

SIMULATION MODELING AT UNION PACIFIC RAILROAD

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ABSTRACT

Despite the potential, the use of simulation technology at US railroads appears to be lagging behind that in manufacturing and other transportation industries. This paper describes three recent experiences of applying simulation at Union Pacific Railroad: validation of yard-queuing data used in a railroad operations planning and control system, evaluation of work-rest patterns for scheduling train crews, and evaluation of strategic transportation plan. Collectively they demonstrate the wide spectrum of possible applications in terms of domain, development effort, planning horizon, etc. We conclude with thoughts on how to promote the use of simulation in the railroad environment.

1 INTRODUCTION

Though not as well established as in manufacturing, military, and other areas, simulation of transportation systems is a growing field (Brunner et al. 1998). The challenges and benefits of applying of simulation models in the railroad environment are discussed by Krueger et al. (2000)

Union Pacific Railroad (UP) is the largest of four Class I railroads in the U.S. with almost 40,000 miles of track, about 50,000 employees and over \$11 billion gross revenues for the year 2000. There are some 2400 train starts per day in the UP system and over 10,000 defined locations where train activity can be recorded.

Past use of simulation models at UP include:

- a railroad intermodal capacity model built to estimate terminal capacity by examining the effect of train schedules, facility design and equipment availability on performance (Weigel 1994);
- examining the concept of “dynamic bowl” as a way to increase yard capacity without adding tracks.

This paper discusses three recent simulation modeling exercises at UP: validation of yard-queuing data used in a

railroad operations planning and control system, evaluation of work-rest patterns for scheduling train crews, and evaluation of strategic transportation plan. Collectively they demonstrate the wide spectrum of possible applications in terms of domain, development effort, planning horizon, etc.

2 YARD QUEUE SIMULATION MODEL

2.1 Background

UP currently has under development a new Computer Aided Dispatching system (CAD III) that will incorporate an automated movement planning component. This system will use an objective function based optimization and will be a major advance in railroad technology. CAD III is an extremely large project that will take an extended period of time to implement. Some fundamental design concepts cannot be fully tested until after considerable work dependent on these concepts has been completed. An example of this is the representation of yard facilities not under direct control of the new system. CAD III will employ a queuing model to reflect capacity constraints of such yard facilities and, in some cases, to predict when trains entering a yard will reemerge on controlled track.

2.2 Purpose

The purpose of this model is to test the representation of uncontrolled yard facilities by the CAD III Movement Planner. It allows us to present a queuing model with historic or projected traffic volumes and patterns and to observe the resulting behavior of the model. We can see when the yard is represented as being at capacity and when trains are held out of the yard. We can also measure the time that the model allows for processing a non-terminating train through the yard and making it available for departure. These observations of the model can be compared with actual or expected results to validate the representation and to fine-tune the parameters used in the representation of a particular yard.

2.3 The Model

This model was implemented using SIMPROCESS (Swegles 1997).

2.3.1 Model Logic

There can be multiple separate paths by which trains can enter the yard. These are referred to as *inbound lines*. Each inbound line is a FIFO queue. When a train reaches the front of its inbound line, a test is made to see if an appropriate slot (or track) is available in the yard. If not, the train waits until a slot does become available and all other trains on that line wait behind it. When a slot does become available, it is reserved for use by the train, a variable amount of time (averaging 0.25 hour) elapses to represent the time it takes to yard the train, and then the train is removed from the inbound line. These steps are then repeated for the next train.

The tracks used for trains entering the yard are considered to be grouped into a number of *slot types* and each arriving train is designated to use a particular type. For example, a particular yard may have:

- a single main track which through trains occupy while crews are changed;

- six tracks in a receiving yard for automatically classifying cars arriving on terminating trains; and
- two tracks reserved for manual classification.

Once a train occupies a track of the appropriate type within the yard (that is, other than a through or main track), a request is made for a *server* of a specified type to process the train. For example, in the case described above,

- the server for a train to be humped would consist of a carman to prepare the train for humping and a hump engine;
- the server for a train to be flat switched would be a switch engine.

There may be one or more servers of each type. Servers are allocated to trains in the order requested. The time it takes for a server to complete processing for a train is a random variable whose mean and standard deviation are specified as inputs.

When a server completes processing of a train, the existence of the train in the model ceases. This corresponds to the fact that all resources required to process an inbound train are now free and available for use on another train. For a non-terminating train, the train is now available for departure.

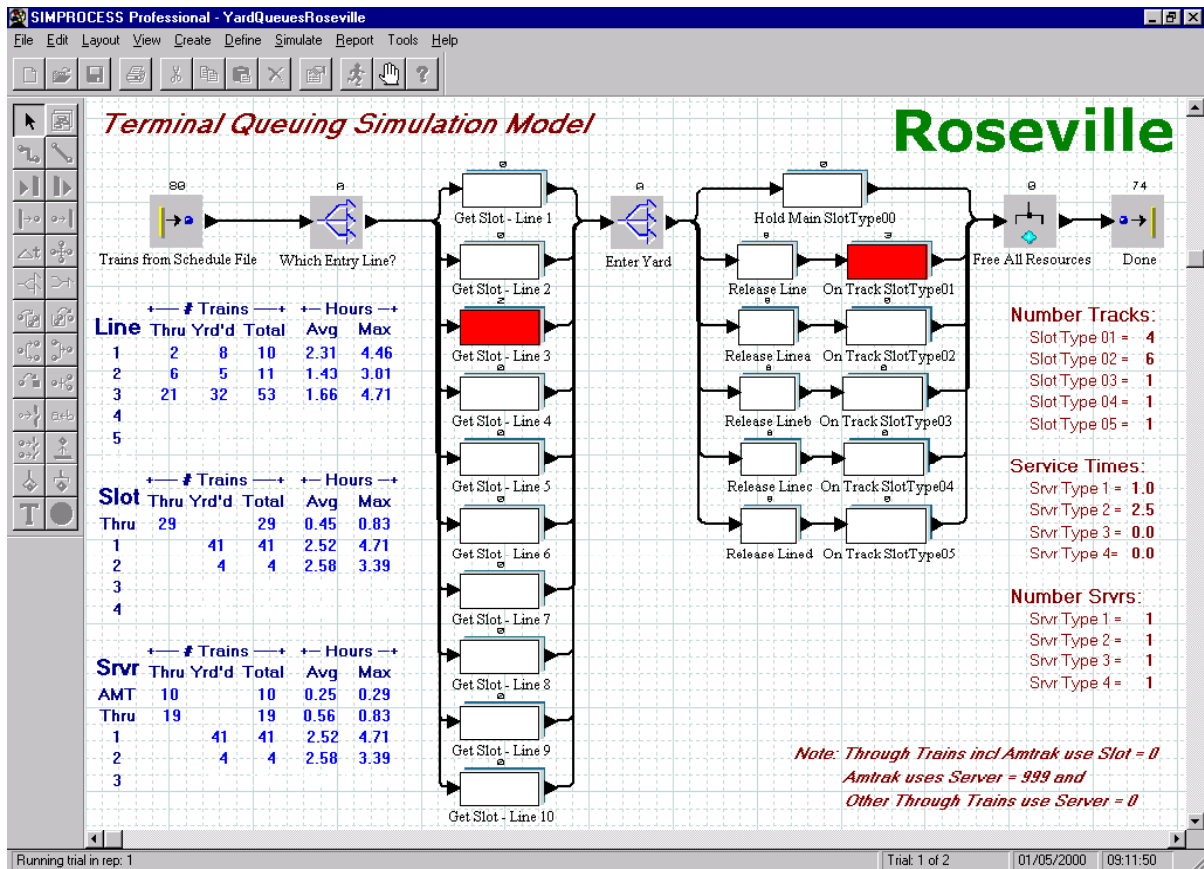


Figure 1: Sample Display for Terminal Queuing Simulation Model

2.3.2 Inputs

Inputs to the model take two forms: model parameters and a file describing train activity.

When a run is started, a window is displayed showing default values for each of the following model parameters:

- Number of tracks for each slot type;
- Number of servers for each server type;
- Mean and standard deviation of the service time for each server type.

The default values may be accepted or any of them may be changed before starting a run.

The train activity file is a text file specifying the trains to arrive at the yard during the course of the simulation run. Each row represents a train and contains the following fields:

- Date and time of arrival in the model. This is the time when the train is added to its inbound line. If trains are already waiting on that line, the event of arrival in the yard will be later as determined by the logic of the model.
- Train ID. This can be any identifying symbol. It is not used by the model except to assist in interpretation of results.
- Inbound Line Number. Identifies the path for entering the yard.
- Slot Type ID.
- Server Type ID.

2.3.3 Outputs

Outputs consist of selected statistics displayed on the screen as the simulation runs, if animation is active, and a trace file which records all events occurring in the model during the course of the simulation run.

The dynamically displayed statistics are in the lower left portion of the screen shown in Figure 1. The “Hours” numbers are the total time in the model from arrival as specified in the input file to completion of processing by the server.

The trace file is a complete log of all events occurring during the model run. It makes possible complete analysis of the results of the run.

2.3.4 Animation

A sample display is shown below in Figure 1. During a run with animation active, black dots representing trains move through the display from introduction at the leftmost box as specified by the input file to completion in the rightmost box labeled “Done”. Numbers above each box show the number of trains in the activity represented by that box at

any given time. The boxes labeled “Get Slot - Line n” will turn red whenever more than one train is waiting for a slot to become available in the yard. This corresponds to a situation in which trains are being held out of the yard due to a capacity problem. The boxes labeled “On Track Slot Type nn” will turn red whenever all tracks of that type are occupied.

This display has proven to be quite effective in communicating simulation results to operating personnel.

2.4 Challenges

The main challenges for this modeling exercise were a small development effort and an easy to use tool.

2.4.1 Small Effort/Rapid Development

The ad hoc nature of the problem addressed by this model meant that it had to be accomplished within the bounds of the CAD III project. That is, without additional personnel or funding. This was accomplished through use of a very high-level simulation tool and through a highly abstracted design that incorporated only the most essential features of the subject.

2.4.2 Ease of Use and Flexibility

Railroad line management personnel tend to be highly oriented toward quick results with limited time for detailed data gathering and analysis. These characteristics of the customer-base were a major consideration in design and implementation of the model. Inputs are either parameters that make sense to operating personnel or information that can be easily extracted from the UP data warehouse. Thus, it can be rapidly configured to represent most terminal facilities in the UP network. Key results are presented as part of the animation and are easily understood by operating personnel.

3 EVALUATING THE IMPACT OF TRAIN CREW WORK SCHEDULES

3.1 Background

Under conventional railroad work rules, train crew members are required to be “on-call” 24 hrs/day, 7 days/week, around the year. However, they do have the option to “lay off” or declare themselves unavailable for a period of time. As a result, train personnel often have a highly irregular work pattern, which makes it impossible to live a normal personal or family life. This unpredictable work environment also results in high levels of fatigue and large numbers of crew members laying off. The resulting uncertainty in availability makes it much more difficult for the railroad to protect train operations. Crew Scheduling is a method

for structuring work, designed to increase predictable time off for train personnel and to reduce absenteeism. It is believed that the resulting consistency will contribute to reducing fatigue and improving quality of life for train personnel as well as ultimately improving service reliability for railroad customers.

Scheduled crew pool operations are implemented through set work-rest patterns (e.g., 8 days work / 3 days guaranteed rest or 7 days work / 2 days rest). The choice of a particular work-rest pattern is a non-trivial decision and depends on several factors including demand pattern, size of crew pool, crew member preference, etc.

3.2 Problem

Train operations tend to exhibit a high degree of natural variability. Therefore, an average-based analysis of crew scheduling alternatives, such as that afforded by spreadsheets, only represents the “normal” situation and fails to provide insight into the frequency and severity of favorable and unfavorable situations, i.e., best- and worst-case scenarios. This insight is critical in evaluating the impact of a particular work-rest pattern on the lives of *individual* crew members. The problem then was to be able observe significant departures from the norm and ensure that worst-case situation is within acceptable limits and occurs infrequently.

3.3 Approach

Personnel from Union Pacific’s Decision Technology Group (DTG) in the Information Technology (IT) Department were brought in during the early stages of the project and provided a set of objectives by the customer. DTG’s first task was to determine the appropriate decision-making technology and the software tool to be used.

Of the various Operations Research and Artificial Intelligence techniques in which DTG members have expertise, discrete-event simulation was the obvious choice for this project given the nature of the problem and the need to incorporate variability into the analysis.

The customer team’s initial preference was to implement the simulation in a spreadsheet. They were convinced by DTG that such an approach would be cumbersome and have many limitations in the long run. As alternatives, DTG demonstrated UP’s Network Simulation (NetSim), and also rapidly built a proof-of-vision model using SIMPROCESS, a flowcharting-based simulation tool.

The need for a short turnaround time (3 months) and the customer’s desire to become self-sufficient in future model enhancement led to the decision to go with a model built in SIMPROCESS.

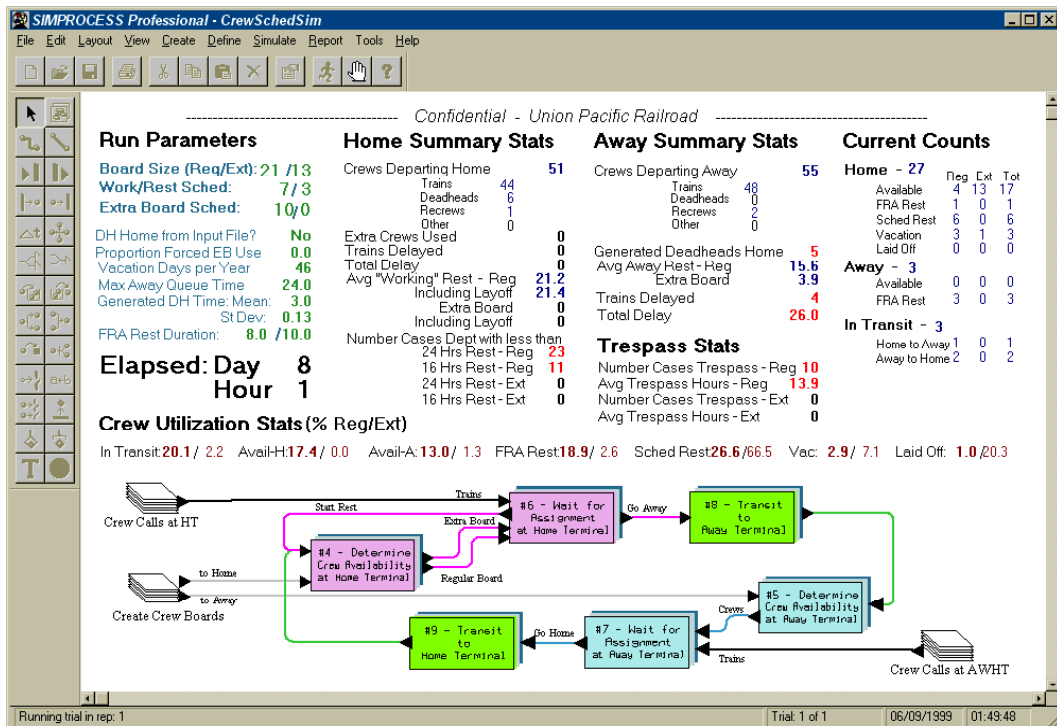


Figure 2: Sample Display of Crew Scheduling Simulation Model

3.4 Goals

The goals of the project were:

1. Assist the customer in building a prototype CrewSim, a discrete-event simulation which models dispatching of crews for a single crew district on the Union Pacific Railroad in order to provide insight into:
 - a. Ability of various work/rest patterns and manpower complements to protect train operations;
 - b. Impact of various work/rest patterns on rest and fatigue factors;
 - c. Evaluation of issues and tradeoffs related to unavoidable deviation from the work/rest pattern.
2. Create self-sufficiency by educating customer team.

3.5 Simulation Model

CrewSim models the process followed by a crew member in going from his or her “home” terminal to an “away” terminal and back. Leveraging the hierarchical modeling capability of the simulation tool, the model was built in a top-down manner, starting with a high level representation of the logic as the nine activities shown in the flow diagram of Figure 2. Incrementally, each of these activities are detailed further in a “drill-down” fashion.

Several key model parameters, such as the work-rest pattern and crew pool sizes, can be altered by the user, without having to edit the code, making it convenient to set up trials.

Using the animation capability of the simulation tool, color coded icons reflect the movement of crew members through the various stages of the process; this has proven invaluable in verification as well as explaining the model to others.

As the simulation runs, the simulation analyst can monitor the health of the simulated operation by observing statistics on crews and trains displayed on the “dashboard”. Each simulation run also produces a trace file of events much like UP's Train History database. This allows comprehensive, custom analysis of the scenario. In the future, simulation outputs will be read by an application to calculate the “fatigue index” of a work-rest pattern.

3.6 Benefits of the Simulation Model

The resulting prototype simulation model:

- Allows alternatives to be tested in a virtual environment rather than in actual operation.

- Shows extreme variations and their frequencies as well as typical or average cases.
- Gives greater confidence in statistical results: multiple runs of the model can be used to create multiple outputs for a single scenario by modifying the stream of random numbers between runs.
- Assists in communication and education during contract negotiations and implementation because of the flowchart-based model and animation.

4 EVALUATION OF STRATEGIC TRANSPORTATION PLAN

The business logic included in this model is detailed in a paper by Lewellen and Tumay (1998), hence in this section we shall focus on the experiences and challenges.

4.1 Background

Strategic planning is a critical component of managing a large railroad. The lead times required to purchase/lease locomotives, hire train crews, and build additional track on the line or in terminals requires the ability to predict resources needs well in advance. While capabilities exist today to predict each of these resources individually, knowing the *interaction* of these resources is critical to determining tradeoffs and insuring that a transportation plan (T-Plan) based on projected market forecasts is achievable and cost effective. Other planning tools in use at the Union Pacific Railroad commonly produce plans based on assumptions of unlimited resources.

4.2 Purpose

The transportation network simulation model—NetSim—developed at Union Pacific is unique in its ability to perform a *resource-constrained* assessment of the T-Plan's ability to move the traffic, and of the resources that must be applied. In other words, the simulation model allows planners to execute the T-Plan in a virtual environment where train operations contend for crews, locomotives, over-the-road track, and terminal inbound/outbound tracks.

NetSim can be used in two distinct analysis modes:

1. Given current or projected resources, identify choke points and points of imbalance;
2. Given infinite resources, simulation results indicate cost of executing a T-Plan.

4.3 Model

The modeling effort initially used SIMPROCESS as the simulation tool. However, this flow-charting-based tool proved to be inadequate for the complex business logic and the magnitude of the network. The model was finally im-

plemented in MODSIM III (Wood and Tumay 1999), an object-oriented simulation language that provided the simulation programmer almost unlimited ability to model business rules.

The simulation is data driven: business logic is encoded inside the NetSim executable but the data for defining the network and the resources is loaded at runtime. As can be expected for a network of this magnitude the model is highly data intensive. And in addition to the several predefined statistical reports generated from each run, the user may enable a detailed trace of simulation events (the trace file may be as large as 150MB per month of simulating train operations). Initially all input and output data was contained in fixed-width formatted text files—about 20 per run—because MODSIM lacked the ability to directly access a database. This made the data cumbersome to manage and verify. Later, when the database connectivity feature was added to MODSIM, all data was migrated to an Access database file which resulted in increased data consistency.

Four utilities have been built to provide automated assistance in creating model inputs from various enterprise databases. The current architecture of NetSim is shown in Figure 3.

4.4 Challenges

This project presented several challenges from both a modeling and management perspective. Some modeling challenges pertaining to model logic and data are discussed below.

4.4.1 Logic

Determining an appropriate level of abstraction for the strategic-level model proved to be a big challenge. In general, most users wanted the business rules represented at a greater level of detail in order to consider the model credible. The obvious drawback of too much detail is additional programming, data collection effort and reduced runtime performance. On the other hand, reducing the level of detail can also result in additional effort for data collection, e.g., reducing the number of terminals means that more individually controlled track segments must be lumped together and their capacity and speed aggregated.

A major conceptual challenge was dealing with the fact that a railroad is not a closed system. Union Pacific connects with other railroads. Trains, together with their resources, may enter or leave at interchange points. Such situations were dealt with by introducing “dummy” stations to represent railroads other than Union Pacific and “dummy” resources to represent resources supplied by other roads.

Unlike the actual system, the simulated operations in NetSim are started-up “cold”, i.e., all trains, terminals, locomotives and crews are inactive. The user must arbitrarily distribute resources at various locations. The model is quite sensitive to this initial placement (and also to an unbalanced T-Plan) and gridlock can result if the placement is not matched to the T-Plan. This corresponds to actual experience with railroad operation. We created a modeling concept referred to as “generic resources” to overcome this problem. Generic resources—crews or locomotives—are

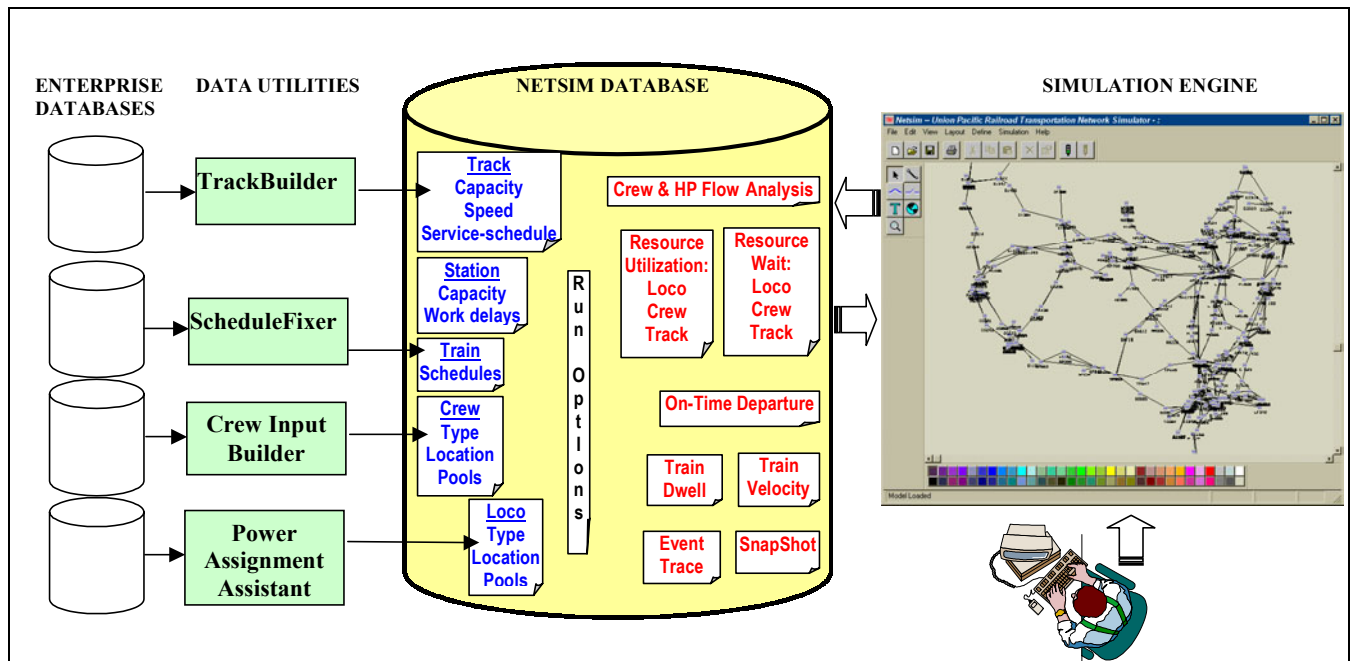


Figure 3: Architecture of NetSim

temporary resources which materialize after a train has waited a specified time, have all the characteristics and behavior of the resource for which they substitute, and are disposed of at the end of the journey. With sufficiently long runtimes, even very slight imbalances are magnified to the point where a gridlock results in the simulated railroad system. Such gridlock seldom occurs in actual railroad operations because adjustments are made to the operating plan as needed to maintain system fluidity. Use of generic resources corresponds to these tactical adjustments making it possible for the model to run for a longer time without gridlock, thus allowing statistics to be generated. Tracking the use of generic resources allows a better initial placement of resources to be found.

4.4.2 Data

It is fair to say that a bigger challenge than modeling business logic has been data: sources, quality, storage, consistency, and interpretation. During NetSim's initial development the focus was on getting the logic right, and small sample data sets were used. It was much later, when a model of the entire network was built, that the number and magnitude of the data-related issues became apparent.

Consolidating all data in a single database file has gone a long way to improve data integrity as well as facilitating exchange of models among developers and users.

The task of building inputs to NetSim is time consuming and tedious; this is consistent with the experience at other railroads (Krueger et al. 2000). The T-Plan (i.e., Train schedules), train history, inventory of locomotives, crew levels and other required data are available from UP's data warehouse but must be converted into an acceptable format. The four utilities shown in Figure 3 ease the data retrieval and formatting burden but an expert is still required to interpret the data in the context of the NetSim model. For example, enterprise databases indicate the physical number of tracks (e.g., receiving) in a terminal, whereas in NetSim these tracks are modeled as resource objects and thus must be specified in terms of effective number of trains that can be simultaneously accommodated.

While the event trace file is invaluable in obtaining custom statistics after a simulation run, it presents its own problems. Since the trace data from some longer runs can easily exceed the 1 GB limit of Access, a filter was added to allow the user to limit the trace to selected events and stations prior to the run.

The performance of a particular scenario may be quickly characterized by measures such as system velocity, train-hours held for crew, locomotive and track resources, percentage of on-time departure rate, etc. But to answer the "why" questions behind the performance and to develop an improved plan it is necessary to dig into the various detailed reports. Interpreting the results and, in particular,

figuring out how much of an impact the setup played and how much was inherent in the T-Plan itself is a challenge.

Due to the large amount of input as well as output data, a Scenario Manager will be useful to organize and analyze the outcomes in a systematic manner. Such a Scenario Manager would:

1. Tie the outputs to the inputs and settings that produced them.
2. Allow a comparison between input options and resulting outcomes.
3. Archive and restore a set of inputs (possibly to re-run with a new version of NetSim, for example)

5 CONCLUSION

The preceding three simulation modeling exercises are indicative of a growing demand for simulation as a planning tool. We perceive an untapped potential for using simulation at Union Pacific in particular and the railroad industry in general.

One of the major barriers to the widespread use of simulation is a general lack of awareness of the technology and its benefits over traditional tools such as spreadsheets. Our experience is that nothing succeeds like success in getting the word out. To get the initial success we recommend:

- Building small, focussed applications instead of trying to solve all problems at once.
- Targeting models that simplify or improve existing tasks; the model is more likely to get built and used if it is not perceived as adding to somebody's already busy schedule.
- Embedding simulations within legacy tools or commonly used office productivity tools such as Excel; users may be intimidated by the need to learn and use a new software technology.

On the other hand, there may be unreasonable expectations as to the benefits to be obtained from a simulation model or the costs for building such a model. Once again, we feel, that the best antidote is successful small, focussed applications.

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