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EVALUATING THE POTENTIAL BENEFITS OF A RAIL TRAFFIC MOVEMENT PLANNING ALGORITHM

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ABSTRACT

Railroads have large investments in capital items such as track, trains, and terminals. Optimizing the use of their resources has the potential of enormous payback. Precision Train Control™ (PTC) is an effort to optimize the flow of trains on the line of road in order to increase the return on capital.

This paper describes a study whose purpose was to quantify the performance improvements that could be anticipated with PTC. A large-scale simulation involving approximately 1000 miles of track and 700 trains was conducted to produce an estimate of potential improvement.

1 RAIL TRAFFIC MOVEMENT PLANNING

Traffic over the US rail network has increased substantially in the decade of the 90's. As we face the new century many railroads are experiencing congestion problems. Correcting the congestion problem by additional capital expenditures is costly in an industry that already has a low return on capital expended. Therefore many railroads are looking to technology to provide better utilization of the capital which is already in place. There are many areas in which technology promises to improve the efficiency of railroad operations.

One of these areas is the management of the movement of trains across the rail network. This movement is managed remotely by dispatchers who control the setting of switches, control of signals, and the issuance of movement authorities in track warrant (unsignaled) territory. In Centralized Track Control (CTC) territory, track occupancy is detected using track circuits and displayed to the dispatcher to provide information on the location of trains. Although this indication displays the presence of a train in a track circuit, the circuit may represent a distance of ten to fifteen miles without providing position information of where in the track segment the train is specifically located. Additional information may be obtained through voice contact with the train crew. A dispatcher must deal with a variety of track and signal infrastructure and a wide variation in train performance based upon the locomotives assigned to the train and the load that is being pulled. In track warrant territory, the dispatcher must rely upon train crews to report their position and a complex process for verbally issuing track authorities to assure the safety of operations. In addition, maintenance crews requiring access to the track must be managed.

Not all trains are of the same economic value to the railroad, therefore priorities are assigned to trains and a dispatcher's performance is often evaluated on how well he moves high priority trains over his network. The expansion of "just in time" industrial operations further strains railroad operations by placing a premium on predictable performance. As a train moves across the rail network, control of the train moves from dispatcher to dispatcher with frequent interactions with terminal managers for fueling, crew changes, and car switching.

Technology offers an opportunity to reduce the workload facing a dispatcher by providing better status information, automating tasks, and solving the complex problem of movement of trains through the network. Precision Train Control (PTC) has been proposed as one approach to improving the performance of the traffic management system for the railroad industry (see Figure 1). In PTC, each train has means to pinpoint its position and transmit that location to a control center. With the precise locations of trains it is possible to more precisely plan the interaction of trains in the rail network. Movement Planning algorithms provide means of optimally planning the movement of trains to their destination based upon the value of the train and the physical constraints on their movement. In PTC, a detailed movement plan may be transmitted to the crew on each train. Software on-board the train, including a track database, provides a means of cueing the crew to reach the waypoints specified in the movement plan ontime. PTC may be implemented as an overlay with the existing fixed block signalling system to obtain proper train spacing or with dynamic train spacing enforced by an in-cab signalling system.

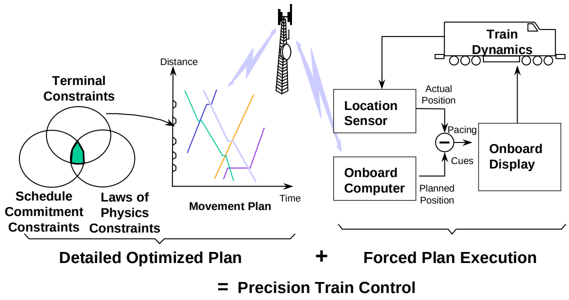

Figure 1: Precision Train Control

GE-Harris Railway Electronics has implemented train movement planning algorithms with its Precision Dispatching System (PDS). PDS contains a sophisticated algorithm to generate a plan for moving trains through a track network in a near optimum manner while satisfying the numerous constraints associated with their movement. The Planner has a planning horizon of 12 hours and may replan on an hourly basis to account for unexpected events. A Schedule Repair facility continually monitors the progress of the trains and makes adjustments in the plan to accommodate deviations between planning cycles. Figure 2 illustrates the process flow for the FORESIGHT™ Movement Planner.

A Preprocessor uses actual train consist (locomotives and cars) data to compute minimum run times for each train over each segment of track. The output of the Preprocessor is an abstract model of the train movement in a form that is convenient for the Planning processes. The Abstract Planner and Scheduler processes work together to build a movement plan for the trains, based upon heuristics (Abstract Planner) and a mathematical search (Scheduler) procedure using a highly tailored version of Simulated Annealing. In the PDS version of FORESIGHT, a Schedule Repair process alters the Movement Plan when unforeseen deviations of the plan occur. In the simulation, a simulator process (Physical Planner) simulates the Movement Plan to provide detailed data for viewing the movement plan in an animated form.

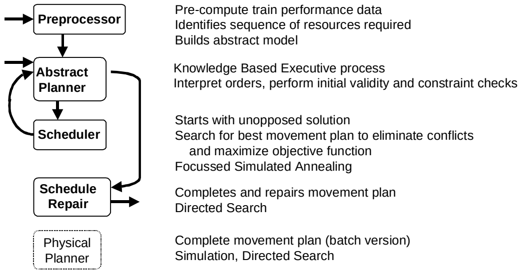

Figure 2: Movement Planning Process

2 SIMULATION OF RAIL NETWORK

Simulation of a "day in the life of a railroad" was chosen to assess the performance benefits afforded by the new movement planner. In this approach, actual departure times and consist information, as well as track conditions affecting performance are captured for a selected period. This data becomes the input for the planning operation. A batch version of the planning system, making maximum use of the developing PDS software, was chosen as the means for generating a movement plan. This choice was driven by the schedule of the PDS software development and the length of time required to conduct multiple cycles of the planning system software. This approach uses one planning cycle for the duration of the simulation process, rather than the one planning process every 1 hour that is used in the PDS. One batch run for 4 simulated days (3 days plus 1/2 day warm-up and 1/2 day cool down) requires about 3-4 hours of computer time on a Sun™ Ultra 10 workstation. To run the simulation with the hourly planning cycle, a simulation would have taken near real time (48 - 96 hours).

Commercial off-the-shelf train simulators were considered for simulating the movement plans. However, existing simulators have built-in logic, different from that used in Foresight for resolving conflicts between trains. Revising this logic was not feasible. In addition, such simulators use average run times in computing the movement of trains, rather than the physical laws of motion. Therefore, a custom simulator was built to simulate the actual movement of the trains. As an additional benefit of the simulation, the movement of the trains can be animated to allow one to observe the interaction between trains.

2.1 Track Network

In the PDS implementation, a rail network is divided into Movement Planning Areas to assure that a complete movement plan can be generated in less than 30 minutes. Typically this area may include 250 - 500 miles of mainline track. The region simulated in this project covered the CSX mainlines bounded by Erwin, TN and Rocky Mount, NC on the north and Jacksonville, FL on the south as illustrated in Figure 3.

This region was divided into 3 planning areas similar to those that would be used by a PDS implementation. The Erwin, TN - Augusta, GA area is 263 miles long and consists mainly of single tracks with sidings. The Rocky Mount, NC to Charleston, SC area covers 322 miles and is a mixture of single track and double track. Early in the investigation Hamlet, NC was identified as a major source and sink of traffic for the mainline, so Hamlet was added to the area. The third area, Augusta/Charleston to Jacksonville is 453 miles and includes a junction point at

Savannah, GA where Jacksonville traffic to/from Augusta meets traffic to/from Charleston. Waycross is a major terminal with connections to the west and is included in the study because traffic in and out of Waycross has a significant impact on the main line from Savannah to Jacksonville.

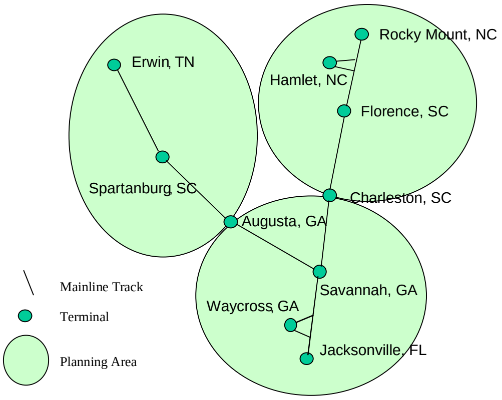

Figure 3: Three Planning Areas of Study Region

2.2 Interface to Terminals and Adjacent Planning Areas

In the real world terminals are not controlled by the network-wide dispatching system. The interface between rail line and terminal operations is managed at an operational level. Because of the independent manner in which these operations are managed, they frequently conflict with one another. Dispatchers attempt to move trains as rapidly as possible out of their area of responsibility and terminal managers do likewise. The PDS movement planning system was designed to link the capabilities of the terminals and the road in order to improve the performance of both line-of-road and terminal.

Terminal Managers make decisions as to movements of trains within terminals. In general terminals may be divided into sub-elements (called yards in this paper) based upon the functions performed. For example a large terminal might contain a run-thru yard (tracks on which through trains are re-crewed), a receiving yard (a yard where arriving trains are held until they can be processed), a classification yard (where cars are sorted by destination to form blocks for departing trains), and a departure yard (where trains are built, crewed, tested, and held until departure). When yards become congested, trains must be held outside the terminal limits. This results in congestion on the line of road. Because dispatchers attempt to move trains as far forward as possible, congestion frequently occurs at the boundary to the yard providing serious restrictions to movement into and out of the terminal.

Figure 4 illustrates the representation of a terminal in the PDS. A terminal is divided functionally and each area of the terminal is represented by a finite capacity queue. PDS does not track the specific track that a train occupies, but keeps track of the number of trains, which occupy each area in order to avoid overloading the queue. In the simulation, the service time for each train in the queue was defined by the actual service time experienced on the simulated day (as indicated in the log maintained by the railroad).

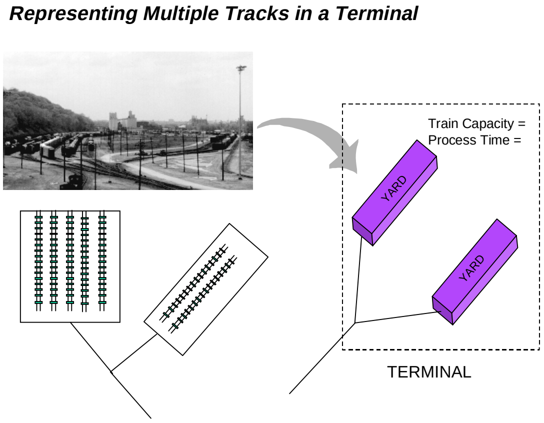

Figure 4: Movement Planner View of a Terminal

2.3 Train Representation

Individual train performance is modeled using a distributed mass model based upon the CN version (American Railway Engineering Association 1993) of the modified Davis equations, that are standard heuristic equations used by the railroad industry. Pertinent data include the length and weight of the train, number of loaded and empty cars, locomotive types, and the type of cars. The model allows individual cars and locomotives to be specified, but typical simulations do not use this level of detail because of the cost of incorporating the data. In addition to the train performance data, each train has an origin and destination point as well as a specification of any intermediate stops required in the course of its trip.

3 DATA NEEDS

Construction of the simulation requires data on the track characteristics including grade, curvature, track layout, speed limits, and speed restrictions that were in force on the days represented in the simulation. In addition, pertinent events that occurred on the subject day, such as stalled trains, are included. Train characteristics, such as weight, length, number of cars (empty and loaded), locomotives, entry and exit points (and times) in the subject corridor, as well as intermediate work points including consist change points, change of direction, and crew change. For this study the following sources were used for data.

1. Timetable for subdivisions
2. Track charts of subdivisions
3. Soft-copy of track data (grade, elevation, curvature, speed limits)
4. Track diagrams of major terminals
5. Functional breakdown of terminals into yards and yard capacity
6. Crew change locations
7. Track Bulletins in effect during study time window
8. Train sheets for trains - including: train speed limit, number of cars, length of train, total tonnage, total horsepower, origin location and time, destination location and time.
9. Site visits - to understand yard constraints and local traffic

4 TESTING AND VALIDATION

Validation is essential to provide confidence in the results of a simulation. On the other hand, validation is expensive and one can easily spend as much resources on validation as on developing the simulation. The key is to identify the degree of validation that is required to establish the desired level of confidence in the results. Simulations are always approximations of real life, either optimistic or pessimistic, and it is essential in assessing the final results of the simulation to appropriately assess the accuracy. In a large simulation, as this one, there is no substitute for experience and engineering judgment. Validating a simulation of a system that is not operational and implements a different paradigm from current operations multiplies the difficulty. The simulation described in this paper contains all of the above complexities.

For example, the purpose of this simulation is to provide quantitative basis for estimates of performance improvement obtained with a new approach to railroad movement planning. Current train operations depend mainly upon human decisions. Dispatchers operate with a fixed priority scheme that focuses on local decisions. For example, the priority structure says that if an intermodal train meets a lower priority bulk train, that the bulk train will always be delayed. In the PDS Movement Planner, however, each train has an objective function that defines the cost of delaying it measured at some destination point. It is quite conceivable that delaying a single intermodal train might improve the performance of a number of other trains whose total value is more than the single high value train.

Comparison of model train performance over individual track segments with actual train performance is one technique that is used to validate the simulated train performance. Differences in performance may be caused by incorrect consist information or crew behavior. In a small number of cases such discrepancies may be resolved by further data search. Inconsistencies in actual train data - e.g., consist data, complicate the task of validation. In many of these cases it is necessary to individually examine multiple sources of operating data and use engineering judgment to select the "most likely" scenario.

The goal of the simulation is to provide an estimate of the performance improvement that can be obtained by using the Movement Planner in the Precision Dispatching System. A key element of the validation procedure is the assessment of railroad experts as to the likelihood that the simulated train moves are feasible. Stringline representations (time-distance graphs) as well as animation of the simulation are analyzed by experienced railroad personnel to assess the validity of these elements. Using these tools one can verify that the spacing between trains is adequate as well as the switch setup times, etc.

5 SIMULATION RESULTS

The Movement Planner generates a movement plan for a planning area that has been simulated to assure that the plan meets all of the constraints associated with railroad operation. Each train operating in the region has a movement plan that provides an ordered list of the track segments that the train will occupy and the time that the train will enter and exit them. In the post-processing phase, these movement plans are analyzed to provide a variety of information. The following lists some of the reports that can be generated.

1. Travel times, enroute delay, and average speed for individual trains along with statistical data for classes of trains, such as bulk, merchandise, passenger, and intermodal.
2. Comparison of movement plan with current operating data collected during the study period.
3. Time lines of terminal utilization to allow assessment of terminal loading
4. Track utilization as a function of time along with the percentage utilization.
5. Stringlines (time-distance plots) showing the interaction between trains
6. Animation of the movement plan to promote visualization of the movement plan.

The bottom line in the assessment of the quantifiable potential financial benefit is the run time and the related average velocity of the trains. A small increase in the average speed with which trains move may result in substantial reduction in asset costs. In areas where crews exceed time of service limits and require recrewing on the line of road, eliminating or reducing recrews may provide substantial payback. Preliminary results for the three baseline areas showed that the implementation of Precision Train Control with the current fixed block signaling system could provide substantial increases in average speed. The capability of the planner to more fully utilize precise planning to minimize delays can result in runtime decreases for a train of as much as 25%. Improvements such as these ultimately provide savings to a railroad of millions of dollars per year.

In addition to the baseline scenarios with fixed block signaling, additional simulations assessing operation with predicted traffic growth and in the presence of unexpected anomalies were run.

6 EVALUATION AND LESSONS LEARNED

Defining a scenario for simulating a system that is highly constrained is itself a challenging assignment. It is quite easy to define a scenario that is over constrained. In the real world, real time adjustments may be made to accommodate constraint violations. In a large simulation such as this one, all of these issues must be addressed prior to beginning the simulation. As a result, it is not uncommon for a scenario to include trains originating in a terminal, which exceed the capacity of the terminal. Using actual data, which is known to have a feasible solution, might seem to obviate the issue. It does not because data is frequently ambiguous and/or missing.

In a large simulation that includes substantial detail, it is easy to lose sight of the purpose of the simulation in the minutia of detail. While the possibility of including such detail is intriguing it increases the complexity and therefore the cost of conducting the simulation. Fortunately, the law of large numbers minimizes the impact of these details on the final results.

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