NATIONAL BUREAU OF STANDARDS REPORT

9066

A COMPUTER SIMULATION MODEL OF RAILROAD FREIGHT TRANSPORTATION SYSTEMS

By

William P. Allman

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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William P. Allman
The National Bureau of Standards and Northwestern University

1. INTRODUCTION

A railroad on which freight cars are moved efficiently benefits from reduced freight car transit times, greater car availability, and lower per diem charges.[1] Therefore methods for evaluating freight car movement under alternative scheduling and associated policies are very significant. Such methods are especially important for planning new railroad systems which result from mergers and acquisitions. This paper describes a computer model which may be used to simulate some basic railroad freight scheduling and associated policies.

2. BACKGROUND

2.1 The Railroad Setting

A major objective of a railroad enterprise is to accommodate demands for the movement of freight cars between points on the railroad. Demands are of two types: regular demands which originate at known points in time with some degree of assurance, and irregular demands which are unexpected. A demand originates when a freight car requires movement from a point which we shall call its demand origin. The car remains a demand until it reaches its demand destination. Demand origins and destinations may be points of loading and unloading on the railroad, as well as interchange points where the railroad connects with other railroads. Demands include both empty and loaded freight cars, for empty cars require movement just as loaded cars do, and typically represent a significant percentage of the car movement on a railroad.[2]

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[1]Broadly speaking, per diem charges are costs which a railroad incurs for the use of freight cars owned by other railroads. Such charges are based upon the number of days a car is on the railroad, and its depreciated value.

[2]Decisions governing the allocation and distribution of empty freight cars over a railroad are beyond the scope of our consideration. From our viewpoint, such decisions determine when and where an empty car movement demand will originate.

A railroad may contain several thousand demand origins and destinations, and numerous switching yards where cars can be switched from one train to another. Local trains move cars between demand points and switching yards, but major car movements are represented by "over-the-road" trains which move cars between major yards. For purposes of planning over-the-road car movements, a railroad may be depicted by a network of nodes (major yards)[1] and links (railroad lines), and demand origins and destinations may be considered to be nodes in the network.

In railroad terminology, a train "picks up" or "takes" a car, "hauls" a car over trackage, and "sets off" (drops) a car. Motive power tonnage capacity and link topography limit the number of cars which a train may haul over a link. For many origin-destination pairs, no single train travels from the origin to the destination. Thus, in completing its transit, a car may have to travel on several different trains, being set off from one train and taken by another at intermediate yards.

At yards cars undergo time-consuming servicing and inspection operations, and are sorted (classified) into categories called "groups" which are commonly identified by (1) traffic class, and (2) that future yard to which cars in the group are to be hauled before being reclassified. Trains departing from yards take cars from groups assigned to them. Sorting at yard i is done according to a set of rules called the yard Grouping Policy, which may be represented by the matrix $G_i = \| g_{kj} \|$, where g_{kj} = that group into which cuts of traffic class k and destined to yard j are sorted. Such policies are normally time-invariant (i.e. the matrix is the same for all points in time), although the sorting of cars into groups at a given time could conceivably depend upon how soon thereafter trains take cars from the various groups.

Because of train capacity limitations, a train may not take all cars in a group assigned to it; however, all cars taken from a group may be considered to comprise that group aboard the train. Thus, trains may be considered to haul groups rather than individual cars. A group is set off from a train at some future yard whereat either (1) the group is "broken" and its member cars are resorted, or (2) the group departs intact on another train. This latter situation is called "pregrouping," and is done to relieve congestion at critical yards and to facilitate making tight train connections. In actual practice pregrouping is the exception more than the rule; however, its occurrence has important effects upon both yard operations and freight car transit times.

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[1]The terms nodes and yards will be used interchangeably.

2.2 Some Basic Questions

In this paper we are concerned with over-the-road freight car movements on over-the-road trains which travel between major yards. To accommodate movement demands, basic operating policies are established by a railroad with respect to train routes, train capacities, train schedules, and the assignment of groups to trains for hauling. Although unscheduled trains are often needed to accommodate voluminous irregular demands, regularly-scheduled trains must exist in order for a railroad to be able to plan and allocate resources efficiently, and to attempt to satisfy customer desires for on-time and reliable deliveries. The establishment of preplanned train schedules includes answering the following basic scheduling and sorting questions of railroad freight operations:

a) When and where should regularly-scheduled trains run, i.e.,

   How many trains should the railroad run over each link?
   What should the routes of individual trains be?
   At what times should trains be scheduled?
   What should the hauling capacities of individual trains be?

b) For each yard, what should the Grouping Policy be, i.e.,

   What sorting classifications (groups) should exist at each yard, and by what rules should cars of various destinations and traffic classes be classified into them?

c) For each link of a train's route, what cars should be assigned to the train for hauling, i.e.,

   At each yard of a train's route, what groups should the train be assigned to take cars from?
   At what future yard should the cars taken from a given group be set off from the train?

The difficulty of answering these interdependent questions is related to the degree of connectivity and size of the railroad network. Answers must be obtained in accordance with operational objectives of the railroad enterprise.[1] For a railroad there exists no single measure by

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[1]The subject of railroad operations performance is one of great sensitivity and inexactness, and differs according to the car ownership position, geographical characteristics, and competitive situation of the individual railroad.

which to evaluate the numerous alternative sorting and scheduling policies which may be employed against likely patterns of traffic demands. However, measures of evaluation may be expressed in terms of key operating performance measures such as freight car transit times, delays due to congestion at yards, number of trains, train lengths, yard volumes, total car-days, and operating costs. The purpose of this paper is to describe how digital computer simulation might offer a fruitful way of experimenting with potential scheduling and sorting policies, and investigating the railroad operating performance which may be expected to result from employing selected policies against specified demand traffic patterns.

2.3 Simulation of Railroad Operations

Only a few railroad simulation studies have been undertaken. Most of them focus attention on a particular subarea of railroad operations rather than on a total network. Examples include the manual simulation of classification yard processes by Crane, Brown, and Blanchard [4], the simulation of Centralized Traffic Control (CTC) installations by the Operational Research Branch of the Canadian National Railways [7], and the four computer models developed by the Railroad Systems Research Group of the Battelle Memorial Institute[1] [9].

Relevant non-simulation network-oriented studies of railroad operations include a mathematical programming approach by Charnes and Miller [3], Feeney's investigation of the distribution of empty freight cars between divisions of a railroad [5], the comprehensive exposition on railroad operations and treatment of specialized problems by Beckmann, McGuire, and Winsten [1], and Boldyreff's flooding technique for estimating the maximal steady-state flow of traffic thru a railroad network [2]. These works illustrate numerous complexities inherent in railroad operations, but do not consider time dependencies or the basic scheduling and sorting policies from a total-network viewpoint.

It appears that at a total-network level, a railroad is too complex to be modeled analytically. Experience is needed to determine how well total-network railroad operations may be simulated using digital computers, and also the degree to which newly-developed computer simulation languages such as GPSS [6] and SIMSCRIPT [8] may aid in the process. Construction of a railroad network model was first attempted (unsuccessfully) using GPSS. The model described below has been successfully constructed in SIMSCRIPT.

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[1]The Battelle models separately deal with: 1) motive power assignment and utilization, 2) single-track over-the-road train movement, 3) classification yard functions, and 4) diesel locomotive servicing functions. The first model is the only one which considers a spatial railroad network; the others consider individual functional activities of a railroad.

3. THE RAILROAD NETWORK MODEL

3.1 Purpose and Scope

The purpose of the model is to serve as a tool with which some basic operating policies of railroad freight operations may be investigated at a total-network level. The model is designed to permit comparisons of alternative policies for specific railroad systems. In addition to the basic scheduling and sorting policies described earlier, other policy questions which may be investigated include those of:

a) Running a few long trains versus running many short trains.

b) Concentrating classification activities at selected yards rather than spreading such activities throughout the entire network.

c) Having selected yards switch only during specific work shifts.

d) Having a large amount or small amount of pregrouping.

The model simulates n days of operation of an N-node network. Major inputs are train routes and schedules, yard Grouping Policies, train group assignments, and freight car movement demands. Several concepts important to railroad-operations planning are represented only thru inputs, as follows:

(1) The model does not consider possible trackage restrictions upon train movement such as single-track links, or siding lengths; all specified schedules are assumed to be feasible with respect to such restrictions.

(2) Road engines are not directly represented in the model; however, a train-length capacity may be defined for each link of a train's route to reflect train length limitations imposed by presupposed motive power.

(3) Although it is recognized that demands upon a railroad for car movement are a function of provided schedules and services, demand inputs to the model are assumed to be fixed i.e., the model does not adjust demands to reflect changes in schedules and associated policies.

At any time, a large railroad may have thousands of freight cars of different traffic classes on its tracks. To investigate railroad traffic flows, car movement may be examined in terms of sets of cars which travel together, rather than in terms of individual cars. In the model, cars which travel together are aggregated into "cuts," i.e., sets of cars which originate as demands at the same yard at the same time, and which have the same destination. Freight car traffic classes are not recognized. A cut is the basic unit of freight car flow in the model, and is not divisible into those cars which it represents.

The model has two forms. In its "extended form," processing rates of cars thru yards are a function of the availability of physical and personnel resources (e.g. operating facilities, switch engines, and work forces) which are essential to the accomplishment of yard operations. In the "basic form" of the model it is assumed that such resources are unlimited.

3.2 The Flow of Cars and Trains

Demands upon the railroad may originate at any time at any yard. A demand consists of a cut of x_{ijt} cars originating at yard i at time t and requiring movement to yard j. Demands may be completely prespecified (deterministic), or be generated probabilistically. For probabilistic demands, the probability distribution F_{it} yields a total quantity of cars originating at yard i at time t. Each originating car is assigned a destination from the probability distribution G_{it}.[1] All cars destined to the same destination are aggregated into a single cut. The basic cycle of a cut is to:

1. be created as a demand upon the railroad at its origin yard
2. be processed thru inbound operations at the yard
3. terminate if the yard is the cut's destination. Otherwise the cut is classified into a group at the yard.
4. be reserved to be picked up by a train which takes cuts from the group
5. be processed thru outbound operations at the yard
6. be picked up by and depart on the taking train
7. remain aboard the train until that future yard at which its group is set off
8. be set off from the train. Go to step 2 and continue the cycle.

[1]The probability distributions F_{it} and G_{it} are assumed to be independent, i.e., the destination of a car input as a demand at a given time is assumed to be independent of the total quantity of cars input at that time.

Steps 2 thru 5 do not occur for cuts pregrouped thru a yard. In the real world, pregrouped cuts are expedited thru yards in order to make connections to outbound trains. To represent this in the model, pregrouped cuts undergo a single "expediting" operation, after which they are eligible for connection.

A train travels thru the network according to its route and schedule (which is met unless the train is delayed waiting to pick up cuts at a yard). Cuts are picked up and set off in accordance with the train's Take List, which specifies, for each yard of the train's route, which groups at the yard the train is assigned to take cars from.[1] Cuts taken (subject to train capacity) are reserved for the train prior to its scheduled departure from the yard (at its "cut-off" time) so that outbound operations prerequisite to their pick-up by the train may begin.[2] The basic cycle of a train is to:

1. reserve cuts to be taken at its first yard
2. pick up the reserved cuts after outbound yard operations have been performed upon them
3. pick up pregrouped cuts which are to connect to the train
4. depart and travel over the link to its next yard
5. reserve cuts to be taken at its next yard such that outbound yard operations to be performed upon them may begin
6. arrive at its next yard and set off approximate cuts
7. terminate if the yard is its destination. Otherwise to go to step 2 and and continue the cycle.

3.3 Yards and Yard Operations

Since yards are so important to total-network performance (and particularly to the times at which cars are eligible for movement), it is necessary to consider yard operations to some extent in any railroad network model. Although yards differ with respect to physical layout, resources, and required operations, there are basic similarities which permit the model to contain a standard yard structure which applies to every node of the network. Fixed parameters govern the number and sequence of operations performed at each individual yard, the time necessary to perform each operation, and hence the availability of freight cars for movement out of yards on trains.

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[1] Each entry of a train's Take List for a given yard contains: 1) a group which the train is assigned to take cuts from, 2) the future yard at which cuts taken from the group are to be set off from the train, and 3) a code indicating if the cuts taken are pregrouped thru the yard where they are set off.

[2] The model does not consider cut tonnage; train capacity is in terms of number of cars. As stated earlier, a train may not take all cuts waiting in a group assigned to it because of capacity limitations, however, all cuts taken from a given group may be considered to comprise that group aboard the train.

The standard yard structure of the model requires that an ordered set of operations be defined for each yard. What each defined operation represents is specified by the analyst, i.e., operations might represent bleeding, inspection, trimming, makeup, etc. One operation must be the classification operation. From a yard-operations viewpoint there are four types of cars at yards. Each type undergoes a different ordered subset of operations. Cars upon which a sequence of operations is performed simultaneously are aggregated into sets called segments. The four types of cars and their corresponding segments are:

a) Cuts originating as demands at the yard within a specified time interval are aggregated into an input segment.

b) Cuts set off from an inbound train, and which are to be classified at (i.e. not pregrouped thru) the yard, are aggregated into a set-off segment.

c) Cuts set off from an inbound train, and which are to be pregrouped thru the yard, are aggregated into a pregrouped segment.

d) Cuts which have been reserved (from groups) to be taken by a specific outbound train are aggregated into a reserved segment.

The time required for a segment to undergo an operation differs by yard and operation as a function of segment size (the number of cars in the segment).

In the extended form of the model, any operation at any yard may require the use of a facility and/or a force. Different types of facilities and forces may be defined for each yard. A facility is defined to be "fixed" resource which may not move about the yard, and which is used solely by the operation with which it is associated. A force is defined to be a resource which may move about the yard and be used by different operations. What each type of facility and force represents is specified by the analyst, i.e., facilities might represent a car servicing area, and the yard hump, while forces might represent switching engines, and car inspection teams. For each yard different levels of each type of facility and force are specified for each of three contiguous work shifts. Facilities and forces are assigned to yard operations on a first-need, first-served basis. An operation upon a segment does not begin until a facility and/or force of the type(s) required by the operation are available to the operation. Segments delayed at operations due to unavailable resources wait in FIFO queues associated with the reason for the delay.

3.4 Operating Costs

Costs are considered in the model as follows:

1. In the real world, costs of hauling cars over links actually depend upon the motive power utilized, speed of travel, link distance and topography, tonnage hauled, and crew costs. In the model, hauling costs are taken to be a step-wise non-decreasing function of train length. Coefficients of the function may differ for individual links. Movement costs are accumulated for each link and for the total network.

2. In the real world, yard operation costs depend upon a multitude of factors. In the model, yard costs are a function of yard switching volumes plus the costs of forces employed at yards. (Since facilities are considered to be fixed resources, costs are not associated with them.) The cost of classifying a car at a yard is different from the cost of pregrouping a car thru the yard. Switching costs are accumulated for each yard and for the total network. Costs of forces are also accumulated.

Although these cost considerations require refinement and extension to be useful for true costing purposes, it is believed that they provide a basis for cost-wise comparisons of total-network operating policies.

3.5 Summary of Inputs and Outputs

At a synoptic level, a simulation model may be summarized by its inputs and outputs. Inputs to the railroad network model consist of:

A network description which includes a network transition matrix, distance matrix, hauling cost information, etc.

Train descriptions for each train which include the train's schedule, route, days the train runs, travel time over each link, cut-off times, scheduled stopping time at each yard, permitted train length over each link, and Take Lists.

Freight car demand descriptions which include a list of input cuts x_{ijt}, and/or probability distributions F_{it} and G_{it} from which cuts are generated.

Yard descriptions which include the number and types of operations at each yard thru which each type of segment is processed, and operation times as a function of segment size. Switching costs must also be provided. If the extended form of the model is used, the following information is needed for each yard: work shift starting times, facility and force levels during each shift, facilities and forces required by operations, and the lengths of time facilities and forces are used by operations.

Control specifications which define control parameters for the individual simulation run, as well as output options.

Major outputs include "progress notices" which may be printed whenever selected events occur, and a system summary. Notices of other important circumstances (e.g. when a train is delayed at a yard because cuts which it is to pick up have not completed outbound yard operations) may also be obtained. The system summary describes (at prescribed intervals) the total simulated network, displaying values of various statistics since they were last reset. Figure 1 shows portions of the summary output for the basic form of the model. If the extended form of the model is used, a facility and force utilization report provides, for each type of facility and force employed at a yard, resource utilization in terms of car and segment volumes, plus statistics relative to delays associated with the type of resource.

3.6 Computer Considerations

The structure (world view) of SIMSCRIPT is convenient for constructing network-flow type models; space does not permit a discussion of useful relevant features of the language. The railroad network model consists of four SIMSCRIPT programs as illustrated in Figure 2. The Pre-analysis Program analyzes input data for logical inconsistencies. The Cut-generation Program prepares a tape time file of cut inputs from freight car demand descriptions. The third program is the main simulation program, which may optionally output a history tape containing records of each cut and/or train movement. This tape may be used as input to a Post-analysis Program which generates statistics from train and cut histories.

In the model, computer storage for descriptions of trains, cuts, and segments, and notices of future SIMSCRIPT events is allocated dynamically by SIMSCRIPT. Table 1 describes train, cut, and yard configurations for some executions of the basic form of the model using the SHARE version of SIMSCRIPT on the IBM 7094 computer. The computer running times given do not include execution times for the Pre-analysis or Cut-generation Programs.

SNAPSHCT AT TIME 2.010 CLASSIFICATION COSTS= 69464 MOVEMENT COSTS= 42144

YARD	CARS AT NCW	CARS ORIG	CARS ARRIV	CARS SETOV	CARS CLASS	CARS CONEC	CARS DEPRT	CARS TERM	TRAINS ORIG	TRAINS ARRIV	TRAINS DEPT	TRAINS TERM
1	383	1200	495	495	1695	0	623	689	4	3	4	5
2	209	1200	638	638	1838	0	837	792	2	13	14	1
3	367	1200	559	559	1759	0	675	717	2	6	6	2
4	437	1200	693	693	1783	0	697	759	0	15	15	0
5	331	1200	684	684	1884	0	702	851	0	10	10	0
6	445	1200	484	484	1684	0	567	672	6	5	6	5
7	290	1200	557	557	1757	0	741	726	8	5	8	5

GRCUP I	J	CARS NOW	TOTAL CARS	AVRG. WAIT
1	2	31	178	0.189
1	3	22	172	0.258
1	4	46	168	0.319
1	5	43	148	0.211
1	6	44	169	0.270
1	7	121	171	0.214
2	1	45	170	0.307
2	3	48	166	0.180
2	4	29	178	0.224
2	5	25	180	0.190
2	6	32	172	0.199
2	7	30	180	0.183
3	1	68	210	0.299
3	2	45	148	0.214
3	4	65	149	0.238
3	5	61	188	0.279
3	6	70	180	0.268
3	7	58	167	0.278
4	1	189	189	0.
4	2	40	154	0.182
4	3	51	150	0.229
4	5	11	179	0.193
4	6	18	162	0.200
4	7	39	190	0.185
5	1	103	208	0.270
5	2	23	170	0.312
5	3	77	158	0.284
5	4	9	159	0.273
5	6	43	179	0.365
5	7	29	159	0.158
6	1	205	205	0.
6	2	55	152	0.253
6	3	67	156	0.250
6	4	48	154	0.180
6	5	51	170	0.292
6	7	19	175	0.198
7	1	121	221	0.245
7	2	33	160	0.242
7	3	65	155	0.232
7	4	10	152	0.184
7	5	50	176	0.140
7	6	13	167	0.228

ORIG= 1 DEST=	1	2	3	4	5	6	7
CARS OVER	194	140	89	44	65	45	77
CUTS OVER	12	9	6	3	6	3	6
AVG TRTIME	0.082	0.646	1.042	0.792	1.229	0.938	1.458
MAX TRTIME	0.118	0.813	1.458	0.958	1.646	1.104	1.875
MIN TRTIME	0.045	0.479	0.625	0.625	0.812	0.771	1.042
ORIG= 2 DEST=	1	2	3	4	5	6	7
CARS OVER	125	154	118	131	113	104	104
CUTS OVER	9	12	9	8	7	8	7
AVG TRTIME	0.875	0.082	0.688	0.526	0.780	0.802	1.009
MAX TRTIME	1.375	0.118	1.125	0.833	0.979	1.146	1.208
MIN TRTIME	0.542	0.045	0.458	0.	0.625	0.604	0.854
ORIG= 3 DEST=	1	2	3	4	5	6	7
CARS OVER	142	103	158	84	127	110	109
CUTS OVER	8	8	12	7	8	7	8
AVG TRTIME	1.042	0.729	0.082	0.881	0.813	1.170	1.042
MAX TRTIME	1.542	1.187	0.118	1.500	1.313	1.646	1.542
MIN TRTIME	0.708	0.521	0.045	0.	0.479	0.812	0.708
ORIG= 4 DEST=	1	2	3	4	5	6	7
CARS OVER	0	114	99	176	142	115	75
CUTS OVER	0	8	8	12	9	9	5
AVG TRTIME	0.	0.635	0.979	0.082	0.644	0.646	0.821
MAX TRTIME	0.	1.021	1.479	0.118	0.958	0.979	1.021
MIN TRTIME	9.999	0.417	0.646	0.045	0.458	0.437	0.687
ORIG= 5 DEST=	1	2	3	4	5	6	7
CARS OVER	118	102	98	118	167	40	119
CUTS OVER	7	7	7	9	12	3	9
AVG TRTIME	1.232	0.854	0.899	0.727	0.082	0.854	0.664
MAX TRTIME	1.708	1.187	1.375	1.042	0.118	1.021	0.875
MIN TRTIME	0.875	0.687	0.541	0.542	0.045	0.688	0.521
ORIG= 6 DEST=	1	2	3	4	5	6	7
CARS OVER	0	97	89	106	119	188	73
CUTS OVER	0	7	7	8	8	12	5
AVG TRTIME	0.	0.940	1.170	0.646	0.958	0.082	0.888
MAX TRTIME	0.	1.417	1.646	1.104	1.458	0.118	1.021
MIN TRTIME	9.999	0.583	0.812	0.437	0.625	0.045	0.687
ORIG= 7 DEST=	1	2	3	4	5	6	7
CARS OVER	110	82	66	100	118	70	169
CUTS OVER	6	6	6	8	6	5	12
AVG TRTIME	1.458	1.049	1.125	0.875	0.604	0.888	0.082
MAX TRTIME	1.875	1.354	1.542	1.208	0.687	1.021	0.118
MIN TRTIME	1.042	0.854	0.708	0.708	0.521	0.687	0.045

LINK I	J	CARS CVER	CUTS OVER	TRAINS OVER	MOVE COSTS
1	2	623	45	4	2868
2	1	495	30	4	2202
2	3	663	50	4	2700
2	4	914	64	6	4374
3	2	729	48	4	2700
3	5	504	36	2	1182
4	2	521	38	5	3210
4	5	708	47	4	3030
4	6	606	43	5	3864
5	3	454	31	2	1020
5	4	543	39	3	2190
5	7	628	45	5	3198
6	4	481	35	4	3030
6	7	86	6	2	1020
7	5	654	47	6	4374
7	6	87	6	2	1182

Figure 1 - Portion of Summary Output

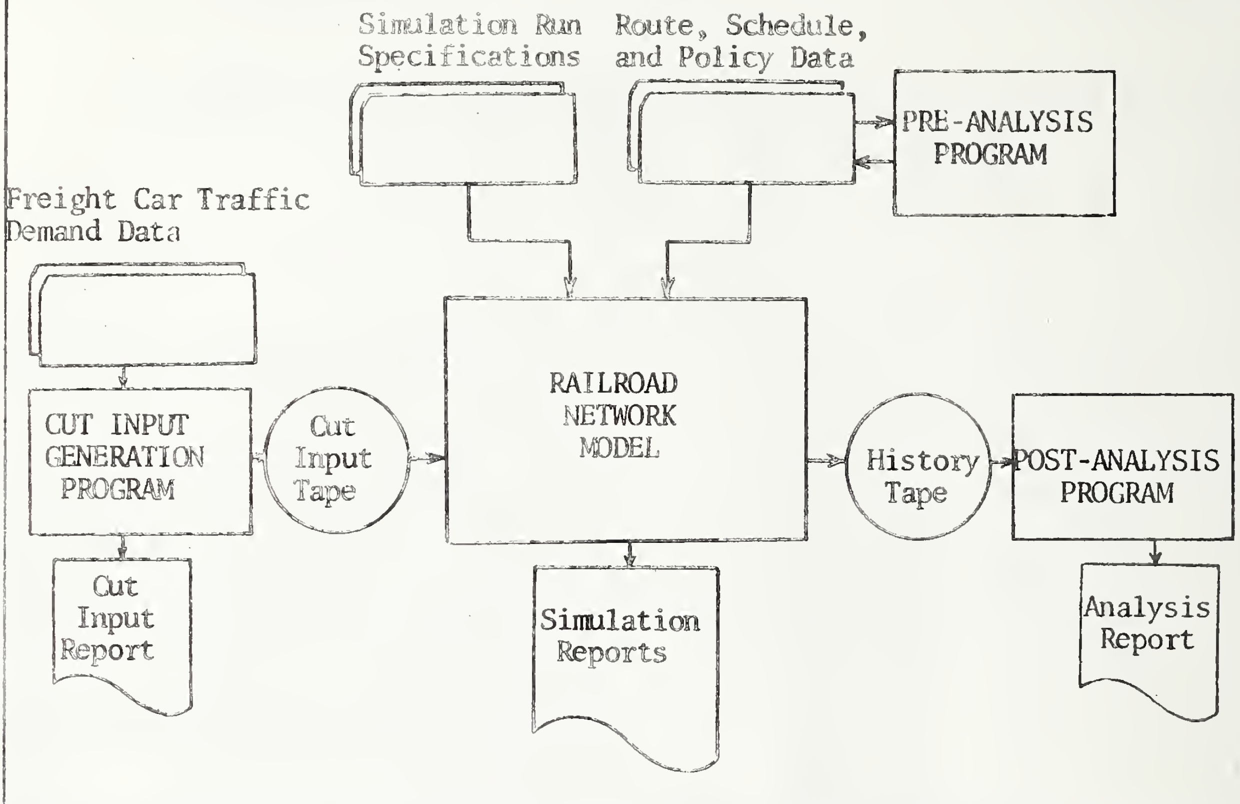

Figure 2 - Diagram of Computer Programs Comprising Railroad Network Model

No. of Yards	No. of Daily Trains	No. Cuts Input Daily	Avg. No. Yards in a Train's Route	Avg. No. Entries in a Train's Take List	Length of Simulation Run (days)	Computer Running Time (minutes)
7	12	294	4.0	5.5	6.0	6.0
7	24	490	4.0	5.5	6.0	6.4
20	85	1500	3.4	6.4	2.0	4.4

Table 1. Railroad Network Model Computer Running Times

The major restriction which limits the size of a railroad system which can be modeled is computer memory required for 1) descriptions of cuts, and 2) SIMSCRIPT event notices, each of which requires four 36-bit computer words. The effective representation of large traffic volumes requires a greater storage capacity than that provided by the 7094, hence it is noteworthy that computers with larger memories and SIMSCRIPT capabilities are becoming available.

4. USING THE MODEL

4.1 Tactical Planning

Starting conditions of a simulation run may range from one extreme of "empty-and idle" conditions to another extreme wherein the railroad is fully operational, and the simulation happens to start "now." In the model the problem of starting conditions (i.e. overcoming the artificiality introduced by the abrupt start of the simulation) is handled in the traditional manner of excluding results of an initial portion of a simulation run from consideration. No general criterion exists for determining when measurement of the actual simulation should begin; the model includes time parameters which govern when:

a) cuts first enter the system (and are not hauled)
b) trains first enter the system (and travel empty)
c) trains first hauls cuts
d) simulation measurement begins
e) accumulated statistics are reset

Since the variability associated with the outputs of even simple Monte-Carlo simulation models is often discouragingly large, one must expect that outputs from the railroad network model will be quite diverse.

4.2 An Application of the Model

As of this writing, preparation is underway to apply the model to data representing a major U. S. railroad. The actual railroad is being represented as a 20-node network thru which approximately 85 regularly-scheduled trains run. Actual freight car traffic demand data has been collected over a ten-day period, and transformed to represent movements between the 20 yards. For each of the 380 origin-destination combinations, data was appropriately reduced to represent the number of cars originating as demands upon the network during each hour of each day. For each yard, input points in time and their associated input quantities were selected from an examination of these hourly tabulations. Destination probabilities for each such input have been simply taken as the percentage of total cars bound for each destination. It is significant to note that development of this time-dependent origin-destination demand data (representing more than 150,000 freight cars) is in itself a major data-processing task, which could not have been reasonably accomplished without the existence of a computerized car movement reporting system.

For this first application of the railroad network model to real data, complete validation of the model is not expected. The abstractions of the model from the real world are substantial, and it is anticipated that this current version will be more of a pilot model than an actual productive tool.

4.3 Cost and Benefits

Experience which permits an appraisal of the economic justifiability of the model in terms of its cost and benefits is lacking, but it is clear that large potential savings in railroad operations are possible. (For example, some railroads absorb large per diem deficits which may be reduced with modest improvements in freight train scheduling which permit cars destined to other railroads to leave the railroad before rather than after midnight.) The ability to investigate the implications of total network policies by experiment rather than by actual operations can clearly contribute significantly towards realizing savings in operating costs.

5. SUMMARY

5.1 Limitations of the Model

Although the model includes important aspects of a total railroad network, it disregards many factors which are quite significant in railroad operations. Among the items which should be considered for addition to the model are the following:

1. Freight car traffic classes, and car movement priorities.

2. Probabilistic travel times and yard operation times, to reflect the non-deterministic nature of the railroad environment.

3. More sophisticated rules which govern what cars specific trains pick up at yards.

A greater ability to draw inferences about real railroads would result from a network model which contained detailed representations of individual yards and links. However, such an all-encompassing model requires strenuous computer programming efforts, and is feasible only with computer speeds and memories superior to those commonly available today.

5.2 Summary

The model described in this paper is believed to be the first railroad network model in which trains and cuts "flow" through the network as time advances, and in which yards and their operations are considered. Although SIMSCRIPT is no panacea for modeling a system as complex as a railroad, its world view permits construction of the model with much less effort than would be required by machine-level or traditional scientific programming languages. Possible applications for the model are as:

1) A tool for predicting what total railroad operating performance will be if specified operating policies are implemented against specified demand traffic patterns, and to compare the associated costs of alternative sets of policies.

2) A training device for railroad operating management. The model may be used to increase management's understanding of the system-wide implications of individual and local operating decisions.

The potential contribution of computers and simulation to the planning and analysis of total-system railroad operations remains to be established, and is severely dependent upon future hardware and software costs and characteristics. Experiences in the development and application of models such as the one described above are needed to provide experiences upon which an appraisal of the benefit of simulation to total-network railroad analysis may be made.

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