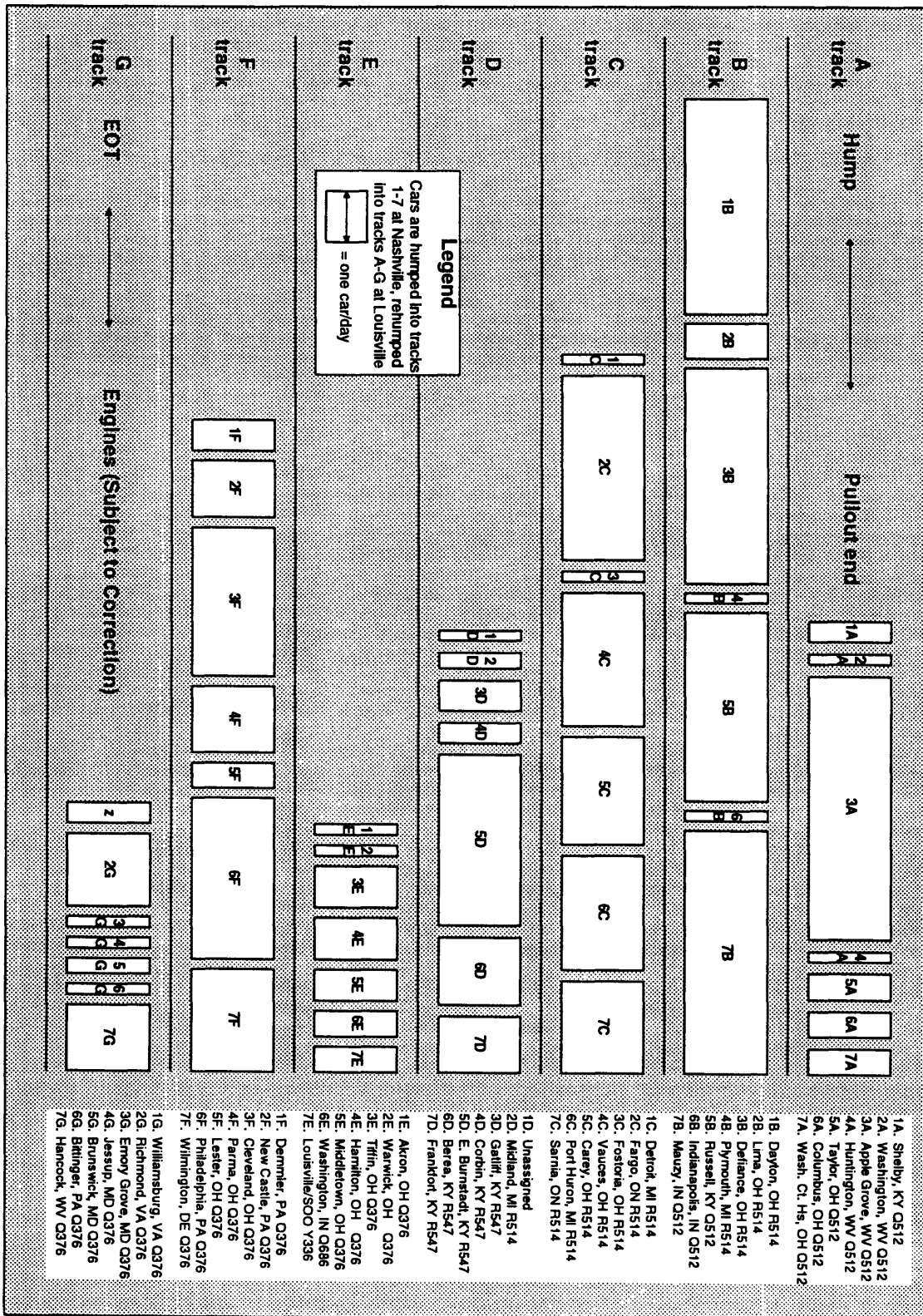
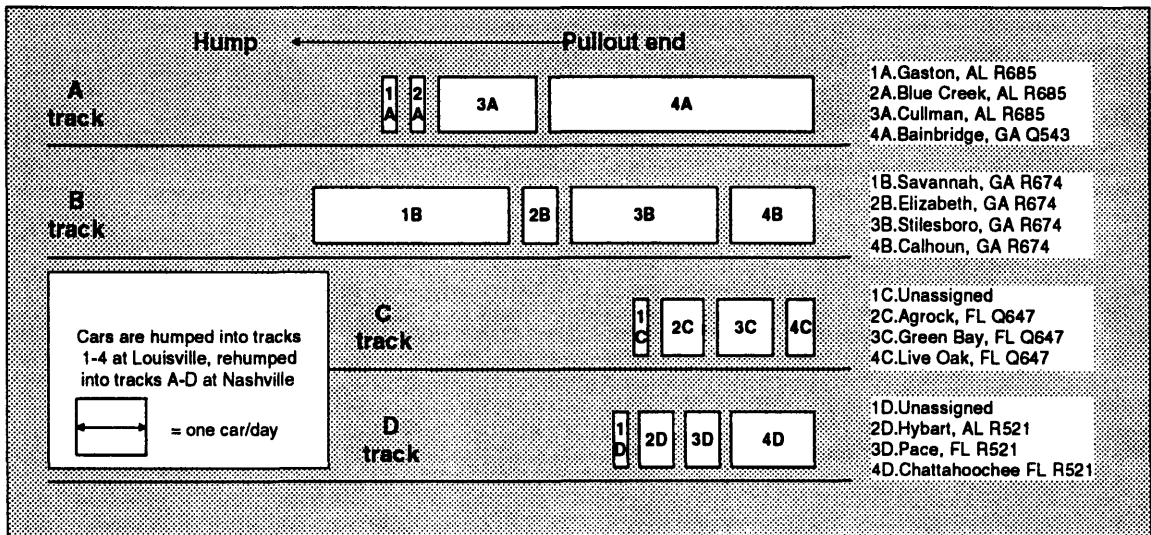


Figure 3.31 illustrates potential bowl track assignments for the southbound matrix blocks at Nashville. The blocks on the 'A' track have been ordered such that Q543's block may be trimmed from the track before its departure at 13:15, while R685's three blocks wait for its 19:30 departure. Block ordering is also determined by each train's departure direction. Train R674 departs Nashville in with engines toward the right side of the figure while the other trains carrying multiple blocks depart Nashville with engines toward the left side, including Q647 which picks up at a separate blockswapping yard rather than from the departure yard. Blocks are ordered so that the next block to be set off is closest to the engines. Had the matrix blocks been larger, block ordering may have been changed to even the number of cars on each track at each matrix yard to minimize the likelihood of a class track overrun.

In both directions, block order on bowl tracks and trains could also be influenced by train makeup issues, such as placement of loads and empties in a train, regular presence of hazardous materials in a block, or long car/short car placement issues. The issue of train makeup is discussed in more detail in Section 3.3.5.

Figure 3.31: Block-to-Track Assignments for Southbound Matrix Blocks



3.3.4 Changes in Performance

Performance of traffic routed through the northbound or southbound matrices due to the Tandem Humping strategy changed in several ways:

- Traffic routed via the matrices underwent fewer handlings downstream from the matrices, as was the intent of the strategy. Such traffic experienced corresponding decreases in trip time, although blockswapping served to increase trip time relative to movement on a through train.
- Traffic routed via the matrices sometimes experienced increases in handling and trip time upstream from the matrices.
- Traffic routed via the matrices experienced both increases and decreases in mileage.
- Traffic diverted from blocks eliminated to make room for the matrix experienced increases in handlings and trip time relative to original routings. Notably, this traffic did not increase in mileage.

Figure 3.32 lists traffic flows affected by the Tandem Humping strategy. Despite the fact that matrix blocks from Nashville and Louisville to every network node were originally offered as options to standard routing, only a very small fraction of the traffic flows utilized the matrices. Whereas the volume of traffic diverted to make room for the matrix is also quite small in absolute terms, it is large relative to volumes processed in the matrix, and the negative impacts of diversion of this traffic have a large overall effect on the results.

Figure 3.32: Traffic Flows Affected by the Tandem Humping Strategy

Description	O/D Pairs	Cars per Day
Northbound Matrix	92	66.4
Southbound Matrix	31	16.2
Diverted Traffic	20	13.2*

*3.5 cars/day of the diverted traffic was diverted to the southbound matrix, and is included in the row above.

Figure 3.33 shows impacts on traffic performance due to the Tandem Humping strategy. Effects are broken out by matrix direction because the original operating plan creation process created new traffic classes to distinguish matrix and non-matrix traffic at the matrix yards.

Note that the base case to which the Tandem Humping strategy is compared is not the base case to which the Local Pre-Blocking and Terminal Complex Strategies were compared. Instead, the basis for comparison is the ABM-Generated Routing strategy. The ABM-Generated Routing strategy is one of two conventional strategies for improving performance evaluated in this thesis. The ABM-Generated Routing strategy involves no

changes to operating paradigms. Instead, it involves using the ABM to generate car routes. The strategy is discussed in detail in Section 4.1.

It was necessary to compare the Tandem Humping strategy to the ABM-Generated Routing case rather than CSXT's historical base case because the process of routing traffic through the matrices caused the ABM to generate routes for all traffic, whereas only a small proportion of that traffic was processed in the matrix. To compare the Tandem Humping operating plan to the historical base case would have attributed effects to Tandem Humping which in reality were caused by the ABM.

The issue of the influence of the ABM also arose in the Local Pre-Blocking and Terminal Complex strategies. Because only a small number of traffic flows were routed using the ABM for these strategies, the results could be taken at face value. However, use of the ABM to route all flows in the Tandem Humping strategy created an impact too large to ignore, necessitating use of the ABM-Generated Routing strategy as the basis for financial and operating comparison.

Use of the ABM-Generated Routing case as the base case also allows us to consider the question of whether savings over and above the ABM-Generated Routing strategy justify the additional complexity of the Tandem Humping strategy.

Figure 3.33: Performance Changes due to the Tandem Humping Strategy

Strategy	Change in Average Dock-Dock Trip Time	% of Cars Arriving Within +/- 24 Hours of Average	Car Hours Saved Per Day	Car Miles Saved Per Day	Car Handlings Saved Per Day
North Matrix Traffic: 66.4 cars/day					
ABM-Gen.	161 Hrs.	79%	0	0	NA
Tand. Hum.	158 Hrs.	80%	209	(2,730)	NA
South Matrix Traffic: 16.2 cars/day					
ABM-Gen.	151 Hrs.	71%	0	0	NA
Tand. Hum.	144 Hrs.	80%	115	(670)	NA
Diverted Traffic: 9.7 cars/day					
ABM-Gen.	106 Hrs.	69%	0	0	NA
Tand. Hum.	120 Hrs.	64%	(130)	0	NA
All Affected Traffic: 92.3 cars/day					
ABM-Gen.	153 Hrs.	77%	0	0	0
Tand. Hum.	152 Hrs.	79%	196	(3,400)	48

The dominant effect on performance due to the Tandem Humping strategy is an increase in car miles relative to standard routings generated by the ABM. This is due to the fact that in routing traffic via the matrix, the ABM was forced to choose between

routing traffic through both matrix yards, or avoiding the second-stage yard entirely. If traffic was processed in a matrix, then routing via both matrix yards was superior to routing avoiding the second-stage yard, but was not necessarily superior to the base case routing. Traffic originating near the matrix yards was particularly hard-hit by this phenomenon, as it sometimes had few alternatives to routing via a second-stage yard. To remove traffic increasing in mileage from the matrix would require examination of individual flow performance and is not feasible at this time.

Other effects on performance are consistent with expectations in direction if not in magnitude. Car hours and classifications decreased for matrix traffic, increased for diverted traffic, with a slight overall decrease. Reliability changes due to the Tandem Humping strategy are notably small for northbound matrix traffic and notably large for southbound matrix traffic, with expected deterioration in diverted traffic and a slight overall increase in reliability.

Figure 3.34 shows cost impacts of the Tandem Humping strategy relative to ABM-Generated Routing. The effects on targeted flows were not extrapolated to the entire network because traffic for which a matrix routing was evaluated and rejected is not included in the tally of performance changes, thus making the set of targeted flows deceptively small, and the resulting extrapolation deceptively large.

Figure 3.34: Additional Costs Saved (Generated) by the Tandem Humping Strategy Compared to the ABM-Generated Routing Strategy

Period	Value of Car Hour Changes	Value of Car Mile Changes	Value of Car Handling Changes	Total
Per Day	\$0.1 K	(\$1.7 K)	\$0.1 K	(\$1.4 K)
Per Year	\$54 K	(\$621 K)	\$53 K	(\$514 K)

Figures do not sum due to rounding.

Examination of individual traffic flows may shed additional light on the Tandem Humping strategy's failure to outperform the ABM-Generated Routing strategy. Figures 3.35a-3.35d illustrates operating changes experienced by individual traffic flows in the Tandem Humping operating plan. Comparisons are shown between the Tandem Humping strategy, the historical base case and the ABM-Generated Routing strategy.

Figures 3.35a-3.35d: Performance and Routing Changes to Individual Traffic Flows due to the Tandem Humping Strategy

Traffic Flow: Gallatin, TN - Berea, KY 1.1 cars/day		
Observations: Traffic between Gallatin and northern points must travel via Louisville. Therefore, the requirement that traffic to northern matrix destinations either pass through both Louisville and Nashville or avoid Louisville leaves this flow and others originating at Gallatin with a single option, causing an increase in mileage and trip time relative to the other cases. Thus, the cost of moving this flow increases considerably as a result of the Tandem Humping operating plan. On the bright side, reliability increases significantly for this flow because of the added departure between Nashville and Louisville and the substitution of a blockswap for a classification at Patio.		
Blocks		
Historical Base Case	ABM-Generated Routing	Tandem Humping
Gallatin-Louisville Louisville-Patio Patio-Berea	Gallatin-Louisville Louisville-Patio Patio-Berea	Gallatin-Nashville Nashville-Louisville Louisville-Berea (swap at Patio)
Schedule		
Historical Base Case	ABM-Generated Routing	Tandem Humping
R534 1730 DP Gallatin 2100 AR Louisville	R534 1730 DP Gallatin 2100 AR Louisville	R573 0430 DP Gallatin 0600 AR Nashville
R547 1900 DP Louisville 0200 AR Patio	R547 1900 DP Louisville 0200 AR Patio	Q526 R534 0400 1200 DP Nashville 1300 2100 AR Louisville
C703 0630 DP Patio 1014 AR Berea	C703 0630 DP Patio 1014 AR Berea	R547 1900 DP Louisville 0200 AR Patio R549 0100 DP Patio 0149 AR Berea
O/D Reliability		
Historical Base Case	ABM-Generated Routing	Tandem Humping
74%	74%	89%
Car Hours, Miles, Handlings		
Historical Base Case	ABM-Generated Routing	Tandem Humping
L/C/B Hours 68	L/C/B Hours 68	L/C/B Hours 96
O/T Hours 25	O/T Hours 25	O/T Hours 20
Miles 301	Miles 301	Miles 343
Class 2	Class 2	Class 2
Blockswaps 0	Blockswaps 0	Blockswaps 1

Figure 3.35b

Traffic Flow: Memphis - Port Huron, MI 1.8 cars/day		
<p>Observations: The Tandem Humping strategy works exactly as intended to improve this flow relative to both the historical and ABM-Generated routes. Addition of a second daily departure between Nashville and Louisville and substitution of a blockswap for a classification at Flint provide a considerable increase in reliability and decrease in average trip time. The favorable performance of this flow is representative of many flows between Memphis and northern matrix destinations. These flows were able to enjoy the downstream benefits of the matrix without increases in mileage and handlings upstream from the matrix.</p>		
Blocks		
Historical Base Case	ABM-Generated Routing	Tandem Humping
Memphis-Nashville Nashville-Louisville Louisville-Flint Flint-Port Huron	Memphis-Nashville Nashville-Louisville Louisville-Flint Flint-Port Huron	Memphis-Nashville Nashville-Louisville Louisville-Port Huron (swap at Flint)
Schedule		
Historical Base Case	ABM-Generated Routing	Tandem Humping
R532 0700 DP Memphis 1930 AR Nashville	R532 0700 DP Memphis 1930 AR Nashville	R532 0700 DP Memphis 1930 AR Nashville
Q526 0400 DP Nashville 1300 AR Louisville	Q526 0400 DP Nashville 1300 AR Louisville	Q526 R534 0400 1200 DP Nashville 1300 2100 AR Louisville
R514 2200 DP Louisville 0400 AR Flint	R514 2200 DP Louisville 0400 AR Flint	R514 2200 DP Louisville 0400 AR Flint
R330 1600 DP Flint 1827 AR Port Huron	R330 1600 DP Flint 1827 AR Port Huron	R330 1600 DP Flint 1827 AR Port Huron
O/D Reliability		
Historical Base Case	ABM-Generated Routing	Tandem Humping
75%	75%	97%
Car Hours, Miles, Handlings		
Historical Base Case	ABM-Generated Routing	Tandem Humping
L/C/B Hours 144	L/C/B Hours 144	L/C/B Hour 118
O/T Hours 34	O/T Hours 34	O/T Hours 34
Miles 949	Miles 949	Miles 949
Class 3	Class 3	Class 2
Blockswaps 0	Blockswaps 0	Blockswaps 1

Figure 3.35c

Traffic Flow: Memphis (SSW) - Stilesboro, GA 0.4 cars/day		
<p>Observations: When the Stilesboro block was added to the matrix because of bowl space requirements at Nashville, this flow was left without a route. Movement to Louisville and back for processing in the matrix was not an option because of the extreme mileage addition. Instead, classifications at Bridgeport and Calhoun were added with no increase in mileage but considerable degradations in reliability, trip time, and operating costs. This flow is representative of the nearly 10 cars per day diverted from the Cullman, Stilesboro, and Etowah blocks at Nashville.</p>		
Blocks		
Historical Base Case	ABM-Generated Routing	Tandem Humping
Memphis-Nashville Nashville-Stilesboro	Memphis-Nashville Nashville-Stilesboro	Memphis-Nashville Nashville-Bridgeport Bridgeport-Calhoun Calhoun-Stilesboro
Schedule		
Historical Base Case	ABM-Generated Routing	Tandem Humping
Q536 1800 DP Memphis 1100 AR Nashville	Q536 1800 DP Memphis 1100 AR Nashville	Q536 1800 DP Memphis 1100 AR Nashville
R589 1500 DP Nashville 0620 AR Stilesboro	R589 1500 DP Nashville 0620 AR Stilesboro	R674 0130 DP Nashville 0700 AR Bridgeport
		R583 0300 DP Bridgeport 0840 AR Calhoun
		R581 1440 DP Calhoun 1510 AR Stilesboro
O/D Reliability		
Historical Base Case	ABM-Generated Routing	Tandem Humping
78%	78%	66%
Car Hours, Miles, Handlings		
Historical Base Case	ABM-Generated Routing	Tandem Humping
L/C/B Hours 61	L/C/B Hours 61	L/C/B Hour 96
O/T Hours 50	O/T Hours 50	O/T Hours 50
Miles 473	Miles 473	Miles 473
Class 1	Class 1	Class 3
Blockswaps 0	Blockswaps 0	Blockswaps 0

Figure 3.35d

<p>Traffic Flow: Gadsden AL - Russell, KY 1.3 cars/day (two flows, 0.2 cars/day and 1.1 cars/day)</p>		
<p>Observations: This flow was initially improved by an ABM-generated route which eliminated the classification at Ragland. Although the Tandem Humping strategy replaced a classification with a blockswap downstream from the matrix at Cincinnati, a classification was added at Nashville, and trip time rose and reliability suffered relative to the ABM-generated route. This flow is characteristic of several northbound flows which incurred an additional classification upstream from the matrix in order to save a classification downstream from the matrix. In such cases, performance was often quite similar to performance on the ABM-generated route, except where the saved classification downstream from the matrix was replaced with a relatively lengthy blockswap, as was the case here. The long blockswap time at Cincinnati suggests that schedule sliding to shorten blockswap times would improve the Tandem Humping strategy.</p>		
<p>Blocks</p>		
<p>Historical Base Case</p> <p>Gadsden-Ragland Ragland-Birmingham Birmingham-Louisville Louisville-Cincinnati Cincinnati-Russell</p>	<p>ABM-Generated Routing</p> <p>Gadsden-Birmingham Birmingham-Louisville Louisville-Cincinnati Cincinnati-Russell</p>	<p>Tandem Humping</p> <p>Gadsden-Birmingham Birmingham-Nashville Nashville-Louisville Louisville-Russell (swap at Cincinnati)</p>
<p>Schedule</p>		
<p>Historical Base Case</p> <p>M770 1158 DP Gadsden 1351 AR Ragland</p> <p>M771 2322 DP Ragland 0300 AR Birmingham</p> <p>Q572 1000 DP Birmingham 0130 AR Louisville</p> <p>R518 0730 DP Louisville 1700 AR Cincinnati</p> <p>R220 1100 DP Cincinnati 1800 AR Russell</p>	<p>ABM-Generated Routing</p> <p>M770 1158 DP Gadsden 1600 AR Birmingham</p> <p>Q572 1000 DP Birmingham 0130 AR Louisville</p> <p>R518 0730 DP Louisville 1700 AR Cincinnati</p> <p>R220 1100 DP Cincinnati 1800 AR Russell</p>	<p>Tandem Humping</p> <p>M770 1158 DP Gadsden 1600 AR Birmingham</p> <p>Q520 2130 DP Birmingham 0830 AR Nashville</p> <p>Q526 R534 0400 1200 DP Nashville 1300 2100 AR Louisville</p> <p>Q512 1745 DP Louisville 0130 AR Cincinnati</p> <p>H788 1830 DP Cincinnati 0030 AR Russell</p>
<p>O/D Reliability</p>		
<p>Historical Base Case</p> <p>64% 55%</p>	<p>ABM-Generated Routing</p> <p>77% 66%</p>	<p>Tandem Humping</p> <p>67% 62%</p>
<p>Car Hours, Miles, Handlings</p>		
<p>Historical Base Case</p> <p>L/C/B Hours 125 125</p> <p>O/T Hours 49 39</p> <p>Miles 741 Class 4 Blockswaps 0</p>	<p>ABM-Generated Routing</p> <p>L/C/B Hours 107 107</p> <p>O/T Hours 49 39</p> <p>Miles 741 Class 3 Blockswaps 0</p>	<p>Tandem Humping</p> <p>L/C/B Hour 125 125</p> <p>O/T Hours 49 39</p> <p>Miles 741 Class 3 Blockswaps 1</p>

The example flows illustrate that, for traffic flows which meet very strict conditions, matrix processing and movement via direct blocks can provide benefits above and beyond routings generated by the ABM. The conditions include:

- Movement in a single block between the origin and the first stage of the matrix
- No increase in mileage due to matrix routing
- ABM-generated route also stipulates handling at both Nashville and Louisville
- As little blockswapping as possible downstream from the matrix

For traffic flows which do not meet these conditions, the Tandem Humping strategy appears to provide few benefits. Classification points are re-shuffled, but not fundamentally reduced relative to standard ABM-generated routes, and routing via the matrix sometimes causes trip mileage to increase.

In addition to the effects on traffic classified in the matrices, the Tandem Humping strategy has significant effects on traffic diverted to make room for the matrices at Louisville and Nashville. Although the Nashville-Stilesboro and Nashville-Cullman blocks were available in the matrix, less than half of the traffic that moved in those blocks in the ABM-Generated Routing operating plan was routed via the matrix, and even this traffic saved no classifications relative to standard routes generated by the ABM. Traffic in these blocks not processed in the matrix incurred additional classification as a result of the Tandem Humping strategy.

3.3.5 Implementation Issues

The following discussion of implementation issues assumes that, through more careful selection of O/D traffic flows and block destinations for matrix processing, the Tandem Humping strategy can provide improvements in service reliability and operating costs beyond those demonstrated by the ABM-Generated Routing strategy. If the Tandem Humping strategy is ever to be implemented, the issues described below will have to be considered.

3.3.5.1 Designing a Tandem Humping Operating Plan

Of the three sophisticated alternatives, the dimensions of the Tandem Humping operating plan are influenced most strongly by the presence, absence, and volume of individual traffic flows. Presence of individual O/D pairs can dictate the inclusion of blocks in the matrix. If a consignor sends traffic to a different destination, then the matrix block designated for that traffic may no longer be justified. Conversely, if an O/D pair experiences a large increase in volume, it may justify creation of a new, direct block, which would surpass the efficiency of the matrix because the traffic would have to undergo even fewer handlings than if moved through the matrix.

Because of its inherent sensitivity to individual O/D pairs and volumes, a Tandem Humping operating plan would require constant updating, requiring much service planning effort. A system which predicts traffic flows either through forecasting methods or early visibility of customer consignments would provide more current traffic flow information than used in this analysis.

In the absence of a new system for generating traffic flow data, current methods will suffice, with some considerations. While raw waybill data was used to determine local pre-blocks, and QBASE connection volume data was used to determine the blocks and trains to be included in the terminal complex, the Tandem Humping operating plan is based solely on information in ABM/TSS/SPM files. Attempts to ensure that data used to develop the plan is accurate must focus not only on the waybilled moves in the WMS file, and their translation into more compact QBASE records, but also on the routines which build ABM/TSS/SPM files from QBASE data.

Presently, the community of users of ABM/TSS/SPM files at CSXT is tiny compared to the community of users of QBASE and WMS data. Accordingly, relatively little attention has been paid to the integrity of ABM/TSS/SPM data. Before a production version of a Tandem Humping operating plan can be built, the ABM/TSS/SPM files and file creation process will have to be reviewed for accuracy and completeness by service planners as well as operations research analysts.

An unanswered analytical question which may further condemn or vindicate the Tandem Humping strategy is the presence of empty cars of common types in the matrix. It may be the case that the fine classification and direct delivery called for by the Tandem Humping strategy could also be achieved without a matrix, simply through the methods and timing with which individual empty cars are matched to customer demands.

Another empty car issue concerns the set of empty car O/D pairs. Whereas empty flows appear in the SPM exactly as do loaded flows, the set of individual O/D pairs generated by empty redistribution will be somewhat arbitrary in a given month. For example, empty grain cars released south of Nashville are classified at Nashville and distributed to Evansville, Danville, Lafayette and other points on and off the Chicago-Nashville corridor every day. While the set of empty car release and demand points are fixed, the resulting O/D matchups depend on magnitude and timing of demand and fluidity of the yards that classify the cars. To use this set of historic O/D pairs as the basis for the Tandem Humping operating plan implies that individual moves will be repeated.

3.3.5.2 Operating Instructions in the Field

The Tandem Humping strategy is complicated. If the matrix switching and coordinated blockswapping called for by the strategy are to be successfully executed, the representation of the plan to train crews, yard crews, and yardmasters must be as simple and transparent as possible.

Yardmasters are responsible for assigning blocks to bowl tracks, whether the blocks are standard yard blocks or part of a matrix. Control of a three- or four-track matrix using current yard systems does not pose a substantial management problem. However, as the matrix grows in size, the amount of information and number of decisions the yardmaster must make will increase exponentially. Superficially complex decisions concerning matrix block-to-track assignment and train assembly may distract yardmasters, and should be made by decision-support systems to the greatest possible extent.

Examples of details which can be made invisible include any instances when a group of matrix blocks can be treated as a single unit. During assembly, when several tracks of matrix cars are added to a single train, the yardmaster should not have to say, think, or add to a switch list an instruction like, "Pull the A, B, C, D, E, F, and G blocks from track B23 and shove into track D7." If the Tandem Humping operating plan is operating smoothly and is well represented in an information system, the fact that there are 48 blocks on 7 tracks in the northbound matrix should be obvious to no one, except perhaps local train crews who must dissect setouts of matrix blocks left by road trains.

Paradoxically, however, in the event that a car is misclassified and must be inserted into a string of matrix blocks, a yardmaster must have the detail available in order to direct the proper placement of the car. Likewise, if the matrix tracks are assembled in the wrong order at the first stage yard, block order in the second stage bowl will change, and yardmasters will have to respond with altered instructions to yard crews. Blocks normally on the ends of tracks would be buried within tracks and vice versa, and yardmasters would have to be capable of generating instructions to cherry-pick blocks during assembly.

Operating plan maintenance causing addition or removal of individual blocks will impact processing at Nashville and Louisville relatively little as long as matrix track requirements remain stable, but will impact the trains which swap matrix blocks and local trains which receive them, especially if swap trains or setoff points are continually added or removed from the plan. Communication of plan changes to the relevant personnel will also be a key factor in the success of the Tandem Humping strategy.

3.3.5.3 Operational Contingency Planning

The Tandem Humping strategy is unlike the Local Pre-Blocking and Terminal Complex strategies in that it does not require greater schedule adherence than in traditional operations. Because the matrices at Nashville and Louisville are operated in a continuous process, hump and assembly schedules for matrix trains may be varied in response to trackwork curfews or other operational contingencies.

The lack of tightly scheduled connections allows additional flexibility in executing a Tandem Humping operating plan. In response to light volume, yard managers could elect to move cars between the two matrix yards on one train rather than two. As long as the cuts were ordered properly on the train, second-stage processing could proceed normally. Likewise, heavy volume could prompt an extra train between stages with no adverse effects on the second stage.

The issue of in-train car placement may burden the Tandem Humping strategy. Ordinarily, cars requiring special placement such as dangerous loads, long cuts of empty cars, and cuts of extra long or short cars are switched into proper position away from the engines or at the rear of the train before departure. In such cases, the integrity of large blocks can often be maintained.

Individually placing cars within trains is time-consuming and sometimes causes train delays but does not unduly complicate switching at downstream yards because single-stage switching does not require cars to be in a preset order. In the Tandem Humping strategy, however, cars which are switched out of block order after the first stage of the matrix must either be put back in order before the second stage of the matrix or humped to alternate tracks and individually placed in matrix blocks after second stage humping is complete. Furthermore, such cars may require reswitching after the second stage of the matrix as well, potentially complicating the task of cluster blockswapping because small matrix blocks cannot easily be kept together when their cars require special placement.

While it is possible to exclude some 'problem cars' such as dangerous loads, from processing in the matrix, other car patterns requiring reswitching may arise unexpectedly due to grouping in the matrix. The extent of this problem is not known, but could be determined through simulation, or ignored until reported by field personnel.

3.3.6 Conclusions for the Tandem Humping Strategy

Even after extensive development and analysis, the Tandem Humping strategy is far from refined, and this lack of refinement undoubtedly contributes to the poor financial and operating performance exhibited by the strategy. However, even if it is assumed that financial performance can be improved by returning poor-performing flows to their base case or ABM-generated routes, the Tandem Humping strategy still suffers from three undeniable weaknesses:

- The strategy is exceedingly complex both from an analytical/service design standpoint and from an execution standpoint. The process of creating a Tandem Humping operating plan is long and confusing. Simple depiction of the plan to those who must execute it would require alterations to information systems, as well as extensive instruction. In addition, the dimensions of the operating plan are very sensitive to the presence and volume of individual traffic flows. An effective plan will need constant revision, and the ability to predict individual traffic movements. Every revision to the plan will require alterations in execution in the field. While such alterations would be minor at the matrix yards, individual trains could be significantly impacted.
- The strategy aids an extremely small set of traffic flows. This weakness can be remedied through further design activity. Inclusion of existing block destinations in the matrices will free bowl tracks for other uses, better utilize the matrix bowl tracks, and create more logical groupings of blocks. The drawback of including existing block destinations in the matrix is that traffic in these blocks must pass

through both matrix yards, or be excluded from the block. Destinations served only from the matrix yards, like New Albany, IN from Louisville, or the Memphis interchange blocks from Nashville, will remain poor matrix candidates because out-of-route mileage caused by routing traffic through both Louisville and Nashville overwhelms savings from avoided classification.

- Matrix switching across two hump yards duplicates costly, time consuming, and reliability-degrading yard processing functions. In exchange for avoiding pullback from the bowl to the receiving yard for rehumping, inbound and outbound inspection and train assembly are replicated. The effects of this are evident in the performance of individual traffic flows for which there is no net decrease in classification, but merely movement of classification to Louisville or Nashville from other yards.

At this juncture, analytic and operational complexity and lack of benefits render the Tandem Humping strategy non-viable. CSXT's many traffic flows over a dense network increase the amount of rerouting and excess mileage required to flow through both matrix yards. For this reason, the future success of the Tandem Humping strategy in the study region is unlikely even if all analytical and operating issues are addressed.

The Tandem Humping strategy's lack of success in the study region does not necessarily imply that the strategy could never provide benefits. If Tandem Humping were applied to a linear network in which most traffic passed through both yards in the base case and local traffic inclusion was minor, the rerouting and mileage drawbacks of the Tandem Humping strategy would diminish. The ability to achieve net decreases in classification is doubtful even for a linear network, however, as the bowl space required to build matrix blocks could be used to build blocks to many linear-network points.

The Tandem Humping strategy's lack of success in no way indicts matrix switching at a single facility, as the mileage, handling, and traffic inclusion problems of the Tandem Humping operating plan would largely disappear if matrix traffic did not have to pass through both Nashville and Louisville.

4 Conventional Changes to the Operating Plan

Modeling the Local Pre-Blocking and Terminal Complex operating plans illustrated several issues related to network performance. In each case, use of the ABM to create origin-destination routes for traffic using new blocks provided benefits that defied expectations. In the case of the Terminal Complex strategy, the overall effects of rerouting traffic from the complex to alternate routes were positive rather than negative. In both the Local Pre-Blocking and Terminal Complex strategies, some cars were routed in ways which increased trip time and car handlings, but which remained superior on a cost basis because of the countervailing effects of large decreases in car mileage. In addition, the Terminal Complex strategy illustrated that a high-performance yard, represented by sharply reduced PMAKE parameters, can significantly reduce O/D trip time and increase reliability for the traffic it processes.

These observations led to the creation of two additional alternative strategies. These strategies are conventional in that they do not call for changed roles for yards, crews, or trains. Instead, the ABM-Generated Routing strategy presumes a change in the service design process, as the ABM is used to generate car-to-block assignments and classification tables. The Improved Yard Performance strategy calls for benchmark-level performance at Radnor Yard in Nashville, classification hub of the Chicago-Nashville corridor.

The question that the two conventional alternatives attempt to answer is no longer that of whether alternative strategies of operational organization can yield significant reliability and cost benefits. Rather, each conventional alternative answers an individual question. Analysis of the ABM-Generated Routing strategy addresses the question, "Can railroads make significant improvements in reliability and cost without an operational paradigm shift, by adopting decision support in the service design process?" Analysis of the Improved Yard Performance strategy addresses the question, "What is the extent of the effect of benchmark-level performance at a yard on O/D reliability and operating costs?"

4.1 ABM-Generated Routing

4.1.1 Description

The premise behind the ABM-Generated Routing strategy is simple. Currently, classification tables holding car-to-block assignments at each yard are maintained by CSXT Service Design staff, and updated as necessary, usually in conjunction with a change to the block destinations maintained at a yard. Traffic routing efficiency is stressed—every attempt is made to avoid overhandling cars, moving cars out of route, and embedding yard dwell time in car routes. However, car routes are seldom mathematically checked to determine whether the tradeoff between handlings, mileage, and time is appropriate to the unit costs CSXT has calculated for car miles, car hours, and car handlings.

The ABM Manu-Block module is designed to produce a set of car-to-block assignments, essentially classification tables, which make the tradeoff between car miles, hours, and handlings in a cost minimizing way. Given O/D traffic flows, a list of blocks built at each yard, line and yard information, and cost parameters, the ABM flows traffic over the available blocks using a variant of Dijkstra's label-setting shortest path algorithm. In the absence of capacity constraints, the problem is "NP-easy", meaning that the exact least-cost solution can be found by a simple linear program in minimal computation time.

If blocks or yards reach capacity, however, the problem becomes "NP-hard", Because the simple shortest-path algorithm does not heed capacity constraints, more advanced mathematical methods such as mixed integer programs are required, and computation time required to find the exact least-cost solution increases exponentially. In practice, the two approaches which arise to address capacity constraints are to use heuristic solution methods to avoid constraint violations, or to ignore the constraints and use the model to locate and estimate the size of operational bottlenecks, and not to generate actual operating instructions.

In creating an operating plan based on ABM-generated car routings, yard and block volume constraints were ignored, for several reasons. Yard volume constraints were ignored because they were static. Many yards can handle additional volume if it arrives during hours that are otherwise relatively idle. If a continuously busy yard is called on by the ABM to handle more traffic, a more effective solution than diverting traffic and causing time and mileage expense may involve manipulating the list of block destinations, a related but separate service design activity. Block volume constraints were considered artificial, as they do not consider the possibility of multiple block dispatches. Finally, flowing traffic over the blocks using the ABM was not expected to cause major volume shifts between lines. Those block volume changes that did occur would cause corresponding changes in volumes of individual trains, but it was thought that these changes could be dealt with largely by manipulating block-to-train assignments, and without a net increase in train service.

Thus to create an operating plan representing the ABM-Generated Routing strategy, the ABM was used in an almost cursory fashion to recreate blanked classification tables. No block destination lists were manipulated, no trains rescheduled, and no blocks reassigned to different trains. Even within the ABM itself, many of the cost parameters which could be varied individually, such as the cost per car mile on a link, were treated as global, as they were for the other strategies.

Before the strategy was modeled, there was limited understanding of the issues and effects that ABM-generated car-to-block assignments would raise. Therefore, to expend large amounts of effort at calibration of individual cost parameters and constraints would have diverted attention from the primary objective, which was to determine whether such effort *could ever* be justified in the use of decision support in the operating plan development process.

4.1.2 Changes in Performance

Generation of car-to-block assignments using the ABM caused each O/D pair to be reviewed to determine whether it moved on its minimum cost route. If a routing change was warranted, it generally took one of the following forms:

- Any cars which did not utilize existing bypass blocks in the base case were rerouted onto those blocks, saving a classification.
- Some but not all cars which moved on greater-than-minimum-distance routes in the base case, usually to save time or classifications, were transferred to lower-cost routes which eliminated mileage but which often increased trip time and classifications and decreased reliability.

To understand changes made by the ABM, one must be aware of the cost relationships driving the selection of routes. The ABM used costs of \$3.00 per car handling, \$0.75 per car hour, and \$0.50 per car mile in determining the cost of potential car routes. Thus, one car handling = four car hours = six car miles. Alternately, if classification at a given yard requires an average of 20 hours, then one handling + handling time = 24 car hours = 36 car miles.

In an average trip, a car will generate between five and ten times as many miles as hours, and more than 100 times as many miles as handlings. Long node-to-node distances create large discrete units of cost, made up of car mileage costs and costs of time required to traverse the route. For these reasons, the ABM tends to minimize car miles at the expense of additional time and handlings. The costs used by the model in this analysis confirm the historical emphasis on maximizing profit by minimizing costs, in this case the costs of car and train miles. However, the costs of time and handlings may be unnaturally low, as they account only for car ownership and direct switching costs, but fail to account for the cost, in terms of lost business or inability to charge higher rates, that may result from slow or unreliable service.

Network-level car mile, hour, and handling savings due to the ABM-Generated Routing strategy are shown in Figure 4.1. Unlike the other strategies, the ABM-Generated Routing strategy was tested on the entire CSXT network rather than a subnetwork such as the Chicago-Nashville corridor. Figure 4.1 reflects changes to all 8171 cars per day in the network, and is not extrapolated.

Car mile reductions are by far the largest source of savings, and represent a savings of approximately 2.6% of network car miles. The numbers in Figure 4.1 reflect aggregate savings. Individual traffic flows may have experienced increases in one or several categories, such as car hours and car handlings, if the corresponding mileage savings resulted in a lower total cost.

It appears to have often been the case that traffic flows suffered increases in trip time or handlings in exchange for car mile savings. One car hour was saved for every 9.5 car

miles saved. 9.5 miles per hour is considerably slower than CSXT's point-to-point line speeds, which range between 20 and 40 miles per hour. Therefore, much time saved on the line was spent in yards, although car hour savings still remained positive due to other factors such as increased use of existing bypass blocks.

Figure 4.1: Changes in Car Hours, Miles, Handlings, and Reliability due to ABM-Generated Routing Strategy

Strategy	Average Dock-Dock Trip Time	% of Cars Arriving Within +/- 24 Hours of Average	Car Handlings Saved Per Day	Car Hours Saved Per Day	Car Miles Saved Per Day
Base Case	86 Hrs.	84%	0	0	0
ABM-Generated Routing	85 Hrs.	85%	608	8,254	78,400

Annual cost savings due to the changes total more than \$17 million, of which more than \$14 million is attributable to reductions in car miles. Daily and annual cost savings due to the ABM-Generated Routing strategy are shown in Figure 4.N2.

Figure 4.2: Annual Cost Savings due to the ABM-Generated Routing Strategy

Period	Value of Saved Car Handlings	Value of Saved Car Hours	Value of Saved Car Miles	Total
Per Day	\$1.8 K	\$6.2 K	\$39.2 K	\$47.2 K
Per Year	\$0.7 M	\$2.3 M	\$14.3 M	\$17.3 M

Figures do not sum due to rounding.

Individual traffic flows experienced a variety of performance improvements and degradations due to the ABM-Generated Routing strategy. Figures 4.3a-4.3f show representative examples of changes to traffic flows.

Figures 4.3a-4.3f: Performance and Routing Changes to Individual Traffic Flows due to the ABM-Generated Routing Strategy

Traffic Flow: Monon, IN - Bittinger, PA			
1.5 cars/day			
<p>Observations: This traffic flow experienced mild decreases in trip time and reliability as a result of its ABM-generated route. However, the increase in mileage experienced by this traffic flow appears to outweigh the car hour and car handling savings. Given the cost relationships used by the ABM, with 125 miles added and two handlings saved, the total trip must be shortened by 85 hours to "break even". Even if the 23-hour blockswap time at Emory Grove were eliminated, car hour savings would not approach those necessary to reduce costs. The reason for this flow's departure from cost minimization is that the ABM determines block mileage based on the minimum-distance route, rather than the route actually taken by the train carrying the block. Thus, the ABM assumed that the Louisville-Baltimore block would move across the coalfields of West Virginia, incurring fewer car miles than the actual route via Cincinnati, Willard, New Castle, and Cumberland. The issue of actual vs. computed block mileage arises in several subsequent example flows, and is a serious issue in routing cars using the ABM.</p>			
Blocks (Read down, then across)			
Base Case		ABM-Generated Routing	
Mt.Vernon-Evansville	Willard-Cumberland	Mt. Vernon-Evansville	
Evansville-Louisville	Cumberland-Hagerstown	Evansville-Louisville	
Louisville-Willard	Hagerstown-Bittinger	Louisville-Baltimore	
		Baltimore-Bittinger	
		(swap at Emory Grove)	
Schedule (Read down, then across)			
Base Case		ABM-Generated Routing	
J734	Q378	J734	
1707 DP Mt. Vernon	0845 DP Willard	1707 DP Mt. Vernon	
2230 AR Evansville	2315 AR Cumberland	2230 AR Evansville	
R561	R342	R561	
1300 DP Evansville	0200 DP Cumberland	1300 DP Evansville	
2300 AR Louisville	0715 AR Hagerstown	2300 AR Louisville	
Q376	B738	Q376	
0500 DP Louisville	0410 DP Hagerstown	0500 DP Louisville	
0130 AR Willard	0413 AR Bittinger	0600 AR Baltimore	
		B739	
		0920 DP Baltimore	
		1304 AR Emory Grove	
		B737	
		1202 DP Emory Grove	
		1425 AR Bittinger	
O/D Reliability			
Base Case		ABM-Generated Routing	
56%		51%	
Car Hours, Miles, Handlings			
Base Case		ABM-Generated Routing	
L/C/B Hours	195	L/C/B Hours	179
O/T Hours	25	O/T Hours	25
Miles	1048	Miles	1173
Class	5	Class	3
Blockswaps	0	Blockswaps	1

Figure 4.3b

<p>Traffic Flow: Defiance, OH - Memphis (SSW) 2.3 cars/day</p>			
<p>Observations: This flow gains considerably in trip time and reliability due to elimination of handlings by the ABM. A key element of the new route is dubious, however. The existence of a Defiance-Nashville block, swapped at Walbridge suggests that R509 or possibly an unmodeled serving local or yard switcher pre-blocks originating traffic at Defiance for Nashville. Since no blocks were added to the base case block list, this block existed in the base case, but was not utilized by the traffic flow. QBASE information for traffic originating at Defiance in November 1993 indicates that most originating traffic was taken to Walbridge to be switched. Therefore, the existence of the Defiance-Nashville block can probably be attributed to a technical error in the process which creates flow, block, and blockswap files from the QBASE database. This error was discovered relatively early in the analysis, but was deemed uncorrectable in the short term. Blocks between points in the Chicago-Nashville corridor were altered individually, but many instances of the error remain in the block list.</p>			
<p>Blocks</p>			
<p>Base Case Defiance-Walbridge Walbridge-Cincinnati Cincinnati-Louisville Louisville-Nashville Nashville-Memphis (SSW)</p>		<p>ABM-Generated Routing Defiance-Nashville (swap at Walbridge) Nashville-Memphis (SSW)</p>	
<p>Schedule</p>			
<p>Base Case</p> <p>R509 0915 DP Defiance 1200 AR Walbridge</p> <p>Q507 0400 DP Walbridge 2359 AR Cincinnati</p> <p>R313 R519 0430 0200 DP Cincinnati 1330 1100 AR Louisville</p> <p>R573 2000 DP Louisville 0615 AR Nashville</p> <p>Q535 0045 DP Nashville 1530 AR Memphis (SSW)</p>		<p>ABM-Generated Routing</p> <p>R509 0915 DP Defiance 1200 AR Walbridge</p> <p>R515 1400 DP Walbridge 2100 AR Nashville</p> <p>Q535 0045 DP Nashville 1530 AR Memphis (SSW)</p>	
<p>O/D Reliability</p>			
<p>Base Case</p> <p>83%</p>		<p>ABM-Generated Routing</p> <p>94%</p>	
<p>Car Hours, Miles, Handlings</p>			
<p>Base Case</p> <p>L/C/B Hours 168</p> <p>O/T Hours 32</p> <p>Miles 832</p> <p>Class 4</p> <p>Blockswaps 0</p>		<p>ABM-Generated Routing</p> <p>L/C/B Hours 139</p> <p>O/T Hours 32</p> <p>Miles 830</p> <p>Class 1</p> <p>Blockswaps 1</p>	

Figure 4.3c

<p>Traffic Flow: Middletown, OH - New Albany, IN 1.0 cars/day</p> <p>Observations: The ABM-generated route results in a modest gain in reliability and a substantial reduction in trip time and elimination of a handling compared to the base case. This route also is problematic, but this time because of oversight on the part of the researcher. R221 is one-half of a pair of trains dedicated to a single customer. While it may appear that this train carries a general purpose Middletown-Cincinnati block, it is unclear whether traffic from other customers or destined for other points is allowed into this block, or even whether this traffic flow originates at the customer served by R220/R221. A general purpose Middletown-Cincinnati block carried by a different train may exist, but the block file creation process designated the most prevalent single train as carrying the Middletown-Cincinnati block. If assignment of a Middletown-Cincinnati block to R221 is accurate, then the composition of the block should be restricted, but this was not manually checked before routes were regenerated.</p>			
Blocks			
Base Case		ABM-Generated Routing	
Middletown-Lima Lima-Cincinnati Cincinnati-Louisville Louisville-New Albany		Middletown-Cincinnati Cincinnati-Louisville Louisville-New Albany	
Schedule			
Base Case		ABM-Generated Routing	
D743 2000 DP Middletown 2129 AR Lima		R221 0430 DP Middletown 0700 AR Cincinnati	
Q507 2230 DP Lima 2359 AR Cincinnati		R313 R519 0430 0200 DP Cincinnati 1330 1100 AR Louisville	
R313 R519 0430 0200 DP Cincinnati 1330 1100 AR Louisville		J772 0800 DP Louisville 1129 AR New Albany	
J772 0800 DP Louisville 1129 AR New Albany			
O/D Reliability			
Base Case		ABM-Generated Routing	
67%		74%	
Car Hours, Miles, Handlings			
Base Case		ABM-Generated Routing	
L/C/B Hours	98	L/C/B Hours	68
O/T Hours	29	O/T Hours	33
Miles	155	Miles	155
Class	3	Class	2
Blockswaps	0	Blockswaps	0

Figure 4.3d

Traffic Flow: Louisville - Nucor, IN 6.1 cars/day			
<p>Observations: The ABM-generated route requires more time, is less reliable, and is physically longer than the base case route. Again, the cause for the failure of the ABM to improve on the base case is that the ABM does not consider block-to-train assignments when calculating block mileage. Rather, the ABM incorporates the assumption that all blocks traverse the shortest series of links between origin and destination. The ABM calculated a lower mileage for the Louisville-Lafayette block than could have been possible. Using the south end of the Monon route through now-abandoned node 144, the distance between Louisville and Nucor via Lafayette is 229 miles. Via Evansville, the distance is 329 miles, hence the ABM's choice of Lafayette as the classification location. This error is the fault of the researcher for not keeping the node and link files up to date, but the issue of the ABM's failure to use assigned train routes to determine block mileage again emerges as a modeling issue.</p>			
Blocks			
Base Case		ABM-Generated Routing	
Louisville-Evansville Evansville-Nucor		Louisville-Lafayette (swap at Evansville) Lafayette-Nucor	
Schedule			
Base Case		ABM-Generated Routing	
R560 1330 DP Louisville 2330 AR Evansville		R560 1330 DP Louisville 2330 AR Evansville	
R590 1600 DP Evansville 2215 AR Nucor		R590 1600 DP Evansville 2359 AR Lafayette	
		J771 1130 DP Lafayette 1609 AR Nucor	
O/D Reliability			
Base Case		ABM-Generated Routing	
77%		71%	
Car Hours, Miles, Handlings			
Base Case		ABM-Generated Routing	
L/C/B Hours	41	L/C/B Hours	67
O/T Hours	39	O/T Hours	39
Miles	329	Miles	387
Class	1	Class	1
Blockswaps	0	Blockswaps	1

Figure 4.3e

<p>Traffic Flow: Nucor, IN - Mt. Vernon, IN 8.5 cars/day (two flows, 6.4 cars/day and 2.1 cars/day)</p>			
<p>Observations: With virtually no change in reliability, trip time and mileage decrease and one handling is eliminated as a result of a new route created by the ABM. The new route calls for southbound traffic at Nucor to be picked up by southbound R591 rather than its northbound counterpart R590. Handled this way, southbound traffic avoids Lafayette yard and the mileage required to get there. The questions of whether Nucor can or will segregate northbound and southbound traffic or whether car release timing is a factor are largely irrelevant because it appears that R590 and R591 perform work at Nucor simultaneously or in short succession. If during switching, R590 makes a block for R591 rather than dragging the tonnage to Lafayette for switching, the trip time savings will likely be achieved.</p>			
Blocks			
Base Case		ABM-Generated Routing	
Nucor-Lafayette Lafayette-Evansville Evansville-Mt. Vernon		Nucor-Evansville Evansville-Mt. Vernon	
Schedule			
Base Case		ABM-Generated Routing	
R590 2230 DP Nucor 2359 AR Lafayette		R591 2300 DP Nucor 0915 AR Evansville	
R591 1830 DP Lafayette 0915 AR Evansville		J734 1130 DP Evansville 1652 AR Mt. Vernon	
J734 1130 DP Evansville 1652 AR Mt. Vernon			
O/D Reliability			
Base Case		ABM-Generated Routing	
68%		69%	
Car Hours, Miles, Handlings			
Base Case		ABM-Generated Routing	
L/C/B Hours	66	L/C/B Hours	37
O/T Hours	16	O/T Hours	20
Miles	246	Miles	188
Class	2	Class	1
Blockswaps	0	Blockswaps	0

Figure 4.3f

<p>Traffic Flow: Decatur, IL - Baltimore 3.6 cars/day</p> <p>Observations: The new route generated by the ABM improves significantly over the base case in trip time, reliability, and handlings. However, both the base case route and the updated route are highly idiosyncratic. The profile of train R594 is unusual among CSXT road-switchers in that it is profiled to make many pre-blocks on its run from Decatur to Danville, including Chicago and Chicago-Eastbound. There is no explanation for why Decatur traffic is not included in this pre-block in the base case. Furthermore, Cayuga is not a yard but a siding and what "classification" could go on there would have to be done by R594 or J706. Once picked up by J706, the traffic logically proceeds in the base case. The new route utilizes R594's profiled pre-blocks, but becomes inexplicable east of Chicago, save for the consideration that the route might be the result of a heuristic work-around of a capacity constraint of some sort. New Castle and Demmler do not have major classification capability, and carrying a through car on local B712 makes little sense.</p>	
Blocks	
<p>Base Case</p> <p>Decatur-Cayuga Cayuga-Danville Danville-Chicago Chicago-Cumberland Cumberland-Baltimore</p>	<p>ABM-Generated Routing</p> <p>Decatur-Chicago (swap at Cayuga) Chicago-New Castle New Castle-Demmler Demmler-Baltimore (swap at Cumberland)</p>
Schedule	
<p>Base Case</p> <p>R594 2120 DP Decatur 2230 AR Cayuga</p> <p>J706 1209 DP Cayuga 1430 AR Danville</p> <p>R592 0915 DP Danville 1300 AR Chicago</p> <p>Q384 0700 DP Chicago 1230 AR Cumberland</p> <p>Q378 0115 DP Cumberland 0930 AR Baltimore</p>	<p>ABM-Generated Routing</p> <p>R594 2120 DP Decatur 2230 AR Cayuga</p> <p>R592 0730 DP Cayuga 1300 AR Chicago</p> <p>Q384 0700 DP Chicago 2312 AR New Castle</p> <p>B712 1800 DP New Castle 2158 AR Demmler</p> <p>R352 0445 DP Demmler 1245 AR Cumberland</p> <p>R346 0700 DP Cumberland 1500 AR Baltimore</p>
O/D Reliability	
<p>Base Case</p> <p>45%</p>	<p>ABM-Generated Routing</p> <p>67%</p>
Car Hours, Miles, Handlings	
<p>Base Case</p> <p>L/C/B Hours 186 O/T Hours 25 Miles 1038 Class 4 Blockswaps 0</p>	<p>ABM-Generated Routing</p> <p>L/C/B Hours 155 O/T Hours 25 Miles 1034 Class 3 Blockswaps 2</p>

Figures 4.3a-4.3f would be well subtitled "A Comedy of Errors", as the individual O/D flows described there demonstrate the wide range of circumstances that can arise when the parameters and data driving a decision support system are not adequately verified. However, before the results are tossed out summarily, it should be noted that approximately 82% of the savings generated by the ABM-Generated Routing strategy are derived from car mile reductions. In no error case described above would mileage reductions be negated if the base case route were used over the ABM-Generated route. This is the case for the majority of the problems with this strategy. The problem of unsanctioned blocks in the file, by far the most widespread problem, is of the general form that legitimate blocks from A to B and B to C have been illegitimately combined to form an A to C block, often with a blockswap at B. The result of eradicating this problem: extra hours and handlings, but no extra miles.

Thus, this first run of the ABM to generate classification tables provides a caution but not a deterrent to use of the general method. But what about the network-level savings? How many flows are affected by the problem? It is impossible to tell without examining every flow, but a reasonable estimate can be made from looking at aggregate statistics on the ABM-Car Routing strategy's effects on all traffic flows.

Figure 4.4 presents a tally of the effects of ABM-Generated Routing on individual traffic flows. If a traffic flow appears in the "Faster trip time > 1 day" row, then its ABM-Generated Routing trip time was more than one day faster than its base case trip time, and so on. The figure shows that although almost 10% of traffic flows experienced trip time changes of one day or more, very few traffic flows experience major changes in O/D reliability. More minor performance changes, especially to O/D reliability, are masked somewhat by the broad central boundaries in this CSXT standard scenario comparison report.

Even if every car which gained a day or more as a result of an ABM-Generated route rode on an invalid block, and if every car was forced to undergo an additional classification and 20 extra hours of O/D trip time, aggregate handlings would still decrease, and aggregate car hours would break even. The strategy would still produce more than \$14 million annually in car mile savings. While the errors might seem glaring, they are far from fatal, suggesting that examining other concerns regarding the unbridled use of decision support systems are in order.

Figure 4.4: Trip Time and Reliability Scenario Comparison Report for the Base Case and ABM-Generated Routing Strategy

CSX TRANSPORTATION
OD SUMMARY REPORT

	MORE RELIABLE > 25% +/- 1 DAY	SAME RELIABILITY +/- 25% +/- 1 DAY	LESS RELIABLE < 25 % +/- 1 DAY
FASTER TRIP TIME < 1 DAY	25 OD PAIRS	633 OD PAIRS	4 OD PAIRS
	12 CARS/DAY	420 CARS/DAY	1 CARS/DAY
SAME TRIP TIME +/- 1 DAY	9 OD PAIRS	7661 OD PAIRS	12 OD PAIRS
	7 CARS/DAY	7432 CARS/DAY	5 CARS/DAY
SLOWER TRIP TIME > 1 DAY	2 OD PAIRS	399 OD PAIRS	41 OD PAIRS
	0 CARS/DAY	268 CARS/DAY	21 CARS/DAY

One concern regarding use of the ABM to generate car-to-block assignments is that classification would be shifted to yards which have superior PMAKE functions but no physical capacity to handle the surge in classification requirements. Figure 4.5 shows the yards whose volume increased the most between the base case and the ABM-Generated Blocking strategy.

Figure 4.5: Classification Volume Increases due to the ABM-Generated Routing Strategy

Node	City	State	Classifications, Base Case	Classifications ABM-Generated Routing	Increase
237	New Castle	PA	27	100.1	73.1
351	Demmler	PA	21.5	84.4	62.9
495	Erwin	TN	96.2	144.1	47.9
174	Vincennes	IN	5.6	46.6	41
173	Lawrenceville	IL	1.8	39.5	37.7
780	Augusta	GA	6.4	40.8	34.4
499	Bostic	NC	12.9	40.7	27.8
782	Greenwood	SC	79	106	27
320	Jessup	MD	0	26.6	26.6
493	Kingsport	TN	0	21.9	21.9
458	East Bernstadt	KY	0	21.2	21.2
650	Montgomery	AL	166.9	186.3	19.4

It is unfortunately true that the yards experiencing the greatest increases in classification volume are small yards, or even groups of customer sidings. In another

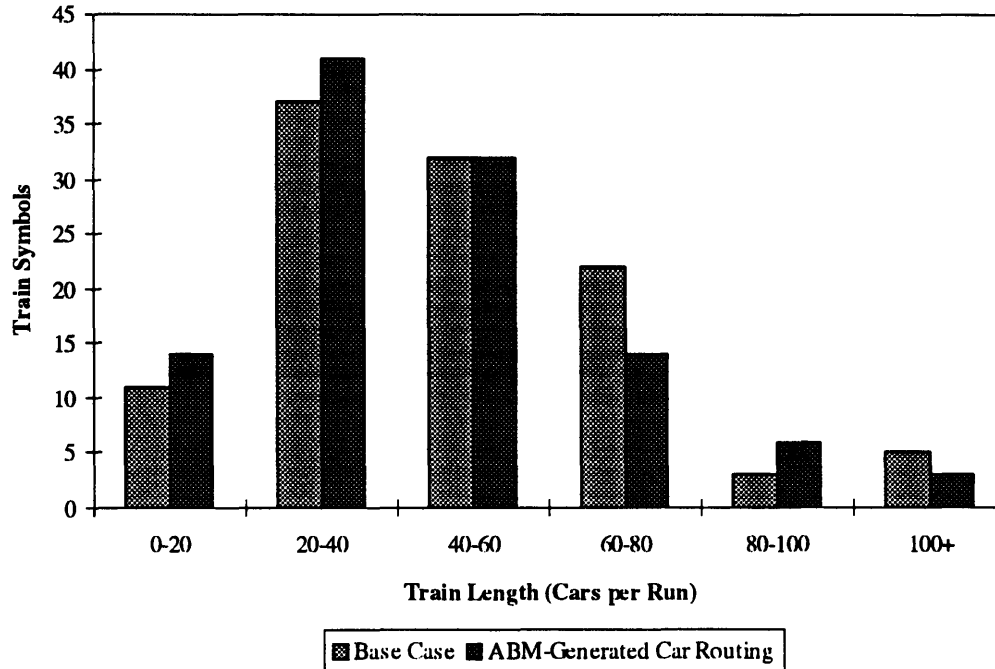
correctable oversight, no yards were considered off-limits to classification, and if local blocks were directed to those yards from two directions, an ad-hoc through route was created with a classification point in the center. The ABM indiscriminately located classification activity at such points in a further attempt to reduce car hours, miles, or handlings.

Like the errors that arose in individual flows, redemption for this error is available as well. Those yards with the largest increases in classification volume tell a more strategic story about traffic flow. In particular, the swelling of activity at Vincennes and Lawrenceville indicates that traffic originating on the Chicago-Nashville does not, because of mileage costs, want to go to Louisville. New Castle and Demmler probably tell a similar story having to do with time or mileage costs, but the details remain unclear even after examining the Decatur-Baltimore traffic flow. Bostic, Greenwood, and Augusta indicate that more merchandise traffic wants to move on the Clinchfield railroad through western North Carolina, probably also for mileage reasons.

Some of these recommendations will be beneficial, while others will not. A new block from Evansville to St. Louis would probably alleviate the demands on Vincennes and Lawrenceville, and save additional handlings as well. On the other hand, the Clinchfield is mountainous, slow, and challenging to operate, and this physical geography imposes additional operating costs of motive power, crews, and track maintenance. Yet, additional car mile costs associated with the Clinchfield that would have counteracted the mileage-saving incentive to flow cars over the route were not included in the link file, again purely an oversight.

Finally, the concern that ignoring block volume constraints would create severe, immediate shifts and imbalances in train tonnage was not supported by train length data. In fact, generating car-to-block assignments using the ABM actually had a very slight moderating effect on train lengths. Figure 4.N4 shows a graph of all trains whose length changed by more than five cars per run between the base case and the ABM-Generated Routing operating plan. In the base case, five trains average more than 100 cars per day, while the ABM-Generated Routing operating plan calls for only three such trains. The most overloaded train links in the ABM-Generated Routing case are on Q648 between Nashville and Evansville, 125 cars per day, and Evansville and Chicago, 137 cars per day. Several alternate trains on these segments have available capacity to absorb excess traffic from Q648.

Figure 4.5: Train Length per Run in the Base Case and ABM-Generated Routing Operating Plans*



4.1.3 Implementation issues

Two barriers stand in the way of immediate implementation of the ABM-Generated Routing strategy:

- Data anomalies in the base case and the models cause the ABM to generate car routes that do not conform to real-world conditions.
- At the time this research was performed, an interface between the ABM and real-time control systems was in the earliest developmental stages.

Removal of these barriers will require concerted effort and interdepartmental cooperation at CSXT. The model itself is maintained by CSXT's Operations Research Group and OR Technology Support, but its success as a decision support tool depends on factors outside the purview of Operations Research:

- Network cost data was originally formatted for the ABM as a one-time project, but if the ABM is to be used to generate classification tables regularly, costs should be regularly updated. Network cost data is generated by CSXT's Cost & Economic Analysis group. A simple interface to C&EA databases would be a

* Only trains whose length changed by more than five cars between the two cases are represented in the graph.

straightforward programming project, but would first require a common understanding of the meaning and use of cost information. A more challenging project would be the creation of a series of expected or desired costs to drive the model.

- Currently, the cost of traversal of a link is based on link mileage alone, and difficult operating conditions such as helper districts or capacity constraints are not considered. Recognition of such constraints is important to the ABM's ability to generate dependable results. Identification and quantification of these constraints by CSXT's Service Planning and Transportation departments is a necessary part of the calibration effort.
- Operating plan data used by the model must be verified for accuracy and completeness by Service Planning before the ABM can be used to route cars over the network. Specifically, general agreement that blocks and block-to-train assignments reflect reality is needed.
- As the operating plan is represented differently in CSXT's real-time control systems than in the ABM, consultation between Service Planning, the maintainers of the real-time control systems, and OR Technology Support is necessary to create a quick means of translating ABM-generated classification tables to real-time systems.

If the ABM is to be an effective car routing tool, commitment on the part of several CSXT groups is needed. It is not unreasonable to assume, however, that several months of intensive effort by a team assembled for the purpose of preparing the ABM could accomplish the necessary tasks. From that point forward, the ABM could have an immediate impact on car routing and operating costs. Continuing efforts to maintain calibration would be required, but would be minimal compared to the initial period of activity.

Even after classification tables were regularly generated by the ABM, alteration of other elements of the operating plan would provide a continuing role for the ABM. For instance, no block destinations were altered in this analysis. Substitution of alternative block destinations may provide additional car handling, time, or mileage savings, and the ABM could provide analytical support for such changes.

In the long term, modeling problems inherent in the ABM will necessitate development of a new decision support system. While several of these problems can be overcome through model calibration efforts, other problems will forever impede the ABM from being used "worry-free" for car route development. These include the ABM's inability to calculate block mileage based on train mileage and inability to calculate connection time in a yard based on schedules of the connecting trains, and the lack of a direct linkage to real-time control systems for input file generation as well as translation of model output.

As an example of additional changes that could be accomplished with a new decision support system, consider the case where average yard time is estimated based on scheduled connections rather than merely estimated from PMAKE functions. For many O/D pairs, there are several routes which have equivalent mileage and classifications. Classifications, however, take place at different yards and involve different train-to-train connections. If classification time is determined solely by the average yard time implied by a yard's PMAKE function, then all cars on a route will be routed via the yard with the lowest average yard time, regardless of the timing of the connection at that yard. If estimates of connection time are instead based on scheduled train-to-train connection times, traffic will be distributed between yards and trains recognizing both yard processing capability and connection timing in a way that minimizes excess dwell time caused when connection time exceeds time required for classification.

4.1.4 Conclusions for the ABM-Generated Routing Strategy

The ABM should be used to generate classification tables for two reasons. First, using the ABM to generate classification tables appears to result in moderate annual cost savings, primarily in the form of car mile reductions, but with additional savings from car hour and handling reductions. Second, using the ABM to generate classification tables would be an important first step towards full use of decision support tools for service design.

Investigation of the ABM's effects on individual traffic flows calls many routes into question, as faulty data creates blocks and classification points whose existence no CSXT service planner would vouch for. Yet, discoveries of faulty data don't indict the major portion of the savings generated by the strategy, nor the ABM itself. They merely suggest that the appropriate next step is not to attempt to implement the ABM's current recommendations. In the short term, the costs, distances, blocks, and trains that the ABM considers as it flows traffic over the network should be policed, while a simple interface between the ABM and real time control systems is built. A period of use of the ABM to generate classification tables could follow after these steps have been taken.

In the long term, modeling issues will have to be addressed, such as the ABM's inability to value reliable service and inability to use train routes and train-to-train connection times as the bases for block mileage and yard time estimates. To incorporate such changes in the ABM would require a major overhaul. In the long term, creation of a new decision support system which performs the same functions as the ABM but is more integrally linked with CSXT's real time block, train, and cost information would be superior to continuing with the ABM platform.

Short-term data verification and long-term adoption of advanced decision support for operating plan development will be effort-intensive measures requiring input from Service Design, Operations Research, Cost & Economic Analysis, and Transportation. Only the committed attention of representatives of all these groups will cause decision support tools to contribute tangible savings to CSXT's merchandise operations.

4.2 Improved Yard Performance

4.2.1 Description

The Terminal Complex strategy demonstrated that expedited yard processing played a significant role in reducing trip time. In response to this finding, the Improved Yard Performance strategy was devised to investigate the effect of improved processing performance, modeled using PMAKE functions as in the Terminal Complex strategy, independent of other possible changes to the operating plan. If the benefits of expedited yard processing were found to be comparable to the those shown by the Terminal Complex strategy then the complexity, maintenance effort, and performance requirements of the Terminal Complex operating plan could be avoided without sacrificing benefits.

The models used in this analysis are not intended to indicate what changes to yard operations are needed to raise performance to benchmark levels. Rather, they demonstrate the impacts of improved yard performance on operating costs and reliability. Therefore the scope of the investigation of the Improved Yard Performance strategy will be limited to an estimation of the benefits to reliability and car time that improved yard performance would be expected to yield.

To create a hypothetical operating plan representing the Improved Yard Performance strategy, two changes was made to the base case operating plan. Two sets of improved PMAKE parameters were substituted for the base case parameters at Nashville. "B" parameters were intended to represent above-average performance, while "A" parameters represented benchmark performance at Nashville. Figure 4.6 lists base case, "B", and "A" parameters used at Nashville.

Figure 4.6: PMAKE Parameters Used at Nashville

Strategy	T50	T90	PMAX
Base Case	18	8	100
Improved Yard Performance "B"	10	0	100
Improved Yard Performance "A"	6	4	100

Nashville's new PMAKE functions were derived from two sources. The "A" parameters were adapted from benchmark PMAKE parameters compiled in AAR/MIT Working Paper 94-3, *Benchmarks for Hump Yard Performance*, and originally were to be the only parameters examined. Upon consultation with Larry Shughart and Dharma Acharya of CSXT Operations Research, "B" parameters were created to represent a ten-hour cutoff for all train-to-train connections at Nashville. A ten-hour cutoff was thought to be a more reasonable goal, as it was half of the base case cutoff time and would itself cause a significant improvement in processing performance and reduction in car time spent at Nashville. The benchmark PMAKE parameters, it was thought, were unreasonable because attainment would require cars to move early whenever possible, eroding right-car/right-train discipline [see Section 4.2.3].

No car routes or train schedules were altered in the Improved Yard Performance operating plans. It was important to the researchers to be able to attribute performance changes strictly to changes in yard processing performance, rather than to a different mix of train-to-train connections which may have added or removed excess dwell time.

4.2.2 Changes in Performance

The only changes in performance that occurred as a result of the Improved Yard Performance strategy were reductions in time spent at Nashville. Because of Nashville's improved processing capability, some traffic was able to depart on earlier trains in the Improved Yard Performance operating plan than in the base case. Because no car routes were regenerated and no train schedules were slid, no changes in car miles or handlings were noted. Figure 4.7 shows the Improved Yard Performance strategy's effects on performance, and Figure 4.8 translates performance changes to annual cost savings.

Figure 4.7: Performance Changes due to Improved Yard Performance at Nashville

Strategy	Average Dock-Dock Trip Time	% of Cars Arriving Within +/- 24 Hours of Average	Car Hours Saved Per Day
Base Case	123 Hrs.	80 %	0
Improved Yard Performance "A"	116 Hrs.	81 %	10610
Improved Yard Performance "B"	119 Hrs.	83 %	5582

Figure 4.8: Annual Cost Savings due to Improved Yard Performance

	Improved Yard Performance "A"		Improved Yard Performance "B"	
	Targeted Traffic Only	Extrapolation to Entire Network	Targeted Traffic Only	Extrapolation to Entire Network
Annual Value of Saved Car Hours	\$2.9 M	\$16.7 M	\$1.5 M	\$8.8 M

Figures rounded.

Interpretation of car hour savings attributable to Improved Yard Performance should be discussed. In the modeling environment, traffic is distributed across a set of possible connections at Nashville and all yards according to PMAKE parameters. As PMAKE parameters improve, two forces are at work. First, less traffic misses connections and moves on later trains, thus tightening yard time distributions by eliminating peaks to the right of the first-connection peak. Second, tight connections which originally were unavailable are made in a small but increasing percentage of trials, decreasing trip time, but also spreading yard time distributions by moving some traffic to the left of the previous first-connection peak. Thus most traffic classified at the improving yard will experience one of the two effects as a result of improvements in PMAKE.

The yard time distributions parameterized by PMAKE accurately represent actual yard time distributions, but do not necessarily represent the wishes of service planners or the car scheduling system. Train-to-train connections embedded in car schedules are determined by cutoffs at each yard. For any car at any yard, if the time between arrival of Train A and departure of Train B on day 1 is less than the cutoff, then the car will be scheduled to connect from Train A of day 1 to Train B of day 1. Otherwise, the car will be scheduled between Train A of day 1 and Train B of day 2. In the planning environment in which car schedules are created and compared, regardless of the actual cutoff and train-to-train connection times, no cars move early and no cars move late, implying the absence of a distribution to yard time for individual traffic flows.

Correspondence between car hours saved in a modeling environment incorporating yard time distributions and car hours saved in a planning environment lacking distributions can be assumed. This is because, in the modeling environment, the spread of each individual flow's yard time distribution is determined by the T90 parameter, while the total time spent by all cars in the yard is determined by the T50 parameter. As T90 decreases, time saved by making early connections and time lost by avoiding late connections decreases in approximately equal proportion, with no net effect on average yard time. As T50 decreases, time saved by making early connections increases, while time lost by avoiding late connections decreases, both effects decreasing average yard time.

The difference between the modeling environment and the car scheduling environment is that the decrease in average yard time is allocated to different sets of traffic. In the modeling environment a drop in T50 causes all cars' yard time distributions to shift slightly to the left. In the car scheduling environment, the same drop in average yard time and total car hours spent in the yard would be allocated to a small subset of traffic flows. The set of improving flows would include all flows whose previous first- or second-connection time was shorter than the old cutoff, but longer than the new cutoff. Therefore, while car hours saved by the Improved Yard Performance strategy are dependable, improvement to individual traffic flows will not correspond to improvements in car schedules generated using cutoffs. In the car scheduling environment, 24% or 62% of all cars could be scheduled 24 hours earlier if yard performance matched the "B" or "A" parameters respectively.

Unlike the other strategies, the Improved Yard Performance strategy caused no traffic to move more slowly. At worst, traffic would advance to an earlier train at Nashville, then drop back to its original schedule at a downstream yard because no earlier train was available there. At best, gains made at Nashville carried through to the destination and total trip time was reduced. Figures 4.9a-4.9c demonstrates examples of traffic flows affected by the Improved Yard Performance Strategy.

Figures 4.9a-4.9c: Changes in Performance of Individual Traffic Flows due to the Improved Yard Performance Strategy

Traffic Flow: Mt. Vernon, IN - Memphis, TN (SSW) 0.2 cars/day		
<p>Observations: This flow's average trip time decreases by approximately 10 hours due to improved processing performance at Nashville. In all strategies, 23'30" is available between R591 and Q535, while 16'30" is available between R557 and Q535. In the base case, these two AVAIL times would lead to probabilities of making the first connection of .78 between R591 and Q535 and .43 between R557 and Q535. In both of the improved cases, the probability of connecting from either R591 or R557 to the first Q535 is 1. The reason for the slight drop in reliability that accompanies the improvement in trip time is not immediately apparent, but could result from interaction between the arrival and final yard distributions and the yard time distributions at Nashville.</p>		
Blocks		
Mt. Vernon-Evansville Evansville-Nashville Nashville-Memphis (SSW)		
Schedule		
<p>J734 1707 DP Mt. Vernon 2230 AR Evansville</p> <p>R591 R557 1600 2300 DP Evansville 0115 0815 AR Nashville</p> <p>Q535 0045 DP Nashville 1530 AR Memphis (SSW)</p>		
O/D Reliability		
Base Case	Improved Yard Perf. "A"	Improved Yard Perf. "B"
80%	78%	78%
Car Hours		
Base Case	Improved Yard Perf. "A"	Improved Yard Perf. "B"
L/C/B Hours 71	L/C/B Hours 61	L/C/B Hours 61
O/T Hours 23	O/T Hours 23	O/T Hours 23
Miles 403	Class 2	Blockswaps 0

Figure 4.9b

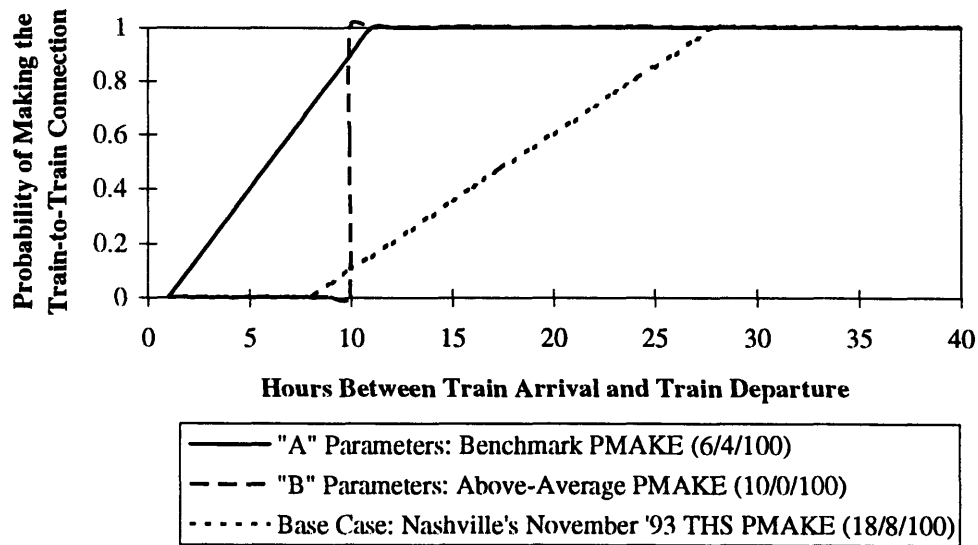
Traffic Flow: Chicago-Bruceton, TN 0.7 cars/day (two flows, 0.2 cars/day and 0.5 cars/day)		
Observations: This flow improved only when Nashville performed at the "A" parameter level. Only five hours is available between Q595's arrival and R533's departure. Therefore, in both the base case and with the "B" parameters, no traffic ever connects from Q595 to the first R533, but all traffic connects to the second R533. With the "A" parameters, however, 5 hours of AVAIL time lead to a probability of .4 that a connection is made to the first R533, with remaining traffic connecting to the second R533. Although average trip time decreases by nine hours with the "A" parameters, reliability drops because the flow's yard time distribution changes from having a single peak at 29 hours to having two peaks at 5 and 29 hours.		
Blocks Chicago-Nashville Nashville-Bruceton		
Schedule Q595 0330 DP Chicago 0430 AR Nashville R533 0930 DP Nashville 0330 AR Memphis		
O/D Reliability		
Base Case 66% 88%	Improved Yard Perf. "A" 61% 84%	Improved Yard Perf. "B" 65% 92%
Car Hours		
Base Case L/C/B Hours 64 64 O/T Hours 53 33	Improved Yard Perf. "A" L/C/B Hours 55 55 O/T Hours 53 33	Improved Yard Perf. "B" L/C/B Hours 64 64 O/T Hours 53 33
Miles 571	Class 1	Blockswaps 0

Figure 4.9c

Traffic Flow: Port Huron, MI - Memphis 2.0 cars/day		
<p>Observations: This traffic flow improves slightly with "B" parameters, and experiences greater improvement with "A" parameters. Only three hours are available between R573 and R533, forcing traffic in the base case to connect to the second R533 (29 hours) with probability of .95 and to the third R533 (53 hours) with probability .05. The "B" parameters eliminate the connection to the third R533, and average trip time consequently decreases by one hour. The "A" parameters create a probability of .2 that the traffic connects to the first R533, with remaining traffic again connecting to the second R533. Reliability is improved between the base case and the "B" parameters, as all traffic makes a single connection. Like the base case, the "A" parameters cause the flow to have a two-peaked distribution at Nashville, with equivalent effects on reliability. Because the flow undergoes three handlings and two blockswaps between origin and destination, the overall effect on reliability of improved performance at Nashville is minor.</p>		
Blocks		
Port Huron-Flint Flint-Louisville (swaps at Walbridge and Cincinnati) Louisville-Nashville Nashville-Memphis		
Schedule (Read down, then across)		
R331 0648 DP Port Huron 0930 AR Flint	Q517 1030 DP Walbridge 2015 AR Cincinnati	R573 2000 DP Louisville 0600 AR Nashville
Q513 0245 DP Flint 1130 AR Walbridge	R519 0200 DP Cincinnati 1100 AR Louisville	R533 0930 DP Nashville 0330 AR Memphis
O/D Reliability		
Base Case 68%	Improved Yard Perf. "A" 68%	Improved Yard Perf. "B" 72%
Car Hours		
Base Case L/C/B Hours 172 O/T Hours 19 Miles 945	Improved Yard Perf. "A" L/C/B Hours 166 O/T Hours 19 Class 3	Improved Yard Perf. "B" L/C/B Hours 171 O/T Hours 19 Blockswaps 2

A not unexpected finding at the network level and for individual traffic flows is that the "B" parameters produced greater reliability than the "A" parameters, by 83% vs. 81% of network traffic arriving in a two-day window. This is due to the fact that yard distributions for each traffic flow are modeled according to the yard's PMAKE function. If a yard's PMAKE function has a flat slope, as indicated by a high T90 value, the yard time distribution for traffic processed there will take on a wider spread. Among the modeled parameter sets, the base case parameters include the highest T90 value and on average yield the widest distributions, followed by the "A" parameters, and then the "B" parameters, which do not create distributions for individual traffic flows because T90 is 0. Figure 4.10 graphically illustrates the PMAKE functions, showing the slopes of the base case and "A" parameters and the non-sloped cutoff of the "B" parameters.

Figure 4.10: PMAKE Functions Used in Modeling the Improved Yard Performance Strategy



In the modeling environment, the effects of the individual PMAKE functions on yard time distributions are influenced both by T90 and by train-to-train connection times. The base case PMAKE function will produce a single-peaked distribution for a traffic flow if the first outbound train is daily and departs Nashville between four and eight hours after the inbound train arrives. If connection time is less than four hours, then processing time will be less than $(T50+T90) * 1.1 = 28$ hours, and some traffic will miss the second outbound train, spreading the distribution to the right. However, if connection time is greater than eight hours, then some traffic will make the first outbound train, spreading the distribution to the left. The "A" parameters will produce a spread distribution for a traffic flow if the time between arrival and first departure is between two and eleven hours, while the "B" parameters produce no spread distributions.

Although not illustrated by the example flows in Figure 4.9, one issue that arose in assessing the results was that earlier movement from Nashville might cause some traffic to dwell longer at a downstream yard due to less than daily train service at that yard, or avoid excess dwell time for the same reason. If lengthened downstream dwells were more prevalent than shortened downstream dwells, then trip savings achieved at Nashville would be eroded at the network level, and vice versa. Modeling the Improved Yard Performance strategy demonstrated that, at the network level, trip time savings achieved at Nashville were neither enhanced nor eroded by the effects of non-daily train service at other locations. Figure 4.11 demonstrates the similarity between car hours saved at Nashville and throughout the network.

Figure 4.11: Car Hours Savings at Nashville and Throughout the Network

Strategy	Average Yard Time, All Traffic	Average Yard Time, Through-Classified Traffic Only	Daily Car Hour Reduction at Nashville	Daily Car Hour Reduction over Entire Network
Base Case	26.5 Hrs.	29.7 Hrs.	0 Hrs.	0 Hrs.
Improved Yard Perf. "A"	16.0 Hrs.	17.5 Hrs.	10,584 Hrs.	10,610 Hrs.
Improved Yard Perf. "B"	21.1 Hrs.	23.7 Hrs.	5,527 Hrs.	5,582 Hrs.

As T50 approximates average processing time, average yard time data in Figure 4.11 indirectly demonstrate that cars will dwell at Nashville around 12 hours longer than required for processing regardless of the yard performance level, with some variation. A yard time exactly 12 hours longer than required for processing at all performance levels implies a uniform distribution of train-to-train connection times. Differences in yard time beyond those which can be explained by variations in processing capability imply that more connections fall in some time buckets than in others during a 24-hour period.

In the absence of individual train schedules and connection volumes, a simple model for determining average yard time may be used. If T50 represents the time required for classification, then:

$$\text{AVG. YARD TIME} = \text{T50} + \text{SLACK TIME}^*$$

For each set of PMAKE parameters used in this analysis, solving the equation above for slack time yields a result near 12 hours. In the base case, T50 = 18 and average yard time is 29.7 hours, yielding slack time of 11.7 hours. Using the "A" parameters, T50 = 6, average yard time is 17.5 hours, and slack time is 11.5 hours. Using the "B" parameters, average yard time and slack time increase slightly. T50 = 10, average yard time is approximately 23.7 hours, yielding slack time of 13.7 hours.

These results suggest that the number of first possible connections in the 6-hour to 10-hour time bucket is slightly greater than in other time buckets, with implications for the "A" and "B" parameter settings used in this analysis. The longer slack time demonstrated by the "B" parameters suggests that improving processing to a point where T50 = 10 would not be fully effective given the base case train schedules. In other words, improvements in processing speed up to the "B" level would be rewarded with less than proportionate decreases in car hours spent at Nashville. An eight-hour decrease in T50 from the base case to the "B" level causes only a 6-hour decrease in average yard time given the base case schedules. On the other hand, improvement to the "A" level causes a

* Slack time is yard dwell time beyond that required for processing.

slightly greater than proportionate decrease in yard time, as a 12-hour decrease in T50 from the base case to the "A" level causes a 12.2 hour decrease in average yard time given the base case schedules.

These results suggest an important relationship between processing performance and train schedules into and out of a yard. Decreases in time required for processing will yield scant results if no connections are scheduled during the time bucket which benefits from the change. Whether it is possible to slide train schedules to increase the effectiveness of an improvement in processing performance is not known, as previous efforts have given conflicting results.

4.2.3 Implementation Issues

That traffic connects to earlier outbound trains if processing performance improves is almost a non-issue in the evaluation of the Improved Yard Performance strategy. By far the largest issues in assessing the promise of the Improved Yard Performance strategy concern the cost of achieving a level of performance, the implications of "benchmark performance" as represented by PMAKE functions on car schedule adherence, and the long-term influences of yard performance on car routing and train scheduling.

4.2.3.1 Resources Required to Change Performance

The benefits that would result from improving processing performance at Nashville are known, while the costs of attaining the increased levels of performance assumed in this analysis remain unknown. It is beyond the scope of this research to engage in the simulation of Nashville yard necessary to determine what if any resource increases would be required to achieve the assumed levels of performance. However, because the yard classification plan at Nashville is central to assumptions of processing performance and car time savings, a consideration of aggregate Nashville yard resources is in order.

Dong (1994:2) reported that during the Nashville yard study period in September 1993, typical staffing levels called for four to five inbound inspectors, one to two hump crews, three to four assembly crews, and four to six outbound inspectors on each shift. These figures are consistent with the transportation budget for the period, which also called for roughly two hostlers, two retarder operators, three clerks, three utility men, and four yardmasters per shift.

For all of 1993, labor and fringe outlays for all transportation employees at Nashville totaled \$11,400,000. At \$0.75 per car hour, the "B" parameters saved \$1,528,000 annually at Nashville, or 13% of total transportation labor and fringe costs, while the "A" parameters saved \$2,900,000 annually, or 25% of transportation labor and fringe costs. If transportation staffing at Nashville was increased due to the desire to improve performance, a net savings would still result if transportation labor costs increased by less than 13% for "B" performance and 25% for "A" performance.

Although other major sources of cost are ignored, the data point represented by transportation labor costs puts car time savings achieved by Improved Yard Performance at Nashville in perspective. For example, if car hire costs consumed at the yard were proportionately greater than staffing costs at the yard, one could conclude using only financial data that queues caused by inadequate staffing were driving yard times up. In terms of economic production theory, the capital/labor ratio would be too high. In this case, if car time savings due to improved performance could pay for, say, up to a 75% increase in transportation labor, little further analysis would be required to back up a recommendation that resources be added at Nashville until yard times decreased.

But because car time savings due to Improved Yard Performance appear to justify relatively small increases in yard resources, then focus on the means of achieving improved performance should turn to better utilization of present resources. Duffy (1994) found that cars processed at Nashville incurred major wait times between arrival and inspection, inspection and humping, humping and assembly, assembly and inspection, and inspection and departure. Average time spent waiting between processes excluding time spent in the bowl was approximately equal to average time required for yard processing. These findings suggest that significant yard time decreases can be achieved merely by more effective work scheduling within the yard.

At the planning level, a shift in focus from *scheduling work to fit the available resources* to *scheduling resources to fit the required work* would be a useful first step toward eliminating intraprocess wait times. At the hour-to-hour level, decision support for matching inspectors and crews to tasks would increase the effectiveness of work hours already committed. Decision-support tools of this type have been envisioned both within the CSXT Operations Group and at MIT by Dong (1994:1) and Armacost (1995).

4.2.3.2 Yard Throughput vs. Car Schedule Adherence

Larry Shughart of CSXT Operations Research once made the point that, by itself, lowering average yard time was a misguided goal. Yard managers, he argued, well knew how to decrease average yard time—by "hemorrhaging" traffic from the yard on the next available outbound train in the right general direction, regardless of whether additional downstream classification would result from the action.

In light of the negative consequences of this practice, CSXT has focused on a measure made possible by the advent of the car scheduling system. The "right-car-right-train" measure compares a car's schedule and its actual movement through a yard. A car scheduled into Nashville, for example, on Q595 of the 13th and out of the yard on R533 of the 14th, would have to follow that exact path in order to be considered a "make". If the car missed its connection and departed Nashville on R533 of the 15th, the result would be an obvious miss. But if Q595 arrived in Nashville 7 hours early, and the car departed on R533 of the 13th, this would also be a miss, as R533 would have departed Nashville with different cars, and possibly more cars, than downstream managers could anticipate by examining car schedules and advance lineups. Advanced cars obviously do not always create problems at downstream yards and pickup points, and may help yard operations if

the effect of advancement is to moderate peak loads. However, advancement at the discretion of individual yard managers erodes the effectiveness of centralized control over train and yard volumes and power movements.

To some extent, achievement of benchmark performance as represented by the "A" parameters is predicated on the idea that cars should depart Nashville on the right train symbol and in the right block, but that early departure is at least as good if not better than scheduled departure, if the scheduled departure is not the first possible. If time between scheduled arrival and first possible departure is greater than 10 hours, the "A" and "B" parameters will produce identically perfect connection performance, given $P_{MAX} = 100$. What differentiates the "A" parameters from the "B" parameters used in the study is that, when first possible connection time is less than 10 hours, the "A" parameters provide for a probability between 0 and 1 that cars make the first possible connection, and distribute trip time accordingly, while "B" parameters cause the traffic to connect to the following train. The necessity of advancing traffic to first possible connections suggests that "A" level performance and 100% right car/right train performance may be incompatible where traffic has first possible connections of less than 10 hours.

Using the above example, if the yard were performing at the benchmark, "A" parameter level, it would be expected that on "good days" (subject to some definition related to train performance) some traffic would depart on the same-day R533, but on "bad days" that same traffic would depart on the following day's R533. Conversely, in order to attain performance whose representative P_{MAKE} parameters were the "A" parameters, yard managers would have to take every opportunity to advance traffic whose first possible connection times were less than 10 hours. This forces a choice between the adherence to cars' original schedules necessary for right car/right train performance and maintaining a single cutoff at the yard for all connections, rather than a yard cutoff for each connection.

Although cutoffs for individual connections could theoretically reconcile the drive for "A" level yard performance and the drive for 100% right car/right train performance, to maintain cutoffs for individual connections increases information processing requirements exponentially, and accuracy has been shown to be extremely difficult to maintain, even when train schedules and yard performance change relatively infrequently.

A uniform ten-hour cutoff has often been cited as an ambitious but attainable goal for Nashville, whose cutoff for most connections in November 1993 when the base case P_{MAKE} parameters were calibrated was 20 hours. Assuming adequate yard crew, road power and road crew levels, achieving performance equivalent to a ten-hour cutoff could happen through attention to simple rules, such as ensuring that all trains are humped no more than four hours after arrival, and no trains are assembled more than six hours before departure. Significantly, these rules do not call for dangerously quick activity within the yard, as they are consistent with the inspection, hump, and assembly times measured for the Nashville yard study. Achievement of this goal seems to be more a matter of resource scheduling and elimination of interprocess dwell times than actually speeding up

inspection, humping, or assembly. Without advancing traffic, "B" level performance could be achieved, with moderate car hour savings.

However, if car hour savings commensurate with "A" performance are to be achieved while yard managers attend to right car/right train performance, then the representative PMAKE parameters are 6/0/100, representing a uniform six-hour cutoff, and not 6/4/100, representing a ten-hour cutoff with scheduled connections less than 10 hours advanced with probabilities related to scheduled connection time. To put in place a six-hour cutoff appears to be a more complicated task, as the sum of the average inbound inspection, hump, assembly, outbound inspection, and brake test times in the Nashville yard study was more than seven hours. A six-hour cutoff requires that some yard processes simply go faster, over and above the assumption that inspectors and yard engines will be in place to process cars with no interprocess dwell time. Within the constraints represented by these yard process times, "A" level performance and car schedule adherence do not appear to be consistent.

In light of this inconsistency, three options are possible. To alter the right car/right train measure to make early movement acceptable under some circumstances would retreat from corporate efforts emphasizing strict adherence to the operating plan, and might reintroduce the negative effects that the run-to-plan initiative was intended to eliminate. To rule out attaining "A" level yard performance would be an equally bitter pill to swallow. The third option, reorganizing yard operations to drive down the time required for processing, is the least understood and may be the most complicated of the options, but would still be preferable to giving up the emphasis on running to plan or the hope of attaining benchmark-level performance. A first step toward changing yard operations may be a review of inspection procedures. The inbound and outbound inspection processes together account for half of required processing time, and are therefore major sources of potential time savings.

4.2.3.3 Related Changes to the Operating Plan

If steps were taken to improve yard performance at Nashville, a later phase of implementation would involve changes to train schedules and car routings in response to faster processing capability.

Traffic should flow through Nashville if expedited processing there would reduce trip time without imposing major additional mileage costs. Once Nashville's performance demonstrably exceeded that of alternate yards, new car routings forcing traffic through Nashville could be generated quickly using a shortest-path-based decision support tool such as the ABM. The problem to be solved in making such operating plan changes is that routing new traffic via Nashville can cause congestion, negating the benefits of classifying traffic at Nashville that originally drove the operating plan changes.

A better overall option that improving performance at Nashville would be to improve performance at the system yards that perform major through classification activity, including hump yards and large flat yards. If a group of yards improves at roughly the

same rate, the likelihood that traffic will oscillate between routes in successive minimum-path trials will be lessened, and the operating plan changes accompanying such oscillations will be reduced as well.

As noted in discussion of the Terminal Complex [Section 3.2.5] and ABM-Generated Routing [Section 4.1.3] strategies, use of the ABM to generate car routes is not an immediately available option because of model calibration and lack of an interface to live control systems. However, use of the ABM is by no means crucial to reducing car hours through improved yard performance. The need for further work to refine the ABM should not be considered a barrier to immediate action on the Improved Yard Performance strategy.

Choosing the traffic that takes advantage of Nashville's or other yards' fast processing may involve market factors as well as geographic characteristics. As shown in Figure 3.18 [Section 3.2.4], the CSXT blocking network includes many parallel routes between two points which require the same number of classifications. Fast classification at Nashville would likely cause a shortest-path based network model to choose routes via Nashville over similar parallel routes. If Nashville or any high-performance yard becomes overburdened, service contracts or car expense can be used to select a subset of traffic for fast processing.

Train schedules are based in part on yards' ability to process cars. Service planners pursue several goals when writing train schedules, including minimizing meet/pass delays, motive power and crew requirements, and also minimizing trip time by eliminating car time spent in yards over and above the time required for classification. As yard performance improves, the time required for classification drops. Train schedules should change correspondingly, eliminating dwell time rendered excess by the improvement in yard performance subject to the other constraints listed above.

Schedule sliding is not central to the Improved Yard Performance strategy, and its omission will not erode the benefits demonstrated here. But, as for other strategies such as Local Pre-Blocking, schedule sliding seems to be a means of achieving additional benefits, again subject to the considerations of other train scheduling and data quality issues.

4.2.4 Conclusions for the Improved Yard Performance Strategy

The Improved Yard Performance strategy offers modest trip time savings, which would be achieved by rescheduling traffic through the yard one day faster as Nashville's cutoff time decreases. The magnitude of cost savings due to "B" level performance is one-third to one-half that of the Local Pre-Blocking, Terminal Complex, or ABM-Generated Routing Strategies, while cost savings due to "A" level performance are of the same magnitude as ABM-Generated Routing and slightly below the Local Pre-Blocking and Terminal Complex strategies. The Improved Yard Performance strategy is unique among the strategies examined in this thesis in that it caused no increase in trip time, mileage, or handlings for any traffic flow. While other strategies caused both

improvement and deterioration with positive net effects, the Improved Yard Performance strategy caused only improvements.

No system-level operating plan changes such as car routing or train schedule changes are required to implement the Improved Yard Performance strategy. Changes to the Nashville yard operating plan are assumed but not explicitly estimated. Achievement of "B" level performance appears to face few barriers to implementation, as average process times measured in the Nashville yard study (Duffy, 1994) support the claim that a ten-hour cutoff is feasible. The Nashville yard study suggests that the primary issue in decreasing the cutoff at Nashville is scheduling of yard processes and resources to eliminate dwell time before classification and between processes.

In light of the benefits offered by the strategy, the lack of negative impacts to any traffic flow, and the lack of network-level changes that have to be made and monitored, achieving "B" level performance at Nashville should be pursued without delay. As with the other strategies examined in this thesis, full-scale implementation, or immediate adoption of a ten-hour cutoff, is not recommended because understanding of the changes that must take place remains limited. Nevertheless, the option of reducing the cutoff by an hour at a time is readily available and poses no analytical problems from a network perspective.

Changes intended to ultimately provide a means of achieving "A" level performance should be studied as well, and implemented as soon as they are developed. Even if performance has not yet reached the "B" level, improvements in operational efficiency can only help in reaching that intermediate goal.

5 Summary of the Thesis

5.1 Background and Methodology

This thesis has presented research into the effects of operating plan design on railroad performance. The research was motivated by railroads' desire to achieve high service levels for carload traffic, and the recognition that design and execution of the operating plan jointly determine railroad performance. The research has addressed the question: *Is it possible for some or all merchandise traffic to achieve large improvements in trip time and reliability through adoption of a significantly more complex operating plan, which stipulates new roles for some yards and train crews?*

The research examined five alternative operating strategies in detail, applying them to CSX Transportation's Chicago-Nashville corridor. Operating plans embodying each strategy were created for the Chicago-Nashville corridor using manual analysis and the ABM/TSS/SPM family of decision support tools were used to create operating plans embodying each strategy. Alternative plans were then compared to a base case representing CSXT's November 1993 merchandise operating plan. Alternative strategies were evaluated on the following criteria:

- Impact on network performance, including changes in O/D reliability, car hours, car miles, and car handlings. Performance changes experienced by traffic targeted for improvement by each strategy were reported, converted to annual cost savings, and extrapolated to the entire CSXT merchandise network, based on costs of \$0.75 per car hour, \$0.50 per car mile, and \$3.00 per car handling.
- Impacts on performance of individual traffic flows. Positive, indifferent, and negative effects on individual flow performance as well as idiosyncratic flow routings were reported and interpreted.
- Implementation considerations. Plan complexity issues, performance requirements faced by operating officers, and operating plan design and maintenance issues faced by service planners are discussed.

5.2 Discussion of Individual Strategies

Three of the alternative strategies were developed from ideas expressed at an October 1993 meeting between MIT researchers and service design personnel representing CSXT and Burlington Northern. They incorporate unconventional operating concepts, in the hope that new operating paradigms would cause major performance improvements. The strategies attempt to eliminate car handlings in yards, and render remaining yard activity more effective. The strategies would achieve this goal by reorganizing required classification activity across facilities and in time, in an attempt to exploit critical traffic flow densities or unused classification capacity, embodied in both trains and yards.

- **The Local Pre-Blocking strategy** calls for local trains to pre-block originating traffic. Pre-blocked traffic would be blockswapped directly to through trains, avoiding classification at the origin serving yard. Coordination of through and local train schedules ("Schedule Sliding") would eliminate excess dwell time at the origin serving yard, reducing trip times. The strategy's potential to increase local train duty time is a drawback. The Local Pre-Blocking strategy was modeled for 22 trains at nine locations in and near the Chicago-Nashville corridor.

The desired effects of Local Pre-Blocking are demonstrated by the Mt. Vernon, In to Bittering, PA traffic flow, whose trip time decreased from 195 to 187 hours and reliability increased from 56% to 73% as a result of blockswapping at the origin yard and schedule sliding. Overall impacts of Local Pre-Blocking on 461 cars per day are shown in Figure 5.1, and annual cost savings extrapolated to the CSXT network are shown in Figure 5.2. Implementation considerations associated with the Local Pre-Blocking strategy are listed in Figure 5.3.

Figure 5.1: Changes in Trip Time, Reliability, and Activity due to Local Pre-Blocking, With and Without Schedule Sliding

Strategy	Average Dock-Dock Trip Time	% of Cars Arriving Within +/- 24 Hours of Average	Car Handlings Saved Per Day	Car Hours Saved Per Day	Car Miles Saved Per Day
Base Case	94 Hrs.	79%	0	0	0
Pre-Blocking Alone	92 Hrs.	80%	147	864	4020
Pre-Blocking with Schedule Sliding	90 Hrs.	82%	147	1639	4020

Figure 5.2: Annual Cost Savings due to Local Pre-Blocking

	Pre-Blocking without Schedule Sliding		Pre-Blocking with Schedule Sliding	
	Targeted Traffic Only	Extrapolation to Entire Network	Targeted Traffic Only	Extrapolation to Entire Network
Annual Value of Saved Car Handlings	\$161 K	\$2.9 M	\$161 K	\$2.9 M
Annual Value of Saved Car Hours	\$237 K	\$4.2 M	\$449 K	\$8.0 M
Annual Value of Saved Car Miles	\$734 K	\$13.0 M	\$734 K	\$13.0 M
Annual Total	\$1.1 M	\$20.0 M	\$1.3 M	\$23.8 M

Figures do not sum due to rounding.

Figure 5.3: Implementation Considerations Associated with the Local Pre-Blocking Strategy

Strategy	Operating Plan Development Issues	Field Execution Issues
Local Pre-Blocking Alone	<p>Few major problems.</p> <p>Incremental addition of blocks decreases need for automated car routing, as could be provided by a calibrated ABM. This capability can be added later while implementation proceeds.</p>	<p>Local trains must have time to switch customers, make pre-blocks, put away train on several serving yard tracks.</p> <p>Yard switchers may be called on to switch traffic left unblocked by heavy or off-schedule local trains.</p>
Local Pre-Blocking + Schedule Sliding	<p>As above.</p> <p>Schedule sliding will require large analytical and data entry effort if done on a regional or network basis.</p>	<p>As above.</p> <p>Elimination of excess dwell time by schedule sliding increases pressure on local trains to maintain schedule.</p>

- The Terminal Complex strategy** calls for a yard to process groups of trains as at an airline hub. Closely spaced groups of four inbound trains would arrive twice per day. Each group would be classified on a tight, coordinated schedule. The resulting blocks would be assembled into outbound trains, which would depart at close intervals. Expedited classification of the two daily groups of trains ("complex trains") would occur on the same set of bowl tracks, freeing some bowl tracks for other uses. The strategy's primary drawbacks include the requirement that blocks built in the complex receive traffic only from complex trains, causing other traffic to be rerouted, and the necessity of extremely reliable train and yard operation. The Terminal Complex strategy was modeled at Nashville.

The desired effects of the Terminal Complex strategy are demonstrated by the Mt. Vernon, IN to Memphis traffic flow, whose trip time decreased from 71 to 53 hours and reliability increased from 80% to 93% as a result of classification in the complex. Another type of desired effect was experienced by the Chicago to Montgomery, AL flow, which saved a classification and 23 hours and increased in reliability from 63% to 73% as a result of moving on a new block created on a bowl track freed by the complex. Overall impacts of the Terminal Complex strategy on 1422 cars per day are shown in Figure 5.4, and annual cost savings extrapolated to the CSXT network are shown in Figure 5.5. Implementation considerations associated with the Terminal Complex strategy are listed in Figure 5.6.

Figure 5.4: Changes in Trip Time, Reliability, and Activity due to the Terminal Complex at Nashville

Strategy	Average Dock-to-Dock Trip Time	% of Cars Arriving Within +/- 24 Hours of Average	Car Handlings Saved Per Day	Car Hours Saved Per Day	Car Miles Saved Per Day
Base Case	123	80%	0	0	0
Terminal Complex	118	82%	204	7977	7730

Figure 5.5: Annual Cost Savings due to the Terminal Complex

	Targeted Traffic Only	Extrapolation to Entire Network
Value of Saved Car Handlings	\$0.2 M	\$1.2 M
Value of Saved Car Hours	\$2.1 M	\$12.5 M
Value of Saved Car Miles	\$1.4 M	\$8.1 M
Annual Total	\$3.8 M	\$21.9 M

Figure 5.6: Implementation Considerations Associated with the Terminal Complex Strategy

Operating Plan Development Issues	Field Execution Issues
<p>Large amount of rerouted traffic calls for automated car routing.</p> <p>Good cost and network data crucial in creating reroutes around the complex.</p> <p>Schedule sliding to coordinate complex trains with connecting trains will require large analytical and data entry effort.</p> <p>Choice of the proper yard important.</p>	<p>Schedule adherence of complex trains and complex yard processing functions is crucial to smooth operation.</p> <p>Volume fluctuations on complex trains may cause problems in yard, require extra trains.</p>

- The Tandem Humping strategy** calls for creation of a large-scale matrix switching operation across two hump yards, building a very large number of small, finely classified blocks, each destined for an individual local train. Matrix blocks would be pulled from the bowl in groups and assembled into trains, and swapped repeatedly until each block connected to its terminating local train. Because the two stages of matrix switching would each be performed at a separate yard, traffic processed in the matrix would have to travel to both yards, but would benefit by moving directly from the second stage of the matrix to its terminating local train without further classification. The strategy's chief drawbacks include its complexity, the requirement that blocks be eliminated to make room for the matrix in the bowl, causing rerouting, and the requirement that traffic processed in the matrix travel to both matrix yards, increasing car mileage. The Tandem Humping strategy was modeled using Nashville and Louisville as matrix yards.

The desired effects of the Tandem Humping strategy can be seen in the Memphis to Port Huron, MI flow, whose trip time decreased from 144 to 118 hours and reliability increased from 75% to 97% as a result of movement on a direct matrix block, which saved one classification. Impacts of the Tandem Humping strategy on 92 cars per day are shown in Figure 5.7. Because of the increase in car mileage caused by movement to both matrix yards, the Tandem Humping strategy did not generate net cost reductions relative to the ABM-Generated Routing strategy, discussed below. Implementation considerations associated with the Tandem Humping strategy are shown in Figure 5.8.

Figure 5.7: Performance Changes due to the Tandem Humping Strategy

Strategy	Change in Average Dock-Dock Trip Time	% of Cars Arriving Within +/- 24 Hours of Average	Car Hours Saved Per Day	Car Miles Saved Per Day	Car Handlings Saved Per Day
ABM-Gen.	153 Hrs.	77%	0	0	0
Tand. Hum.	152 Hrs.	79%	196	(3,400)	48

Figure 5.8: Implementation Considerations Associated with the Tandem Humping Strategy

Operating Plan Development Issues	Field Execution Issues
<p>Elements of plan hinge on existence of individual traffic flows.</p> <p>Plan entirely developed within ABM/ SPM modeling environment.</p> <p>Automated car routing crucial to strategy development.</p> <p>Representation of matrix blocks in real-time control system may be difficult.</p>	<p>Yard managers and train crews must keep straight large matrix and blockswapping requirements.</p> <p>Out-of-order matrix blocks may require blocks to be individually ordered by yard crews, causing yard congestion.</p> <p>Train makeup rules may cause problems during assembly and lengthen time required for blockswapping.</p>

After reviewing the results of the three unconventional strategies, two additional, conventional strategies were developed. These strategies presume no change in operational paradigms, but instead focus on the effects of decision support on the operating plan, and the effects of yard performance on network reliability:

- The ABM-Generated Routing strategy** changes the means by which classification tables are generated. Classification tables, which determine the blocks used by traffic flows, ordinarily were generated by service planners using manual analysis to determine the best route for each flow. The ABM generates classification tables using a cost-minimizing shortest-path algorithm, using route mileage and yard performance data and car hour, car mile, and car handling costs. Cars would benefit by traversing shorter routes, avoiding classifications, or substituting classification at fast-processing yards for classification at slow-processing yards. The ABM-Generated Routing strategy was modeled on CSXT's entire merchandise network.

The desired effects of the ABM-Generated Routing strategy can be seen in the Nucor, IN to Mt. Vernon, IN traffic flow, whose trip time drops from 66 to 37 hours and trip mileage decreases from 246 to 188 miles as a result of a new routing generated by the ABM. Although this traffic flow also avoids one classification on its new route, reliability is nearly unchanged. Overall impacts of the ABM-Generated Routing strategy on the entire set of modeled flows, 8172 cars per day, are shown in Figure 5.9, and annual cost savings due to the changes are shown in Figure 5.10. No aspects of field operations would change as a result of implementing ABM-Generated Routing. Therefore, implementation considerations are limited to issues of operating plan design: if the ABM is to be used to generate classification tables, it must be calibrated to reflect real-world

costs and constraints, input and output data must be checked for accuracy and completeness, and an interface between the ABM and real-time control systems must be built to handle the volume of information generated by the model.

Figure 5.9: Changes in Car Hours, Miles, Handlings, and Reliability due to ABM-Generated Routing Strategy

Strategy	Average Dock-Dock Trip Time	% of Cars Arriving Within +/- 24 Hours of Average	Car Handlings Saved Per Day	Car Hours Saved Per Day	Car Miles Saved Per Day
Base Case	86 Hrs.	84%	0	0	0
ABM-Generated Routing	85 Hrs.	85%	608	8,254	78,400

Figure 5.10: Annual Cost Savings due to the ABM-Generated Routing Strategy

Period	Value of Saved Car Handlings	Value of Saved Car Hours	Value of Saved Car Miles	Total
Per Day	\$1.8 K	\$6.2 K	\$39.2 K	\$47.2 K
Per Year	\$0.7 M	\$2.3 M	\$14.3 M	\$17.3 M

- **The Improved Yard Performance strategy** calls for faster classification, represented in the models by PMAKE parameters. Two sets of altered PMAKE parameters were tested. "A" parameters represented attainment of benchmark-quality performance, while "B" parameters represented a moderate performance improvement. In each case, a portion of the cars classified at the improved yard would connect to earlier trains as a result of faster processing. The Improved Yard Performance strategy differs from the other strategies investigated in this thesis in that it calls for improved execution of the operating plan with no changes in design. The Improved Yard Performance strategy was modeled at Nashville.

A flow exhibiting "ideal" effects of Improved Yard Performance, a 24-hour decrease in trip time, was hard to find because of the PMAKE function's representation of variability. Flows which exhibited effects close to the desired effects include the Mt. Vernon, IN to Memphis flow, whose trip time decreased from 71 to 61 hours as a result of both "A" and "B" processing, and the Chicago to Bruceton, TN flow, whose trip time decreased from 64 to 55 hours as a result of the "A" parameters only. Both flows exhibited slight decreases in reliability when processed with the "A" parameters, a result strongly influenced by the flows' individual scheduled connection times. Overall impacts of the Improved Yard Performance strategy are shown in Figure 5.11, and annual cost savings

extrapolated to the CSXT network are shown in Figure 5.12. Implementation considerations associated with the Improved Yard Performance Strategy are listed in Figure 5.13.

Figure 5.11: Performance Changes due to Improved Yard Performance at Nashville

Strategy	Average Dock-Dock Trip Time	% of Cars Arriving Within +/- 24 Hours of Average	Car Hours Saved Per Day
Base Case	123 Hrs.	80 %	0
Improved Yard Performance "A"	116 Hrs.	81 %	10610
Improved Yard Performance "B"	119 Hrs.	83 %	5582

Figure 5.12: Annual Cost Savings due to Improved Yard Performance

	Improved Yard Performance "A"		Improved Yard Performance "B"	
	Targeted Traffic Only	Extrapolation to Entire Network	Targeted Traffic Only	Extrapolation to Entire Network
Annual Value of Saved Car Hours	\$2.9 M	\$16.7 M	\$1.5 M	\$8.8 M

Figures rounded.

Figure 5.13: Implementation Considerations Associated with the Improved Yard Performance Strategy

Operating Plan Development Issues	Field Execution Issues
<p>Short-term, a yard operating plan to improve performance must be developed.</p> <p>There is little latitude to add resources to the yard in order to boost performance.</p> <p>Long-term, altered yard costs and performance may drive major traffic rerouting, necessitating automated car routing and train schedule analysis.</p>	<p>Benefits of strategy hinge on decreasing yard times.</p> <p>Pressure to perform is on yard management.</p> <p>Yard management must reconcile right car/right train and yard time goals.</p>

5.3 Issues Common to All Strategies

5.3.1 Network Performance

The four successful strategies caused only minor improvements in O/D trip time and reliability and reductions in operating costs. In fact, most railroad executives reviewing these results would probably conclude that *it is not possible for some or all merchandise traffic to achieve large improvements in trip time and reliability through adoption of a significantly more complex operating plan, which stipulates new roles for some yards and train crews*. Although not small in absolute terms, in proportion to aggregate service levels and total operating costs, the changes caused by the alternatives were not “large,” nor were they even entirely due to the alternative plans’ added complexity and new roles for trains and yard crews.

However, there is reason to believe that predicted performance changes and cost reductions were unrealistically small. Reasons for this are related to the modeling process, to the strategies themselves, and to the characteristics of CSXT's merchandise network.

The modeling process caused performance changes to be smaller than expected for the following reasons:

- Subsets of traffic targeted by each strategy included extra flows not affected by the strategies. The set of traffic flows targeted by the Local Pre-Blocking strategy contained traffic originated by local trains in reality but not in the modeling environment. Node aggregation caused this traffic to originate at serving yards rather than at outlying points served by local trains, eliminating the representation of classification between local pickup and movement on through trains.

The set of traffic flows targeted by Terminal Complex and Improved Yard Performance strategies included traffic not classified at Nashville. The set of traffic flows included all traffic passing through Nashville as part of its shortest route. Some of this traffic passed through Nashville on bypass blocks such as Louisville-Birmingham or Chicago-Waycross, and was not classified. Evidence of the diluting effect of the extra traffic flows can be seen in the fact that the average yard time at Nashville dropped by 12.2 hours between the base case and Improved Yard Performance "A". If all targeted traffic flows were classified at Nashville, the corresponding drop in average O/D trip time would also have been 12.2 hours, while the models showed a drop of only 7 hours.

The ABM-Generated Routing and Tandem Humping strategies were not affected by this issue.

- The research modeled a subset of the merchandise traffic flows, rather than all merchandise traffic flows. Because of idiosyncrasies in input data, some traffic flows were excluded from the modeled flow file. The exact percentage of November 1993 merchandise traffic captured by the input data generation process

is not known, but is thought to be between 65% and 85%. It is likely that a higher than average percentage of corridor traffic was captured, lowering the multiplier used when extrapolating benefits to the entire network.

- Increases in network reliability caused by the Improved Yard Performance strategy were smaller than expected because the improvement was modeled at a single yard rather than at all network yards. Because most traffic passes through several yards, variability is introduced at several points over the course of a trip. To improve yard performance at only one yard eliminates only one of several sources of variability.
- Some increases in car mileage caused by the Tandem Humping strategy could have been avoided by returning increased-mileage cars to their base case routes. This would have required performance of every traffic flow to be compared and every flow route manually altered. No single-stage process for routing cars over matrix blocks was available.

Characteristics and requirements of the strategies themselves also caused performance improvements to be smaller than expected:

- All strategies except the Improved Yard Performance strategy involved routing some traffic with the ABM. Cars routed by the ABM in each alternative strategy were subject to the ABM's tendency to minimize car miles at the expense of trip time and reliability. For example, using the ABM's costs of \$0.50 per car mile and \$0.75 per car hour, a reduction of 150 car miles would allow trip time to increase by as much as 100 hours without a net increase in cost.
- All strategies except for Improved Yard Performance caused some O/D flows to move slower and less reliably as well as faster and more reliably. Every strategy except Improved Yard Performance involved complex operating changes intended to improve network performance on an overall basis, resulting in some O/D flows deteriorating in performance while others improved. Figure 5.13 describes groups of traffic affected positively and negatively by each strategy.

Figure 5.14: Positive and Negative Effects of Alternative Operating Strategies on Traffic Flows

Strategy	Traffic Improved by the Strategy	Traffic Made Worse by the Strategy
Local Pre-Blocking Alone	Traffic pre-blocked on the Chicago-Nashville corridor	Some pre-blocked traffic connecting to different outbound trains moved more slowly because of changed connection times
Local Pre-Blocking + Schedule Sliding	Traffic pre-blocked on the Chicago-Nashville corridor, some overhead corridor traffic which moved faster because of schedule sliding	As above, plus a minority of overhead flows on trains with slid schedules had slower trip times and decreased connection performance
Terminal Complexes	Traffic classified in the complex at Nashville	Some traffic on non-complex trains in the base case was rerouted around Nashville and forced onto longer routes
Tandem Humping	Traffic classified in the matrices with no increase in mileage	Traffic forced from blocks eliminated at Nashville moved more slowly, was classified more often
ABM-Generated Routing	Traffic routed by the ABM on shorter or faster routes	Some traffic was routed by the ABM to save car miles at the expense of trip time, reliability, and additional classification
Improved Yard Performance	Traffic classified at Nashville	None

The dimensions and complexity of the CSXT network also resulted in lower benefits than might have been expected:

- Out-of-route mileage generates costs which are hard to justify. Results from the Local Pre-Blocking, ABM-Generated Car Routing, and Tandem Humping strategies demonstrated that, given current relationships between handling, time, and mileage costs, the mileage costs of out-of-route movement seldom outweigh the costs of time and handling avoided by such movement. If long trip times and frequent classification called for by a direct route are unacceptable, creation of direct blocks to avoid excess classification should be considered as an alternative to out-of-route movement if at all possible. East St. Louis-bound traffic originating on the Chicago-Nashville corridor classified at Louisville illustrates this issue most clearly.

- The benefits of blockswapping as an alternative to classification are not guaranteed. Substitution of a blockswap for a classification may improve reliability of a movement, but may not decrease trip time if the time available for blockswapping is as great as was available for classification. This finding points out the importance of schedule sliding in reducing excess dwell time for blockswapped cars.

Schedule sliding to shorten connection time and blockswap location choice influence the likelihood that a blockswap actually replaces a classification. For instance, if a blockswap replaces a classification at a major yard, and the schedules of the connecting trains are not brought closer together, the "blockswap" will functionally remain a classification, with no real car handling savings, as the block will be shuttled between the inbound train and the outbound train via the hump and the bowl to preserve yard fluidity. This circumstance suggests that, although blockswapping can definitely improve the performance of traffic by eliminating classification, blockswapping as an alternative to classification should not dilute an intense focus on improving yard performance.

5.3.2 Implementation of Alternative Strategies

As noted in discussions of individual strategies, all strategies evaluated here faced at least minor barriers to immediate implementation. The most common barriers were: *relatively minor*
is dealt w/ issues that could be addressed through dev. of

- The necessity of further analysis on unaddressed issues such as development of a yard classification plan, or even complete regeneration of the operating plan because of faulty data. *more*
- The ABM's lack of calibration and an interface to real-time control systems. The extent to which the ABM is used to generate car routes determines the seriousness of the barrier to implementation. *informa*
serv
desig
piece

Issues of plan complexity and present performance levels affected only the Terminal Complex and Tandem Humping strategies, of which only the Terminal Complex strategy is a serious candidate for implementation. Phased or incremental implementation was anticipated to ease potential implementation problems of all strategies except ABM-Generated Routing. These findings are encouraging, suggesting that revisiting the relatively simple items listed above could allow most of the benefits offered by each alternative to be captured.

The success of sophisticated strategies like Local Pre-Blocking and Terminal Complexes requires field officers across the system to know and understand the plan. As an alternative plan is implemented, communication of the actual operating changes and also their anticipated effects should be carried out. For instance, particular attention should be paid to schedule adherence of trains processed in the terminal complex and trains connecting to pre-blocking local trains. However, at yards far from the complex or pre-blocking yards, the additional positive consequences of good schedule maintenance

and bad consequences of non-adherence may not be readily apparent to busy terminal managers facing many demands. Explanation of the plan to all field officers who play a role in its execution, will be a major factor in smooth and successful implementation.

5.3.3 Data, Service Design, and Decision Support

The research presented in this thesis represented a major effort at “from-the-ground-up” operating plan development. The analysis diverged from present methods of operating plan development and maintenance, which are largely incremental and driven by seasonal or track maintenance factors. In this respect, the analysis provided a glimpse of the future, in which decision support tools will be integral to the service design process, and in which wholesale changes to the operating plan can be generated, communicated, and implemented on a repeated basis in response to evolving critical volumes and other network economies, and yard and line capacity and performance.

Development of alternative operating plans used data from different CSXT data sources at different levels of specificity, from waybill data (most detailed) to ABM/TSS/SPM model input data (most condensed). Although it would be preferable to use a single, detailed data source to avoid problems with reconciliation or condensation, there are several reasons why the use of several data sources for plan design is likely to remain the norm:

- Using a single, detailed data source such as CSXT’s WMS waybill file is very slow and computationally expensive. It is for this very reason that the QBASE condensation of waybill data was created.
- Model input files would have to be generated using an interface program, no matter what the source of raw data. Using a single, detailed data source would not ease the modeling process, because large files of raw data are not in a model-ready format. The problem of maintaining an interface between the raw data source and the model would not go away, regardless of the data source.
- In order to keep a network-wide model within the bounds of computing capabilities, some abstraction of the network and traffic flows is necessary. It would be impossible to model every car from customer to customer.
- Modeling data cannot be used as the sole input to the operating plan because it is not detailed enough. For instance, at least six blocks built at Nashville for points between Nashville and Memphis were consolidated into two modeled blocks because of node aggregation, and yard and local blocks for points within the Nashville node aggregation area were lost entirely in the model. To omit such large operational elements from the plan would decrease rather than increase the specificity of the plan, leaving field managers to act at their discretion in ways that could diminish service or increase costs simply because of a lack of knowledge.

Given the infeasibility of consolidating analysis in support of plan changes into a single database, it will be necessary to frequently affirm that car move and train activity data stored in the most detailed databases is effectively translated to more condensed forms. While the data reconciliation process is very important to the quality of operating plan analysis and design, it is time consuming and requires a detailed knowledge of the railroad, and therefore has often been ignored or scapegoated as a “non-core” activity.

When condensed car move and model input data was only being used for relatively broad strategic studies, the data reconciliation process in fact was a non-core activity. But, as operating plans become more sophisticated and utilize more analysis and decision support in their creation, the data reconciliation process will become a core element of the service design process.

Full automation of the process of creating alternative operating plans faces two major obstacles. First, the service design process will continue to use of many data sources which often do not directly correspond in format or meaning. Second, even if a single data source could have been used, the analysis performed in creating the alternative operating plans left many decisions up to the service planner’s discretion, such as the determination of number of pre-blocks built by local trains sharing a common serving yard.

Nevertheless, creation of alternative operating plans would be made much easier if the design process were automated between decision points. Automation of the plan design process would not necessarily entail creation of decision support tools from the ground up, but would often require only the creation of simple mechanisms of information presentation tools, as have already been completed for the Local Pre-Blocking strategy.

Developers of such information presentation routines will face a tradeoff between the desire to make the routines broad, containing many user-specified parameter options and therefore presumably applicable to more situations in the long run, and the necessity that routines be created quickly and tested thoroughly. It is my view that routines should be as sufficiently flexible to be used in a series of analyses, in order to speed the plan development process by substituting regular use of a tool for handcrafted analyses.

If some plan design decisions will always be made manually, and if information presentation tools will be used to perform much of the analysis between these decisions, what, then will be the future role of decision support in service design?

The short answer is that the future role decision support in service design will be much like its role in this research, with several notable expansions. Major potential uses of decision support tools include:

- Generation of car-to-block assignments, as was done using the ABM in this research.
- Generation of block-to-train assignments, as was done using the Shan/Rinker model in this research.

- Generation of block destination lists, which would require a new model with the capability to incorporate the requirements of alternative strategies such as Local Pre-Blocking or Terminal Complexes in the decision.
- Generation of train routes and schedules, which could be done using the TSS assisted by data manipulation routines or by a new model.
- Generation or simply prediction or information presentation on elements of the plan not addressed in this research, such as crew-to-train and locomotive-to-train assignment and the meet/pass plan.

The primary differences between the current planning environment and the future environment are that decision support tools would be:

- Used regularly to generate routine information
- Increasingly integrated and capable of determining several major aspects of the plan simultaneously as computing power increased
- Calibrated and supported by representatives of several departments
- Linked directly to real-time control systems.

More specific ideas to be incorporated in a new generation of decision support tools are discussed in more detail in Section 5.4. It should be emphasized that many of the information presentation routines which would automate plan generation for alternative strategies would actually be shell-like user interfaces masking interaction with one or several of new decision support systems.

As an example of the use of an automated routine which called on decision support systems, consider a routine designed to create a Terminal Complex operating plan at a yard. The user would specify the yard at which the complex was to operate, and a list of parameters describing yard process times. The routine would then query the block destination list and traffic flows at that yard and use the Yard Stringline Model and Factor Model [see Appendix 1], and block destination generator (future decision support tool) to generate recommendations for complex blocks and trains and new block destinations and present them to the user. After review, the routine would flow traffic over the new blocks and present yard, train, and block volume shifts. After a second review, the routine would change schedules of affected trains and present performance changes for affected traffic. After adjustments were made to ensure that service-committed traffic was not jeopardized by the new plan, and the plan was reviewed to ensure that no distortions resulted from node aggregation, several more keystrokes would notify the field of the new plan, and would load the plan into real-time control systems. While this hypothetical process might seem arduous and time-consuming, it would represent a major advance over the methods used to generate the Terminal Complex operating plan evaluated in this research.

5.3.4 Additional Observations

Although the five strategies were intended to improve performance in different ways, they held several aspects in common. The first two common aspects described below are favorable characteristics of the alternative operating strategies, while the third and fourth are simply observations, which could lead to additional research or generation of alternative strategies.

- In general, the alternative strategies did not call for significant increases in train, yard, or line costs, although several strategies left minor questions about exact resource requirements unanswered, such as the number of yard crew starts eliminated by Local Pre-Blocking that are actually converted to local train starts. No strategy as modeled calls for an increase in train starts or train miles. Each strategy that calls for an increase in blocks built does so only under controlled circumstances, and does not simply pass the task of determining how new blocks would be built to yard managers. No strategy explicitly calls for an expansion of any facility, although further analysis may indicate that improving yard performance to benchmark levels requires alleviation of physical bottlenecks.
- If implemented together, benefits from several strategies would be additive, while others would overlap. It would be nearly impossible to implement both the Terminal Complex and Tandem Humping strategies at a single yard at the same time. Likewise, the Terminal Complex strategy calls for high-performance classification of the complex trains and blocks, while Improved Yard Performance calls for high-performance classification of all traffic, suggesting that benefits of the two strategies would largely overlap if implemented at a single facility. In addition, effects of the ABM's routing of traffic are present in every strategy in which the ABM was used, causing some overlap in benefits reported by those strategies. Apart from those considerations, however, it is reasonable to expect that two operating strategies implemented together would provide benefits close to the sum of the benefits provided by each strategy separately.
- Alternative operating strategies affected the performance of individual flows because of network or geographic rather than market factors. Critical volumes, rather than contribution per car dictated operating plan changes like designation of a local pre-block or complex block. Although not rate-related, high-volume shippers would still be favored over incidental shippers because of the synergies that arise from regular, high-volume shipment.
- The strategies examined in this thesis targeted subsets of traffic with very different average lengths-of-haul. Average base case velocity increased slightly with length of haul, as shown in Figure 5.15, indicating the increased impact of classification on total trip time for short-haul flows, and suggesting that a strategy based on separate networks for short- and long-distance flows might yield benefits. A research question which arises concerns the geographic characteristics or critical

volumes that prevent—or could enable—short-distance flows from moving at the same speed as their long-distance counterparts.

Figure 5.15: Size, Length of Haul, and Velocity of Traffic Subsets Targeted by Each Strategy

Strategy	Targeted Cars Per Day	Average Base Case Length of Haul	Average Base Case Velocity
Local Pre-Blocking	461	407 Mi.	4.3 MPH
Terminal Complexes	1422	666 Mi.	5.4 MPH
Tandem Humping	92	753 Mi.	4.9 MPH
ABM-Generated Routing	8172	358 Mi.	4.2 MPH
Improved Yard Performance	1422	666 Mi.	5.4 MPH

5.4 Next Steps

Next steps in several areas arise from the research presented in this thesis, including implementation of alternatives and audit of results, adoption of decision support tools for service design, and consideration of research questions that arose during the research. Recommendations for implementation of alternative strategies include:

- Implement Local Pre-Blocking.** The combination of Local Pre-Blocking and Schedule Sliding offers the greatest benefits of any alternative operating strategy, and faces the fewest barriers to operating plan creation and implementation. Local Pre-Blocking is conceptually straightforward and has been successfully instituted on CSX Transportation and other major railroads. Local Pre-Blocking alone may be implemented incrementally, as a demonstration project, and gradually expanded throughout the system, while the capability to slide schedules quickly and easily is being developed. The strategy is highly promising, but, like many recently documented leaps forward in freight transportation and logistics, requires commitment on the part of the railroad and close relationships with its customers.
- Implement a Terminal Complex at an appropriate yard.** The Terminal Complex strategy was almost guaranteed to have a major impact at Nashville because of the heavy volumes classified there. That major impact was represented not only in substantial decreases in yard time for traffic classified at Nashville, but also in the large volumes of traffic rerouted around Nashville because of the complex. If implemented immediately, a Terminal Complex at Nashville could cause major disruption. The car-flow shifts that would result are not fully understood, train schedule and car routing changes would take man-months to generate, and no yard operating plan which addresses both the yard's complex and non-complex classification commitments yet exists.

An alternative yard would lessen many of the problems cited above. A yard whose

trains came and went from two or three directions rather than five would require much less rerouting. A smaller yard could include a higher percentage of its classification commitments in the complex. A superficial glance at the CSXT map suggests that yards at Evansville, Grand Rapids, Cumberland, Mobile, Wauhatchie, or Rocky Mount might be better locations at which to launch the original terminal complex.

- **Improve yard performance.** CSXT has already begun efforts to lower cutoffs and speed cars through Nashville, and preliminary indications are that the changes have been successful. Continued focus on good yard performance on a network basis could yield benefits nearly equivalent to complex, network oriented strategies, and the Improved Yard Performance strategy has the added advantage that it causes no traffic flow to perform worse than in the base case. Evidence from the Nashville yard study and CSXT's reengineering effort suggests that minimal additional resources would be required to achieve at least "B" level performance. Savings generated by the improvement from base case to "B" level performance could fund any additional resources required to achieve "A" level performance, while analysis of yard processes generates recommendations to eliminate time required for classification.
- **Audit actual performance changes following from implementation.** The research presented in this thesis would be made much more relevant if it were followed by a sequel documenting actual operating changes made in implementing the strategies mentioned above, and the individual and network performance changes that resulted.

Several short and long term actions should be taken to incorporate decision support in the operating development and maintenance process. In the short term, the following actions should be taken:

- **Calibrate the ABM/TSS/SPM suite of models** by revising the input file creation process, reviewing all network costs, and having service planners approve the network representation. The Local Pre-Blocking, Terminal Complex, Tandem Humping, and ABM-Generated Car Routing strategies raised the possibility that bad data influenced the dimensions of an operating plan created using the models. If decision support tools are to be incorporated into the service planning process, they must have the support of service planners.
- **Use the ABM to generate car routes.** While it has not been CSXT's intent to use the ABM/TSS/SPM suite of models in roles directly supporting service planning, the ABM could have an immediate impact, both by simplifying and speeding the process of regenerating car routing tables at a yard as the block destination list changes, and by ensuring that each car is routed over its minimum cost path, assuming that the network is calibrated. The true impact of the ABM on network

traffic flows, though, is still subject to some conjecture because of model calibration issues discussed above and effects of empty car flows discussed below.

In the long term, a new generation of decision support systems should supersede the ABM/TSS/SPM suite of models:

- **Develop a next generation of decision support tools for the operating plan.** Although I call for a rejuvenation of the ABM/TSS/SPM suite of models in above, these models will always face certain drawbacks, such as their difficulty of use, tremendous file storage requirements, limitations on simulation size, and conceptual rigidity. While the first two of these can be overcome with effort spent to train users and money spent to buy storage, growth of the CSXT network and complexity of the operating plan will make continued use of these models for whole-network analysis untenable. Furthermore, the effort spent to model even one of the unconventional alternatives described in this thesis makes the ABM/TSS/SPM suite's success as timely scenario comparison tools unlikely.

A new generation of decision support tools should contain two new interfaces. First is a *bi-directional* interface with real-time control systems. In one direction, real time control systems could provide more timely traffic flow data, and could render blocks, trains, and car routes, good or bad, in the model exactly as they are expressed to the executors of the plan. The second interface is a user interface which enables sweeping changes to be specified and reviewed with little effort. Creation of the operating plans reviewed in this thesis required manual editing of ABM/TSS/SPM input files, a lengthy and error-prone process aided only to a small degree by sorting and batch programming. Automated operating plan editing mechanisms would speed the creation of new plans significantly.

Another significant element of the next generation of decision support tool is a hierarchical representation of the railroad network, operating plan, and traffic flows. The modeling performed for this thesis encountered problems caused both by node aggregation, the distortion of pickup and delivery activity, and by node disaggregation, the large simulation size and many low-volume O/D flows. Reconciliation of issues demanding more and less detailed network representations requires the ability to pivot between two representations depending on the design task at hand.

It is important that a new decision support tool used for car routing and blocking plan generation overcome the ABM's three major modeling shortcomings. These are the use of link mileage to approximate block mileage, the use of averages rather than actual connection schedules to determine expected yard time, and the ABM's inability to determine which block destinations should be maintained.

Increasing the specificity of cost information, such as assigning each traffic flow a unique car hour cost based on market considerations and car type, is less important than overcoming the shortcomings listed above. However, if such information can

be generated quickly and easily from cost and rate data, it would be a first step toward service differentiation, as block and train capacity could be allocated in constrained situations to the most service sensitive traffic.

At the heart of a new decision support system, advanced optimization techniques are less important at this juncture than the ability to quickly and clearly estimate the effects of changes in car routes, blocks, or train routes and schedules on diverse elements of the plan such as locomotive and crew requirements, yard processing schedules, and the meet-pass plan. A single system need not, and indeed cannot at this time optimize all elements of the plan development process. However, to even be able to illustrate crew-to-train coverage or a potential meet-pass plan as train schedules change would be a major advance.

In addition to the plan development work needed to ready the alternative strategies for implementation, further analytical work is needed to answer questions raised by this research. These research questions are not immediately pressing, and it is doubtful that a particular answer would change the interpretation of the results of this analysis. However, as railroad service planning and operating plan development become more sophisticated, research in these areas will be increasingly relevant.

- **Determine whether the empty-car distribution patterns** create the appearance of excess classification in the network modeling environment, the reality of excess classification in the field, or both. In all strategies in which a substantial number of cars were routed by the ABM, significant reduction in car miles and car handlings resulted. Empty O/D flows are represented no differently than loaded flows in the modeling environment, although an actual empty O/D move may be the amalgamation of several moves under uncertainty to empty car gathering points before the car is assigned to a customer. In a pathological case, eliminated miles and handlings "found" by the ABM for common empty types such as covered hoppers would only be achievable if advance information on customer car ordering patterns were available.

Moreover, empty flows contribute to "critical densities" which give rise to such operating plan elements as local pre-blocks and complex blocks, even when empty car distribution patterns may change significantly from month to month. In many cases, empty flow patterns can be counted on, at least on a yard-to-yard if not on an O/D basis, but distribution patterns sometimes gyrate too randomly to serve as a basis for proactive service planning. Further consideration should be given to the effects of empty car movements on operating plan design.

- **Determine the value of an additional point of reliability** for different traffic types and O/D pairs. The service design process is fraught with tradeoffs between reliability and cost. Should a set of customer switching be covered by two daily assignments or three? Should a switch be added in the throat of this yard? Many such decisions have local effects and do not require network models to determine the effects on reliability and operating costs.

As the service design process and operating options become more sophisticated, however, knowledge of the margin must improve. For instance, at Nashville, the Terminal Complex and Improved Yard Performance strategies are mutually exclusive. Both improve the performance of a set of O/D flows. The Terminal Complex strategy achieves potentially greater benefits for a subset of traffic in selected lanes, while disrupting movement patterns for other traffic. The Improved Yard Performance strategy offers improved processing performance for traffic in all lanes which moves to earlier connections as a result of the change. Assuming for a moment that network-level performance and complexity are equal, how should the best option be selected?

- **Devise additional alternative operating strategies.** Local Pre-Blocking, Terminal Complexes, and Tandem Humping do not represent the last word in alternative operating strategies by any means. Further examination of network and market characteristics of traffic flows may lead to additional ideas on how to improve performance by stepping beyond the conceptual bounds of traditional operations.

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Appendix 1: Spreadsheet Models for Developing Terminal Complex Operating Plans

The two models described here address two preliminary issues associated with creating a Terminal Complex operating plan.

- The Yard Stringline Model uses measured or estimated process times for yard functions such as inspection, humping, and assembly to determine a feasible size for a complex in each direction at a yard, predict train-to-train connection times, and create a processing schedule for the inbound and outbound complex trains.
- The Factor Model helps a user choose the “best” set of trains and blocks to schedule for processing in the complex, given the number of trains and blocks the complex. The Factor model simplifies the tradeoff between maximizing the volume of traffic processed in the complex and minimizing the disruption to preexisting routes caused by the constraint that all traffic which is included in an outbound block in the complex must arrive on one of the inbound trains in the complex.

A1.1 The Yard Stringline Model

The Yard Stringline model was developed to support the design of a Terminal Complex operating plan. The Yard Stringline Model uses user-input parameters to generate the following information:

- The maximum feasible size for a complex at a yard, based on bowl track occupancy, time requirements for internal processes, and resources devoted to the complex
- Yard processing schedules, train arrival and departure times, engine and crew work schedules, track occupancy schedules, and expected train-to-train connection times for all trains in the complex

A processing schedule generated by the Yard Stringline Model was used as the basis for design of the Terminal Complex operating plan analyzed in this thesis, discussed in Section 3.2. A diagram of the processing schedule is illustrated in Figure 3.9.

Using the Yard Stringline Model

The user enters desired attributes of a terminal complex, including:

- Number of inbound and outbound trains
- Number of inbound and outbound inspectors working at one time
- Number of hump and trim engine crews working at one time

- Departure time of the first outbound train

The user also enters design and performance characteristics of the yard at which the complex will operate, including:

- Effective capacity of the trim end, i.e. number of trains that can be built at one time
- Required times for internal processes including inspection, hump, and trim operations

Defaults may be used for any of the inputs. The defaults in the model represent measured times and resource levels from the Nashville yard study [see Duffy 1994].

The model then produces the following information:

- Inspection and hump start/end times for all inbound trains, in timetable and graphical form
- Trim, inspection, and brake test start/end times for all outbound trains, in timetable and graphical form
- Total time that the bowl holds the complex
- Scheduled yard times, including:
 - Yard time for each train-to-train connection
 - Average yard time
 - Average yard time weighted by train-to-train connection volume
- Activity schedules for each hump and trim engine and inspector crew
- (Implicit) Occupancy schedules for each receiving and departure track

Variations in manpower and yard engines have been accounted for in the schedule-building equations. There will never be a situation in which an individual inspector crew or yard engine must be in two places at once. Likewise, the processing schedule is built with as little slack as possible, given available resources, in order to minimize total time in the yard and total bowl occupancy.

Additional documentation appears on the spreadsheet itself.

Figure A1.1: The Yard Stringline Model

Yard Stringline Model, by Marty Schlenker, MIT Rail Group

This model will demonstrate the processing schedule at a yard which operates a terminal complex.

The model creates the schedule for a single complex. If two complexes are desired, (for example, a northbound and a southbound complex each day) several options are possible.

If the two complexes include the same number of trains and blocks, then the bowl occupancy period of each complex must be less than 12 hours, including any time between processing of the two complexes. Output of one run of the model may be used as the basis for all complex schedules. The two directions' schedules will be identical, but staggered by 12 hours.

If the two desired complexes are not the same size, (for example, a complex of five trains northbound and three trains southbound each day) then each complex should be scheduled using a separate run of the model. The sum of the bowl occupancy periods of the two complexes must not exceed 24 hours.

Necessary input includes the average time required for yard processes (defaults or expert opinion may be used in the absence of a specific study) and also the desired size of the terminal complex, as described by the number of inbound and outbound trains processed, and also the number of blocks per outbound train.

ENTER INPUT BELOW

Time variables are in hours:minutes.

VARIABLE NAME	VALUE	DESCRIPTION OF VARIABLE
---------------	-------	-------------------------

INBOUND INSPECTION

in_inspectors	<input type="text" value="2"/>	Number of inspector teams assigned to receiving yard (set to 8 to ignore this parameter)
in_insp_time	<input type="text" value="2:00"/>	Average time required for inbound inspection of 120-car train

HUMPING

hump_time	<input type="text" value="1:00"/>	Average time required to hump 120-car train
hump_engines	<input type="text" value="2"/>	Number of hump engines per shift
shove_time	<input type="text" value="0:15"/>	Time required to shove a train from receiving yard to crest
hump_return_time	<input type="text" value="0:30"/>	Average time between cuts for a hump engine (relevant if there is a single hump engine per shift, or if the time between cuts is longer than hump_time)

TRIMMING (BUILDING OUTBOUND TRAINS)

trim_engines Number of trim engines per shift
 trim_capacity Number of outbound trains that can efficiently be built at one time
 trim_penalty Time penalty per outbound train for building more outbound trains than normal, presumably congesting the throat between the bowl and departure yard
 pull_time Average time required to pull one bowl track to departure yard
 trim_return_time Average time required for a trim engine to return to bowl for next pull

OUTBOUND INSPECTION

out_inspectors Number of inspector teams assigned to departure yard (set to 8 to ignore this parameter)
 out_insp_time Average time required to outbound-inspect 120-car train

BRAKE TEST

brake_test Average time required to perform the outbound brake test

INTERIM TIME

interim_time Desired time between complexes (time when all complex bowl tracks are free)

DIMENSIONS OF THE COMPLEX

inbound_trains Number of desired inbound trains in the complex (max 8)
 outbound_trains Number of desired outbound trains in the complex (max 8)
 blocks_per_obtr Average number of blocks per outbound train

TIME

depart_time Desired departure time of first outbound train

MOVE THE CURSOR UP AND TO THE RIGHT TO VIEW:

- PROCESSING SCHEDULE
- BOWL OCCUPANCY
- EXPECTED YARD TIMES

INBOUND TRAIN SCHEDULE			
Trains must be in receiving yard ready for inspection by the scheduled start of inspection.			
Inbound Train	Begin Inspection	End Inspection	Inspector
1	3:20 AM	5:20 AM	1
2	4:20 AM	6:20 AM	2
3	5:20 AM	7:20 AM	1
4	6:20 AM	8:20 AM	2
5			
6			
7			
8			

HUMP SCHEDULE				
Inbound Train	Hump Engine Couples On	Humping Begins	Humping Complete	Hump Engine
1	5:20 AM	5:35 AM	6:35 AM	1
2	6:20 AM	6:35 AM	7:35 AM	2
3	7:20 AM	7:35 AM	8:35 AM	1
4	8:20 AM	8:35 AM	9:35 AM	2
5				
6				
7				
8				
BUILD SCHEDULE				
Outbound Train	Pull First Bowl Track	Ready For OB Inspection	Trim Engine	
1	9:35 AM	12:00 PM	1	
2	9:35 AM	12:00 PM	2	
3	12:15 PM	2:40 PM	1	
4	12:15 PM	2:40 PM	2	
5				
6				
7				
8				
OUTBOUND INSPECTION				
Outbound Train	Begin Inspection	End Inspection	Inspector	
1	12:00 PM	1:30 PM	1	
2	12:00 PM	1:30 PM	2	
3	2:40 PM	4:10 PM	1	
4	2:40 PM	4:10 PM	2	
5				
6				
7				
8				
BRAKE TEST				
Trains may depart immediately upon completion of brake test.				
Outbound Train	Begin	End		
1	1:30 PM	2:00 PM		
2	1:30 PM	2:00 PM		
3	4:10 PM	4:40 PM		
4	4:10 PM	4:40 PM		
5				
6				
7				
8				

BOWL OCCUPANCY

9:05

MATRIX OF TRAIN-TO-TRAIN CONNECTION TIMES IN THE COMPLEX									
	Outbound	1	2	3	4	5	6	7	8
Inbound									
1		10:40	10:40	13:20	13:20				
2		9:40	9:40	12:20	12:20				
3		8:40	8:40	11:20	11:20				
4		7:40	7:40	10:20	10:20				
5									
6									
7									
8									

AVERAGE YARD TIME, ALL CONNECTIONS WEIGHTED EQUALLY 10:30
MINIMUM YARD TIME 7:40
MAXIMUM YARD TIME 13:20

OPTIONAL INPUT: NUMBER OF CARS MAKING EACH TRAIN-TO-TRAIN CONNECTION										
	Outbound	1	2	3	4	5	6	7	8	TOTAL
Inbound										
1		50	5	7	50	0	0	0	0	112
2		20	9	7	2	0	0	0	0	38
3		5	7	5	3	0	0	0	0	20
4		3	6	80	5	0	0	0	0	94
5		0	0	0	0	0	0	0	0	0
6		0	0	0	0	0	0	0	0	0
7		0	0	0	0	0	0	0	0	0
8		0	0	0	0	0	0	0	0	0
TOTAL		78	27	99	60	0	0	0	0	264

TOTAL CARS PER DAY 264
MAXIMUM CARS ON A SINGLE TRAIN-TO-TRAIN CONNECTION 80
MINIMUM CARS ON A SINGLE TRAIN-TO-TRAIN CONNECTION 2

CAR HOURS PER DAY EXPENDED IN EACH TRAIN-TO-TRAIN CONNECTION										
	Outbound	1	2	3	4	5	6	7	8	TOTAL
Inbound										
1		533	53	93	667					1347
2		193	87	86	25					391
3		43	61	57	34					195
4		23	46	827	52					947
5										0
6										0
7										0
8										0
TOTAL		793	247	1063	777	0	0	0	0	2880

AVERAGE YARD TIME WEIGHTED BY CONNECTION VOLUME 10:54
MINIMUM YARD TIME 7:40
MAXIMUM YARD TIME 13:20

Time	Inb 1	Inb 2	Inb 3	Inb 4	Inb 5	Inb 6	Inb 7	Inb 8	Out 1	Out 2	Out 3	Out 4	Out 5	Out 6	Out 7	Out 8
0:00																
0:15																
0:30																
0:45																
1:00																
1:15																
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1:45																
2:00																
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3:30	Insp															
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4:30	Insp	Insp														
4:45	Insp	Insp														
5:00	Insp	Insp														
5:15	Insp	Insp														
5:30	Hump	Insp	Insp													
5:45	Hump	Insp	Insp													
6:00	Hump	Insp	Insp													
6:15	Hump	Insp	Insp													
6:30	Hump	Hump	Insp	Insp												
6:45		Hump	Insp	Insp												
7:00		Hump	Insp	Insp												
7:15		Hump	Insp	Insp												
7:30		Hump	Hump	Insp												
7:45			Hump	Insp												
8:00			Hump	Insp												
8:15			Hump	Insp												
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11:45									Build	Build						

12:00		Build	Build		
12:15		Insp	Insp	Build	Build
12:30		Insp	Insp	Build	Build
12:45		Insp	Insp	Build	Build
13:00		Insp	Insp	Build	Build
13:15		Insp	Insp	Build	Build
13:30		Insp	Insp	Build	Build
13:45		Test	Test	Build	Build
14:00		Test	Test	Build	Build
14:15				Build	Build
14:30				Build	Build
14:45				Insp	Insp
15:00				Insp	Insp
15:15				Insp	Insp
15:30				Insp	Insp
15:45				Insp	Insp
16:00				Insp	Insp
16:15				Test	Test
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23:45					

A1.2 The Factor Model

The Factor Model is used to choose the best inbound trains and outbound blocks to be included in a terminal complex, based on train-to-block connection volumes and total outbound block volume.

In the case study of CSXT's Radnor Yard in Nashville, for which the model was developed, several approaches to choosing the traffic targeted for expedited processing in the complex were examined. The method which yielded the best results involved sorting all cars processed at the yard by their inbound train and outbound block. High-volume inbound-train-to-outbound-block combinations are good candidates for processing in the complex.

This sorting method yields a group of inbound complex trains, and a group of outbound blocks to be built in the complex, and assigned to the outbound complex trains. Some outbound blocks may need to be reassigned to outbound complex trains. Likewise, existing blocks assigned to the outbound complex trains may need to be reassigned to non-complex outbound trains in order to avoid overloading the outbound complex trains.

One drawback of targeting high-volume inbound-train-to-outbound-block combinations for processing in the complex is the fact some very high volume blocks may receive many cars both from complex and non-complex inbound trains. Although these blocks receive many cars from the complex inbound trains, a high percentage of their total volume must be rescheduled either to the complex inbound trains (so that the traffic is processed in the complex and can move on its original outbound block, which would be built in the complex) or to a different outbound block (because it may not be classified into a complex block if it does not arrive on a complex inbound train).

Rerouting cars typically decreases efficiency and performance and should be avoided. However, avoiding rerouting often causes fewer cars to be processed in the complex. In order to achieve sufficient volume on the outbound complex blocks, a tradeoff must be made. Some high-volume blocks must be included in the set of outbound complex blocks, even though inclusion of these blocks may cause more cars to be rerouted. The user specifies the degree to which car rerouting should be accepted in exchange for greater volume through the complex by adjusting the Factor, as described below.

Unlike the Yard Stringline Model, the Factor Model is "data-driven" rather than "parameter-driven". In order to use the Factor Model for a new terminal, a large data set specific to that terminal must be input, and the spreadsheet must be built from scratch. While it may seem arduous to have to create the Factor Model spreadsheet from scratch, it can be done very quickly, especially if the input data set exists or is easily generated. The data required by the model is maintained by most railroads, does not require manual input, and is manipulated using spreadsheet commands.

Figure A1.2 shows the finished Factor Model spreadsheet created for Nashville. Below is and a step-by-step guide to creating a Factor Model spreadsheet for a different

terminal, including data requirements and spreadsheet commands. The commands are based on Microsoft Excel 4.0 for Windows, although it is likely that the process would work on other versions of Excel. Because the Factor Model uses both horizontal and vertical sorting and requires initial production of a crosstab report, the Factor Model may not be transferable to early versions of Lotus 1-2-3. CSXT's version of Lotus 1-2-3 did not have these capabilities.

In order to create a Factor Model spreadsheet, the following steps are necessary:

Step 1: Prepare a data set for the terminal which will operate the complex. This data set should be based on all cars processed at the terminal during a typically busy month, such as October or November. The data should be arranged in columns, as shown below:

Inbound Train ID	Outbound Block ID	Car Volume
-------------------------	--------------------------	-------------------

Step 2: Parse Data into columns in Microsoft Excel if necessary.

Step 3: Create column headings such as "Inbound Train", "Outbound Block", and "Volume".

Step 4: Highlight the entire dataset and choose "Set Database" from the "Data" pulldown menu.

Step 5: From the same menu, choose "Crosstab". As prompted, choose to put "Inbound Train" on the vertical axis of the report, "Outbound Block" on the horizontal axis of the report, and "Volume" as the calculated values in the interior of the report.

At this stage, the spreadsheet will contain a report which shows the volume connecting from every inbound train to every outbound block. The report will be sorted alphabetically by lowest to highest train and block ID. Inbound trains will be listed vertically on the left side of the spreadsheet, while outbound blocks will be listed horizontally across the top of the spreadsheet. The task now is to choose the set of inbound trains and outbound blocks which maximizes the number of cars processed in the complex without causing an excessive number of cars to be rescheduled out of non-complex inbound trains and complex outbound blocks. This is accomplished by sorting the report, using the Factor as a sorting criterion.

Step 6: The "Total" column to the right of the crosstab report shows the total number of cars that arrived on each inbound train. To the right of the "total" column, set up a column which demonstrates the number of cars which depart on the leftmost n blocks, where n is the number of outbound blocks in the complex. Create a column to the right of that column which shows the percentage of the total cars carried by each train ID that departed on the leftmost n blocks.

Step 7: The "Total" row below the crosstab report shows the total number of cars which departed on each outbound block. Set up a row below the "Total" row which shows the number cars which connected from the top m trains, where m is the number of inbound trains in the complex. Set up an additional column which contains the percentage of all cars on the block which arrived on the top m trains.

Step 8: Using the "Sort" functions in the "Data" pulldown menu, sort the horizontal rows from highest to lowest, using the column containing the number of cars in the top n blocks as the sort key. Then, sort the vertical columns, highest on the left and lowest on the right, using row containing the number of cars arriving on the top m trains as the sort key. If the IDs of the top m trains change as a result of sorting the blocks, or vice versa, re-sort until the top volume trains and blocks are stable. This should not take more than three sorts.

At this point, the upper left hand m by n region of the spreadsheet contain the train-to-block connections which collectively allow the most cars to be processed in the complex. Assess the preliminary results. It is easy to calculate the number of cars which would move in each block in the complex, the total number of cars processed in the complex, and the total number of cars which would require rerouting if the complex were implemented.

No further analysis needs to be performed here if the resulting set of inbound trains and outbound blocks appears satisfactory. However, it is very likely that this result requires a large percentage of cars to change from their original inbound train to outbound block routing. Cars would change from their original inbound train to outbound block routings if they previously entered the yard on a non-complex train, but departed on a complex block. The Factor addresses this problem.

The Factor is an index of the desirability of including the block in the complex. It balances the number of cars that would be included in the complex with the number of cars which must be rerouted.

Sorting the blocks using the Factor, rather than the number of cars that arrived on the top m trains, as the sort key, results in a different set of outbound blocks in the complex. These blocks will contain fewer cars than the set of blocks that was chosen purely on the basis of block volume, but the new blocks will have a higher percentage of cars in the complex, and thus fewer cars will have to be rerouted.

Outbound blocks fed by more inbound trains will have lower Factor values. They are less desirable for the complex, regardless of high volume, because a lower percentage of the cars which previously departed on the block arrived on the top m inbound trains.

Step 9: Create another row at the bottom of the spreadsheet. This row will contain the Factor. The Factor is the *product* of the number of cars in an outbound block that arrived on the top m trains and the percentage of total outbound block volume that arrived on the top m trains. Both of these figures exist in the

spreadsheet already, making the row that contains the Factor easy to generate. To increase the relative importance of avoiding reroutes, square or cube the percentage of total block volume which arrived on the top m trains within the Factor. Note that this weighting factor decreases in effectiveness when the power to which the percentage is raised increases beyond 4 or 5.

Step 10: Re-sort the *columns*, using the Factor as the sort key. The number of cars processed in the complex will drop, but the number of cars which must be rerouted will drop by a larger degree. It is possible that sorting by Factor may change the inbound trains selected for the complex. If this happens, re-sort the *rows* and proceed.

Step 11: Assess the results. Was the drop in rerouted cars vs. the drop in cars processed in the complex satisfactory? If not, increase or decrease the relative weight of the percentage of cars arriving on the top m trains in the Factor and re-sort.

If the results still are not satisfactory, either because too little volume is being processed in the complex or because a large number of cars must be rerouted, consider dispatching one or more of the highest-volume blocks from both “directions” of the complex.

In the case of Radnor Yard, creation of northbound and southbound complexes would have required the rerouting of many cars to and from Memphis, because Memphis is west of Nashville and the Nashville-to-Memphis blocks receive cars from both northbound and southbound trains. Furthermore, blocks destined to CSXT’s Memphis interchange partners have high volume, and would otherwise have been selected for the complex.

To dispatch large blocks from both complexes allows each block to occupy a single bowl track throughout the day. This cuts down greatly on the number of rerouted cars because the block may now receive cars from any inbound train, instead of receiving cars from only the m inbound trains in the complex.

Figure A1.2: The Factor Model

	2	PEVY	EVL	DAN	LAF	DTR	ZSO	MEMP	LOU	CEIG	MESW	ZBR	BOW	MEIC	LO2	LO3	26NB	MEM	SAT	LO	ATK	GUT	50AS	56	LO1	LO4	MLN	ZN				
Q520	311	167	202	38	42	15	96	158	907	11	55	73	105	196	3																	
R673+R675	673	111	133	141	57	69	208	247	234	22	124	9	16	150	32		151	89	49	147	45	69	1	154	78	36	3	5				
Q684	113	38	183	115	223	127	3	283	337	25	116	33	111	205	1		253	20	105	8	34	5	14	4	3	20	2					
R582	481	118	215	51	24	13	104	294	72	55	171	36	105	44	48	18		153	63	202	31	25	1	9	123	4	4	12				
R573	77						18	20	187	2	184	4	279	198	14			84	3	20	15	31		12	10	38	14	12				
R532	160	2	30	6	9	1	24	8	746	3	12	47	62	98				177	10	326	40	27		16	192	52	32					
Q575				1				495	5	1	50	2	2	35	52	10		63	10	134	40	34		358	67	5	13	1				
Q536	28		43	3	8		4	7	317		2	14	14	2	61			382	24	165	28	5	1	102	9	8	2					
R530	63		45	5	1		11	33	468		2	32	32	1	107			94	11	102	17	40		56	231	1	8	2				
M717							17	1	72		144							20	11	102	17	40		98	75	8	1	2				
Q595	23		1	3			47	27			2	50	2	147	1			32	2	122	1	1		6	47	17	23					
M719	74		8	9	9		69	129		2	28	21	43	10	1			35		29	35	72		46	33	33						
R591	3	1	7	1	2	1	124	19		7	7	3	20	15				80	108			2		2	6	58	2					
R229							4	290		1								72	101	2			1		1	1	14	1	27			
R557	6		4	4			1	55	59	3	69	8	15	34	2			13		58	7	6		2	7	7	14	1				
M796	31		4	3	1		22	26	125	3	10		32	5	1			10	1	21	7	6		14	1		2					
R515			12				5	14			37		4	21				73		76				17			2					
M787	33						42	3	47											2			23		18							
Q572							98																	1	1							
Q649	1		2				3	3	2	2	1	3	3	40	2			1	28			5		1	1							
R519							1	1	1	3			10	5				3	11													
Q544							29																									
R546							20																									
R214							3													1				1								
R270							1																	1								
R538							42	3	47																							
R576							98																									
Q543							1																									
M798																																
Q571																																
R228																																
M718																																
Q647																																
R589																																
Q614																																
R553																																
M779																																
Total cars	2078	437	896	377	379	228	587	1880	4211	130	1015	45	408	920	1274	103																
top 4 trains	1578	434	733	345	346	224	411	982	1550	113	466	45	227	410	481	67																
percent	0.76	0.99	0.82	0.92	0.91	0.98	0.70	0.52	0.37	0.87	0.46	1.00	0.56	0.45	0.38	0.65																
FACTOR	691	425	401	264	263	212	141	140	77	3	74	2	45	39	1	36	29	25	9	18	8	6	65	4	7	2	2	1	1			

FACTOR = number of cars arriving on top 4 trains * (percent of total cars)^3

Total cars moving in the top 16 blocks 14968 Nov-93 499 per day
 Cars in top 16 blocks on the top 4 trains 8412 Nov-93 280 per day
 Percentage in top 4 trains 56%
 Number of cars which must be rescheduled 6566 Nov-93 219 per day
 0.324

Appendix 2: Network Node Names

CSX Transportation's modeling network consists of 537 network nodes. Network nodes are defined for major and minor yards or junction points, and to recognize agglomerations of customer sites. Figure 2. illustrated CSXT's modeling network, with node numbers. Following is a list of node names and interchange partners. Names are abbreviated to nine letters, and names with multiple words are abbreviated using the first three letters of each word.

Node #	City	St.	Interch. Road	Node #	City	St.	Interch. Road
100	CHICAGO	IL		160	WATSEKA	IL	TPW
101	CLEARING	IL	BN	161	DANVILLE	IL	CR
102	PROVISO	IL	CNW	162	DANVILLE	IL	KBSR
103	CHISCHPAR	IL	SOO	163	DANVILLE	IL	NS
104	CLEARING	IL	ATSF	164	DECATUR	IL	IC
105	CHICAGO	IL	WC	165	DECATUR	IL	NS
106	CHICAGO	IL	MP	166	OAKCITY	IN	AWW
107	CHICAGO	IL	CC	168	EVANSVILL	IN	
108	CHICAGO	IL	IC	169	EVANSVILL	IN	IHRC
109	CHI100STR	IL	CSL	170	BREESE	IL	
110	CHICAGO	IL	SSWN	171	FLORA	IL	
111	BLUISLAND	IL	IAIS	172	SALEM	IL	MP
112	CHICAGO	IL	NS	173	LAWRENCEV	IL	
113	BLUISLAND	IL	CMNW	174	VINCENNES	IN	
114	CHICAGO	IL	BRC	175	WASHINGTON	IN	
116	BLUISLAND	IL	GTW	176	MITCHELL	IN	
117	EASCHICAG	IN	CSS	178	SEYMOUR	IN	
118	CHICAGO	IL	IHB	180	SAILOUMAD	IL	
119	CLEARING	IL	CR	181	EASSAILOU	IL	MP
122	GARRETT	IN		182	EASSAILOU	IL	SSW
123	NORJUDSON	IN	JKL	183	EASSAILOU	IL	BN
124	CURTIS	IN		184	EASSAILOU	IL	NS
125	MILLER	IN	CSS	185	EASSAILOU	IL	CNW
126	CURTIS	IN	EJE	186	EASSAILOU	IL	ALS
127	WELLSBORO	IN		187	EASSAILOU	IL	GWWR
128	ROCKDALE	IL		188	EASSAILOU	IL	TRRA
129	OTTAWA	IL		190	MOUVERNON	IN	
130	MONON	IN		191	WOODLAWN	IL	BN
131	DELPHI	IN	NS	192	HENDERSON	KY	
132	BROOKSTON	IN		193	ANACONDA	KY	
135	LAFAYETTE	IN		195	ATKINSON	KY	
136	NUCOR	IN		196	PROVIDENC	KY	TWRY
137	LAFAYETTE	IN	NS	197	PARADISE	KY	
141	BLOOMINGT	IN		199	GUTHRIE	KY	RJCM
144	BEDFORD	IN		212	ELDEAN	OH	
146	NEWALBANY	IN		214	DAYTON	OH	
147	WATSON	IN	SIND	215	DAYTON	OH	CR
150	WATSEKA	IL		216	LIMA	OH	
151	HOOPESTON	IL		217	LIMA	OH	CR
152	DANVILLE	IL		220	SAINTJOE	IN	
153	CAYUGA	IN		221	DEFIANCE	OH	
154	DEWEYOS	IN		222	FOSTORIA	OH	
155	DECATUR	IL		223	FOSTORIA	OH	NS
156	TERHAUTE	IN		224	TIFFIN	OH	IHRC
157	TERHAUTE	IN	CR	225	WILWEST	OH	
158	TERHAUTE	IN	SOO	226	LESTER	OH	

Node #	City	St.	Interch. Road	Node #	City	St.	Interch. Road
227	PARMA	OH		303	WILMINGTO	DE	
228	CLEVELAND	OH	RT	304	ELSJUNCTI	DE	OCTR
229	CLEVELAND	OH	CUVA	305	WILMINGTO	DE	CR
230	STERLING	OH		306	CHATHAM	ON	CP
231	WARWICK	OH	RJCL	307	CHATHAM	ON	CN
232	AKRON	OH	WE	308	BALTIMORE	MD	
233	CANTON	OH	WE	310	BALSPAPOI	MD	PBR
236	LORDSTOWN	OH		311	BALBAYVIE	MD	CR
237	NEWCASTLE	PA		315	LOYER	MD	
238	YOUNGSTOW	OH	CR	320	JESSUP	MD	
239	NEWCASTLE	PA	BPRR	321	POTYARD	VA	NS
240	DETROIT	MI		322	POTYARD	VA	DH
241	DETROIT	MI	CP	323	POTYARD	VA	CR
242	DETROIT	MI	CN	324	BRUNSWICK	MD	
243	DETROIT	MI	NS	326	MARTINSBU	WV	
245	DETROIT	MI	CR	327	SHEJUNCTI	WV	NS
246	DETROIT	MI	DC	328	HANCOCK	WV	
247	PLYMOUTH	MI		329	GRESFRING	WV	SBVR
248	ANNPERE	MI	TSBY	330	EMOGROVE	MD	
249	LANSING	MI		331	BITTINGER	PA	
250	GRARAPIDS	MI		332	PORTERS	PA	YKR
252	HOLLAND	MI		333	GETTYSBUR	PA	GETY
254	WESTOLIVE	MI		334	HAGERSTOW	MD	
255	BENHARBOR	MI		335	HIGHFIELD	MD	MMID
262	WHICLOUD	MI		337	HAGERSTOW	MD	CR
264	MANISTEE	MI		338	HAGERSTOW	MD	NS
265	KEWAUNEE	WI	GBW	340	LURGAN	PA	
270	WALBRIDGE	OH		341	LURGAN	PA	CR
271	TOLEDO	OH	GTW	342	ROXBURY	MD	
272	TOLEDO	OH	CR	345	CUMBERLAN	MD	
273	TOLEDO	OH	NS	346	ROCKWOOD	PA	
274	NEWBOSTON	MI		347	CAMBRIA	PA	
275	WAYNE	MI	CR	350	GLASSPORT	PA	
276	WIXOM	MI		351	DEMMLER	PA	
277	GRABLANC	MI		352	HOMESTEAD	PA	CR
278	FLINT	MI		353	BESSEMER	PA	URR
279	FLINT	MI	GTW	354	ALIQUIPPA	PA	ALQS
280	MIDLAND	MI		355	BESSEMER	PA	CR
281	ESSEXVILL	MI		364	GAMBLES	PA	
282	BAYCITY	MI	DM	365	PITTSBURG	PA	MCRK
283	SAGINAW	MI		366	PITTSBURG	PA	CR
284	SAGINAW	MI	HESR	367	ZELIENOPL	PA	
285	PAINES	MI	MMRR	368	MCBRIDE	PA	
286	PORTHURON	MI		369	NEGBRANCH	PA	
290	WINDSOR	ON	ETL	370	KEYSER	WV	
292	FARGO	ON		372	METTIKI	MD	
293	SUSBRIDGE	NY		374	PATPREPLA	WV	
294	SUSBRIDGE	NY	CR	375	GRAFTON	WV	
295	BUFFALO	NY	DH	377	HAYWOOD	WV	
296	BUFFALO	NY	BPRR	378	RIVESVILL	WV	CR
297	BUFFALC	NY	CN	379	MCW2	WV	
298	SAGINAW	MI	CMGN	380	SENTINEL	WV	
299	SARNIA	ON	CN	381	ELKHEAD1	WV	
300	PHIEASSID	PA		382	ALEXANDER	WV	
301	PARJUNCTI	PA	CR	384	CRAWFORD	WV	
302	PARJUNCTI	PA	DH	385	BURNSVILL	WV	

Node #	City	St.	Interch. Road	Node #	City	St.	Interch. Road
386	JULIANA1	WV		495	ERWIN	TN	
390	BENWOOD	WV	WE	499	BOSYARD	NC	
392	BROJUNCTI	WV		500	COLUMBUS	OH	
393	WILISLAND	WV		501	COLUMBUS	OH	CR
394	PARKERSBU	WV		502	VALCROSSI	OH	NS
395	WASHINGTON	WV		503	TAYLOR	OH	
396	RAVENSWOO	WV		504	NEWARK	OH	
397	APPGROVE	WV		505	CAMBRIDGE	OH	
400	CINCINNAT	OH		506	MOUVERNON	OH	
401	CINCINNAT	OH	CR	507	CAREY	OH	
402	CINCINNAT	OH	NS	508	HEATH	OH	CR
403	CINCINNAT	OH	GTW	509	SPRINGS	OH	
408	HAMILTON	OH		510	WASCOUHO	OH	
411	MIDDLETOW	OH		511	MARION	OH	CR
422	COTGROVE	IN		512	VAUCES	OH	
426	MAUZY	IN		513	COLUMBUS	OH	IOCR
427	INDIANAPO	IN		514	CHILLICOT	OH	
428	INDIANAPO	IN	IU	515	SILOAM	KY	
429	INDIANAPO	IN	CR	516	MAYSVILLE	KY	
432	KIJUNCTIO	KY		518	CAREY	OH	CR
433	OBANNON	KY		522	MARMET	WV	
436	RIVERPORT	KY		524	HUNTINGTO	WV	
437	SKILLMAN	KY		525	RUSSELL	KY	
438	OWENSEBORO	KY		526	PAINTSVIL	KY	
440	LOUISVILL	KY		528	MARTIN	KY	
441	LOUISVILL	KY	PAL	529	SHELBY	KY	
442	LOUISVILL	KY	SOO	532			
443	LOUISVILL	KY	CR	534	PEACREEK	WV	
444	LOUISVILL	KY	NS	540	BILCREEK	WV	
445	LEXINGTON	KY		542	DANVILLE	WV	
446	FRANKFORT	KY		544	ELKRUNJUN	WV	
447	BARJUNCTI	KY	RJCR	552	TOMSFORK	WV	
449	GALLATIN	TN		553	SOUCAR9	WV	
450	MEMJUNCTI	KY	RJCM	554	ALLOY	WV	
451	PARIS	KY		557	GAUBRIDGE	WV	CR
452	PARIS	KY	TTIS	561	RUSHRUN	WV	
453	LEXINGTON	KY	NS	562	QUINNIMON	WV	
456	BEREA	KY		563	MAPMEADOW	WV	
458	EASBERNST	KY		564	STOCCOAJUN	WV	NS
462	PATIO	KY		565	HINTON	WV	
463	RAVENNA	KY		568	COVINGTON	VA	
465	HAZARD	KY		570	CLIFORGE	VA	
470	CORBIN	KY		571	GLASGOW	VA	NS
474	GATLIFF	KY		573	LYNCHBURG	VA	
475	EDGEMOOR	TN		574	LYNCHBURG	VA	NS
476	HARRIMAN	TN	NS	576	BREMO	VA	
478	ALCOA	TN		577	LUCK	VA	
479	ETOWAH	TN		582	FISHERSVI	VA	
480	BAILEYS	KY		584	CHARLOTTE	VA	
481	CLOVER	KY		585	GORDONSVI	VA	
482	CAIRNES	KY		586	VERDON	VA	
483	SARAH	KY		597	WILLIAMSB	VA	
486	LOYALL	KY		598	NEWNEWS	VA	
490	DANTE	VA		599	CHESAPEAK	VA	
491	SAINTPAUL	VA	NS	600	JOHYARIC	TN	
493	KINGSFORT	TN		601	MEMPHIS	TN	MP

Node #	City	St.	Interch. Road	Node #	City	St.	Interch. Road
602	MEMPHIS	TN	SSW	690	NEWORLEAN	LA	
603	MEMTENYAR	TN	BN	691	NEWORLEAN	LA	MP
604	MEMPHIS	TN	IC	692	NEWORLEAN	LA	SP
612	BRUCETON	TN		693	NEWORLEAN	LA	KCS
613	BRUCETON	TN	KWT	694	NEWORLEAN	LA	IC
614	NEWJOHNSO	TN		695	NEWORLEAN	LA	NS
615	NASHVILLE	TN		696	NEWORLEAN	LA	NOPB
616	VINEHILL	TN	NERR	700	ATLANTA	GA	
617	MADISON	TN		701	ATLANTA	GA	NS
618	SPRHILL	TN		702	FULCO	GA	
619	NATCO	TN	TSRR	703	UNIONCITY	GA	
622	ATHENS	AL		706	SENOIA	GA	
624	OAKWORTH	AL		710	JUNCITY	GA	
625	DECATUR	AL	NS	711	COLPARK	GA	
626	CULLMAN	AL		712	LAGRANGE	GA	
630	BLUCRE7	AL		713	GASTON	AL	
631	ENSLEY	AL	BS	715	WAUGH	AL	
632	BROOKWOOD	AL	SR	721	OGLETHORP	GA	
638	RAGLAND	AL		722	CORDELE	GA	
639	GADSDEN	AL		723	EASCORDEL	GA	GSWR
640	BIRMINGHA	AL		726	FITZGERAL	GA	
641	BIRMINGHA	AL	BN	728	AMBROSE	GA	
642	BIRMINGHA	AL	NS	732	CEDARTOWN	GA	
643	BIRMINGHA	AL	SR	735	CALHOUN	TN	
645	CALERA	AL		737	COPPERHIL	TN	
648	COOSADA	AL		740	ELIZABETH	GA	
650	MONTGOMER	AL		741	ELIZABETH	GA	GNRR
651	MONTGOMER	AL	NS	742	STILESBO	GA	
653	SELMA	AL		743	CALHOUN	GA	
654	MYRTLEWOO	AL	MBRR	744	WAUHATCHI	TN	
662	BRUNDIDGE	AL		745	CHATTANOO	TN	NS
663	DOTHAN	AL		746	BRIDGEPOR	AL	
664	DOTHAN	AL	ASAB	747	BRIDGEPOR	AL	SQVR
665	DOTHAN	AL	HS	748	MURFREESB	TN	
666	BAINBRIDG	GA		749	SMYRNA	TN	
667	SAFFOLD	GA	CIRR	752	LAWRENCEV	GA	
668	BAINBRIDG	GA	GSWR	753	ATHENS	GA	
670	MCGEHEES	AL		755	ABBEVILLE	SC	
671	BAYMINETT	AL		756	GAINESVIL	GA	NS
673	CANTONMEN	FL		761	LITHONIA	GA	
674	GOULDING	FL		762		GA	
675	PACE	FL		763	HARLLEE	GA	
676	COTTONDAL	FL	ASAB	764	BARNETT	GA	GWRC
677	BREWTON	AL		774	HAMPTON	SC	
678	HYBART	AL	BN	775	HAMPTON	SC	HB
679	GEORGIANA	AL	AFLR	780	AUGUSTA	GA	
680	MOBILE	AL		781	AUGUSTA	GA	NS
681	MOBILE	AL	IC	782	GREENWOOD	SC	
682	MOBILE	AL	NS	783	GREENVILL	SC	
683	MOBILE	AL	BN	784	LAURENS	SC	CPDR
684	MOBILE	AL	TASD	785	SPARTANBU	SC	
685	PASCAGOUL	MS		786	SPARTANBU	SC	NS
686	PASCAGOUL	MS	MSE	787	IRMO	SC	
687	BILOXI	MS		788	EASCHESTE	SC	LC
688	GULFPORT	MS	MSRC	789	CATAWBA	SC	
689	HARBIN	MS		800	EASSAVANN	GA	

Node #	City	St.	Interch. Road	Node #	City	St.	Interch. Road
801	SAVANNAH	GA	NS	887	COLLIER	VA	
802	INTERSTAT	GA		888	PETERSBUR	VA	NS
803	SAVANNAH	GA	SSDK	889	WHEELWRIG	VA	
810	SAVGEOPOR	GA		890	RICACCA	VA	
811	RAVENEL	SC		892	SOURICHMO	VA	NS
812	CHARLESTO	SC		898	PORTSMOUT	VA	NPB
813	CHARLESTO	SC	NS	899	FRANKLIN	VA	NS
814	CHARLESTO	SC	PTR	900	JESUP	GA	
815	CROSS	SC		902	WAYCROSS	GA	
817	FLORENCE	SC		903	BRUNSWICK	GA	
818	FLORENCE	SC	SCRF	904	BRUNSWICK	GA	NS
823	NORCHARLE	SC		906	FOLKSTON	GA	
825	GEORGETOW	SC		907	CRAWFORD	FL	
826	MULLINS	SC		908	VALDOSTA	GA	
827	MULLINS	SC	MRR	909	VALDOSTA	GA	VR
828	MCCOLL	SC	PDRR	910	VALDOSTA	GA	NS
830	RINCON	GA		916	THOMASVIL	GA	
831	DUNBARTON	SC		918	ALBANY	GA	AGLF
832	SWANSEA	SC		920	JACKSONVI	FL	
833	CAYCE	SC		921	JACKSONVI	FL	FEC
835	EASTOVER	SC	NS	922	JACKSONVI	FL	NS
836	SUMTER	SC		923	JACEXIM	FL	JXPT
837	ALCOLU	SC		925	BUSCH	FL	
838	LUGOFF	SC		926	FERBEACH	FL	
839	ROBINSON	SC		927	KINGSLAND	GA	
845	HAMLET	NC		928	KINGSLAND	GA	SM
846	RALEIGH	NC		930	LIVEOAK	FL	
847	ABERDEEN	NC	AR	932		FL	
849	RALEIGH	NC	NS	936	FOLEY	FL	
851	MONROE	NC		937	TALLAHASS	FL	
852	WINSALEM	NC	NS	938	CHATTAHOOC	FL	
853	WADESBOBO	NC	NS	939	CHATTAHOOC	FL	AN
854	MATTHEWS	NC		942	BOSTWICK	FL	
855	CHARLOTTE	NC		945	TAFT	FL	
856	CHARLOTTE	NC	NS	946	AUBURNDAL	FL	
858	SHELBY	NC		947	GREENBAY	FL	
859	SHELBY	NC	NS	948	ARCADIA	FL	SGLR
864	WILMINGTO	NC		949	GRIFFIN	FL	
870	DIXIE	NC		950	BALDWIN	FL	
871	FAYETTEVI	NC		952	HODGSON	FL	
872	FORJUNCTI	NC	CF	953	REDLEVJUN	FL	
873	DIXIE	NC	LRS	954	NEWBERRY	FL	FWCR
874	FAYETTEVI	NC	NS	955	HAWTHORNE	FL	
875	WILSON	NC		956	WILDWOOD	FL	
876	SELMA	NC	NS	965	BUSHNELL	FL	
877	GOLDSBORO	NC		966	BUSHNELL	FL	
878	ROCMOUNT	NC		972	WINSTON	FL	
879	ROCMOUNT	NC	NCYR	973	AGROCK	FL	
880	LEECREEK	NC		980	TAMPA	FL	
881	BATTLEBOR	NC		982	DREW	FL	
882	ROARAPIDS	NC		984	ROCKPORT	FL	
883	FRANKLIN	VA		985	ONECO	FL	SGLR
884	PORTSTOFC	VA		990	PALCENTER	FL	
885	SUFFOLK	VA	NS	996	FORLAUDER	FL	
886	VULCAN	VA		998	MIAMI	FL	

¹ February 1995 SPM simulation of historical operations. This figure is calculated based on the storage size of the report files, rather than the data contained therein. Because some information is redundant and many of the reports are stored inefficiently, the storage space consumed by the reports may be 10 times as great as necessary. Nevertheless, even 10 MB of SPM output data would be difficult for an individual to monitor effectively.

² Not all cars originating at nodes served by pre-blocking local trains were reflowed by the ABM over the system blocks. There are two reasons for this, one related to actual operations, and one related to use of the models.

As an operational example, some traffic originating at node 168, Evansville, IN, is picked up by Evansville local trains, and therefore may be pre-blocked, receiving the attendant benefits of earlier availability and fewer actors in the process of moving it through the serving yard. Other traffic originating at node 168 is picked up by Evansville yard switchers, because of placement of yard limits. While yard switchers could still pick up these cars in block order, the benefits of earlier availability would probably not be as great because yard switchers could switch this traffic immediately after returning to the yard, even if no attempt was made to pick up in block order. Because traffic picked up by yard switchers and traffic picked up by local trains within a single node is indistinguishable in the modeling environment, no traffic originating at nodes containing the actual serving yards was reflowed.

In addition to the operational concerns, traffic originating at nodes containing serving yards poses modeling problems. For example, traffic originating at node 191, Woodlawn, IL, is picked up by Evansville local trains and set off at Evansville for switching. To represent pre-blocking of this traffic, the modeler is required only to create blocks originating at node 191 and terminating at the pre-blocking destinations. These newly created pre-blocks are assigned to Evansville local trains for the trip from Woodlawn to Evansville. At Evansville, the pre-blocks are swapped to through trains, and the benefit to trip time and reliability is expressed in the substitution of a blockswap for a classification at Evansville for all cars in the block.

However, pre-blocking of traffic originating at or near Evansville proper (within node 168) cannot be represented as described above. If traffic originating at node 168 is picked up by a local train, switched at Evansville yard, node 168, and finally departs node 168 on a through train, this activity is expressed not by explicit representation of the blocking and classification activity, but rather in the time distribution describing the traffic flow's entry into the system. While it is possible to alter the arrival distribution of the traffic to approximate pre-blocking, this representation would not necessarily reflect actual activity any more accurately than if the distribution were not changed.

Traffic originating at nodes containing serving yards represents a large proportion of all traffic targeted for pre-blocking. In the case of cars originating on Evansville local trains, 69 cars per day in 56 O/D pairs originate at node 168, while only 44 cars per day in 45 O/D pairs originate at outlying nodes 166, 190, 192, and 193. Although much traffic originating at node 168 is handled by yard switchers, benefits due to Local Pre-Blocking are understated, as some moves on local train are not subject to improvement in the model, and, for those traffic flows in the model which do traverse two nodes before reaching the a through train, the results are under-extrapolated at the network level.

³ Train R532 moved an average of 127 cars per day between Bruceton and Nashville, while train R590 moved an average of 123 cars per day from Nashville to Evansville. On the balance of their routes, R532 and R590 carried less than 90 cars per day. No other complex trains exceeded 100 cars per day on any route segments.

⁴ Train symbols listed are current as of May 1995, and are different from those used during November 1993.

⁵ A recent list of classifications maintained at Nashville had 58 separate class codes, not including distinctions between local blocks on the same local train. Of these, 31 were represented in the base case block file. At Louisville, the classification list contained 52 class codes not including local train distinctions. Of these, 37 were represented in the base case block file.