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An Introduction to Computer-Assisted Train Dispatch

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This paper provides a framework for assessing the progress that is being made in the computer-assisted dispatching of trains. The state of the art is described in general terms, and future research needs are identified.

Introduction

Train dispatchers on a centralized traffic controlled (CTC) line control the movement of trains over a line, including the planning of where meets and overtakes are to occur and the aligning of the switches to control each train movement. Increasingly, computers are being used to assist the dispatchers in performing this critical function. This paper is an introduction to the topic of computer-assisted dispatch, and will provide both a framework for judging the progress that has been made and an outline of the research that remains to be done in this area.

Centralized traffic control has been in use for over fifty years, the first system being installed in 1927 on the New York Central Railroad. This system permitted a single dispatcher to control the operation of trains in a territory without the use of train orders (detailing to the train engineer before the start of his run exactly where each meet is to take place).

Immediate benefits from CTC were the increased productivity of trains (in terms of ton miles per train hour) and increased traffic capacity of a line. Subsequently, improvements in communication and signalling technology enabled economies of scale to be realized, with a single dispatcher

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Table 1. Dispatcher Workload

75–80%	Information gathering, record keeping
	90% routine
	maintenance of train sheets, train graphs, etc.
	10% dispatcher judgment
	identifying and coping with unpredictable events
20–25%	Control and planning of control
	85% routine
	clearing signals ahead of train clearing trains out of sidings
	15% dispatcher judgment
	planning of meet/pass locations

controlling larger and larger territories. Almost all main line traffic in North America is now under CTC. With increasing traffic and larger territories being controlled by a single dispatcher, the dispatcher's time has become the factor limiting the performance of the traffic control system.

Dispatcher Workload

Several industry studies of dispatcher workload have been performed (Means 1978, Steiner 1978), and a representative breakdown of the types of activities and the percentage of time spent performing each type is given in Table 1.

The largest proportion of the dispatcher's time (some 75-80 percent) is spent in information gathering and record-keeping. Of these activities, approximately 90 percent are routine, with the remaining 10 percent involving dispatcher judgment in identifying and coping with unpredictable events.

It is relatively easy to set up a computer system to cope with the routine clerical activities. We shall refer to such a system as a Dispatcher Information System. First introduced in the railroads in the early 1970's, these systems have increasingly been used to assist the dispatcher by removing most of the clerical functions he previously had to perform.

Table 2. Evolution of Computerized Dispatching

DISPATCHER INFORMATION SYSTEM
Local and remote entry of data:
Train characteristics
Train location and status, etc.
Record keeping:
Automatic preparation of train sheets
Preparation of train performance reports
COMPUTER ASSISTED DISPATCH
Automatic signal clearing:
Clearing signals ahead of trains
Clearing trains out of sidings
Manual selection of meet/pass locations
Computer calculated ETAs at next conflict
Computer suggests dispatch decisions
Dispatcher accepts (or over-rides) decisions and aligns switches
AUTOMATED DISPATCH
Computer selection of meet/pass locations
Computer control of switches and signals
Dispatcher over-ride in exceptional circumstances
INTEGRATED DISPATCH AND TRAIN CONTROL
Continuous feedback of dispatch decisions to modify train operating decisions.

While most of the information gathering and record keeping activites can be computerized, we should stress that there is one component that will not be computerized in the foreseeable future. This component consists of the non-routine activities associated with unpredictable events. The nature of these pattern recognition and adaptive response activities requires that they be performed by highly trained and experienced dispatchers, and argues against the installation of total automation.

Returning to Table 1, the remaining 20 to 25 percent of the dispatcher's workload involves the control and the planning of control of train movements. This activity is divided into a large routine portion and a smaller, more cognitive requirement to plan the meet/pass locations. Both of these

duties are candidates for computerization. The routine parts are relatively easy to automate, and dispatch logic is being developed to supplement the cognitive abilities of the dispatcher.

Evolution of Computerized Dispatching

The evolution of the computerized dispatching system is shown in Table 2. The sequence runs from a basic computer-assisted dispatch system, through automated dispatch, to a global system that integrates the dispatching operation with the control of each train.

At the basic level, computer-assisted dispatch frees the dispatcher from routine activities, but the dispatcher remains the active controller within the system. All critical decisions must be implemented by the dispatcher. As these systems become increasingly complex, additional functions are added in the following order:

Automated Signal Clearing

Given the destination of each train, the system can select the route to that destination and clear the signals ahead of the train, providing no conflicts are encountered. This permits a train to proceed under its least restrictive signal. This system can automatically clear trains out of sidings.

Computer Calculation of Expected Arrival Time

The next function normally included in a computer-assisted dispatch system is the automatic determination of meet and pass locations. This requires that the system must be able to calculate the expected time of arrival for each train at successive locations. Several levels of complexity are possible in these calculations. The simplest approaches use average time for each train class. Increasingly complex representations bring in more detail on trains and track characteristics with the other extreme involving the use of a detailed train performance calculator (TPC) which estimates the running times based on the power to weight ratios for the train, acceleration/deceleration performance and details on the track profile and restrictions.

Dispatch Logic

The final level of complexity in computer-assisted dispatching systems involves the use of dispatching logic to examine conflicts and to suggest to

the dispatcher how these should be resolved. Again widely differing levels of complexity can be included in the choice of the appropriate dispatching logic. In increasing order the following types of logic can be employed.

Standard Operating Procedures. Standardized rules for resolving conflicts can be formulated, with the computer implementing these rules and providing the dispatcher with a suggested decision. These rules may be as simple as "high priority trains take precedence over lower priority trains" and, with equal priorities, "eastbound trains have priority over westbound." These rules can be expanded to include factors such as shift time left for a train crew, deviation from schedule, etc.

Myopic. Myopic dispatch logic looks at the next conflict and resolves it to minimize the priority weighted delays encountered by both trains. Only single conflicts are considered. Such an approach is appropriate on a light traffic line.

Limited Look-Ahead. In this approach conflicts are resolved so as to minimize the total priority weighted delays in the next several conflicts. This permits the immediate consequence of decisions to be evaluated and included in the decision.

Optimal Dispatch. The computer searches over all possible conflict solutions (at least implicitly), and selects the optimal dispatch decisions. We shall discuss this approach further in the next section.

All the non-optimal approaches to dispatch logic must ensure that the selected dispatch decision are feasible and do not cause a line blockage. This problem has been solved by Petersen and Taylor (1983).

Automated Dispatch

With automated dispatch, the computer controls the dispatch decision directly, though allowance is made for the dispatcher to over-ride the computer decisions. At this level, the dispatcher is removed from the control loop and replaced by the computer. The dispatcher assumes a higher order level of control over the system, interrupting only when unanticipated events are encountered.

Southern Railroad (Saunders 1983) has done some very significant work at this level. In the Southern system, the decision to hold a train at some location awaiting some other train is modelled as an integer programming problem (see below for a description of such a model). Southern

solves this problem using a branch and bound solution technique, which is feasible given their low traffic levels. They have achieved substantial savings in meet delays, with corresponding cost savings, using this logic. The clear indication is that major economic benefits exist for railroads in adopting higher levels of automated dispatching. Effort is continuing to develop efficient dispatch techniques for high density lines.

Integrated Dispatch and Train Control

The highest level of dispatching systems, currently in the preliminary design stage, would employ continuous feedback of dispatch decisions to the train engineer, or onboard train computer, to modify train operation to minimize both fuel consumption and delays. For example, if a train is to be delayed for a meet, then this information could be used by the engineer to reduce the train operating costs by slowing early. Although beyond the realm of current railroad operating systems, such an integrated system appears to be feasible in the not-too-distant future and is being actively investigated by a number of railways.

The Optimal Dispatch Problem

In this section we formulate the dispatch problem mathematically for a single track line between two stations or yards. Consider the line to be composed of segments delineated by switches permitting a train to pass from one track to another. Segments with two tracks permit trains to meet or overtake.

The optimal dispatch problem determines where meets and overtakes should occur and which track each train should be on to achieve some objective such as minimum overall train delay (priority or cost weighted). Initial conditions are the location of each train and the expected time the current movement will be completed. Train movements for the next T hours are scheduled. We may formulate the problem as follows.

Consider a track with K segments, M of which permit trains to pass each other in a meet or overtake. Suppose a set I of trains travels in direction 1 and set J travels in direction 2. Denote the exit times of trains $i \in I$ from segment k as x_{ik}, and of trains $j \in J$ by y_{jk}. Let $m_{ij} \in M$ be the location where trains i and j meet with train i being on track l_{ij} during the meet. Tracks are numbered $l_{ij}=0$ if i stays on the mainline and $l_{ij} = 1$ if i takes the passing siding. Train j is on track $1 - l_{ij}$. Similarly, let $q_{i_1 i_2}$ be the

location where train i_1 overtakes train i_2 and $r_{j_1 j_2}$ be the location where j_1 overtakes j_2. In all cases the overtaken train takes the siding with the faster train remaining on the mainline. Let $t1_{ik}$ and $t2_{jk}$ be the free running times for i and j, respectively, across segment k. Also let $s1_{im}$ and $s2_{jm}$ be the minimum transit time including turnout delays if the trains transit the segment on the passing track. (This depends on turnout speed and the speed limit on the passing track.) Finally, let h_{ij} be the safety headway required between trains after a meet or overtake.

Minimizing total delay is equivalent to minimizing the sum of completion times given the current location $k1_i$ and $k2_j$ of each train. Thus the scheduling problem can be represented as the programming problem:

select m_{ij}, l_{ij}, $q_{i_1 i_2}$, $r_{j_1 j_2}$ to

$$\min \quad \sum_{i \epsilon I} x_{ik} + \sum_{j \epsilon J} y_{j1}$$

subject to:

timing constraints

$$x_{ik} \geq x_{i,k-1} + t1_{ik}; \qquad k = k1_i + 1, \ldots, K$$

$$y_{jk} \geq y_{j,k+1} + t2_{jk}; \qquad k = k2_j - 1, \ldots, 1$$

meet constraints

$$x_{i m_{ij}} \geq y_{j, m_{ij}+1} + h_{ij}$$

$$y_{j m_{ij}} \geq x_{i, m_{ij}-1} + h_{ji}$$

$$x_{i m_{ij}} \geq x_{i, m_{ij}-1} + l_{ij} s1_{i m_{ij}}$$

$$y_{j m_{ij}} \geq y_{j, m_{ij}+1} + (1 - l_{ij}) s2_{j m_{ij}}$$

for all $i \epsilon I$, $j \epsilon J$.

following and overtake constraints

$$x_{i_1 m} \geq x_{i_2 m} + h_{i_1 i_2}; \qquad q_{i_1 i_2} < m$$

$$x_{i_2 m} \geq x_{i_1 m} + h_{i_2 i_1}; \qquad q_{i_1 i_2} \geq m$$

$$x_{i_2 m} \geq x_{i_2 m-1} + s1_{i_2 m}; \qquad q_{i_1 i_2} = m$$

for all $i_1 i_2 \epsilon I$

$$y_{j_1 m} \geq y_{j_2 m} + h_{j_1 j_2}; \qquad r_{j_1 j_2} < m$$

$$y_{j_2 m} \geq y_{j_1 m} + h_{j_2 j_1}; \qquad r_{j_1 j_2} \geq m$$

$$y_{j_2 m} \geq y_{j_2 m+1} + s2_{j_2 m}; \qquad r_{j_1 j_2} = m$$

for all $j_1, j_2 \in J$.

Direct solution of this programming problem is computationally infeasible unless there are few trains with limited overtakes. Special structure of the problem must be exploited if an efficient algorithm is to be developed. Currently, this is an area of active research. Otway and Salzhorn (1979) describe the difficulties inherent in a brute force solution of this problem.

This problem is called "NP hard" which means that the computation time grows exponentially with the problem size. The problem size depends on the following factors:

- number of meets/passes, which in turn depends on
  - time horizon
  - length of line and train speed
  - traffic intensities.
- single versus double track.
- diversity of train types.

The most important factor is the number of conflicts that must be resolved, which, in turn, depends on the time horizon over which the dispatch schedule is developed. Typically a horizon of four to eight hours will be needed. As the time horizon increases, more conflicts will need to be resolved. Secondly, if train transit times are short (short lines or fast trains), then fewer interferences will occur. However, the single most important factor in determining the number of meets/passes is the traffic intensity. For example, as the traffic intensity in each direction doubles, the number of meets increases by at least four times.

The problem formulation is simplest for a single track line, and becomes quite complex for multiple tracked lines. The complexity is increased because there are more ways in which conflicts can be resolved, implying more alternatives to sift through to find the best one.

Finally, as the diversity of train types increases, more passes are possible, again increasing the number of alternatives to check.

As an example of how the size of the problem grows, consider the situation where there are three possible locations for each meet (that is, the most likely siding for the meet and one on either side). If, in the planning horizon there are 10 meets that must be resolved (corresponding to three

or four trains in each direction) then there are $3^{10} = 59{,}000$ combinations of meet locations that must be considered. If the traffic now doubles, there will be at least 40 meets that must be resolved during the same planning horizon. There are now $3^{40} = 10^{19}$ combinations that must be considered.

This suggests that integer programming solution methods such as branch-and-bound will be applicable only where the traffic intensities are low. Heuristic methods that provide good solutions need to be developed and are a focus of current research. (In addition, suitable models for testing these heuristics are required. See Petersen and Taylor (1982) for an example of such a model.) These methods will concentrate on only examining possibilities that are likely to lead to good solutions. For example, while double tracking leads to more possible ways to resolve conflicts, in practice dispatching is much easier as most meets can occur without delay to either train.

Conclusion

In this paper we have provided a framework for analyzing progress in the area of computer-assisted dispatch. Railroads are keenly interested in this area as it promises further increases in the productivity of train operations. Good solution procedures for the optimal dispatch problem remain a challenge for researchers.

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