Review and Assessment of Train Performance Simulation Models

STEPHEN M. HOWARD, LINDA C. GILL, AND PETER J. WONG

Train performance simulation (TPS) models are used extensively in railroad operations and research applications to simulate the operation of a train over a specific route. To increase the railroad industry's awareness of the current state of development, usefulness, and availability of these models, the Office of Freight and Passenger Systems of FRA initiated a study of TPS technology. Results from a comprehensive review of 27 existing TPS models are summarized. The primary sources of information were TPS designers, users, and researchers and the National Technical Information Service. A generic model, based on the capabilities of existing models, was developed to describe the basic component algorithms of TPS models as well as the overall architecture of these models. A brief summary and analysis of existing TPS models is given, which includes comments on their train-modeling and computer-programming characteristics.

A train performance simulation (TPS) or train performance calculation (TPC) model is a computer program that simulates the operation of a single train over a specified railway route. It does not model the interaction of multiple trains in a railway network. Numerical and graphical output from the model provides information on such performance variables as travel time, train velocity, and energy or fuel use as the train moves along the route. In addition, a TPS model may provide more detailed information describing brake applications, tractive effort, train resistances, and track profiles.

Although the TPS model concept can be implemented in various ways, the underlying structure of all TPS models is essentially the same and can be described generically.

GENERIC MODEL

The basic components of a TPS model, its overall architecture, and the process involved in applying it can be understood by delineating the steps in program use as follows:

1. Initial collection of the required input data and specification of the data in computer-readable form,
2. Simulation of the train run, and
3. Reporting of simulation results and postprocessing of simulation output data.

Each of these functions is described below.

Initial Data Collection and Specification

Three types of input data are required for a TPS run: route data, train data, and operating-scenario data. Route data are generally obtained from railroad track charts. Locomotive and car data are derived from manufacturers' data sheets and specifications. Data obtained from the manufacturer can differ significantly from the actual performance characteristics of a particular locomotive or car, which are affected by use, maintenance procedures, and age. The accuracy of the input specification can become important when the model is used for detailed analysis of fuel or energy use, but it may be somewhat less important for examining broader policy issues. Operating-scenario data are specified to describe the train-control parameters for the run.

Input data can be specified to tne model as (a) hard-wired, internally coded program data that are unalterable at program execution time; (b) sequential card-image data that are read in at program initiation and that fully describe the track, locomotive, consist, or operating scenario for the run; and (c) higher-level descriptors that point to a data base containing complete routes (stored on a segment-by-segment basis) or train specifications.

Data bases facilitate both routine use of the model by operations personnel (by greatly reducing input requirements) and transfer of the data from one application to another.

Typical data requirements for route, train, and operating scenarios are described below.

Route Data

Any track segment can be specified by data that describe curves, grades or elevations, speed limits, and station stops (usually by milepost). Enhancements to these data can include specifications of equations of track, direction of travel or reverse segments, and complex curve descriptions of the point-tangent-spiral form.

Track data can be formatted in either point or interval form. Point data describe characteristics that hold at a single point on the track, such as elevation or station stops, whereas interval data describe a track characteristic that holds between two points, such as grade or speed limit.

Train Data

Train data requirements depend on the intended application of the model. Some models represent the propulsion system in great detail and consequently require extensive and detailed data. In general, the locomotive specifications include tractive-effort curves, aerodynamic and mechanical resistance characteristics, fuel or energy consumption, and brake-system parameters. Specification of the train makeup can range from the individual description of each car and locomotive in the consist to the number of cars of a single type.

Operating-Scenario Data

In addition to descriptions of the route and train makeup, certain operating parameters and strategies must be specified for the running of the train. These may include train starting time, train starting speed, place and time of stops along a route, temporary speed orders, consist changes en route, velocity and direction of prevailing winds, explicit throttle settings and brake application specifications, and maximum allowable acceleration and deceleration.

Simulation of Train Performance

The simulation of train performance requires several mathematical or algorithmic models, including a train operating and handling model, a resistance model, a power-system model, and a brake model. The train operating model drives the simulation by determining when to recompute the state of the train and by deriving the total forces acting on the train at a specific time point based on the resistance, power-system, and brake models. Each of these component models is described in more detail below.

Train Operating and Handling Model

The approaches used to control the overall simulation of the train operations can vary in mathematical terms as well as in terms of their correspondence to actual train handling.

In mathematical terms, the algorithms all use iterative computational cycles based on time, distance, or velocity increments. In some cases, a combination of incremental controls is used. For example, a model that uses a time step for basic iterative control may restrict the step length so that the corresponding change in velocity will not exceed a specific value. The models then compute, by means of numerical integration or differentiation techniques, the changes in the state of the train corresponding to the iterative variable change. Because most of the attributes describing the state of a train in motion are highly velocity dependent (including resistances and tractive and braking effort), the algorithms should generally recompute the state attributes at small increments of velocity (e.g., 1 mph).

A common mathematical approach in the TPS models is the use of variable-length simulation steps instead of a constant length. This improves algorithm efficiency by recomputing the train state frequently when the route conditions are rapidly changing and relatively infrequently when the train is in a fairly steady-state mode of operation.

The train can be represented as a single unit, as multiple point masses corresponding to cars or groups of cars, or as a line. Although the single-unit approach is computationally efficient, it can introduce inaccuracy when the terrain changes rapidly and the train is long. In passenger service applications, however, this approach is entirely adequate.

The overall simulation method used by most TPS models involves an n-record look ahead in the route data to determine the existence of speed restrictions and changes. When upcoming changes are sensed, a braking or acceleration point is computed and a braking or acceleration event is scheduled for that point.

The simulation of train handling is generally based on a simple philosophy: minimize running time by accelerating and decelerating the train at the maximum feasible and allowable rates. When explicit inputting of throttle and brake settings is permitted, the model can function in an interactive mode as an operational simulator.

Resistance Model

Resistance to forward motion on level, tangent track is computed by using an equation with the general form (1)

$$R = A + BV + CV^2 \qquad (1)$$

where

R = train resistance on level, tangent track;
V = train speed;
A = mechanical or friction drags that are at least partly weight dependent;
B = all effects that depend on the first power of the velocity, such as flange resistance caused by the nosing action of the truck and car and the consequent impacting of flange on rail; and
C = effect of air resistance.

Resistance due to track grade and curvature is added to the resistance on level, tangent track. Curve resistance is usually taken as 0.8 lb/(ton•degree of curvature) and grade resistance as 20 lb/(ton•percentage of grade) (1,2).

The conventional approach is to use the basic or modified Davis coefficients in the resistance equation. The Tuthill modification (describing the coefficients as a matrix of velocity-dependent coefficients) to the Davis equation is usually recommended for speeds above 40 mph. Various other specialized equations for describing aerodynamic and rolling resistance of the total train are sometimes included to represent more accurately particular types of operations such as passenger service. Because the most widely used equations for modeling resistance of special car types, such as streamlined and unstreamlined passenger cars and trailer-on-flatcar and container-on-flatcar types, are of the same quadratic form, a TPS model that allows the input of each resistance equation coefficient for each car will enable the user to generate customized equations for a specific application.

Power-Systems Model

A central design feature of the TPS model that has a significant effect on input-data requirements is power-systems modeling. TPS models are generally written to simulate either diesel-electric or fully electric propulsion systems. Those models that optionally simulate both types of propulsion systems usually do so by modifying the tractive-effort curve and the units of energy consumption.

Power systems are modeled by either a component approach or a black-box approach, which represent different levels of detail. In either case, the primary function is to compute the available power for acceleration, the loss and use of power internally, and the energy consumption characteristics.

The component approach to modeling power systems entails decomposition of the complete power source into a number of interconnected components. The models for each component can then be selected from a library, and the TPS can be designed to interface the data flows between each component. This type of model generally computes and displays energy use in more detail than the black-box model.

The black-box approach involves the specification of the total power system by a tractive-effort curve, a transmission-efficiency curve, and a fuel-consumption or energy-demand curve. Tractive effort is usually input in tabular form at fixed velocity increments. Many models reference only a single tractive-effort curve, which does not represent the tractive effort by throttle position.

The modeling of diesel-electric propulsion systems is generally via the black-box approach, with emphasis on determination of available power for driving the wheels and overall fuel consumption. In some models, the fuel consumption is broken down into the component fuel use involved in overcoming resistances and losses in the transmission. The detailed breakdown of internal auxiliary loads, such as auxiliary alternators or generators and air compressors for train brakes and their individual effects on fuel use, is not ordinarily handled.

One other possible power-system modeling feature is the computation of regenerative energy or power available from the propulsion system due to electrical braking.

Brake-System Model

The brake-system model simulates the behavior of friction or air brakes, and in some cases dynamic brakes, and the blending of both types. Because many railroads promote a policy of extensive dynamic brake use by engineers, this is usually a desirable modeling capability. Also, because a fuel-consumption rate is associated with dynamic braking, the capability of modeling dynamic brake application realistically is required in fuel and energy use studies.

The two predominant approaches for computing the available braking force are

1. Use of brake-force, distance, and time equations derived from fundamental physical and mechanical system parameters (several factors are usually approximated, such as adhesion, coefficient of brake shoe, and brake pipe propagation time; more sophisticated equations improve the estimates by including variable brake-application rates and brake pipe leakage) and
2. Use of empirically derived braking curves that describe the braking performance of a particular vehicle type.

A third approach to brake modeling is to specify only a fixed deceleration rate that the train follows when braking.

Ordinarily, the assumptions in TPS models are that the air-brake system is fully charged and the transients due to release and reapplication of brakes are ignored. Dynamic braking capability is generally summarized in a single curve decribing force available by velocity. The usual approach to modeling brake blending is to attempt first to achieve a specified braking rate through the use of dynamic brakes and to increase the braking capability with friction brakes only when dynamic braking is inadequate.

Reporting of Simulation Results

A TPS model generally can produce, in tabular form, both detailed output and summary statistics of the train's performance. The detailed output provides results such as timetables, overall fuel consumption, energy and fuel use breakdowns, instantaneous speed, and so forth, at every program iteration or at a designated interval (such as every milepost), whereas the summary output includes total running time, average running speed, total fuel consumption, throttle position distribution, and tonnage ratings. In addition, track and train input data can be output in tabular form to facilitate verification of the accuracy of data coding.

A TPS model can also produce printer plots and off-line plots. Off-line plot features are usually based on a particular hardware plotting device such as CALCOMP or VERSATEC, and the data link from a TPS model is achieved through the use of a stand-alone program that processes TPS output data files to produce the necessary driver tape. Graphical profiles of the input track data may be produced, which facilitate the verification of data correctness. Since track data coding is a tedious and error-prone process, some form of data validation is desirable to avoid execution of the program with incorrect data. Plots of output variables are valuable for comparing the results of a number of simulation runs with one another or with data recorded in the field.

Use of TPS Models

The TPS model is frequently used in railroad operations and research to (a) determine fuel requirements and energy use, (b) estimate train operating costs, (c) determine scheduled operating time for a train, (d) determine the locomotive power necessary to make a run in a given time, (e) determine the effects of adding or dropping a locomotive unit or tonnage, (f) determine the route tonnage rating based on trains operating over the ruling grade at specified minimum speed, (g) study the effects of changing the scheduling and distribution of trailing tonnage among available locomotives, (h) determine minimum speed on the ruling grade, (i) compare running a specific train over different routes, (j) study the effects of changing speed restrictions or station stops, (k) determine the effects of slow orders, (l) study the effects of track relocation reconstruction or new construction, (m) determine the most desirable siding location, (n) model intercity passenger train service, and (o) generate data for lawsuits and legal hearings.

REVIEW OF EXISTING TPS MODELS

Twenty-seven existing TPS models were reviewed relative to computer and programming aspects, train and track data formats, general train-modeling capabilities, and availability. The models reviewed were from Aerospace Corporation; AiResearch Manufacturing Company of California; Association of American Railroads (AAR); Bechtel Corporation; Burlington Northern; Canadian National Railways; Canadian Pacific Limited; Carnegie-Mellon University (CMU); Chessie System; Day and Zimmermann, Inc.; Electro-Motive Division, General Motors; General Electric (GE); Transportation Systems Division, General Motors; Jet Propulsion Laboratory; TVS Program and VIP3 Program, Louis T. Klauder and Associates; Louisville and Nashville Railroad Company; Manalytics, Inc.; Missouri Pacific Railroad; Norfolk and Western Railway Company; Southern Railway; T.K. Dyer, Inc.; Transportation and Distribution Associates, Inc. (TAD); Transportation Systems Center (TSC), U.S. Department of Transportation; Union College; Union Pacific Railroad Company; and the Train Operations Simulator (TOS), AAR. Detailed abstracts of each model and an extensive bibliography of TPS research and methodology may be found elsewhere (3).

The available TPS models exhibit considerable variety in terms of implementation and considerable replication in terms of capabilities. The following comments summarize the characteristics of the existing models.

Programming Languages and Computer Aspects

Most TPS models (90 percent) are now written in FORTRAN but generally include a number of features not specified by the American National Standards Institute (ANSI). Program documentation--technical modeling information, programmer's information, user's information, and results of validation efforts--is limited for most TPS models. Consequently, the programs are not easily transportable from one computer facility to another. The lack of documentation leads to difficulties in maintenance and enhancements as well as redundancy in TPS design work. The TPS models of TSC, CMU, and Union College are exceptions in that the documentation is complete and of good quality. Many (60 percent) of the models run only in batch mode (i.e., specification of runs cannot be made iteratively via a cathode-ray tube).

Data Collection and Input

Obtaining accurate TPS input data describing the locomotive, cars, and track is difficult. The inaccuracy of input data is a primary source of error in fuel-use predictions. The difficulty in obtaining accurate data is compounded by the differences among various TPS models in format and content of input requirements. Moreover, because of these differences, users have difficulty in sharing data.

Roughly half of the current TPS models are reported to have locomotive and track data bases. Available documentation, however, sometimes does not indicate clearly whether a TPS model has a true key-access track data structure or simply a large collection of track data stored in an ordinary sequential data file.

Track data are generally obtained from railroad property track charts. As stated, the process of coding the track data for input to the TPS model is time consuming and subject to error. This is a major impediment to widespread TPS use.

Resistance Modeling

The inability to simulate accurately the forces due to aerodynamic and mechanical resistance is a significant factor in fuel and energy use prediction (1,4-7). When only a single resistance equation is hard coded in a TPS model, it is almost always the Davis or modified Davis equation. Studies of simulation model performance (4,8) indicate that the Davis and modified Davis equations have not been substantiated for use in modern train simulations. Therefore, further study is necessary.

Power-Systems Modeling

Power-systems models range from the low-detail black-box models to the high-detail, modular, component-by-component models. Five of the 27 TPS models reviewed perform detailed component modeling of electric propulsion systems, and half of the TPS models perform simplified modeling. More than 90 percent of the existing TPS models are used for diesel-electric propulsion systems.

Three models have been developed that compute regenerative energy or power available through electrical braking and apply this capability to an on-board or wayside energy storage system.

One limitation of the existing models is the use of a single tractive-effort curve to compute available force for acceleration. The tractive effort for each notch setting can be described, and simulating the application of tractive effort in this way is more accurate and realistic. Fuel and energy computations are based on the time spent in particular notch settings, so the existing models must compute approximate notch settings.

Brake-Systems Modeling

The two methods generally used to simulate air-brake systems are idealized theoretical brake equations or empirically derived brake curves. Many TPS models can now simulate dynamic braking and blending of dynamic and air brakes.

Other Modeling Considerations

Train-handling algorithms that minimize running time by accelerating and decelerating the train at the maximum feasible and allowable rate are not useful for studying the effects of train handling on fuel consumption or other dependent train parameters. Half the models reviewed represent the train as a single point or unit, and the others represent the train as multiple point masses or as a line.

Output Data

The visual summary of certain output values in the form of graphical display either by off-line pen plotting devices or on-line terminals and printers can facilitate making inferences about both the performance of the TPS models (as in validation studies) and the train system under study. Approximately 30 percent of the TPS models now have graphical printer or off-line plotting capabilities.

Availability

Six of the models were found to be readily available to the railroad industry or other interested users: AiResearch, AAR, Carnegie Mellon, TSC, and Union College TPS models and the AAR TOS.

Use

The majority of the TPS models are capable of modeling both freight and passenger service, although many are used predominantly for simulating one type of service. The TOS and 20 percent of the TPS models reviewed have been used only for modeling freight service, and 10 percent have been used solely for passenger service simulation.

The predominant uses for TPS programs at present are operational studies of scheduling, locomotive assignments, tonnage ratings, calculation of effects in speed-limit changes, and so forth. TPS models are also frequently used in fuel and energy studies involving train makeup, train handling, and engineering modifications.

The AAR TOS is used widely in safety studies involving the analysis of train makeup and handling to determine potentially hazardous operating practices and train consists.

Model Validation

Sensitivity analysis and validation of TPS models are still relatively undeveloped. However, a few models have been validated by using the following approaches: comparison with measured train fuel use (TSC, Chessie System, Norfolk and Western, Union Pacific, Southern Railway), graphical data comparison (AAR TOS), comparison with other TPS models (CMU, Bechtel, TAD, GE), comparison with dynamometer car output (Canadian National), and comparison of calculated running time with that of actual runs (GE, Canadian Pacific, Missouri Pacific, Union College, Union Pacific).

CONCLUDING REMARKS

An industry standard TPS model should satisfy a broad spectrum of software quality factors while meeting the requirements of industry (operational) and research applications. The TPS design should accommodate the requirements of the predominant use areas--i.e., fuel and energy use, safety, and common operational studies.

The three categories of fuel and energy use studies are (a) train handling, (b) engineering modifications, and (c) train makeup. Each category requires that certain characteristics be included in TPS model design, such as abilities to collect data describing train handling and fuel use as well as track characteristics at a detailed level; ability to simulate realistic train-control techniques; component-by-component representation of propulsion systems (as in the Carnegie-Mellon TPS model); high confidence in aerodynamic and mechanical resistance modeling; and the ability to specify train makeup car by car.

Safety studies entail analysis of train makeup and handling to determine potentially hazardous operating practices, train consists, and track locations. This area of analysis is somewhat beyond the capability of TPS models. The AAR TOS model is used widely in this area and is capable of detailed simulation of brake systems--a basic requirement in these studies.

Common operational studies involve scheduling, locomotive assignments, tonnage ratings, calculation of effects of changes in speed limits, and the like. These studies may be considered the core use of TPS programs at present and should continue to be well supported. Most existing TPS models produce results in this area. A major requirement for this study area (and all the other areas) is data accessibility in the form of up-to-date data bases.

The second major requirement for an industry standard TPS model is software quality. Software quality is defined by such general concepts as reliability, testability, usability, efficiency, maintainability, flexibility, and portability. Among the many TPS specific design requirements attached to these criteria that should be integrated into an industry standard model are

1. Up-to-date, easily modifiable library data bases for train and track data;
2. Interactive maintenance and access of the model and all supporting data for convenience of use;
3. Verification of data and graphical output representation of the input data;
4. Complete and accurate documentation, for example, technical modeling information, programmer's and user's information, sample runs, as well as results of validation work performed;
5. Ability to model various train-handling philosophies--a set of parameters that embody the variability in various approaches to train handling should be identified; possible models to work from include the AAR TOS (9-11) and the FUEL model by Muhlenberg (7); and
6. ANSI standard programming.

Many users of existing TPS models consider the models sufficiently accurate for the routine operational applications. Carefully executed studies (4,5), however, suggest that TPS models exhibit many limitations in fuel and energy use prediction. The major function of TPS validation currently is to identify limitations and sources of errors and to determine where further refinements can produce the greatest improvement.

One of the major limitations in validation attempts to date has been the lack of data-collection capabilities. The ability to collect data accurately and to synchronize the data with existing track data bases would greatly facilitate and improve determination of TPS accuracy and limitations. In this regard, the capabilities of computer-based data-collection instrumentation such as the Locomotive Data Acquisition Package (12-14) and the Advanced Locomotive Cab Instrumentation System (15) may be useful. These data-acquisition devices may be applicable to several different areas related to TPS use, including

1. Identification of the behavior of high-variance locomotive parameters such as fuel use and correlation of parameter values with particular operating conditions,
2. Identification of train-handling techniques and effects on fuel use, and
3. Precise recording of scenarios (a common problem in processing such train data as fuel consumption is identification of the conditions under which measurements are being made, such as idling and dynamic braking).

In the long run, on-board microcomputer technology may create an entirely new TPS application. With increased real-time information, engineers could improve run time, fuel economy, and safety. A TPS-type model may then be used to define control strategies based not on general situations but on specific situations measured through on-board microcomputer systems. Because the on-board microcomputer is capable of increasingly sophisticated functions, the insights gained through TPS simulations of train operations and statistical analysis of train operations data may be applicable in real time to assist in complex decision making that the engineer is otherwise incapable of making.

REFERENCES

1. J.D. Muhlenberg. Resistance of a Freight Train to Forward Motion--Volume 1: Methodology and Evaluation. Metrek Division, Mitre Corporation, McLean, VA, Rept. PT-280 969, April 1978.
2. W.W. Hay. Railroad Engineering, Volume 1. Wiley, New York, 1953.
3. S.M. Howard, L.C. Gill, and P.J. Wong. Train Performance Calculators: A Survey and Assessment. SRI International, Menlo Park, CA, Nov. 1980.
4. J.B. Hopkins and others. Railroads and the Environment: Estimation of Fuel Consumption in Rail Transportation--Volume 3: Comparison of Computer Simulations with Field Measurements. Federal Railroad Administration, Rept. FRA-OR&D-75-74.III, Sept. 1978.
5. J.D. Muhlenberg. Further Comparisons of Freight Train Fuel Consumption with Predictions. Metrek Division, Mitre Corporation, McLean, VA, Working Paper, Jan. 22, 1980.
6. J.D. Muhlenberg. Resistance of a Freight Train to Forward Motion--Volume 2: Implementation and Assessment. Metrek Division, Mitre Corporation, McLean, VA, Rept. FRA/ORD-78/04.II, April 1979.
7. J.D. Muhlenberg. User's Manual for Freight Train Consumption Program. Mitre Corporation, McLean, VA, Tech. Rept. MTR-80W127, July 1980.
8. J.D. Muhlenberg. Freight Train Fuel Consumption: Economic Analysis and Correlation of Predictions with Field Data. Mitre Corporation, McLean, VA, Tech. Rept. MTR-8DW77, July 1980.
9. E.M. Low and V.K. Garg. Programming Manual--Train Operations Simulator. Association of American Railroads, Washington, DC, Rept. R-359, March 1979.
10. E.M. Low and V.K. Garg. Technical Documentation--Train Operations Simulator. Association of American Railroads, Washington, DC, Aug. 1977.
11. N.W. Luttrell and others. User's Manual--Train Operations Simulator. Association of American Railroads, Washington, DC, Aug. 1977.
12. R.K. Abbott and others. Locomotive Data Acquisition Package, Phase 1. Lawrence Berkeley Laboratory, Univ. of California, Berkeley, Sept. 1978.
13. R.K. Abbott and others. Locomotive Data Acquisition Package, Phase 2, System Development--Volume 1: System Overview. Lawrence Berkeley Laboratory, Univ. of California, Berkeley, March 1980.

14. R.K. Abbott and others. Locomotive Data Acquisition Package, Phase 2, System Development--Volume 2: LDR Operations and Maintenance. Lawrence Berkeley Laboratory, Univ. of California, Berkeley, March 1980.
15. W.G. Ambrose, S.M. Kiger, and S.H. Patel. Enhancing Train Operations Through On-Board Processing: The Advanced Locomotive Cab Instrumentation System. Presented at AAR Track-Train Dynamics Conference, Chicago, IL, Nov. 27-29, 1979.

Publication of this paper sponsored by Committee on Railroad Operations Management.

Car Management Opportunities: Actual Return Mileage Versus Optimal Return Mileage

BERNARD P. MARKOWICZ AND ALAIN L. KORNHAUSER

Recent developments in the research on car management currently undertaken by Princeton University under the sponsorship of the Association of American Railroads are described. The research makes extensive use of the Princeton Railroad Network Model and Information System. Car management opportunities are examined by comparing simulated actual empty return mileage (ARM) with optimal empty return mileage (ORM). ARM is the mileage obtained when empty cars that terminate on foreign roads are returned home under New Car Service Rule 2 (Rule 2) or Special Car Order 90 (SCO90) or both. ORM is the mileage obtained when empty cars that terminate on foreign roads are returned according to a cost (mileage-based) minimization criterion. The concept of ARM versus ORM is presented for the Southern Pacific Railroad by using 1980 1 percent waybill data for unequipped 50-ft boxcar traffic.

Recent developments in the research on car management currently undertaken by Princeton University under the sponsorship of the Association of American Railroads (AAR) are described. The research makes extensive use of the Princeton Railroad Network Model and Information System.

Car management opportunities are examined by comparing simulated actual empty return mileage (ARM) with optimal empty return mileage (ORM). ARM is the mileage obtained when empty cars that terminate on foreign roads are returned home under New Car Service Rule 2 (Rule 2) or Special Car Order 90 (SCO90) or both. ORM is the mileage obtained when empty cars that terminate on foreign roads are returned according to a cost (mileage-based) minimization criterion. The concept of ARM versus ORM is presented for the Southern Pacific (SP) Railroad by using 1980 1 percent waybill data for unequipped 50-ft boxcar traffic.

PROBLEM DEFINITION

Empty cars on a foreign road (not the owner's or not part of the owner's system) can be either reloaded by the terminating road or sent back to the owner (it is assumed here that cars will not be reloaded en route to the owner). If sent back to the owner, the car will travel over foreign roads. Once on the owner's road or system, the car will be repositioned in order to meet the next load.

The current return of empty railroad cars to their owners is achieved mainly through a set of commonly accepted industry rules. The industry rules (chiefly SCO90 and Rules 2 and 6) provide member roads with instructions as to where cars for each owner should be received and forwarded. By a chaining process, in which they proceed from their unloading points back toward their home road, the cars eventually reach the owner's gateway.

SCO90 and Rule 2 have been designed to assure the direct return of empty cars to their owners, but under the current system, car hire penalizes the roads carrying empty foreign cars. Therefore, SCO90 and Rule 2 have also been designed to distribute the empty-car-mile obligations among roads for the sake of fairness. Carriers of empty rail cars, because of car hire, will forward the cars to the closest SCO90 third-party or owner junction (Rule 2) in order to minimize car-mile obligations. The car owner then has little power over where the empty cars are returned.

Once the cars have reached the owner's system, they may appear at junctions where reload opportunities are low. The owner then has to reposition the empty cars within the system, sometimes over considerable distance, in order to meet demand. The sum mileage of the SCO90/Rule 2 return and the system repositioning is referred to as ARM.

The owner can specify, however, through an incentive system, the best return path that would minimize repositioning efforts. The junction with foreign roads where empty cars are to be returned would be indicated. To minimize the incentive payoff, the owner would specify the optimal path over foreign roads from the unloading point to the specified owner junction.

In this paper, the ORM concept is introduced and its effectiveness in the case of the SP system is evaluated. [The system includes SP, the Cotton Belt Route (SSW), and the Northwestern Pacific (NWP).]

SIMULATION OF ARM

Data on the movement of SP 50-ft unequipped boxcars are obtained from the 1980 1 percent waybill sample (Interstate Commerce Commission). From all SP and Cotton Belt marked cars, the following data are selected from the sample: originating railroad, terminating railroad, terminating station, and number of cars.

Assessing Reload Behavior and Percentage of Return

From the selected waybill records, a percentage of reload has been computed for each railroad. The percentage of reload is defined on each road as the ratio of terminating SP cars to originating SP cars. The percentage of cars to be returned is defined on each railroad as (1 - percentage of reload). The location and number of cars to be returned are derived by uniformly factoring termination records by the return percentage on each road.