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OVERVIEW OF COMPUTER-BASED MODELS APPLICABLE TO FREIGHT CAR UTILIZATION

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16. Abstract

This report documents a study performed to identify and analyze twenty-two of the important computer-based models of railroad operations. The models are divided into three categories: network simulations, yard simulations, and network optimizations. The simulations are used to assess the impact of certain operating policies and planning procedures. The network simulations examine system-wide effects, while the yard simulations focus on the operations performed within a single yard. Network optimizations typically are used to calculate optimal distribution for a rail system's empty freight cars based on the railroad's car distribution rules and goals. The description of each model includes its history, design approach, fundamental logic, unusual features, hardware and software specifications, and its extent of application. In the case of a model's implementation on a rail system, attempts were made to obtain test results and evaluations. This served as a basis for reviewing each model.

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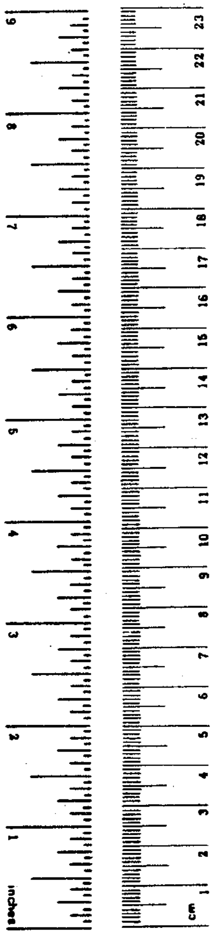
PREFACE

This report documents analysis performed at the Transportation Systems Center in support of the Freight Car Management Program of the Federal Railroad Administration. The program requires the use of computer-based planning and analysis tools capable of assessing potential improvements in freight car management. This document provides a review and summarization of some of the important models developed within the railroad industry. This report should be useful to government analysts in selecting tools to support their program objectives and to railroad personnel contemplating development of computer-based models. I wish to thank Dennis Goeddel for contributing the material on yard simulations. I am also indebted to Ken Troup for kindly providing me with a great deal of the documentation that is referenced in this report. Finally, I wish to acknowledge Peter Segota for his constructive criticisms during the report's preparation.

METRIC CONVERSION FACTORS

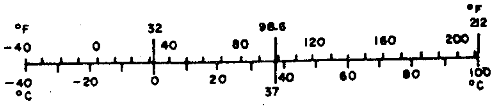
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. EXECUTIVE SUMMARY

Three types of railroad models are reviewed in this report: network simulations, yard simulations, and network optimizations. The simulations are used to assess the overall impact of certain operating policies and planning procedures. Railroads use network simulations to examine how a change in a particular policy will affect the movement of cars and trains through the entire network. A yard simulation is a detailed representation of the geography of a single yard. It focuses on the operations (e.g., switching, humping, classifying, blocking) performed within the confines of a yard. Network optimizations typically are used to calculate optimal distribution for a rail system's empty freight cars based on the railroad's car distribution rules and goals.

The first simulation of railroad operations was developed in 1966 by William Allman. His work did not represent a particular network and was not intended for actual implementation. Allman's model did stimulate research and influence simulations that were subsequently developed for specific railroad applications. Since that time a number of railroads have developed or adapted network simulation models for utilization in classification yard development, blocking policies, rail terminal consolidation and relocation, crew scheduling and freight car control techniques.

Yard models have been used by several railroads in order to analyze classification procedures, yard resource assignments, and the redesign of yard facilities.

Optimization models are used by several railroads to allocate their empty freight fleets. The implementation of these models has resulted in better car utilization, reduced fleet size, fewer empty car miles, and improved response to shipper car demand. An optimization model developed by FRA is being used to analyze the economic impact of various national railroad network configurations.

Of the twenty-two models studied, nineteen were written for direct application to railroad problems. Results from the network simulations have been somewhat disappointing, primarily due to expense associated with the initial development, with data acquisition and preparation, and with actual simulation runs. All of the yard simulations have been used by railroads with some success. The optimization models have been very useful in the scheduling and distribution of empty cars. With the exception of the Thomet model, all of the optimizations have been applied directly to rail operations.

The chart shown in Table 1 outlines the descriptive information on all of the freight car utilization models reviewed in this report.

TABLE 1. FREIGHT CAR UTILIZATION MODELS

MODEL NAME	SECTION REF	CATEGORY	IMPLEMENTATION	COMPUTER	LANGUAGE	COMMENTS
AAR	3.7	network simulation	St. Louis terminal project (1974)	applicable to several machines	SIMSCRIPT	difficult and costly to implement particularly in terms of data collection and detail specification
Allman	3.1	network simulation	validated with New York Central data	IMB 7094	SIMSCRIPT	prototype for models developed by Frisco and Canadian National
Battelle TERMINAL II	4.2	yard simulation	Frisco-Tulsa Yard; Great Northern; & C&O/B&O	CDC 6600	FORTRAN	C&O/B&O (Chessie) has added a post-processor that when used in conjunction with TERMINAL II will simulate the receiving yard
Canadian National	3.3	network simulation	used since 1969	IBM 360/65	SIMSCRIPT	flexible output reports, absence of information on system costs (e.g. crew costs)
Chessie Systems Mini-Network	3.8	network simulation	change in crew hrs; evaluate Chicago/Buffalo service	CDC 6600	SIMSCRIPT	mini-network simulates entire trains instead of individual cars; logic borrowed from AAR model
Decision Systems Associates, Inc.	5.8	optimization	no-still in validation phases	CDC 6600	FORTRAN IV	multiple-criteria objective; Ford-Fulkerson out-of-kilter Algorithm, validated with TOPS data from the Southern Pacific
Empty Freight Car Distribution-Queens University	5.3	optimization	Canadian Pacific	IBM 360	FORTRAN	used by CP for optimal empty car distribution; Ford-Fulkerson out-of-kilter Algorithm
FRA	5.6	optimization	incorporated into a network costing model by TSC	IBM 360/40	FORTRAN	originally a highway model, modified by John Williams of FRA to do study of economic potential of U.S. rail network
Frisco	3.2	network simulation	abandoned by Frisco in 1969	CDC 6400	SIMSCRIPT 1.5	Frisco spent over $400,000 before the project was discontinued
Louisville & Nashville Simulation	3.5	network simulation	used by L&N and later by SCL/L&N	IBM 360/50	COBOL GPSS	tested effects of sudden gains and losses in traffic levels; model has ability to create extra train for surplus cars
Louisville & Nashville Scheduling Model	5.1	optimization	used by L&N since 1966	IBM 360/30	a simplex algorithm package	helped L&N to allocate empty cars efficiently; simplex algorithm

MoPac's Simulation System	3.10	network simulation	installed within the last year	IBM 360/50 or CDC 6400	FORTRAN IV	used to test scheduling policy on a day-to-day basis, integral part of a huge information system
New York Central	4.3	yard simulation	used in 1967	not available	GPSS III	simulated the proposed design for the Alfred E. Pearlman Yard
Railcar Network Model-Queens University	3.8	network simulation	Canadian Pacific	IBM 360/65	FORTRAN	product of Queen's business school; model recognizes problem of assigning a stochastic distribution to train departure behavior
SCL/L&N (2)	4.4	yard simulation	used since 1965, updated model 1972	IBM 360/40 or IBM 360/50	GPSS III	original model simulated L&N's Boyles Yard; used to facilitate SCL/L&N merger; 1972 model studied effect of projected 1978-80 traffic volume
SRI	4.5	yard simulation	analysis of CONRAIL policies	CDC 6400	FORTRAN IV	no built-in decision logic; high degree of user interaction required
Southern's Network Model	3.4	network simulation	used since 1972	IBM 360/65	GPSS	studied train length and frequency
Southern Flow Rules	5.4	optimization	manual form since 1967, computerized in 1975	IBM 360/65	any standard LP package will solve the optimization	originally a manual distribution process; in the last year Southern has implemented its Flow Rules as a linear program
Southern Pacific's Network Model	3.6	network simulation	S.P's West Colton Yard justification study	IBM 360/40G	GPSS	used to justify multi-million dollar investment in SP's West Colton Yard
Southern Pacific's Pool Analysis	5.6	optimization	used for SP's multilevel pool fleets	IBM 360/40G	FORTRAN	minimizes total empty car days; these cars are used to transport automobiles from assembly plants to distribution centers
Swiss Federal Railroad	5.8	optimization	implemented early 1976	IBM 360/65	FORTRAN IV	distribution plan for empty cars, uses modified Ford-Fulkerson-out-of kilter algorithm
Thomet	5.2	optimization	1971 Ph.D dissertation Carnegie-Mellon	not available	not available	"user-oriented" distribution scheme considers "additional" costs borne by shippers along with the usual railroad cost

2. MODEL APPLICATIONS IN THE RAILROADS

2.1 INTRODUCTION

This report addresses the results of a task to review the use of computer models as planning and analysis tools in assessing the potential improvements in freight car management that result from changes in operational policies or practices. The intention of this report is to review and summarize the available literature and documentation on some of the important freight car simulation and optimization models that have appeared in the last decade. It is by no means a comprehensive or exhaustive presentation nor does it intend to be a survey. The approach was to provide an overview of each of the three model categories; network simulations, yard simulations, and network optimizations. The report reviews several models in each category. In the case of a model's actual implementation on a rail system, attempts were made to obtain test results and evaluations. In addition, special attention was given to the underlying assumptions made by the designers during the model's formulation. This served as a basis for reviewing each model.

2.2 RAIL MODELS - AN OVERVIEW

There is a growing concern with the efficient utilization and management of railroad freight cars. The problems that plague practically every rail system in the country have disturbed people both inside and outside the rail industry.

"Typical problems of rail freight transport include low equipment utilization, long and variable origin/destination transit times, congested and costly terminals, expensive and loosely controlled local movements, and ever-present high direct labor costs."[1] All these factors help to contribute to an inefficient allocation of rail resources and a variable standard of freight service.

In the last decade railroads have discovered the potential of the mathematical model as a sophisticated planning tool. Railroads have hoped that the adoption and implementation of computer-based models would help to alleviate some of their problems and improve freight service. This report reviews some of the models that address the issue of freight car utilization.

A model is an abstract mathematical representation of a real-world situation. A typical railroad model duplicates the movements of whole trains or cars across a network. The two types of models primarily used in the rail industry are simulations and optimizations.

Simulations attempt to represent over-the-road train operations in terms of various mathematical expressions. They simulate movements of trains over a set time period

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[1] R. Mehl, "A Call for Practical Rail Transportation System Models," presentation notes ORSA-TIMS Joint National Meeting, Boston MA, April 22-24, 1974, p. 2.

through a network for a specified input schedule. This type of model serves as a tool for analysis and evaluation of freight car operations. It is primarily useful in establishing an order of magnitude for comparison of one alternative policy to another. For example, a railroad may be contemplating a change in its blocking strategy. Naturally it could institute the change, collect data over a long period of time, and then evaluate the results. This could prove to be a time consuming and costly project, especially if a railroad desires to test more than one strategy. With a simulation, however, the task is simplified. Certain input parameters are designed to correspond to each alternative blocking policy that is to be tested. Simulation runs are made for each alternative and the results are organized in output reports. The railroad then has an idea of how a particular change in its blocking policy will affect the performance of its freight service.

The two types of simulations generally utilized in the rail industry are yard and network models. A yard simulation focuses on policies pertaining to the detailed operations within a single yard. Network simulations provide information concerning policy changes at a system-wide level. Both yard and network simulations are characteristically expensive to run. The tasks that these models address require the simulations to duplicate rail operations on a very detailed scale. In order to provide significant results, a model must simulate these operations for a sufficient amount of time. These factors are the primary contributors to the long computer time required for each run of a model.[2]

The distribution and scheduling of empty freight cars has been an area of great concern for railroads. They are aware of the desirability to control use of valuable rail resources. Optimization models provide the key to efficient car allocations. These models can be used to effectively provide freight car distribution plans that will satisfy such objectives as maximization of filled demands, minimization of transshipment costs, customer delays, and car substitutions, and the efficient utilization of foreign cars. The particular performance criteria selected by model builders reflect their approach to improving freight car service. Because optimization models do not require a precise description of every train operation, it is possible to eliminate and aggregate some of the details in yard, link, and node representation and still produce meaningful analytical results. Due to the macro quality inherent in network optimizations, they are generally less expensive to run than yard or network simulations.

Unfortunately, railroads have faced some obstacles when attempting to incorporate various models into their opera-

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[2] Joseph F. Folk, "A Brief Review of Various Network Models," Studies in Railroad Operations and Economics, Vol. 7, MIT Report No. R72-42, June 1972, p. 1-2, 21.

tional schemes. Often they have found it hard to adapt a generalized all-purpose model to fit their particular needs. A common complaint is that it is initially difficult to choose the level of detail for the model parameters required to define the network geometry, the significant yard operations, and train movements over the links.[3]

In order to facilitate model design, developers have been forced to make a number of underlying assumptions. Critics of some of the current freight car models point out that these modified representations bear little resemblance to real life situations. This causes many people to doubt the validity of test results. They feel that the models tend to over-estimate the performance level of rail systems. A model that generates inaccurate results will hinder improvement in freight car utilization. Therefore the evaluation of a rail model should include information on the underlying assumptions. This provides a basis for determining how reliable a model's output will be.

There are several problematic assumptions that appear in freight car simulations and optimizations. When a combination of these is present in a particular model, it is reasonable to question the reliability of the model. The nine primary assumptions to be aware of are:

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[3] Ibid., p. 18-19.

a. There is an infinite pool of locomotives at every node in the network.

b. Trains meeting on single tracks affect the lower priority train only by an average delay constant.

c. Work operations can be expressed as a simple mathematical function.

d. Empty freight cars move according to a distribution policy.

e. Railroads maintain a honogeneous car type in captive control.

f. Railroads assign only one locomotive per train.

g. Trains move according to a fixed schedule.

h. All costs can be represented as linear mathematical functions.

i. A stochastic phenomenon (e.g., train arrival, train departure, average service time) will fit a specific probability distribution.[4]

The first assumption implies that it is possible to dispatch a train at every node at any point in time. Although this simplifies the dispatching algorithm, it tends to overestimate the level of service a railroad can expect to provide. The problem inherent in the second and third assumptions can be eliminated if the model allows for some measure

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[4] Mehl, op. cit., p. 7-8.

of variance in the constant delays and in the work time function. Since most railroads maintain a distribution policy only for certain specified car classes, the fourth assumption is too general. The fifth assumption ignores the existence of foreign cars. Because of Interstate Commerce Commission (ICC) Car Service Rules, the control and utilization of foreign cars plays an important role in any freight system. The sixth assumption over-simplifies the assignment process. Because railroads typically run heavy freight trains, they often require more than one diesel unit per train. In the real world, freight trains usually move as a function of traffic, not a pre-specified schedule. Train departure time is dependent on the variable arrival times of the connecting cars. This condition clearly violates the seventh assumption. Linear functional costs permit the simple formulation of the objective function (mathematical expression representing the user's goal) used in the optimization. This is one assumption that is difficult to eliminate particularly because many solution techniques are dependent on a linear objective function. With the ninth assumption, it is important to remember that it is not always possible to describe random behavior in terms of a specific distribution function. A model designer should carefully analyze a situation before concluding that it is a classical random process.

Mathematical models occupy a significant position in freight car management. They represent one approach to improving car utilization. It is, however, important to realize that both simulation and optimizational models contain certain problems and implementational drawbacks. The following sections describe a number of simulation and optimization models. The report analyzes the contributions of these models to the area of freight car utilization.

3. NETWORK SIMULATION MODELS

Railroads use network simulations to test proposed changes in their operational policies (e.g., blocking, routing, crew assignment, train length and frequency). A simulation model represents a rail system's network geometry and operational procedures with series of mathematical and logical equations. Management can alter the model parameters corresponding to the specific policy change under study. The results from the model provide the figures that are essential for the evaluation of the proposed changes. This section loosely follows the historical development of the rail network simulation model.

3.1 ALLMAN MODEL

The first model of railroad operations was a SIMSCRIPT simulation developed in 1966 by William Allman. While working for the National Bureau of Standards, he formulated a network model consisting of 11 nodes with connecting links. The model had the capacity to simulate up to 28 trains through the system. The nodes represented yards. The original formulation used a linear function, $t = a + bx$, to calculate the time required for each yard operation. Allman defined x as the number of cars processed through a particular operation. In a later extension of the model, he used a more detailed yard representation and included a first-in, first-out queueing policy.[1]

The simulation was written originally in both GPSS and SIMSCRIPT, because Allman wished to determine which language was more efficient. He soon discovered that although GPSS could adequately handle his small network, a larger model would be too taxing on the storage capacity. The routines that handled the data also consumed a great deal of computer time. Moreover, GPSS was a rather restrictive language to use for programming the freight car problem. For these reasons, Allman abandoned the GPSS model and continued his work using SIMSCRIPT on the IBM 7094.[2]

The model's output included the hauling costs between nodes, the classification costs at each yard, and the mean transit time. Allman used these data to study how changes in train length restrictions, train frequencies between yards, and blocking strategy could contribute to more efficient utilization of freight cars. Allman did not have a particular railroad in mind when he formulated his model. He intended his work to serve as a prototype and to stimulate research in the industry. Two railroads, the St. Louis-San Francisco (Frisco) and the Canadian National (CN) were influenced significantly by the Allman model. Drawing on Allman's basic network definition, they each expanded and

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[1] Joseph F. Folk, "A Brief Review of Varoius Network Models," Studies in Railroad Operations and Economics , Vol. 7, MIT Report No. R72-42, June 1972, p. 4-5,21.

[2] Ibid, p. 4.

modified the simulation to satisfy their own particular needs and system specifications.[3]

3.2 FRISCO MODEL

Because Frisco already possessed a computerized traffic data collection system suitable for simulation testing, it was a logical candidate for model development. The Frisco immediately expanded the number of nodes from 11 to 25 and the trains from 28 to 51. (Subsequent revisions increased the nodes to 70 and the trains to 67). In order to duplicate real-world operations with a greater degree of accuracy, Frisco modified Allman's model to allow for recognition of different traffic classes, and the classifications of cuts (a set of cars with identical origin and destination) in any specified sequence. The original program was converted into SIMSCRIPT-1.5 and implemented on the Frisco's CDC 6400 with 65K memory.[4]

Frisco wanted to simulate operations and study problems in terms of its total network. It concentrated on six operating policies:

a. Where and when to run trains.

b. Longer vs. shorter trains (scheduled more frequently).

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[3] W.P. Allman, "A Network Model of Freight System Operations," <u>Simulation of Railroad Operations</u>, Railway Systems and Management Association, Chicago IL, 1966, p. 129-140.

[4] Folk, op. cit., p. 7.

c. Pre-blocking locations.

d. Yard grouping policies.

e. Car assignment.

f. Selection of yards for classification switching.

The Frisco simulation's inputs and outputs were designed and subsequently modified to satisfy the requirements of these projects.[5]

The model inputs fell into two categories. The first included the specified cuts, traffic data, car cycle information and the particular operating policy that was to be tested. The yard costs embraced the costs of inbound inspection, classification, connection switching, and outbound operations. This value was proportional to the volume of cars participating in each operation. The train-hauling cost was a function of the engine and train crews and the diesel unit costs. The crews' costs were determined by the size of the locomotive and the number of cars in a train.

In order to determine the effectiveness of a particular policy change, the Frisco could draw on three major sources of simulation output: yard snapshots, train departure notices, and the cut transit times. The snapshots, which were calculated at periodic and pre-specified intervals for

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[5] J.A. Bellman, "Railroad Network Model," Second Annual Symposium on the Use of Cybernetics on Railways, Montreal PQ, 149, 1967.

each yard, included the number of cars, the number of origins, destinations, classifications, the queue sizes and their average waiting time. In addition to the yard data, the snapshot provided the movement costs for the cars over each link during the prescribed interval. The train departure notice contained information on the composition of all departing trains. Two important portions of this notice were messages indicating:

1. when a train was delayed due to incomplete outbound operations, and
2. how many cars were left behind at the yard when a train's capacity was exceeded.[6]

This information was vital when testing variations in train length and blocking policies. The third output provided a histogram of the model's cut transit time for each origin-destination combination; this allowed the Frisco to compare the model's transit times with those in the real-world.

Unfortunately the Frisco's test results revealed that there were discrepancies (some of large magnitude) between the model's output and the real-world data. Apparently, Frisco's simulation tended to overestimate the yard and classification workloads and to underestimate the total transit times. In 1969, after $400,000 of combined manpower and computer time, the Frisco suspended the project.[7]

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[6] Ibid., p. 150-152.

[7] Folk, op. cit., p. 8.

3.3 CANADIAN NATIONAL NETWORK SIMULATION

CN recognized a need to maintain a stable flow of traffit through its network in order to meet specified traffic volumes and customer service requirements. Its aim was to predict the effects on system service resulting from simultaneous changes in the CN market, its service target, the operating rules, and the physical resources. In order to accomplish this task, CN concluded that it would require a powerful network simulation model.

In 1967, the CN acquired the "Allman-Frisco" model and began to modify it extensively. The revised model contained over 6500 SIMSCRIPT statements and needed nearly 650K core storage. The network represented operations in three of the five CN regions with 500 nodes and 200 daily trains. A single run of a 21 day simulation required approximately one hour of computer time on the IBM 360/65.[8]

Besides enlarging the network substantially, the CN incorporated over-the-road logic to approximate link interference and delays. For example, if two trains met on a link, the model added an additional time factor to the transit time of the lower priority train. This time corresponded to the average delay for trains meeting on that particular link. Similar adjustments were made when one train overtook another or when two trains entered a node together.

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[8] Ibid., p. 9.

The CN took great care in modeling its nodes. The internal operations performed at small yards were not prime determinants of traffic movement over the network. The nodes corresponding to these yards required practically no detail. On the other hand, large classification facilities demanded careful attention. Local geography, yard resources, and the processing operations had to be included in the nodes' representation. The CN associated an interval of time with each operation. The total time was then a linear function dependent on the number of cars participating in each operation.

The train connections that occurred at each node were classified as absolute or limited. An absolute connection implied that an outbound train would wait indefinitely for connecting cars arriving on a late inbound train. For limited connections there was a prescribed wait time. The model projected ahead to determine if a train were scheduled to arrive after this time. If so, the inbound train cancelled the connection allowing the outbound train to leave.[9]

A special feature of the CN model was its flexible range of analysis reports, patterned along the lines of the Frisco output. The CN could easily access information

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[9] Canadian National Railways, "The CN Network Model-User's Guide, Operational Research Branch, Research and Development Dept., 1971, Chapters 2, 3, Montreal PQ.

ranging from volumes of traffic between nodes to the detailed movements of an individual train. The performance reports included histograms of the total transit times for each train between its origin and destination. This proved to be an essential tool for the analysis of change in operational strategy.[10] The CN has used the model to effectively upgrade its customer service since 1971. A possible drawback to the CN model was the absence of information on costs. It would have been an arduous task to extract the cost data and calculate the figures for 200 trains and 4,000 cars that moved through the system each simulated day.

Three other railroads active during this period in the field of network simulation were the Southern, the Louisville and Nashville, and the Southern Pacific. Although these simulations were not as detailed or as extensive as the work of CN, they did represent a contribution and indicate a need for further model development within the rail industry.

3.4 SOUTHERN NETWORK SIMULATION

The Southern was attacking the problem of train-size reduction. They used a GPSS model called SIMNET to analyze the scheduling changes when the number of cars per train was reduced and more trains were run. SIMTRAN, an expansion of SIMNET, was developed in 1972 and intended for use in evaluation of Southern's blocking procedures. The model used over

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[10] Ibid., Ch. 5.

3,000 GPSS statements to describe a network with 60 terminals and 400 trains. SIMTRAN was implemented on Southern's IBM 360/65 and required approximately nine minutes of computer time for each simulated day.[11]

3.5 LOUISVILLE AND NASHVILLE NETWORK SIMULATION

In 1970, the Louisville and Nashville (L&N) implemented its network simulation. The model was written in COBOL and GPSS for use on the IBM 360/50. The L&N's motives for model development were essentially identical to the motives of the railroads that had preceded them in simulation. The L&N concentrated on the conventional problems of blocking policy, train lengths, train frequency, and scheduling. It also wished to explore the effects of increased traffic levels (given the existing yard capacities) and of a sudden gain or loss of a large segment of traffic. An interesting feature of the model was its ability to create an extra unscheduled train automatically when a certain critical volume was exceeded.[12]

The L&N opted for deterministic historical inputs over probabilistic artificially generated data. Historical data were used to drive the simulation, because it was not overly

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[11] Folk, op. cit., p. 11-12.

[12] Louisville & Nashville Railroad Company, "Progress Report Network Simulation Model of Traffic Flow," Engineering Sciences Division, October 3, 1970, p. 11-15, Louisville KY.

difficult to gather and process. Deterministic inputs also reflected seasonal changes in traffic volumes more accurately than artificially generated data. The L&N also programmed the model to facilitate parameter changes in such areas as train schedules, inbound yard action, number of trains in the network and blocking strategy.[13]

In 1972 the L&N joined the Seaboard Coast Line and the Clinchfield, Georgia and West Point Railways to from the Family Lines System. The new company incorporated L&N's model into its operations. The simulation has been an active input into Family Line policy decisions since that time.[14]

Similar in its design to other railroad simulations, the L&N model requires input of network characteristics, railroad operating procedures, and traffic on the system during the similation period. Typical train and yard functions are modeled in the 2 major sections of the mail -- over the road and yard. Typical applications deal with the effect on the SCL/LN system of changes in train schedules and priorities, classification and blocking strategies, and the levels and mix of traffic.[14a]

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[13] Ibid, p. 1.

[14] IBM, "Simulation on the Family Line System," New York NY, p. 1.

[14a] SA. Alward, "The Practical Applications of Simulation and Other Aids in Improving Train Operations" <u>Proceedings</u> Fourth International Conference on Railway Cybernetics, April 1974, p. 1.049-1.050, Washington DC.

Three specific applications of the L&N model illustrated its importance to the railroad:[14b]

1) The effect of an additional runthrough train with another railroad was examined. The model predicted a train with 53-85 cars each day and no depletion of tonnage from other trains. It also predicted a transit time improvement of 18-36 hours. Despite doubts from some operating people, the train was added and the model results were born out.

2) Another runthrough situation was examined with the model-trains with an average of 79 cars and 75 cars in the two directions were predicted with an improvement in transit time of 10-37 hours. Actual experience during a one-month period early in the program showed average train lengths of 83 and 68 cars and a transit time improvement in the range predicted.

3) A blocking strategy case was also explored. Traffic increases between two points indicated the potential for changes in classification policies. The model was used to determine the effect of running 2 trains so as to by-pass intermediate classification. The model predicted that an average of 73 cars would arrive daily on these trains with an improvement in transit time of 12-14 hours. Actual experience with the train showed 71 cars on the average each day with a savings in transit time of 17 hours.

The foregoing applications are especially significant because of the comparisions with actual operating experience.

[14b] Ibid p. 1.050-1.051.

3.6 SOUTHERN PACIFIC'S NETWORK SIMULATION JUSTIFICATION FOR WEST COLTON YARD

During the 1960's, Southern Pacific (SP) was faced with the decision of whether or not to build a multimillion-dollar classification yard outside of Los Angeles. It devoted over three years and $400,000 to the formulation of a GPSS model that could accurately evaluate the situation. Primarily the SP wished to study how the addition of the proposed classification yard (West Colton) would effect its total rail operations.

The model simulated a 21-day period on the SP network. The main program (excluding the postprocessing routine) contained nearly 3500 GPSS statements and needed 450K of core storage. In 1969 the simulation was run five times. Each run required 3.5 hours of computer time. Including the cost incurred by data preparation this amounted to approximately $5,000 per run.

The SP was pleased with the simulation's results and proceeded with construction plans for the West Colton yard. Because it applied to only a specific problem posed by the SP, the scope of this simulation was somewhat limited. The SP model is, however, a valuable prototype for study by other railroads, since it illustrates how a particular model has been used successfully in the rail industry.[15]

3.7 ASSOCIATION OF AMERICAN RAILROADS (AAR) ALL-PURPOSE SIMULATION MODEL

In order to further the model work produced by the individual railroads in the late 1960's, the AAR began to outline the guidelines for what they felt would be a totally flexible network simulation. In 1968, a contract for model development was awarded to the Midwest Research Institute in Kansas City. The simulation was written in SIMSCRIPT and consisted of 22,000 statements (including 5,000 COMMENT statements).[16]

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[15] Folk, op. cit., p. 13-14.

[16] Ibid, p. 14-15.

Unfortunately, the AAR model required a vast amount of input data that was relatively difficult to assemble. Due to the model's prescribed flexibility, the user also had to discern the level of system detail which would yield the required degree of accuracy. This was no easy task. For example, one could choose from a list of five alternative definitions for a node. The user had to decide initially whether a macro-level or micro-level definition would satisfy the rail system's simulation needs.[17]

The model was tested and validated in 1970-71 with data from the C&O/B&O (Chessie System). Despite the small section that was simulated (30 nodes, 36 trains), it took the Chessie System over seven months and 6,000 cards to assemble the required input deck. The simulation period was set at 15 days. After some adjustments, programmers were able to reduce the cost per run to $1000 of computer time on Chessie's UNIVAC 1108. The AAR was pleased with these initial results and made efforts to encourage the model's implementation within the rail industry.

The feedback from the railroads who made early attempts to implement the AAR model was rather disappointing. They expressed concern about the extensive amount of time required just to assemble the data deck. For example, the Illinois Central (IC) estimated that it used nearly 12 labor

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[17] Ibid., p. 16.

months in this portion of the project alone. This was particularly alarming because the network only described the Iowa Division of the IC rail system (19 nodes, 20 trains). The input consisted of 7000 cards for the 21-day simulation. Although the simulation required only 17 minutes of computer time, the run time for the total program (including all seven output reports) was one hundred minutes on the Illinois Central's IBM 360/65. Twenty minutes of this time was used during the preprocessing phase; the remaining times were allocated to postprocessing which on the average required nine minutes for each report.[18]

In order to study a major project of any depth, the IC realized that it would have to assemble the data deck for the entire network (84 nodes, 112 trains). Its Computer Systems Department predicted that the network description for such a system would exceed the 512K core storage capacity available on the Illinois Central IBM 360/65. By this time the team of graduate students from the University of Illinois, who had originally gathered and prepared the Iowa Division data, had graduated. Attempts to reactiviate interest at the University failed. In addition, the Illinois Central greatly altered their network structure after a merger with the Gulf, Mobile and Ohio. In the face of all these problems

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[18] Ibid., p. 16-17.

the IC decided to abandon the project; consequently its only implementation of the AAR model was the small-scale study on blocking policy performed with the data from the Iowa Division.[19]

The problem of system definition (e.g. specifying node and link detail), because it was so intimately tied in with the data deck preparation, also contributed to implementation delays. The Canadian Pacific (CP) reported that it had experienced several difficulties in this area. In 1971 it began study of the AAR model. A good portion of the first 1-1/2 years of the project was devoted to describing the network. Besides deciding which trains and nodes to include in the simulation, the CP had to determine an acceptable level of detail for each individual element of the model.

The large investment of time and money necessary for the data preparation and system definition discouraged many of the possible candidates for model implementation. The difficulties inherent in the AAR simulation caused many within the rail industry to doubt seriously the practicability of projects with the model.[20]

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[19] K. F. Troup, ed., "Railroad Classification Yard Technology -An Introductory Analysis of Functions and Operations," TSC, Cambridge MA, Report No. FRA-OR&D-75-55, 1975, p. 67-68.

[20] Ibid.

A successful application of the AAR model did not appear until late in 1974. Two years previous the East-West Gateway Coordinating Council, which was in charge of modernizing the rail facilities in the greater St. Louis area, had enlisted the aid of Parsons, Brinckerhoff, Quade, and Douglas to study possible yard consolidation and relocation plans. The team from Parsons (joined by W. Arthur Grotz and Eric Hill Associates) realized that with some modification and adaptation the AAR model would be a useful tool in their analysis.[21]

At that time, there were two switching railroads, The Terminal Railroad Association of St. Louis (TRRA) and the Alton and Southern Railway Company (A&S). After extensive study, three choices were proposed :

a. retain both switching companies, but give trackage rights to all railroads

b. combine the two switching companies

c. establish a new terminal operating company.

By the end of 1974, the three proposals had been run through the simulation. The results obtained from the AAR model were:[22]

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[21] "Working on the Railroads - St. Louis Railroad Consolidation and Relocation Study," Parsons, Brinckerhoff, Quade and Douglas Notes, St. Louis MO, Fall 1975, p.13-16.

[22] Ibid.

Choice	Average Transit Time
a	33
b	29
c	11

The model validation for the St. Louis project performed principally by Wayne Minger of the AAR along with Parsons, revealed that the model was a reliable representation of the St. Louis terminal network.[22a] Difficulties with the selection of alternative restructuring plans to be evaluated caused the railroads and FRA to abandon the restructuring effort shortly after delivery of the five volume final report.[22b] In 1976, the restructuring of St. Louis was examined again under FRA sponsorship. This time, no simulation model was used.[22c]

[22a] T. Hoover and W. Minger, "Computer Simulation of a High Volume Rail Gateway" Proceedings - Sixteenth Annual Meeting Transportation Research Forum, Vol. XVI, No. 1, 1975, p. 139-147, Washington DC.

[22b] East-West Gateway Coordinating Conrail, Comprehensive Areawide Railroad Consolidation and Relocation Study, St. Louis Region, Parsons, Brinekerhoff, Grotz, and Eric Hill, June 1974.

[22c] A particularly notable study of simulation application in St. Louis was performed for TSC by Bolt, Beranek and Newman and specifically addressed strong and weak points of the AAR model for terminal study as in St. Louis. A draft report on the subject was prepared: E. William Merrian, "Use of Computer Simulation for the Analysis of Railroad Operations in the St. Louis Terminal Area," July 1977.

Several other railroads have investigated the use of the AAR model or have actually applied it on a limited basis. The uses have not been well publicized, so are not described here. The railroads involved include the Southern Pacific and the Canadian Pacific.

3.8 CHESSIE SYSTEM - MINI-NETWORK

The Chessie System, building on some ideas generated during its participation in the AAR project developed a "mini-network model". The simulations's over-the-road train logic was copied primarily from the AAR Model. Unlike most network simulations, the Chessie chose to duplicate movements of whole trains rather than individual cars. The model was viewed as an evaluation guide for the study of problems that affect an entire rail system rather than a small segment.[23]

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[23] R.W. Drucker et al., "A Mini-Network Computer Simulation Model for Railroad Planning", Rail International, Nov.-Dec., 1973.

The first application was to predict the effect of the change of the Hours of Service Law for Crews from 14 to 12 hours. First, the model was used to evaluate what would occur if the existing system and train schedules remained unchanged. Chessie then simulated the addition of a few main tracks, various yard improvements, and revised train schedules in order to determine how to best satisfy the constraint of reduced crew service hours.

The mini-network also played a leading role in a Chessie System study designed to upgrade service between Chicago and Buffalo. They formulated three basic questions:

a. What is the minimum operation time for a train between Chicago and Buffalo?

b. What delays would an additional train dispatched from Chicago encounter?

c. What delays would this additional train impose on trains presently in the system?[24]

The Chessie wanted its output to reflect the effect of change in dispatch time (e.g., morning vs. afternoon). The project was further extended to consider the ramifications of adding a second proposed train.

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[24] "Advanced System Planning, "Chicago-Buffalo Service Study, Research Dept., Report No. 71-122, Oct. 1971, p. 1-3, Cleveland OH.

The Chessie chose two alternative routes connecting Chicago and Buffalo. The first one ran via Grand Rapids, Michigan; Rougemere, Ontario, and St. Thomas, Ontario; the second route went via Deshler, Ohio, Toledo, Ohio, Plymouth, Michigan; Rougemere, Ontario, and St. Thomas, Ontario. Tests were made over each section. The model required input of data describing operations of all existing trains in the system. This included train origin, destination, route, running time and location and schedule for work enroute. In addition, it was necessary to provide a description of the current train operation. Because there was a choice as to the size of the simulation region, the programmer had to specify the network as an input.[25]

The mini-network was particularly suited to determining the conflicts and delays caused by meets, passes, and work required enroute and at intermediate yards. This aspect of the simulation contributed significantly to the schedule analysis of the Chicago-Buffalo project.

The study was initially divided into four phases. Phase I considered eastbound trains only. Over a time period of ten simulated days, 66 different trains (both high and low priority) were simulated. The output from this portion of the project included average running time, number of conflicts and total delay for each train.

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[25] Ibid, p. 4-6.

During the second phase, the Chessie chose 18 of the original eastbound trains for further study. Each train was matched with an identical westbound one. The simulation results revealed that the eastbound trains were more consistently on time than the westbound. For the third and fourth phases, two trains, an eastbound and a westbound designated with numbers 40 and 41 respectively, were added to the system. The Chessie conducted the simulation a number of times. The train length for the proposed trains was either 40 or 80 cars and their priority was either high or low. The results indicated that trains with high priority would generally meet their schedule. The shorter trains performed only slightly better than the longer ones. On the basis of this study, the Chessie updated its service between Chicago and Buffalo and added trains 40 and 41. It used the schedule that was proposed and tested during the final phase of the project.[26]

3.9 THE RAILCAR NETWORK MODEL - QUEEN'S UNIVERSITY

The Railcar Network Model was published by E.R. Petersen and H.V. Fullerton of Queen's University School of Business, Kingston, Ontario. The model is a steady-state simulation of a railway system. Its purpose was to assist in the preliminary evaluations of proposed modifications in yard facilities, suspected shifts in traffic demands,

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[26] Ibid., p. 9-13.

and changes in operational strategies. The Railcar Network Model was intended to provide a general measure for weighing alternative plans and preparing initial cost benefit analysis. Rail planners can use these results to eliminate proposals which do not meet certain preset standards. Petersen and Fullerton recommend the use of a more detailed model (perhaps along the lines of the Canadian National Simulation in Section 3.3) to ascertain the specific operational implications of the alternatives which remain after preliminary evaluation is performed using the Railcar Network Model.[27]

The model recognizes five classes of trains (passenger, express, through freight, unit freight, and way freight) each with a user-specified priority, but most analyses have used passenger, through freight and way freight trains. The number of trains per day in each class can be preset before each simulation run. Users can include single and dual hump yards, flat yards and their classification areas, and simple switch track sidings in their network design.[28]

Petersen and Fullerton divided the model into three components; the line module, the yard module, and the system module. The line module provides an estimate of over-the-road

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[27] E. R. Petersen and H. V. Fullerton, et al."The Railcar Network Model," Canadian Institute Guided Ground Transport, Queen's University, Kingston ON, Report No. 75-11, p. 3-4.

[28] Ibid., p. 6-8.

time for each segment of track and the associated velocity for each train class. This portion of the model generates a matrix of expected inteference delays as a function of train class and track configuration. The model calculates the number of meets and overtakes based on the number of daily trains in each class, their schedules, and the congestion-free run times over the links. Total over-the-road transit time is then determined. The line module of the Railcar Network Model is particularly useful in predicting the effect of different mixes of traffic on daily transit times. Unfortunately the model is unable to calculate variance in transit times caused by changes in departure times or sudden shifts in the general weight-to-power ratio.[29]

Queuing theory plays a vital role in the logic of the yard module of the Queen's model. Based on data supplied by the Canadian National Railroad, Petersen and Fullerton made assumptions concerning yard arrival and departures, processing times, and service procedures within the queues. The results of their study indicated that the two extremes in link traffic levels yielded two distinct types of yard behavior. They discovered that they could use an exponential distribution to describe the time between train departures when link traffic was high. This corresponded to random inter-train departure times with long service

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[29] Ibid., p. 19-22.

queues forming in the yards. On the other hand, when traffic was light, a train could depart according to a regular schedule. This behavior corresponds to a regular departure pattern with low queue build up. In addition trains could demonstrate behavior that registered between these two extremes. Petersen and Fullerton found that they could use the Erlang distribution to describe the time between yard departures for any level of traffic. By letting the value of a parameter run from one to infinity, the Erlang probability density can represent any departure behavior. (For a more detailed mathematical explanation see Appendix A).[30]

The amount of time required to switch, classify, and assemble each train is based on the particular yard configuration, capacity, and availability of classification tracks. No consideration is given to variations due to time of day or week.

The output to the yard module includes the mean throughput time and standard deviation for each yard. In addition, the user can access the predicted times necessary for train

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[30] E. R. Peterson et al., Canadian Freight Transport Model Summary: Phase I, Queen's University, Kingston ON, 1972, p. 2-5.

breakup, classification, connection delays, and assembly. Also included is yard utilization measured in terms of the occupancy of the receiving, classification, and departure tracks.[31]

The system module combines and integrates the yard and line modules. The primary function of the system module is to generate traffic flows that will ultimately reduce link and yard congestion. The module assigns traffic to specific routes based on an optimization that minimizes the total car days required to move the trains from their origin to destination (see also Section 5). Petersen and Fullerton devised this heuristic so that the traffic would be assigned to alternative routes to avoid excessive waiting time in yards and anticipated delays along the links. The train routes generated by the system module are then simulated through the yard and line modules in order to determine yard throughput and over-the-road transit times.[32]

Among potential applications identified by Petersen and Fullerton are:[32a]

transit time variability between yards

identification of congestion points

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[31] E.R. Petersen and H.V. Fullerton, loc.cit., p. 7-10.

[32] Ibid., p. 11-15, 227-228.

[32a] E.R. Petersen and H.V. Fullerton, "An Optimizing Network Model for the Canadian Railways" Proceedings Fourth International Symposium on Railway Cybernetics, April 1974, p. 1.053-1.058, Montreal PQ.

impact of changes in demand
impact of train length on service
impact of new train operating rules or procedures.

The optimization algorithm, while an important aspect of the Queen's model, does not justify classification of this model as an optimization model. The interaction of the modules, and the representation of yards and line haul delays are much more like the characteristics of the other simulations discussed. The types of applications noted above are common to other simulations. The optimization is but one facet of the system module. Telephone discussions with the Canadian Institute of Guided Ground Transportation indicated the relatively minor role which the optimization plays in most model applications. In its current form, the Railcar Network Model is used more for simulation applications than for the route rationalization or schedule optimization type applications described by Folk.[32b] In fact, Merriam reviewed the Railcar Model as a potential <u>simulation</u> for a terminal area, but found most of its usefulness to be at more aggregated levels, often not even dealing with individual train movements.[32c] It is for these reasons classified in this report as a simulation.

The Railcar Network Model is coded entirely in FORTRAN and has been successfully run on the IBM 360, UNIVAC 1108, CDC 6600 and the Burroughs 6700. The principal application

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[32b] Folk, op.cit. p. 21

[32c] Merriam, op.cit. p. 44

of the model is a Canadian National-Canadian Pacific project to determine the cost and benefit of joint trackage usage in western Canada. The current network includes 72 nodes with 147 arcs.[33]

3.10 MISSOURI PACIFIC SIMULATION SYSTEM

Missouri Pacific Railroad (MoPac) developed the Car Activity Regularizing Scheduler (CARS) as a tool to assist NoPac management with the analysis of various scheduling methods. The CARS simulation is an integral part of MoPac's Transportation Control System (TCS), an on-line real-time information system. Car demand and empty and loaded car locations are fed into TCS via terminals situated at points throughout the MoPac network. Because of the dynamic nature of this information MoPac can maintain constant control of its freight cars.[34]

The CARS simulation uses the data stored in TCS for inputs to its computer program. MoPac can access this data to help them make scheduling decision. At points during the simulation, a decision-maker is required to input the car scheduling policies that direct car movements and assignments.. The model's postprocessor compiles the data on

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[33] Ibid., p. 241.

[34] R. L. Yoakum and L. H. Beaumont, "A Railroad Scheduling System Incorporating Simulation,: Missouri Pacific Railroad, St. Louis MO, Internal Project Paper, undated, p. 1-5.

all car movements, train loadings, and yard inventories into a history file. This output includes the information necessary for scheduling policy evaluation.

Rex Cobb of the MoPac staff emphasized the importance of MoPac's flexible information system. It provides management with a current updated picture of the car movements. With this information MoPac management can make intelligent scheduling decisions and receive immediate feedback from the simulation results.[35]

The model is written in FORTRAN IV and contains approximately 3000 source statements. The simulation requires nearly 200K bytes of main memory and 1000 tracks of direct access storage (7K characters/track). MoPac designed the model to run on an IBM 360/50. Because the original program logic was developed in the time-sharing mode on a CDC 6400, MoPac reports that small test networks can be implemented on this system.[36]

In 1972 NoPac validated CARS using the portion of its network stretching from Kansas City, Missouri north to Omaha, Nebraska and west to Stockton, Kansas. Because this region contained only a single interface with the remaining MoPac network (Kansas City), it eliminated

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[35] R. Cobb, "Interview at Missouri Pacific Railroad," St. Louis MO, December, 1976.

[36] Yoakum, op. cit., p. 17-18.

potential boundary problems. The region consisted of four major yards and seventeen minor ones. During the simulated two week period, the model simulated 22 trains and serviced customer demands with 6000 cars. A single run required four minutes of CPU time. Based on these figures, MoPac estimated that for a simulation of its entire network with normal traffic, CARS execution should use fifteen minutes of CPU time per simulated week. The implementation of the CARS simulation across the entire MoPac network is slated for 1977.[37]

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[37] Missouri Pacific Railroad, "CARS Simulator," MOPAC, St. Louis MO, September 1972, p. 1-6.

4. YARD SIMULATION MODELS

4.1 BACKGROUND

A freight car in the United States spends approximately two-thirds of its time in intermediate classification yard facilities. It is exceptional for a train to run from one origin to one final destination without some classification and aggregation of cars at intermediate yards.[1] Because classification of freight cars is an integral part of railroad procedures, railroads typically require a detailed evaluation before they will modify yard facilities and operations. Moreover, the construction of a new yard is such a major investment that a railroad needs a measure of its effect across the entire system.

Computer simulations provide the most direct and advanced tool available to the rail industry for the analysis of yard operations. Simulation models can predict the results of changes in yard procedures or the transfer of classification work from one yard facility to another.[2]

A majority of the yard models developed by the rail industry are generally uniform in terms of data input, yard functions simulated, and statistical output. Typical input required by the simulations include: physical layout and

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[1] K.F. Troup, ed., "Railroad Classification Yard Technology -An Introductiory Analysis of Functions and Operations," TSC, Cambridge MA, Report No. FRA-OR&D-75-55, 1975, p. 70-76.

[2] Ibid.

capacity of all tracks, time schedules of inbound trains, the number of cars per train, specific train priorities, and the statistical time distributions of key yard functions (e.g. bleeding, inspection, humping, classification).

Yard models provide a detailed simulation of car movements into the receiving yard through the humping and yard classification procedures and into departure yard for formation of outbound trains. Constraints external to the operation of the yard (e.g. inbound/outbound train schedules, train size, outbound destinations) are defined based on historical data; model functions representing internal yard operation are defined as stochastic processes. Because the reclassification and repair of defective cars cause significant delays in the classification procedure, many models generate bad order cars and defective cars based upon a pre-defined frequency function. Because many yard models assume an infinite supply of readily available locomotives for outbound trains, they cannot be used to study the implications of road motive assignment.

Yard simulations maintain statistics and provide detailed data on the performance and operations of the tracks, trains and the service facilities within the yard. Typical output reports include the time distributions for the completion of specific yard tasks, track utilization, and yard throughput time for individual cars.

4.2 BATTELLE'S TERMINAL II MODEL

Battelle Memorial Institute developed one of the first yard simulations. Battelle's model, TERMINAL II, can simulate the operations of either a flat or hump classification yard. The model provides the quantitive data necessary for the analysis of changes in yard geometry, blocking strategy, and traffic volumes and patterns.

The model processes freight cars by car groups rather than entire trains or individual cars. This unit is determined by the train arrival status, the individual car destinations, and the commodity carried by the cars. The principal output of the model includes a series of time histories that describe the movement of the car groups and the track and resource utilization. (Resources include such items as the number of switch engines and the size of the inspection crews.) This information is fed into an analysis program that calculates various measures of yard performance. These measures include the mean yard throughput time and standard deviation, operational data indicating track inventories and assignments, and a statistical breakdown of the specific resources required to perform each yard task.[3]

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[3] D. Nippert, "Simulation of Terminal Operations" Simulation of Railroad Operations, Railway Systems and Management Association: Chicago IL, 1966, p. 169-180.

The model is written in FORTRAN for implementation on a CDC 6600. The simulation period can be specified from ten days to two weeks. The model assumes that the yard is empty at the start of the simulation. Two simulated days are required to generate a representative yard inventory.

TERMINAL II has been used successfully by a number of railroads. The St. Louis-San Francisco (Frisco) used the model to determine how it could modify its Tulsa Yard in order to increase the yard's capacity to form outbound blocks. The Frisco was interested in whether the yard could accommodate fifteen additional blocks of traffic without increasing its current fleet of switch engines. The results from TERMINAL II indicated that the Tulsa Yard could absorb the additional workload with the present engine resources if it added ten new classification tracks.[4]

The Great Northern Railroad (GN) used the Battelle model to help design a new yard and plan its operational procedures. The GN had realized that if its merger with the Northern Pacific (NP) were approved, it could replace two existing

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[4] D. Nippert and S.G. Guins, "Terminal Model II," Battelle Memorial Institute, C&O/B&O Railroad, Internal Project Report, updated, p. 28, Columbus OH.

yards with a new one. TERMINAL II helped the GN to evaluate the possible alternatives for yard design.[5]

Battelle's TERMINAL II package did not include a detailed simulation of a terminal's receiving yard. The original model simply assigned all inbound trains to a receiving track without consideration of train or track length. In addition, the TERMINAL II output did not provide any statistics that would reflect receiving-yard utilization. Because the C&O/B&O was interested particularly in the adequacy of its various receiving yards it was forced to manually simulate the particular facility under study. The pertinent calculations and analysis required over two labor weeks. In 1970 the C&O/B&O added a receiving yard simulation postprocessor to TERMINAL II.

The postprocessor considered each arriving train and attempted to place it on the shortest available track that would hold the entire train. If it were possible to place a train on a single track, the model could double the train onto available sections of tracks. C&O/B&O have successfully used this postprocessor in conjunction with Batelle's TERMINAL II.[6]

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[5] Ibid., p. 5-8.

[6] R. Buck, "TERMINAL Model II - Receiving Yard Post-Processor," Advanced Systems Planning, C&O/B&O, September 1970, p. 1-8, Baltimore MD.

4.3 NEW YORK CENTRAL YARD CLASSIFICATION MODEL

In the late 1960's, a yard classification model was developed by the New York Central railroad to assist in the design and in analysis of the operations of a planned new hump classification yard.[7] The model, written in GPSS III simulation language, provided a detailed simulation of the operations in the receiving, classification, and departure facilities. Movements of car groups (i.e., cars blocked together for a common destination) were tracked by the model and statistics were maintained on the various servicing operations and delays.

The model was developed to simulate the proposed design of the New York Central's new Alfred E. Pearlman Yard. It was used to determine the proper number, capacity, and geometry of the yard's receiving, classification, and departure tracks, to improve their overall utilization and to minimize any interferences in train movements. The simulation was also used to evaluate the effects of different car grouping policies, changes in train schedules, and any shifts in the volume or mix of the freight traffic.

4.4 SEABOARD COAST LINE/LOUISVILLE & NASHVILLE YARD CLASSIFICATION MODELS

Computer simulations have traditionally been a key element in the management and operations of the SCL/L&N

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[6] R.H. Nadel and C.M. Rovner, "The Use of a Computer Simulation Model for Classification Yard Design", Paper presented at Second International Symposium on the use of Cybernetics on the Railways, Montreal PQ, October 1967.

Railroad. Such models have been used consistently in the decision-making process, in the control of railroad operations, and in the evaluation of overall management and system performance. Primary advancements in the SCL/L&N's simulation of railroad operations has been its development of yard classification and terminal models.

Initial work in this area began in 1964 with the development by the L&N of a computerized simulation model to evaluate the efficiency in the design and operations of a major classification yard in Birmingham, Alabama. The primary goal of the project was to create an accurate model that could realistically simulate the structure and the operations of the L&N's Boyles Yard. The model written in the GPSS III Language, performed the following major functions:

a. generated inbound freight traffic,

b. handled trains or cuts of cars within the yard,

c. classified inbound cars,

d. assigned cars to scheduled outbound trains.[8]

The simulation model maintained accurate data on all train/car movements in the yard, the processing times on all yard service functions, and the utilization of all yard resources. The model was designed to operate on an IBM 360/40 or 360/50 computer system. On such a system, ten

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[8] L. D. King, "Simulation of a Railroad Classification Yard," Louisville and Nashville Railroad Company, Internal Project Report, undated.

days of yard operations could be simulated with two minutes of CPU time. The model was effectively used to test a plan by the L&N and another co-owned railroad to consolidate the terminal operations of both railroads into the Boyles yard. Even though the simulation results showed that consolidating the terminal operations would lead to congestion at the Boyles yard, both railroads proceeded with the consolidation plans. Soon thereafter, the freight traffic through Boyles exceeded the yard's capacity and the terminal operations of the two railroads were later separated.

Shortly after the affiliation of the L&N with the SCL in 1972, a second yard simulation model was developed to help the L&N and SCL design and plan a new classification yard near Louisville, Kentucky.[9] Yard operations in the Louisville area were handled by five different yard facilities with a traffic volumeover 120,000 cars per month. The new classification yard was designed to relieve the congestion at the other yards and to reduce the inefficient cross movement of cars between the yards. A model of the planned classification yard was developed and simulation runs were conducted using projected 1978-1980 traffic were conducted volumes. Unlike the earlier L&N yard simulation model, this model was driven by manual user commands in place of

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[9] IBM, "Simulation of the Family Lines System," New York NY, 1974.

pre-defined priority rules and yard operating procedures. Railroad management and transportation staff, familiar with yard operations, executed the model through a series of commands that simulate the decisions made in controlling actual yard traffic. GPSS routines were incorporated into the model to track the car movements and to capture the resource utilization statistics. Initially, actual train arrival data for May, 1973 was used as input to the model. By executing commands such as pull, hump, and receive, participants could control the actual traffic flows within the model.

At the end of each set of commands, reports were produced showing the status of the freight traffic in the receiving, classification, and departure yard for the previous four-hour simulation period and input for the next four-hour simulation period. Once the model was validated using the historical data, additional analysis using a 30 percent increase in traffic volume was conducted to simulate the 1978-1980 yard operations. The results of these simulations showed that the same yard configuration could handle the 1978-1980 traffic volumes, although with significantly additional yard resources. In general, the SCL/L&N have found the yard model to be extremely effective with the manual commands from experienced yard personnel adding an element of credibility to the model's results.

4.5 STANFORD RESEARCH CLASSIFICATION YARD SIMULATION MODEL

In 1974, the Stanford Research Institute, working on a contract for the United States Railway Association (USRA), developed a model that simulates the operations of a railroad hump classification yard. The model was developed as part of an effort to develop system-wide operating and management plans for the consolidation of the bankrupt railroads in the Northeastern and Midwestern states.[10] In the study the model was used to construct and test various operating schemes for the blocking and classification of cars and to assess the capacity and efficiency of the railroad classification yards under given traffic demands.

The SRI yard simulation model is a deterministic event-oriented system that requires a extensive user interaction and operational experience in defining the procedures and in making the more complex judgmental decisions on yard operations. The model has no built-in decision logic to determine optimum operating procedures for the blocking and classification of cars, the humping of trains, or the assignment of yard resources.

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[10] W. Siddigee, et al., "Blocking and Train Operations Planning," Stanford Research Institute, SRI Project 3759, October 1975, Palo Alto CA.

The SRI yard classification model is composed of two composed separate programs: a preprocessor and a yard simulation program.[11] The preprocessing program provides a simulation of the buildup of various car blocks as a function of the schedule of arrival trains and the hump sequence for trains in a classification yard. The output of the preprocessor program is useful in making initial decisions relating to track assignments and the possible time-sharing of tracks. The yard simulation model provides a detailed simulation of the yard operations including car classification, humping, and car movements through the various yard facilities. Inputs to the program include the geometry of the yard's receiving, classification, and departure tracks, the schedule of inbound trains, the shift schedules of work crews, the processing times of specific yard operations, and the scheduled departure times of the outbound trains. This simulation time period usually represents the number of days necessary for the model to reach a steady-state condition (i.e. when the yard operations of the next simulated day is almost identical to the operations of the previous day). A steady-state condition within the model is generally reached after two or three days of

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[11] P. Tuan and J. Proctor, "A Railroad Classification Yard Simulation Model," Stanford Research Institute, Internal project paper, undated, Palo Alto CA.

simulation depending upon the volume frequency, and the patterns of the in-bound traffic. Outputs of the SRI yard simulation model include statistics on car transit times, the utilization of yard facilities, the formation of blocks on outbound trains, and work crew schedules.

The SRI yard simulation model has effectively been used by the USRA in the analysis of alternative blocking and train operating plans for the CONRAIL network. The yard simulation model was written in the FORTRAN IV programming language for execution on a CDC 6400 computer. A two to three day simulation of a classification yard's operations requires approximately 60-120 seconds of CPU processing time.

5. OPTIMIZATION MODELS

The traditional method of empty car distribution was built around a system of decentralized control and communication. A railroad was divided first into regions and then into districts. Dispatchers within these areas were responsible for moving cars around in order to satisfy customer demands with the available supply of freight cars. Unfortunately cars were often hoarded and system imbalances were created. Because slight fluctuations in the supply/demand picture greatly complicated the problem, dispatchers could not always rely on set distribution patterns. Moreover, in situations such at this, there was not sufficient amount of time for a dispatcher to consider the ramifications of all possible car movements. Developments in operations research and mathematical programming have provided railroads with a tool to improve their distribution methods. With the computerization of many standard algorithms, it has become feasible to solve large-scale allocation problems. This section outlines several approaches to the empty freight car distribution problem.

5.1 LOUISVILLE AND NASHVILLE FREIGHT CAR SCHEDULING MODEL

The Louisville and Nashville (L&N) was aware of the problems inherent in the distribution process. It was particularly concerned with its inability to maintain close control over its specialized fleets of empty freight cars.

As early as 1966 the L&N began to look toward linear programming as a means for regulating the cars. It formulated an optimization model that would maximize customer service. The objective was to fill as much demand as possible while minimizing the empty car movements and the associated transit costs.[1]

Through daily telephone contact with yards in the network, the L&N could assemble the relevant and up-to-date supply/demand information. This data was used in the constraint equations. The model considered the car movements for a two-day period. It was implemented on an IBM S/360 Model 30 using a simplex algorithm to solve the linear program. The results were then relayed to the division dispatchers via the L&N's IBM 1050 teleprocessing network.

Car demand and supply estimates for 44 wood loading points and 16 supply yards were developed for each of the two days. The model then attempted to satisfy demands with the best car movement combinations, where "best" was the least number of car hours consumed in moving cars to the demand points. The output was the number of cars needed from each supply yard to each wood loading point and between supply points.[1a]

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[1] C.D. Leddon, "Scheduling Empty Freight Car fleets on the Louisville and Nashville Railroads," Second Annual Symposium on the Use of Cybernetics on Railways, Montreal PQ, p. 154, 1967.

[1a] Association of American Railroads "Louisville and Nashville Wood Rack Linear Programming "Case Study IV-6 <u>Manual of Car Utilization Practices and Procedures</u>, June 1976, p. IV-51-53, Louisville KY.

The model was applied in 1967 to L&N's fleet of 1500 woodrack cars. These vehicles were used for hauling pulpwood from the forests to the paper mills. The results were encouraging. The L&N estimated the filled demands rose from 60-70 percent under the old system to over 90 percent with the model. In addition, the L&N discovered that it could remove 75 cars from the system and still maintain this high level of service.

After the removal of these excess cars, the average car trips/month rose from 2.4 to 3. This increased car utilization by 25 percent. The savings realized by the removal of 75 cars amounted to $1.7 million. The L&N reported that its customers responded favorably to the upgraded service.[2] Use of the linear programming model caused the L&N to allocate its cars using a systematic approach. As car distributors began to understand the approach and the effects of local decisions on the system, other factors were taken into account in allocating cars. These factors tended to be related to shipper behavior and demand fluctuation and were not suitable for analysis using linear programming.[2a] It was possible, then, for the L&N to phase out the model without losing its benefits. More complex problems were suitable for examination using simulation. (See Section 3.5).

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[2] Ibid., pp. 155-160.

[2a] Association of American Railroads, Car Utilization Practices, p. IV-53.

5.2 A USER-ORIENTED OPTIMIZATION MODEL

Michel A. Thomet felt that the "additional" costs borne by shippers had a substantial effect on freight car utilization. He reasoned that a shipper had to absorb losses due to delays, enroute accidents, and devaluation of this product. If this extra cost were large relative to the costs incurred using an alternative mode of transportation, the shipper would tend to decrease or eliminate his train shipments. To account for this problem, Thomet decided that a model should be built to minimize both the railroad operating costs and the secondary costs imposed on the shippers. The output to the model would be a set of empty car movements that would satisfy Thomet's objective. For his 1971 doctoral disseratation (Carnegie-Mellon) Thomet prepared a computer optimization model along these lines.[3]

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[3] Folk, op. cit., p. 21-22.

The program was written to work with an arbitrary network. The input included the amount of average daily traffic originating and terminating at each network node. The cost-minimizing algorithm contain four steps. The first was named the minimum transit time policy. It figured the cost of grouping all cars with the same origin and destination nodes and sending them through on a direct train. This step minimized the shipper's transit time, but could impose high railroad operating costs. During the second step, the model calculated the savings realized (including costs incurred to the shipper) by canceling a train and assigning its cars to two or more trains. This figure was determined for each train. The third step cancelled the train corresponding to the greatest savings and adjusted the parameters on the intermediate trains affected by this move. The fourth step, using the same algorithm employed in the second step, refigured the savings for each train. Then, the program looped through the third and fourth steps until further train cancellations would yield no more savings. The output, consisting of a list of all trains, their routes, number of cars and the gross weights, reflected minimum transit time, minimum railroad and shipper costs and the minimum number of required trains.[4]

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[4] M.A. Thomet, "A User-Oriented Freight Railroad Operating Policy," IEEE Transactions on Systems, Man and Cybernetics, Vol. SMC-1, No. 4, October 1971, p. 351-355.

Thomet's model calculated optimal train routing for fixed demand. The program's outputs included a table of empty car movements, traffic demand statistics, measures of yard activity, and a table containing the values of the system variables.

The Thomet model underestimated the time a train spent waiting in the intermediate classification yards. This was a serious disadvantage since it noticeably lowered the train transit times. Because the shipper costs were estimated as proportional to transit times (weighted by shipment values), an incorrect value yielded a nonoptimal solution.[5]

Since the model minimized the total transportation cost, the advantage to the shipper was obvious. The railroad benefitted from a reduction in the number of required car days days and yard-engine hours. This would allow the railroad to reduce the car fleet and to decrease the yard activity. Thomet also felt that his model would ultimately maximize the railroads' profits. He argued, using an elasticity curve, that if shippers were given a reliable level of rail service for a minimum price, they would continue (and probably expand) their use of the rail industry for freight transportation. Because the algorithm has already minimized the total cost, the resulting distribution strategy should yield maximum

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[5] Folk, op. cit., p. 23-24.

railroad profits. Unfortunately, there is no available information on implementation (successful or otherwise) of the Thomet model by anyone in the rail industry.[6]

5.3 EMPTY FREIGHT CAR DISTRIBUTION MODEL - QUEEN'S UNIVERSITY

Another successful modeling effort produced at Queen's University (see Section 3.9) was devised by Gilles Quimet. The basic ideas he presented in his Empty Freight Car Distribution Model have been incorporated into a model that is used currently by the Canadian Pacific Railroad as an efficient guide in the system-wide allocation of its freight cars.

The initial assumption of the model was that the user was searching for a reliable operating policy for prepositioning empty cars in anticipation of car orders. For this reason, the program required a reasonably accurate forecast of system supply and demand. The aim of the program was not to match individual cars to particular orders, but rather to have a sufficient supply of cars readily available to meet the general demand in each of the 20 CP divisions.

The model used a two week demand/supply horizon as the forecasting input. Because the program was intended to be run weekly, the week-two forecast from the preceding run was updated before it became the week-one figure for the next run. The model attempted to fill the current and predicted demand with the available resources while minimizing (in order) the service delays, empty car miles,

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[6] Thomet, op. cit., p. 353-354.

and empty cars held in yards. First and foremost the Canadian Pacific wanted to fill its customers' orders at the earliest date possible while holding the associated operating costs to a minimum.[7]

Quimet's model used a capacitated network or digraph (roughly corresponding to the CP rail system). The flow through the network that satisfied the constraints and minimized the objective function would yield the optimal distribution for the freight cars. Quimet solved the problem through application of the Ford-Fulkerson-out-of-kilter algorithm.[8]

The Canadian Pacific is satisfied with its use of the model. It has been part of the CP empty car distribution process for over a year. The CP's version, a slight modification of Quimet's original optimization program, was written in FORTRAN for implementation on the IBM 360. The basic system inputs were the demand forecast and the number and location of the available empties. The main program constructed the appropriate capacitated network. Subroutine 1, which contained the out-of-kilter algorithm, calculated the optimal flow while subroutine 2 prepared and printed the allocation reports. The output of the model

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[7] Canadian Pacific Railroad, "Specification of Kilter Program, Research Dept.," March 1975, p. 1-4, Montreal PQ.

[8] Canadian Pacific Railroad, "The Optimal Freight Car Allocation Model - The Kilter Program," Research Dept., August 1975, Ch. 1, Montreal PQ.

consisted of directions for the distribution for each empty CP car over a one week period.[9]

5.4 SOUTHERN RAILWAY'S OPTIMAL FLOW RULE MODEL

Southern Railway sought to move surplus freight cars through its rail network to those areas where demand exceeded supply. The Southern's goal was not to match particular cars to specific orders, but rather to make available a sufficient supply of freight cars to satisfy the anticipated demand.

The Southern's rail network consists of two main corridors crossing in Atlanta (one from Cincinnati to Jacksonville, the other from Washington, D.C. to New Orleans). It covers nearly 11,000 miles in 11 states. As early as 1967, the Southern had formulated a method with flow rules to distribute the empty cars in its general purpose fleet. The Southern divided its network into 43 districts. Each month the district sales managers derived demand estimates based on the present information and historical data reflecting the number of filled orders from the year before. A deficit area was designated as a point with more originations than terminations. The empty cars which exceeded the two-days' average demand for a district were defined as surplus cars. The surplus/deficits were plotted on a map. Flow rules for moving the surplus cars to the deficit areas were generated by hand. Some attention was given to

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[9] Ibid., Ch. 3.

minimizing the transit cost associated with each move. Of the 75,000 cars in the general purpose fleet, approximately 40 percent were eligible for movement via the flow rules.[10]

In the last two years, the Southern has developed a computer-based solution to the empty car allocation problem. Very little documentation on the model has been made available for review. Most of the information has been obtained through conversations with Dan Berman of the Southern staff. The optimization was formulated as a linear programming transportation problem. The objective was to make the necessary moves using flows that would yield minimum transit costs. The cost equation appears in Appendix B.

The transportation algorithms also required the predicted demand as an input. A more recent innovation to the program included a routine that used a 24 month trend line to forecast the demand figures.[11] Berman indicated that because trend line predictions were very inaccurate, the Southern has had to rely on the forecasts of the district sales managers. Berman reported that the Southern Railroad was pleased with the flow rules generated with the distribution algorithms and the demand forecasts prepared by the district sales managers.[12]

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[10] M.D. Berman, "Interview at Meeting at TSC," Cambridge MA, December, 1975

[11] M.D. Berman, "Correspondence Concerning Southern Flow Rules," November 1975.

[12] Berman, "Interview," December, 1975.

5.5 SOUTHERN PACIFIC'S POOL ANALYSIS MODEL

Railroads were generally more eager to invest in model development if they could apply the results to solve a specific problem directly. For example, the Southern Pacific (SP) Transportation Company handled a fair volume of orders from the automobile industry. It was SP policy to supply each assembly plant that it serviced with a pool of multi-level flat cars. The pools were run loaded to the distribution point, unloaded and returned empty. The assembly plants and distribution centers were situated throughout the country. Often the traffic flow was in one direction; one pool of empty car was travelling in the same general direction as a pool of loaded cars. Clearly, this was a needlessly expensive operating policy. The SP felt that this situation was neither efficient nor economical. They wished to determine when it was physically and economically feasible to reload cars at a plant near their distribution point so that a formerly empty car movement in one pool became a loaded movement in another.[13]

The first step was to classify the pools of cars into two groups, eastern and coastal (western). An acceptable model would have to determine when it was advantageous to reload eastern cars at coastal pool assembly plants.

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[13] Southern Pacific Railroad, "Multilevel Pool Analysis," Analytic Services Office, February 1975, p. 1-5, San Francisco CA.

Because the reloading policy increased the average cycle time, the SP required the model to re-assign the coastal cars to the eastern pools. To eliminate foreseeable complications, the return loading movements had to be as simple as possible. In other words, the eastern pool cars reloaded at the coastal assembly plants would be returned immediately following their unloading in the east to their originally assigned plant.

The objective function was to minimize the total empty car days subject to certain constraints. All flows of cars through the system had to be accounted for and balanced. That is, the number of cars returned empty plus the number reassigned should equal the number of the original pool at all times. The pool problem with only small modifications assumed the form of the "classic" transportation problem. Certain costs, proportionate to the transit times, were associated with each possible flow. In order to make a particular path infeasible, one simply assigned an arbitrarily large cost of the flow. (This, of course, corresponds to an unusually long transit time.)[14]

The model program was divided into three sections. A preprocessor converted the prescribed service pools into the transportation problem. A main processor solved the problem.

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[14] Ibid., p. 7-11

Packaged program solutions in several languages can be incorporated readily into the main processor. The SP recommended two FORTRAN programs, each requiring about 32K core and one bulk storage unit. A postprocessor prepared the output report which contained the detailed description of the car movements.[15]

The Southern Pacific wrote its Pool Analysis Model to address a particular problem. The staff successfully tailored it to the SP's network configuration and specifications. It is an optimization model worthy of study by railroads concerned with freight car utilization.

5.6 SWISS FEDERAL RAILROAD'S DISTRIBUTION MODEL

Up through the early 70's, the Swiss Federal Railway (SBB) utilized a manual technique for distribution of its empty cars. Because the SBB maintained a network which was comparably smaller than most railroads, it was reasonably successful with this method. There were, however, a number of drawbacks inherent in this technique. Because each day there were about 10,000 cars requiring allocation at points throughout the network, the SBB was forced to divide its

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[15] Ibid., p. 16-19.

network into five distribution districts. During a daily 20 minute joint telephone conference, district controllers attempted to offset any substantial surpluses and deficits by directing car movements between districts. Each controller was then responsible for making local distribution decisions within each district. Because the manual allocation process was transacted under time pressure, it was impossible for the controllers to consider alternative car distribution solutions.[16]

Although the controllers were fairly successful at filling shipper's demands, it was not possible for them to consider solutions that would minimize switching operations and empty car mileage (measures of operational costs). The division of the network into five districts created communication barriers that made a centralized distribution process infeasible.

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[16] H. Herren, "The Distribution of Empty Wagons by Means of Computer, An Analytical model of the Swiss Federal Railways", Rail International, October 1973, p. 1005-1006.

The SBB outlined a list of over ten objectives that the railroad felt should be a part of its revised distribution policy. The list included minimizing the operational costs, maximizing demand satisfaction, eliminating district boundaries, controlling distribution from a single center and planning car distribution wisely. The specifications outlined above far exceeded the capabilities of any manual distribution method. The SBB required a sophisticated computer-implemented model to provide its decision makers with the optimal distribution policy.[17]

European railroads are governed by certain rules that bear a close resemblance to the AAR Car Service Rules. The SBB chose to give preliminary assignments to all freight cars affected by these rules and to eliminate them from the main distribution process.

The SBB relied on graph theory in the formulation of its model. The railroad represented its plan for empty freight car distribution as a network flow model. The Ford-Fulkerson out-of-kilter algorithm was chosen as the solution technique to determine the most ecnomical flow. Using the designated matrix and the standard solution package, the solution would have required approximately 100 hours of computer time.

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[17] Ibid., p. 1006-1007.

In order to reduce the computer time, the SBB made certain adjustments in the original formulation and solution scheme. Because not every station experienced a surplus or deficit for each car type every day, it was often possible to eliminate nodes before a particular calculation. All cost units were rounded to the nearest ten and negative costs were considered only on return flow arcs.[18]

The SBB also discovered that towards the end of a computation, the number of cars still eligible for destination assignment was small. This meant a relatively long computer time was being alotted to a few additional fills of demand. To counteract this effect, SBB programmers installed a time break in the system. A run of the model was stopped automatically when the computer time exceeded this predetermined limit. Unsatisfied demand was given high priority for the following day's assignment run. The program was written in FORTRAN IV for use on SBB's IBM 360/65 with a 500K byte memory. Validation runs revealed that the entire distribution process required 40 minutes of computer time (10 minutes for the preliminary distribution, 30 minutes for the main distribution).

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[18] Ibid., p. 1009.

Results indicated that with the optimal distribution plan, the SBB could reduce its car fleet by 2 percent and still maintain maximum fill of demands. In addition, there was a considerable reduction in the empty car mileage and its associated transit costs. The most recent schedule indicates that the model should be fully implemented into the Swiss Federal's system by late 1976.[19]

5.7 DSAI'S COMPUTER-BASED MODEL FOR OPTIMAL RAILROAD FREIGHT CAR DISTRIBUTION

In 1974 Decision Systems Associates, Inc. (DSAI) developed an innovative optimization model, designed to address the empty freight car distribution problem. The aim of DSAI's FRA-sponsored project was to supplement a real-time freight car management information system with a centralized mathematically programmed plan for optimal freight car distribution.

During its preliminary design effort, DSAI outlined the following model objectives:[20]

a. maximize accomodation of shipper demands

b. minimize operational costs (particularly transshipment and switching costs)

c. minimize delivery delay for empties

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[19] Ibid., p. 1010.

[20] R. S. Hatch et. al., "Development and Evaluation of a Computer-Based Model for Optimal Railroad Freight Car Distribution" Final Report DOT-FR-30013-1, Washington DC, November 1974, p. 28-30.

d. maximize the return of foreign cars to their respective home lines

e. minimize car substitution.

The development of a model that would simultaneously satisfy all five of these conflicting criteria would be an impossible task. For this reason, DSAI established a priority for each objective. The design was such that the "optimal solution to each objective constrained the space of feasible solutions for each lower-ordered objective."[21]

The model required six steps in order to optimize the distribution objectives. The first step maximized the fill of all shipper demands subject to the available supply and an assignment eligibility matrix. (This matrix contained the identified cars which were eligible for the different demand categories). In the event of a shortage of eligible cars, assignments were made first to orders with the highest priority. The second step helped to maintain a buffer of empty cars across the entire system. The purpose of this group of cars was to meet unanticipated demands and to fill orders in emergency situations. This step maximizes the buffer demands without affecting the percentage of filled orders achieved in the first step. The optimization was subject to

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[21] R. S. Hatch et al, "Development and Evaluation of a Computer-Based Model for Optimal Railroad Freight Car Distribution." Phase II Report, DOT-FR-30013-2, Washington DC, August 1973, p. 38.

the assignment eligibility matrix and the available supply.[22]

DSAI set its problem horizon at 12 days (this represented the maximum transit time on the system plus three extra days for enroute switching). During this time frame a number of cars would become available for future release. The third step maximized the number of these future available cars that could be assigned for future release during the problem horizon. During the fourth step, the model maximized the number of foreign cars eligible for assignment to the empty foreign return quota. The eligible set of cars included on-line unassigned foreign cars slated for release during the first day of the time frame. All the cars assigned to this quota were immediately directed toward their respective home lines. Finally, during the fifth and sixth steps, all extra system cars (if any) were assigned to excess system storage.[23]

Since 1968, the Total Operations Processing System (TOPS) had been an integral part of the Southern Pacific's (SP) operations. It made the SP a logical candidate for use in the development and subsequent validation of the DSAI model. The model represented the SP system. DSAI chose

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[22] Hatch, Final Report, loc. cit., p. 37.

[23] Ibid., p. 38.

to consider optimizing the distribution patterns for only the SP flat cars because the fleet offered the widest range of possible car substitutions, interesting loading patterns, and a reasonable ratio of system-to-foreign cars. Flat cars are also affected by a great number of AAR Car Service Rules. One of the aims of the DSAI model was to provide optimal distribution without violating the relevant Car Service Rules.

The solution technique developed by DSAI was in iterative process called QUOTFIND. It "integrated a family of primal-dual algorithms with a nonlinear optimization method of Langrange".[24] Corresponding to each demand point, there was a desired quota. A quota was assigned priority relative to the importance of filling its demand. All quotas with identical priority were members of the same priority group. For example, since the most important objective was to fill shipper demand, all the shipper demand points belonged to the same priority group. Associated with each quota was a share coefficient. When shortages existed within a priority class, the resources were allocated among the quotas according to these coefficients. QUOTFIND first assigned cars to the demand quotas in the highest priority group according to the present

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[24] Ibid., p. 39.

available cars and the additional constraint that the fills of all higher priority quotas must be maintained. Because the cars designated to the higher priority quotas are assigned only tentatively, a car may be reassigned to a lower priority if and only if rearrangements can be made within the higher priority class so that the percentage of fills within this class remained the same. Iterations continued until assignments had been made for the lowest priority group.[25]

DSAI programmed the model in FORTRAN IV for implementation on a CDC 6600. The large word size of the CDC computer allowed them to keep all model solutions in core.[26]

The results from the validation using TOPS data indicated that a user could realize significant benefits by using the DSAI computer-based distribution model rather than the standard manual method employed by the SP. DSAI found that over a 12-day horizon the model could:[27]

1. increase filled demand 40 percent
2. decrease delays to shippers by up to 59 car days
3. decrease car type substitution by as much as 96 percent
4. decrease up to 41 percent the per diem, mileage and other empty transshipment costs.

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[25] Hatch, Phase II Report, Loc. cit. p. 31-52.

[26] Hatch, Final Report, loc. cit. p. 13.

[27] Ibid., p. 67-81.

The exact results depended on the optimization order of the objectives. It is important to realize that this initial design of DSAI was not intended for immediate operational implementation. The model's implementation requires not only a sophisticated information retrieval system, but also an accurate method for forecasting supplies and demands. DSAI has prepared a proposal for further model developments. Its long-range plan includes development of a large-scale simulator (suitable for testing the model in a dynamic environment), a detailed cost-benefit analysis of the model, and the operational implementation in a rail system.[28]

5.8 FRA NETWORK MODEL

An entirely different application of optimization model has been performed by FRA. The model is for use by FRA as a policy tool. The original motivation behind the development of the Federal Railroad Administration (FRA) model was to provide a network optimization that was capable of measuring the economic potential of the U.S. rail network. John Williams of the FRA did the initial work on the project. The model required an algorithm to calculate the shortest routes between any specified origin and destination (O-D) pair. Williams and IBM adapted to a railroad network, the Bureau of Public Roads' Highway Planning Model that contained a suitable method for computing shortest paths.[29]

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[28] Ibid., p. 83-87.

[29] Folk, op. cit., p. 28.

The program required three sets of input. The first and most basic piece of information was the set of nodes and links that comprised the relevant network geometry. The second set of data was the link description file. It contained all the information necessary to identify each link. This included traffic density, distance, posted speed, signalling system, number of tracks, owning railroad and trackage rights. The third input, the O-D traffic file, contained the supply and demand data for each node.[30]

For the FRA model's first application, Williams created a network with 500 O-D pairs to represent total U.S. rail freight demand. With the resulting 500 x 500 matrix, he ran the traffic assignment program. The output gave the minimum path between pairs and the resulting traffic density over each section of trackage (i.e., the loadings for each link in both net ton and car loads). From these figures, Williams estimated that only 25,000 to 30,000 miles out of the total network of 205,000 miles registered a high level of traffic density under the optimal routing policy determined by the FRA model. This was a substantial reduction from the 81,000 miles of high density track required for scheduling without the model. Williams felt that his results

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[30] D. M. Nienhaus and J. F. Murphy, "Method for the Application of Engineering Costs and Service Measures to the FRA Rail Network Model," on file at TSC, Cambridge MA, June 1975, p. 3-5.

gave credence to the belief that if optimal routing were maintained throughout the U.S. rail system, the total track miles could be reduced from 205,000 to 130,000 and still serve all O-D's. In addition to the $25,000 the FRA spent modifying the highway planning program, there was a $200-300 cost for each run of the model.[31]

During the last two years, the Transportation Systems Center (TSC) has incorporated the original FRA model into a large network costing model. Prior to this time, TSC had developed a scheme for assigning annual costs to mainline rail routes and terminals. These measures were formulated in terms of traffic volume (e.g., net tons, annual car throughput, number of trains per year). The costing model, as it exists to date, is a set of computer programs that uses the logic of the TSC rail costing method of assigning costs to the traffic generated by the FRA network model. Present plans for the costing model call for a test application over the New York to Buffalo rail corridor after validation runs are completed.[32]

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[31] Folk, op. cit., p. 29.

[32] Niehnaus, op. cit., p. 46-50.

5.9 THE QUEEN'S OPTIMIZATION ALGORTHM

As noted in Section 3.9, the Railcar Network Model is classified in this report to be a simulation model. While train routes are established using an optimization alogorithm, the basic structure of the model as described in 3.9 is that of a simulation. This classification is contrary to that described in Folk op.cit., and is worthy of discussion. Folk's analysis was documented in 1972. At that time, only a "Feasibility Report" had been documented by Queen's University. The model was still in the early stages of development with "transit time optimability" as an important aspect. The 1974 Cybernetics Symposium paper by Petersen and Fullerton, op.cit., gave an excellent overview of model status 2-3 years after Folk. Despite the Petersen title: "An Optimizing Network....", there is but one small reference to the optimization algorithm:

> "The traffic... is assigned using our optimal routing algorithm."[32a]

The remainder of the paper described features and applications which have to do with simulation. Hence, the model is a simulation for this report.

[32a] Petersen Cybernetics, op.cit., p. 1.057.

APPENDIX A. MATHEMATICAL EXPLANATION OF QUEEN'S UNIVERSITY MODEL

Peterson, Fullerton, and Cloutier found that they could use the Erlang probability distribution to describe the time between departures for any level of traffic. The probability density for this distribution is expressed as:

$$f(t) = \frac{(\mu)^k}{(k-1).} t^{k-1} e^{-\mu t}$$

The two parameters, μ and k, corresponded, respectively, to the mean train departure time and the order of the distribution. For the case with a high traffic level, one required k=1. The Erland distribution became an exponential:

$$f(t) = \mu e^{-\mu t}$$

If one allowed k to approach ∞, the Erlang distribution became a delta function:

$$f(t) = \delta \left(\frac{1}{\mu}\right)$$

This function concentrated all the probability mass at one specific point. This implied that the event (in this case, the train departure) would occur with absolute certainty. Therefore, for k = ∞, the Erlang distribution produced a regular train departure pattern and corresponded to a light load of traffic. In order to derive the distributions for the intermediate traffic levels, they chose values for k between 1 and ∞[1].

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[1] E. R. Peterson et al., "Canadian Freight Transport Model Summary Report: Phase I "Queen's University, Kingston ON, 1972, p. 3-4.

APPENDIX B. THE COST EQUATION USED IN THE SOUTHERN RAILROAD FLOW RULE MODEL

The Southern Railway used the following equation to derive the origin-destination transit cost:[1]

$$\text{Cost} = AD + BD + (EG/24) + (7G/2F) + C_o + C_d + C_i$$

where

A = average mileage cost for general purpose cars

B = average system-wide operation cost/car mile

C = average operation cost/car handled in a yard (o, d, and i stand for origination, destination and intermediate yards)

D = O-D distance (miles)

E = O-D time (hours)

F = opportunity frequency/week for moves from O to D

G = average time cost/day for general purpose cars.

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[1] M.D. Berman, "Correspondence Concerning Southern Flow Rules," November 1975.

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