TRACK CONFIGURATION FOR A HIGH-SPEED RAIL LINE

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ABSTRACT

We present a method for determining the design of a high speed, frequent passenger service. The paper identifies measures of train performance and relates these to the track design parameters. Both a theoretical construct for an idealized line and the use of a simulation model to examine design sensitivity under traffic perturbations are discussed. Performance of a proposed single track line is compared with the fully double-tracked equivalent.

INTRODUCTION AND SUMMARY

The Canadian rail passenger corporation, VIA Rail, is considering the establishment of a high speed, frequent passenger service between the two principal population centres in Eastern Canada, Toronto and Montreal. The proposed route studied calls for 357 kilometers of new single line track to be laid, with passing sidings to permit two-way flow over the line. A large unknown in determining the capital cost for this new line is how much additional passing track is required and where it should be located. This paper describes both a theoretical construct for an idealized line and the use of a simulation model to examine design modifications to handle system perturbations. (The structure of the simulation model itself is described in (1)).

We introduce two measures of passenger train performance, the Best Attainable Tight Schedule (BATS), and the robustness of the system. BATS is that performance achievable if all trains work as planned, executing flying meets with no unanticipated delays encountered by any train. We examine the length and location of passing tracks necessary for BATS performance, which yields the design necessary to achieve a given performance under ideal conditions. Robustness measures how well the system can cope with unexpected delays or traffic. We break this into what we call robustness in the small, which is a direct measure of how large a delay an individual train can incur while allowing the system to maintain on-time performance for other trains. Robustness in the large measures how well the system can permit a train that has undergone a large delay to transit the line without affecting the performance of the other passenger trains. It also measures the capability of the system to permit work trains or other non-passenger trains to operate on the line without impacting on the passenger service.

In this study we show that these three measures of train performance depend on different and independent design parameters. This is a very strong result from our study and greatly simplifies the design of a passenger service.

We begin by designing the system necessary for a BATS service for a given single track line with specified stops and given train cruise speed and acceleration/deceleration characteristics. Here we show how the number of passing tracks depends on headway and journey time and we show where these passing tracks must be located for a BATS schedule. We demonstrate that if we have headway slack, then within limits the passing track can be moved along the line, keeping the cycle time between the centres of adjacent passing sidings equal to the headway between trains.

The minimum length of passing track for BATS performance is a function of the signal system response time, acceleration and deceleration performance and the turnout speed. These relationships permit calculation of minimum length of passing siding and meet delays.

We then show how to calculate the location of each passing siding to ensure that all meets are flying and no delays are encountered if all trains operate as planned. This provides the minimum track configurations. Simulation results verify that the BATS design does indeed perform as anticipated.

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We then examine the robustness of the system in the small. We show that for the system to be able to absorb delays and still maintain on-time performance, slack must be designed into the system. Slack is attained by either an overspeed capability for the trains whereby, if late, they can overspeed to catch up, or by allowing schedule slack along each leg of the journey. By schedule slack we mean the difference between the time table and BATS performance. We show that the trains can overspeed or if schedule slack is available, then the effectiveness of the slack can be increased by increasing the length of the passing sidings. It is only in this way that passing sidings longer than that required for BATS are utilized in increasing the robustness of the system.

We then demonstrate, using the simulation model, how extra passing track improves the robustness in the small, or the capacity of the system to damp out small delays. The length of passing track required for BATS was approximately 5 percent of the length of the line. These simulation runs suggest that the length of these passing sidings could be doubled to 9 - 10 percent to usefully increase the robustness of the line.

We then examine how track design can be modified to ensure robustness in the large. That is, how to ensure that if individual passenger trains incur large delays or if work trains or other slower trains operate on the line, then there is no spillover to the other passenger trains. We introduce the concept of the system of primary passing tracks and secondary sidings. To maintain on-time performance for the passenger trains, then no secondary traffic (a passenger train which has undergone a large delay, or slower speed traffic) may utilize the primary passing tracks and the primary passenger trains have absolute priority on meets or overtakes.

The location of the secondary sidings can then be calculated given the desired performance we wish this traffic to attain. If we wish this traffic to move with flying meets then this can be designed in the same way that the primary siding length and location was determined for BATS performance. We demonstrate the necessary siding spacing if traffic of a given speed must be able to move along the line without affecting the performance of the passenger trains.

With a secondary siding located every 20 km, trains moving at 75 km/hr can transit the line without interfering with primary traffic. These sidings can be short (1 km) and add approximately another 4 to 5 percent of sidings to the line. Thus a good robust design can be achieved with 13 to 15 percent of the line doubled as passing tracks or as sidings.

We conclude the paper with simulation demonstrations of the designed line and of a fully double-tracked alternative to underscore the value of the designed line.

DETERMINANTS OF PASSENGER TRAIN PERFORMANCE

Various measures of passenger train performance and how they are affected by design parameters are described below.

The first measure of performance is the journey time attainable under ideal conditions, which we refer to as the Best Attainable Tight Schedule, or BATS. The parameters that affect BATS are summarized in Table 1.

Table 1: Determinants of BATS
cruising speed
acceleration/deceleration performance
number of scheduled stops and dwell times
number of meets encountered (traffic intensity)
meet delay which depends on:
turnout speed
passing track length
dispatcher or switching response time

The location of the passing tracks are not parameters in that for BATS we assume there are sufficient number so that the traffic can be accommodated. We address the optimal placement of these tracks below through an example.

The second performance measure we define is robustness in the small. This is the ability of trains, when delayed, to recover and arrive at their destination on time. Given that trains are scheduled according to their Best Attainable Schedule (BATS) the parameters that contribute to this performance measure are summarized in Table 2.

Table 2: Determinants of Robustness in the Small
train overspeed capability
extra passing track length (in excess of that necessary for BATS)
schedule slack

The final performance measure is robustness in the large, or the capability of the system to isolate the passenger trains from slower trains, or from trains that have been delayed so that they can not possibly arrive on-time. This depends on the availability of slack capacity that can be used to handle these secondary trains so that the primary passenger trains are not interfered with. This is achieved by the use of secondary sidings that increase the capacity of the line. These secondary sidings are not used by the primary passenger trains but are used only to handle passenger trains that have been delayed by a considerable amount, or slow, or work trains.

This identification of the different performance attributes of a passenger train service is essential to the efficient design of the line. It permits us to clearly determine the effects of each of the design parameters and show how different performance capabilities can be obtained.

EVALUATION OF BATS

The number of passing sidings and their locations depend on the time it takes for each train to transit the line and the headway between departing trains. The line transit time, W, is the free-running time (at cruise speed) plus any stop and meet delays on the way. The headway between trains, h, depends on the traffic intensity and is the time between train departures in each direction. The number of meets, M, is given by

$$M = \text{int}\ (2W/h)$$

where "int" means the expression is truncated to the next lowest integer. Thus if the transit time on a line is 2 hrs. 20 min., with 1 hr. headway, each train would meet 4 other trains.

The number of meets is the number of passing tracks required in a BATS schedule. For a given number of meets, the location of the passing track will depend on the headway slack (the time between the arrival of a train at its destination and the departure time of the next returning train) and on how it is allocated to each end of the line. Figure 1 illustrates the number and location of the passing tracks as a function of the headway. In this figure, the transit time across the line is plotted against the headway time, h, between trains. The regions corresponding to different numbers of meets are shown by vertical separation, with the shaded areas indicating the range over which the passing tracks can be shifted using the headway slack. The dotted line shows the location of the passing tracks if the headway slack is assigned equally to each end of the line. In general, the location of the passing tracks is such that the "loop" time for an outbound train and an inbound train to transit from the center of one meet point to center of the next is equal to the headway. This rule permits us to "tune" any line with stops, different direction speeds and schedule slack. The passing tracks are spaced so that the cycle time including all delays is exactly the headway time.

The length of passing track required to execute a flying meet depends on whether or not the train taking the passing siding accelerates on the siding after slowing for the switch. Figure 2 shows the effect that accelerating on the passing track has on the meet delay. Actual performance will be within the envelope between zero and the maximum speed gained on the passing track.

FIGURE 1 LOCATION OF PASSING SIDINGS

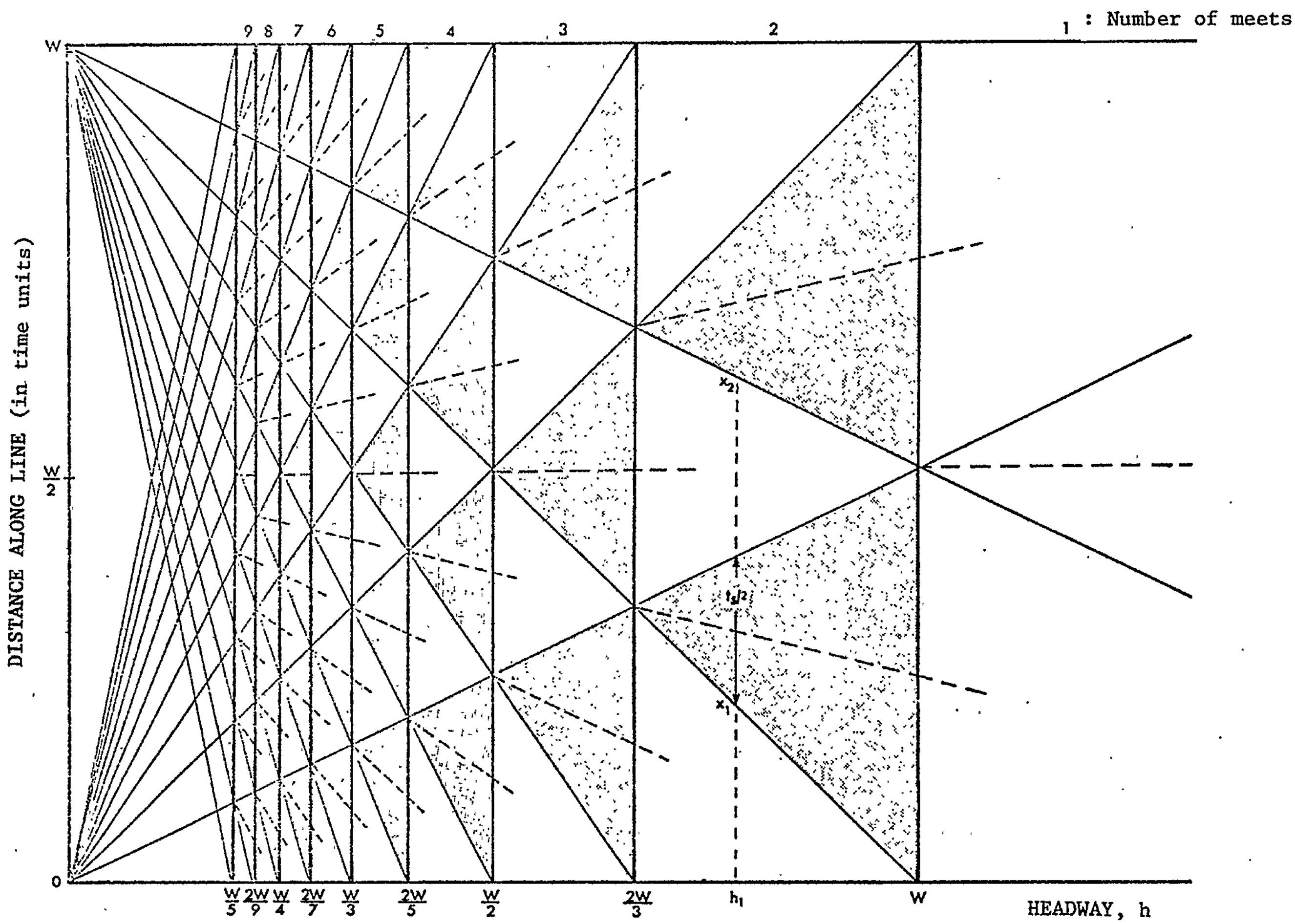


FIGURE 2 MEET DELAY VERSUS PASSING TRACK LENGTH

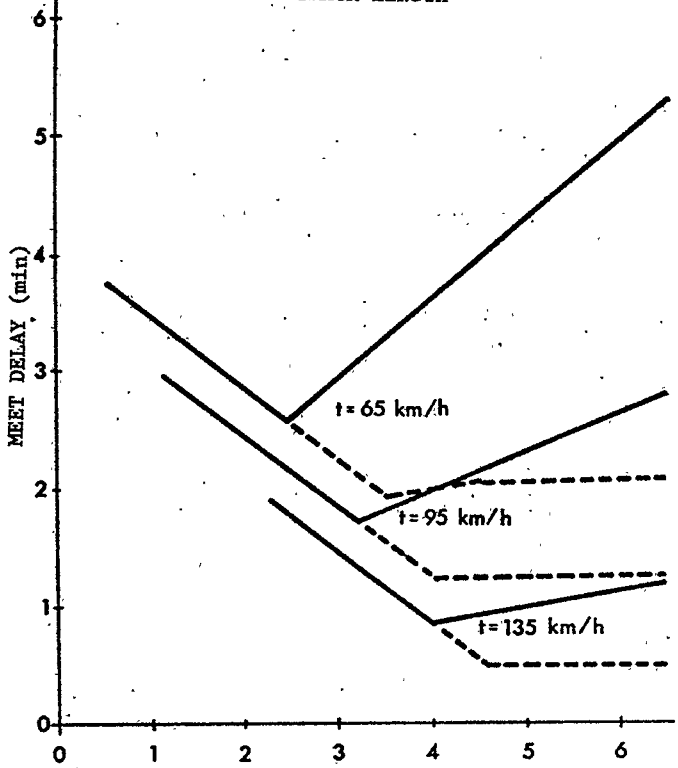
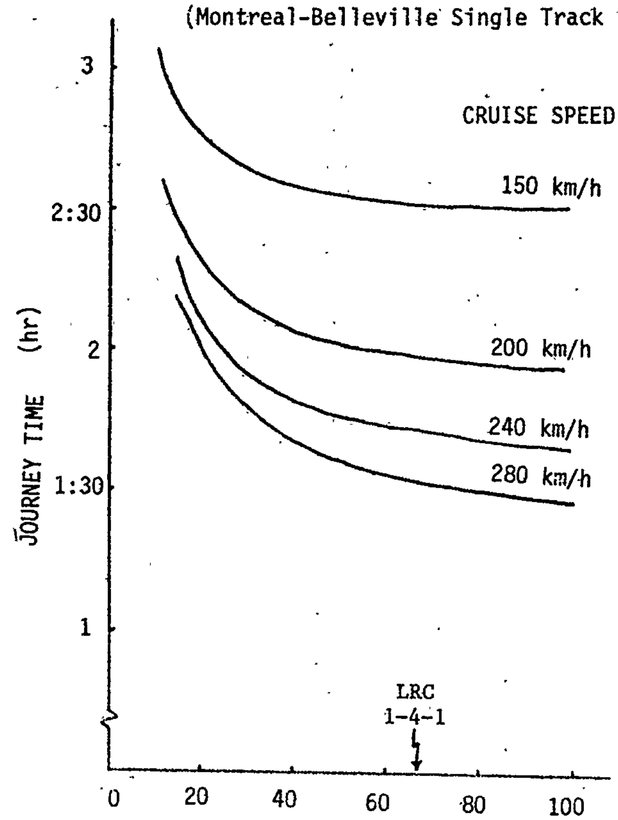


FIGURE 3 JOURNEY TIME VERSUS TRAIN SPEED
(Montreal-Belleville Single Track Line)



Using passing tracks which are sufficiently long to permit flying meets, the BATS journey train can now be calculated.

The line used in our study is a single track, separated, passenger line from suburban Montreal to Ottawa, Kingston and to Belleville where it rejoins the existing Montreal to Toronto line. The line is 357.2 km in length with scheduled stops at Ottawa and Kingston. We assume that high performance passenger trains will operate with a cruise speed of 200 km/hr. One hour service in each direction for 16 hours each day is provided.

Figure 3 illustrates how the journey time on this line varies with train performance (cruising speed and acceleration/deceleration characteristics). This figure demonstrates that improvements in train acceleration/deceleration performance beyond that attained, for example, by the newest Canadian high speed train (the LRC) have relatively minor impact on journey time. Journey time, however, decreases substantially with increasing cruising speed.

ROBUSTNESS

Robustness measures the capacity of the system to absorb train delays without serious deterioration of service. Since the BATS design is "tight" in that no margin for delays is allowed for, we must modify the design to include some slack to compensate for delays.

There are two sources of slack, train overspeed capability and schedule slack (excess time built into the train schedule). This slack allows a train which suffers a small delay to be on time and not affect the performance of other trains. In addition, extra passing track length allows the slack to be shared between trains. Note, however, that extra passing track length does not increase the slack. For example, if the trains could not over-speed and there was no schedule slack, then even with a double tracked line, no delays could be absorbed by trains on a best attainable schedule and maintain on-time performance. Thus, there would be zero slack even though we have these very long passing tracks.

For the line studied, we use a simulation model assuming a 2 minute schedule slack per station stop. We examine the impact on train delays and the cascading effects on other trains for varying passing siding lengths.

For siding lengths varying from 5 to 11 km, the system is simulated for different imposed delays that are quite small (i.e., for 0 to 5 minutes delay per train delayed). The results are plotted in Figure 4. For small delays the system can absorb these delays with excellent on time performance. As the delays increase, there is insufficient slack to absorb these delays and total system performance deteriorates rapidly. This demonstrates that in the small the system is very stable, but without altering the speed, times, procedures and line design, large delays cannot be absorbed.

FIGURE 4 TRAIN LATENESS UNDER SMALL DELAYS

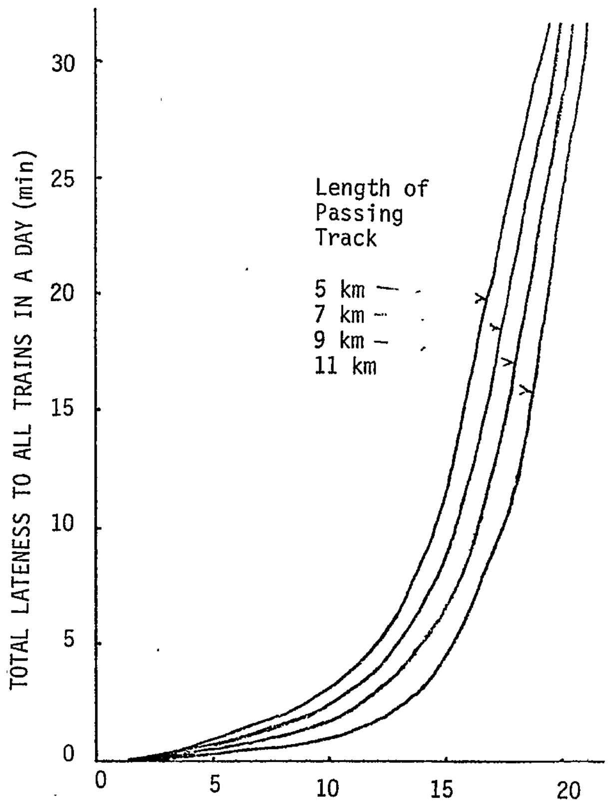
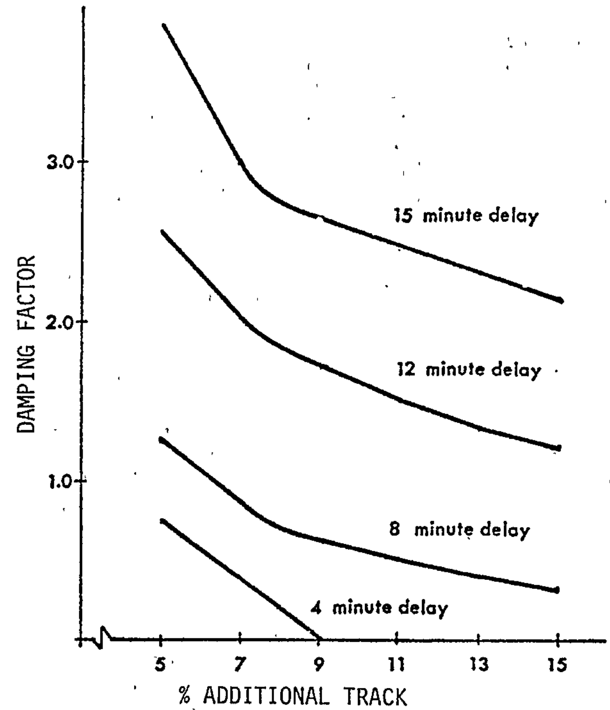


FIGURE 5 EFFECT OF ADDITIONAL TRACK ON DAMPING FACTOR



To further examine the performance with larger delays, we repeated this procedure for flying meet siding lengths of 5 km, 8 km, 12 km, and 16 km. The results of these runs are summarized in Figure 5. We define a quantity we call the damping factor, which is the ratio of the total delay experienced by all trains divided by the delay imposed on the line on train departure (i.e., the number of trains delayed times the departure delay move). The damping factor thus forms a good measure of how well the line responds to a small delay.

We observe that, although performance improves with extra passing track length, most of the benefit has been gained with about 9% of the total line double tracked, corresponding to 10 km sidings for flying meets.

Robustness in the large relates to a system's ability to cope with large disturbances without the system performance deteriorating excessively. As we have seen, when delays to individual trains become large, then major system delays result from the spillover effect to other trains. When a train experiences large delays, then the planned meets can no longer be executed without causing the on-coming trains to experience excessive delays. These disturbances then cascade through the system resulting in a major deterioration in performance.

We consider the following types of disturbances:

1. Large delays to individual high speed passenger trains, and
2. The ability to move slow speed trains without causing excessive impact on the passenger service.

Robustness in the large deals with how to design into the system the extra capacity required to cope with these disturbances.

Consider now the problem of minimizing the impact of a passenger train that has encountered a major delay. With passing sidings located for a BATS schedule, no excess capacity is available and extra trains can not use any of the passing sidings without interfering with the passenger trains. A train that has experienced a large delay appears to the system like an extra train that must be dispatched over the line.

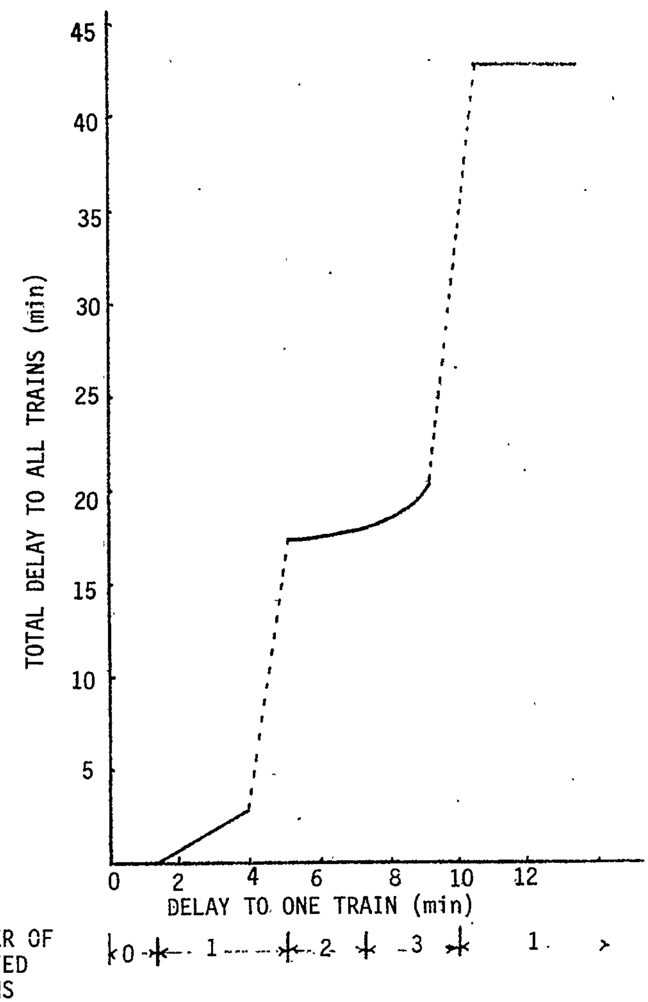
The strategy to cope with this problem is to design an alternative set of passing sidings to be used by the delayed or slow trains, with the BATS passing tracks used exclusively by the regular passenger trains. The design issues then relate to the performance desired when trains operate on this secondary system. For example, it may be a design requirement to move the delayed train as quickly as possible, but ensure that all delays are incurred only by that train. This would suggest that the secondary system should consist of long passing sidings, permitting flying meets with the regular passenger traffic. Alternately, if the desire is only to ensure no spillover, then short sidings could be provided, spaced such that the delayed train could move along the line in the open time windows between passages of the regular traffic.

This system with secondary passing tracks and sidings requires a dynamic dispatch logic as follows. When a primary train becomes delayed beyond a certain amount, it is reclassified as a secondary train and is dispatched so not to interfere with the primary trains. Within the secondary trains, the original priority still holds so that a delayed passenger train still has priority over a slower freight or work train.

The system of secondary passing tracks must also have the capacity to move the slower freights or work trains.

Figure 6 summarizes simulation of the impact on both total system delay and number of affected trains for a specific set of short secondary sidings, as a single train is delayed by increasing amounts. Note the relationship between robustness in the small and robustness in the large. In this example, delays of 4 minutes or less affect only one train with most of the delays absorbed by the slack. As the delay increases, 2 and then 3 trains are affected with corresponding increases in total system delays. When delays to a train exceed 10 minutes, then the train proceeds using the secondary sidings, avoiding interference with the primary traffic. Then only it is delayed, but quite substantially. The figure thus illustrates the robustness of the system in the large, showing that only one train is affected with the other trains maintaining on-time performance.

FIGURE 6 SYSTEM DELAY DUE TO A SINGLE DELAYED TRAIN



EVALUATION OF A PROPOSED DESIGN

This section uses the simulation model to evaluate the proposed design. The following assumptions are made:

<u>Passenger service</u> train cruising speed 200 kmh (no overspeed)

elapsed time to reach cruising speed 3 minutes
braking time 1.5 minutes
train length 0.3 km
schedule slack of 2 minutes on each leg
station stops at Kingston and Ottawa of 2 minutes

<u>Fast freight</u> cruising speed 120 kmh

elapsed time to reach speed to 6 minutes
braking time 3 minutes
train length 0.5 km

<u>Work trains</u> cruising speed 75 kmh

elapsed time to reach speed 10 minutes
braking time 5 minutes.

On this line, each on time passenger train has 4 flying meets. One of these occurs at Ottawa, with the other meets occurring on 9 kilometer passing sidings.

Letting Belleville be milepost 0, these flying meet (or primary) sidings begin at mileposts (in km) 45.4, 123.5, and 298.8. The Kingston stop is located at 71.3, Ottawa at 215.5, and Montreal suburban at 357.2.

With a work train cruising speed of 75 kmh, a secondary inter-siding distance of approximately 20 km is required to permit passage of the work train with no interference to the passenger service. These sidings are 1 kilometer in length.

The total mileage of the three primary sidings plus secondaries is 45 km, or about 13% of the total distance.

Turnout speeds of 95 kmh are assumed for the primary sidings, and 65 kmh for the secondary sidings. Finally, to reflect the need for safety at these high speeds, we have assumed no intermediate signals between siding locations.

To compare how well the proposed line performs when constrasted with the fully double tracked equivalent, we make the following assumptions about the daily line traffic.

Passenger trains:	16 trains per day with 1 hour headways, 10% probability of a train delay of 5 minutes, occurring at a random point in the journey
Express freights:	2 per day each way during the high traffic period, no delays
Work train:	1 per day in one direction, during the high traffic period

Table 3 summarizes the simulation results for this traffic pattern over a 50 day period.

Table 3: Comparison of Proposed Line and Double Track

Variable	Proposed Line	Double Track
% of late passenger trains	16%	12.5%
Average lateness of late trains	4.3 min.	2.6 min.
Express Freight transit time	6.31 hr.	3.3 hr.
Work Train transit time	11.2 hr.	5.8 hr.

The data shows that the proposed line (13% double track) performs very well for the primary high speed passenger service when compared to the double tracked line. On this basis, it is hard to justify the additional very high capital cost of the additional line construction for full double tracking. The dramatic difference between the two designs appears in the supplementary traffic performance. Naturally, since this traffic is immediately relegated to the secondary system in the proposed design, it suffers a great deterioration in journey time under this system.

The implications for design policy from this date are clear if the system is established with the main focus on high speed passenger service, the proposed line is feasible in operation and offers a good alternative. The principal benefit from increased trackage lie in more efficient handling of supplementary traffic

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