DELAY AND REQUIRED INFRASTRUCTURE INVESTMENT TO OPERATE LONG FREIGHT TRAINS ON SINGLE-TRACK RAILWAYS WITH SHORT SIDINGS

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SUMMARY

Use of distributed power locomotives in heavy-haul service has allowed for greater efficiencies through operation of longer freight trains. In North America, where the majority of mainline routes are single track, the potential economic and operational advantages offered by long trains are constrained by the inadequate length of many existing passing sidings. This research builds upon previous work conducted by the authors, and seeks to more formally understand at which point, given long train operations, the construction/extension of longer passing sidings becomes inconsequential to maintaining a baseline level of service. The operation of a single-track line is simulated under different combinations of percent long sidings (i.e. sidings adequate for the operation of long trains), percent long trains, and combinations of long and short train lengths (train replacement ratios). The experiment design scenarios are simulated via the Rail Traffic Controller (RTC) simulation software, used by most Class I freight railroads in the United States. Results indicate a linear relationship between the ratio of train lengths and the level of infrastructure investment required to realize the operational efficiencies afforded by running long heavy-haul freight trains.

INTRODUCTION

The economies of scale afforded by longer heavy-haul freight trains are partially realized through reduced labour and fuel costs. Operating longer train lengths also requires fewer train runs to move a given amount of freight, thereby decreasing capacity consumption on busy corridors. Natural use of longer train consists, however, is hindered by existing track infrastructure in North America, where mainlines are predominantly single track with passing sidings. Many passing sidings lack sufficient length to stage longer trains in excess of 100 cars, effectively setting an upper bound to heavy-haul train lengths in North America.

The emphasis on utilizing ever-longer unit train consists to move bulk freight has experienced a recent surge in the United States. In 1980, the average freight train in the western United States contained 68.9 railcars. Twenty years later in 2000, this had only increased to 72.5 railcars. Just ten years later, in 2010, the average train had grown to 81.5 railcars and railroads had begun to operate 150-car trains on select corridors [1].

Contemporary utilization of 150-car unit trains and its relationship to track infrastructure has been addressed in various forms throughout both academia and industry. Newman et al. described the economic and operational benefits of increasing the length of unit trains on one Class 1 Railroad [2]. Operational advantages of longer freight trains is discussed by Barton and McWha, who cited the need for lengthened passing sidings in response to the utilization of longer freight trains up to 12,000 feet in length by several North American Class I railroads [3]. The sentiment for siding extension programs was shared by Martland, who elaborated on the insufficiency of existing passing sidings to handle long-train operations by his conservative estimate that two-thirds of unit trains in operation are “length-limited” by passing sidings [4]. The ability of siding length to dictate the maximum practical length of trains run on a particular corridor is further echoed by Dick and Clayton, who demonstrate that, at the time of writing, most sidings on Canadian Pacific Railway (CP) and Canadian National Railway (CN) were insufficiently long to adequately support long-train operations. To overcome its siding-length disadvantage relative to CP, competitor CN began to run 150-car trains (9,000 feet, or 2,745 meters, in length) in a single direction to avoid the problem of meets between long trains [5]. For perspective, typical existing passing sidings on single track in North America range in length from 6,000 to 7,500 feet (1,830 to 2,285 meters), or from 100 to 125 railcars. Most new siding construction projects are in the range of 9,000 to 10,000 feet (2,745 to 3,050m) to support the operation of 150-car trains and seven locomotives in a distributed power configuration.

Previous work conducted by the authors has highlighted general trends associated with the relationship between train delay, percent long sidings along a route, and the percentage of long trains operated on that same route [6].

The research presented in the following sections aims to build upon the relationships generalized in previous studies through a more comprehensive simulation and analysis of the infrastructure build-out required for routes operating with different combinations of short and long train lengths, as expressed by the "train replacement ratio". The results from this study can be used to develop a better understanding of the interaction between train delay, the lengths of passing sidings, and lengths of trains. Ultimately this knowledge can help streamline the decision-making process associated with the implementation of long-train operations and rail infrastructure expansion in the form of passing siding extension/longer-siding construction programs.

RAIL TRAFFIC CONTROLLER

This research develops train delay and capacity metrics with the use of Rail Traffic Controller (RTC), the industry-leading rail traffic simulation software in the United States. RTC is used by a wide range of public and private organizations, including most Class I railroads, Amtrak, and Bay Area Rapid Transit (BART). Specially developed for the North American railway operating environment, RTC emulates dispatcher decisions in simulating the movement of trains over rail lines subject to specific route characteristics.

Inputs for the simulations run in RTC include factors such as track layout and signaling, speed limits, and train consists [7]. Outputs include train delay reports, dwell, siding usage, and train energy consumption. For the analyses that follow, infrastructure (in the form of routes with varying fractions of short and long passing sidings) and freight train parameters were variable inputs, while train delay was the desired output. In the North American operating environment, train delay is a proxy for level of service and is used to establish the capacity of a rail line.

As a whole, the results described in the following sections consist of data from five simulation days that are each replicated five times. Thus, each data point is based on an average of 25 days of simulated train operations. To simulate the flexible scheduling of North American freight operations, each replication specifies a distinct freight train operating pattern where each train departs randomly from its respective terminal within a 24-hour window. Long trains and short trains are distributed randomly within this pattern according to a uniform probability distribution; no efforts are made to fleet the trains by length.

NOTATION

The concept of a train "replacement ratio" is frequently referred to in the following sections, and is worth defining here for the sake of clarity.

Replacement ratio can be defined as the ratio in the length of long trains on a route as compared to short trains on the same route. For example, if a route operates long trains of 150 railcars and short trains of 100 railcars, two of the long trains can move the same amount of freight (railcars) as three short trains. In other words, two long trains can *replace* three short trains and contribute to a reduced total train count. The corresponding train replacement ratio is 3:2. In general, the larger the replacement ratio, the larger the disparity between long and short train sizes, and vice versa.

METHODOLOGY

The overarching simulation methodology used throughout this study builds upon the previous work of the authors, and is based upon a representative single-track heavy-haul route with general characteristics as outlined in Table 1, along with the properties of the freight trains. Two siding lengths are specified: a shorter length to represent current passing siding conditions and a second longer length to represent a passing siding that has been extended through capital investment. Different freight train lengths are

Route Characteristics	Values
Length	240mi/386km
Siding Spacing	10mi/26km
Total No. of Sidings	23
Siding Lengths	2mi/3.2km (long), 1.25mi/2.0km (short)
Traffic Composition	100% Freight
Locomotives	4300hp SD70 (x2 or x3)
Number of Cars	50, 75, 100 (short train); 120, 150 (long train)
Total Length of Cars	2750ft/838m, 4125ft/1257m, 5500ft/1676m (short train) 6600ft/2012m, 8250ft/2515m. (long train)
Max. Freight Speed	50mph/80kph (45mph/72kph through siding)
Traffic Control System	2-block, 3-aspect CTC

Table 1: Simulated Route and Freight Train Characteristics

specified and used in different combinations to achieve the train replacement ratios specified in the experiment design. The number of locomotives assigned to each train is varied in proportion to its length in an attempt to maintain a constant hp/ton ratio. Adding power to the longer trains helps control for any subtle differences in performance that may result in additional congestion and delay, and confound the simulation results.

The experiment design for the RTC simulations is comprised of three main variable factors: percent long sidings, percent long trains, and train replacement ratio.

Percent long sidings is the fraction of total sidings on the route that have been extended from the base length of 100 railcars to be longer than the length of the long trains, in this case either 120 or 150 railcars. It should be noted that an idealized strategy was used in distributing long sidings along the simulated route. More specifically, long sidings were always distributed evenly such that the route remained balanced from an infrastructure perspective.

Percent long trains is the fraction of total railcars on the route moving in long trains, or restated, the percent of short trains that have been replaced by long trains to move the same volume of freight (number of railcars).

For example, consider a route operating 150-car long trains and 100-car short trains, with a traffic level of 2,400 railcars per day. The absence of long trains would require 24 short trains to move the given freight volume. A case with 50-percent long trains, however, would consist of 18 short 100-car trains and 12 long 150-car trains. Thus, the percent long trains factor is the number of railcars being moved in long trains divided by the total railcar throughput, rather than just the ratio of long trains to total number of trains.

The train replacement ratio was defined earlier as the ratio of the number of short trains to the number of long trains that can replace them by carrying an equivalent number of railcars. To achieve a range of replacement ratios different combinations of 150, 120, 100, 75 and 50-car trains were used. The cases of 6:5 and 3:2 replacement (100 & 120-cars trains, and 100 & 150-car trains, respectively) represent common operational situations facing North American heavy-haul operators as they increase the length of unit trains. The 2:1 and 3:1 cases use artificially short train lengths that are not truly representative of current operating conditions but are used to extend the trends and relationships apparent in the results without resorting to simulating extremely long 300-car trains.

Each of these three factors has a specific number of values, or “levels” associated with it. For example, the percent long trains factor was subdivided into four levels: 0, 25, 50, and 75-percent long trains. A summary of each of the factors and their respective range of values are provided in Table 2. The analyses performed in this study are based upon simulated factorial combinations of these different values.

It should be noted that the throughput volume considered in this study remained fixed at 2,400 railcars per day, and the directional distribution of all traffic along the route was 50-50, or evenly distributed in both directions. There are particular efficiencies afforded by uneven directional running of long trains (such as reduced long train-long train meets), which has been covered in the authors’ previous related work [6]. However, the goal of this study was to focus on the case where heavy-haul unit train cycles with fixed train consists make it impractical to only run long trains in a single direction.

Finally, it should also be noted that this study does not consider the ability of heavy-haul unit train loading facilities, unloading facilities, and any intermediate staging and inspection yards to support the operation of longer trains. While the focus of this paper is on mainline single-track operations, in practice, additional terminal infrastructure investments may be required to establish tracks and loops of sufficient length to support operation of long trains.

Experiment Design Factors	No. of Levels	Level Specification
Percent Long Sidings	14	0, 4, 9, 13, 22, 30, 48, 52, 70, 78, 87, 91, 96, 100
Percent Long Trains	4	0, 25, 50, 75
Train Replacement Ratio	4	6:5 (100-car short & 120-car long) 3:2 (100-car short & 150-car long) 2:1 (75-car short & 150-car long) 3:1 (50-car short & 150-car long)

Table 2: Experiment Design Factors and Levels

RESULTS

Simulation results for the combination of scenarios presented in the methodology section were compiled to highlight the relationship between track infrastructure (number of siding extensions), and length and degree of long train operations (train replacement ratio).

The results support the generalized relationship between percent long sidings and train delay presented in Figure 1. The data from the simulations conducted for this study agree with previous results suggesting there are two types of behaviour exhibited when long trains are operated on single-track lines with short sidings.

Type I behaviour describes the condition where the extra delay associated with the inflexibility of long train meets on routes with inadequate numbers of long sidings outweigh any delay benefits from the reduction in train count afforded by the long trains. The result is that the route operates with a higher average train delay than the baseline condition of pure short train operations, even though the baseline has a higher total train count.

Type II behaviour, on the other hand, describes a condition where there are sufficient long sidings providing flexibility in long-train meets such that the benefits of reduced train count can be realized. Under these conditions, the route operates at a lower average train delay than the baseline condition even though the train dispatcher is still restricted in where meets between long trains can be arranged. Although some long trains may still be delayed for meets, the majority of trains are seeing positive delay benefits arising from the reduced total train count.

The “transition point” between these two types of behaviour is the level of infrastructure investment in siding extensions required to mitigate any negative delay effects of long train operations and return the route to its baseline level of service. The critical juncture of the transition point will be explored in more detail later in this paper.

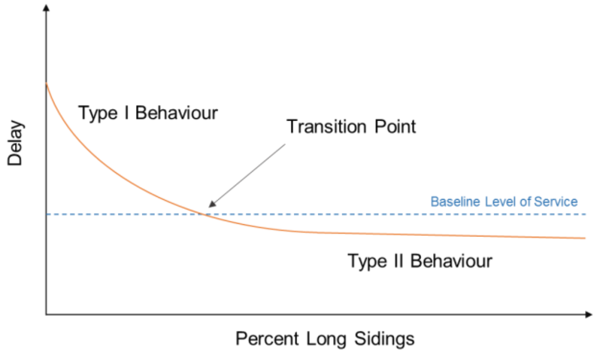

Figure 1: Delay Behaviour for Long Train Operations

To quantitatively illustrate this general relationship in more detail, the simulation results for a 3:2 replacement ratio (150-car long trains, 100-car short trains, 2,400 cars per day) are presented in Figure 2, and updated from previous work of the authors [1]. Figure 2 is intended to highlight the relationship between route capacity (in the form of train delay) and percent long sidings as a function of percent long trains (for a 3:2 replacement ratio).

The form of Figure 2 clearly falls into three natural “zones” of delay response – one between zero and 50-percent long sidings, one near 50-percent long sidings, and one between 50- and 100-percent long sidings. The first zone exhibits Type I behaviour, or more specifically, an exponential decrease in delay as long sidings continue to be added along the route, and shows cases with relatively high percent long trains as having the highest average train delay. The third zone, on the other hand, shows Type II behaviour in the form of lower delay values for cases that include higher percent long trains due to their contribution to larger reductions in overall train count.

An important bit of information from Figure 2 is the point of convergence of all lines near the 50-percent long sidings mark. This “transition” point indicates that, for this combination of train lengths and traffic volume, in order to operate with a high percentage of long trains, only half the sidings on a route need to be extended in order to maintain the baseline level of service (i.e. that corresponding to the case with no long train operations). After this transition point, the economies of scale of long-train operations come into play, showing reduced delay for cases with more long trains, since total train count along the line is also reduced.

The broader range of replacement ratio values in the experiment design were selected to test the consistency of this transition point. In other words, does changing the ratio of long and short train lengths have an effect on the amount of infrastructure investment required to restore current levels of service under long train operations?

The results from simulating the same volume of 2,400 railcars but with a replacement ratio of 2:1, 3:1, and 6:5 are shown in Figures 3, 4, and 5, respectively.

As before, three natural zones of activity are apparent, but there are slight differences between each plot with its unique replacement ratio. In particular, it is immediately apparent that the transition point, originally near the 50-percent long siding mark in Figure 2, has now been shifted to left in Figure 3 and is located nearer to the 30-percent long siding mark. This result implies that the transition point is not constant but varies with the ratio of train lengths being operated along any one particular route.

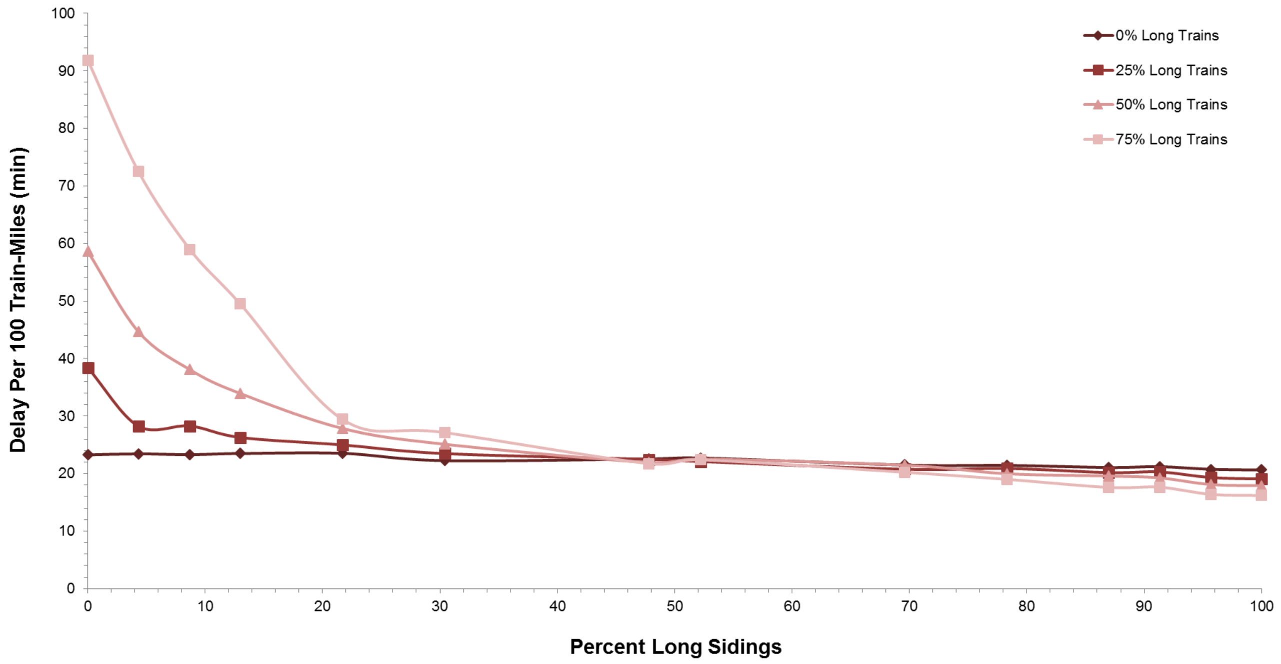

Figure 2: Delay as a Function of Percent Long Sidings
Along the Route (3:2 Replacement Ratio)

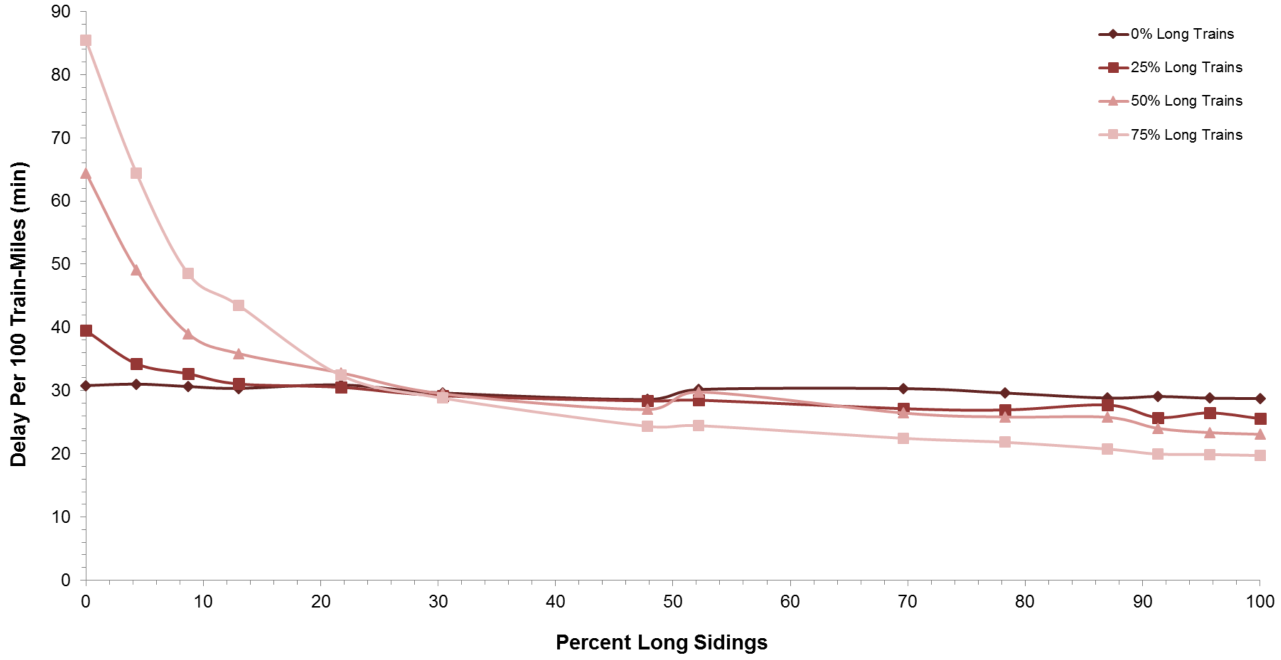

Figure 3: Delay as a Function of Percent Long Sidings
Along the Route (2:1 Replacement Ratio)

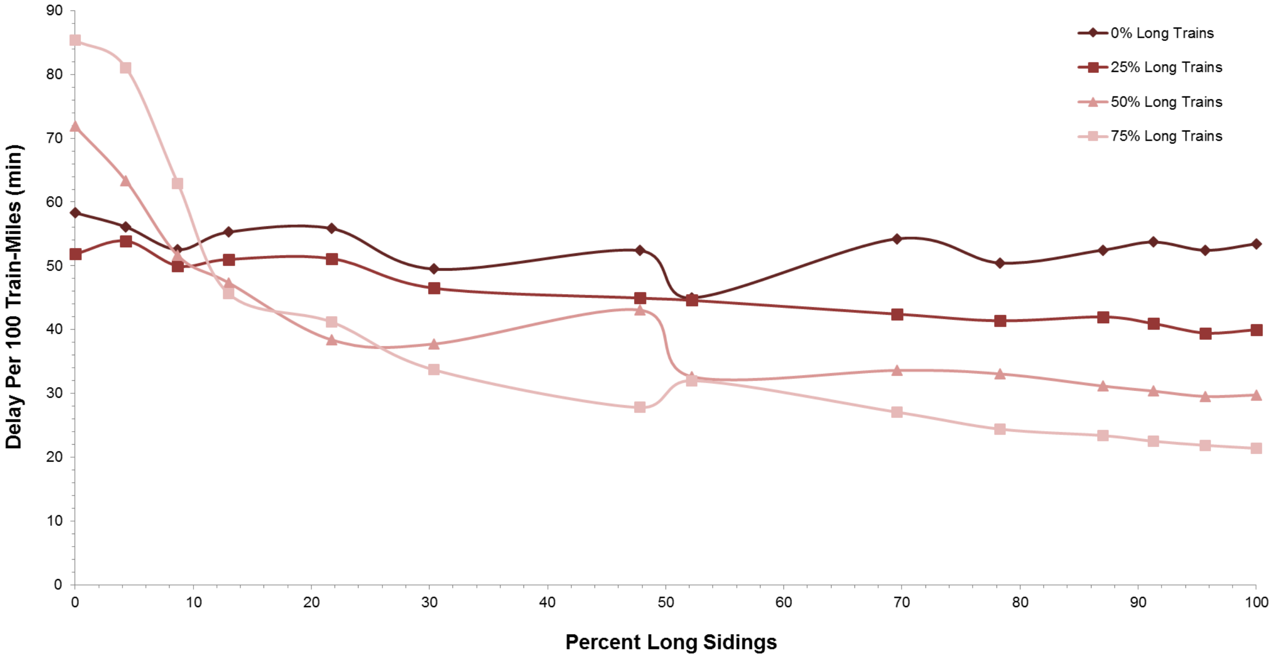

Figure 4: Delay as a Function of Percent Long Sidings
Along the Route (3:1 Replacement Ratio)

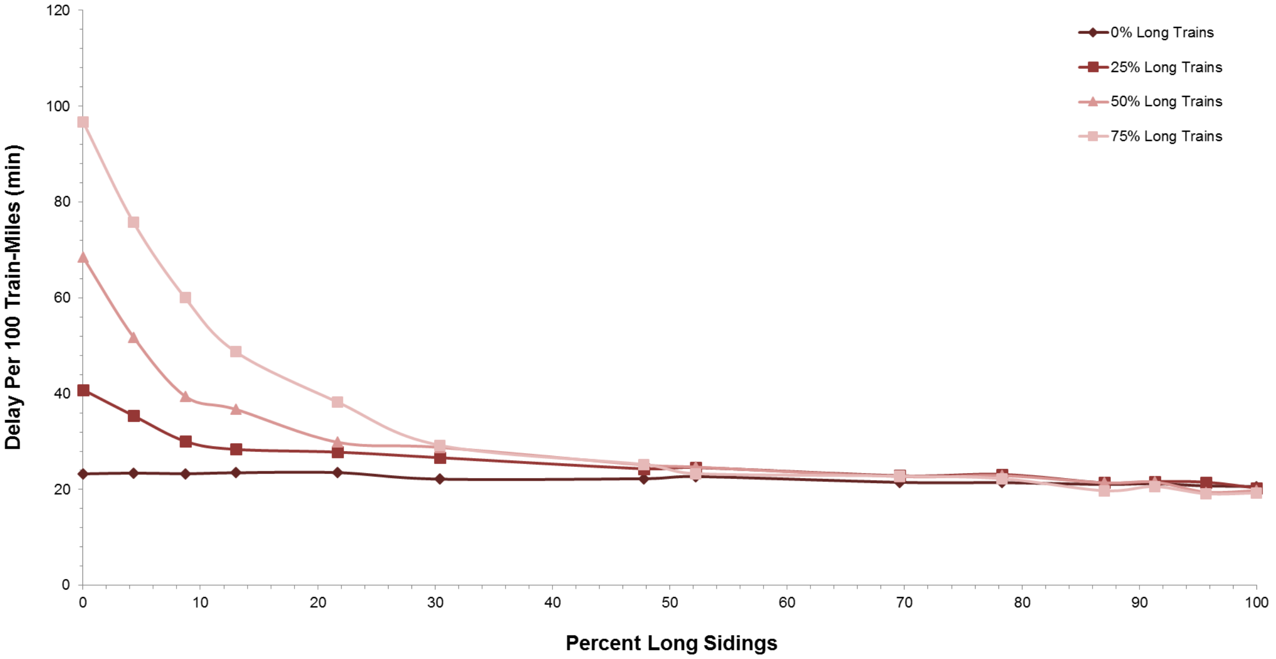

Figure 5: Delay as a Function of Percent Long Sidings
Along the Route (6:5 Replacement Ratio)

That the transition point moved to the left from Figure 2 to Figure 3 implies that the larger the difference between long and short train lengths (i.e. replacement ratio), the less infrastructure investment is required to reach the transition point between Type I and Type II behaviour. From a practical standpoint, the results in Figure 3 imply that, in order to achieve economies of scale from running longer trains at a 2:1 replacement ratio, roughly 30-percent of sidings need to be extended on a route in order to accommodate the longer trains.

It should be noted, however, that a change occurred not only in the location of the transition point, but also the relative trends inherent to Type II behaviour. Again comparing Figure 3 to Figure 2, the lines exhibiting Type II behaviour in Figure 3 are spaced farther apart, indicating a greater delay reduction resulting from the operation of long freight trains where long sidings are more frequent. This result is intuitive, based on the expectation that operation of longer and longer freight trains compared to existing short trains will continue to improve operational efficiency, if nothing else than from total reduced train counts along the route.

This effect of replacement ratio on the transition point is further supported by the results of the other two replacement ratios (Figures 4 and 5). The transition point moves furthest to the left for the highest replacement ratio (3:1) and furthest to the right for the lowest replacement ratio (6:5).

To determine if there was any discernible trend between the train replacement ratio and the level of infrastructure investment at the transition point, Figure 6 was developed.

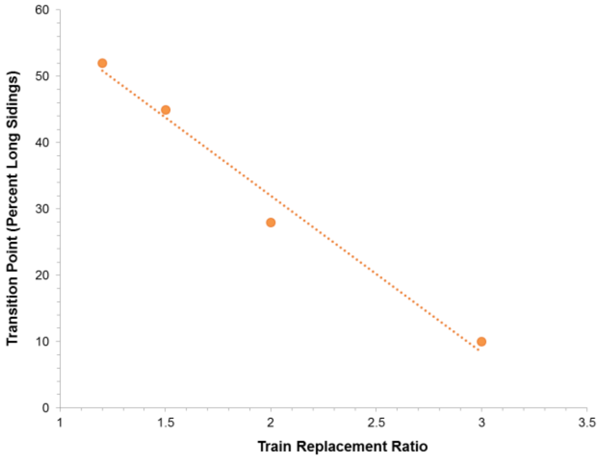

Figure 6: Transition Point as a Function of Train Replacement Ratio

The resulting plot of infrastructure investment at the transition point (measured in percent long sidings) as a function of train replacement ratio in Figure 6 shows a fairly linear relationship, with the transition point decreasing as replacement ratio increases. These results could be applicable to railway industry practice in that they provide some foresight into siding extension programs or, alternatively, train length optimization from a delay perspective.

For example, consider the case of an infrastructure owner that desires long train operations but only has enough capital to extend a certain percent of their passing sidings. This owner can use the relationship derived here to get a better sense for how long their trains would need to be lengthened in order to maintain their current level of service. Alternatively, if a target train length (and corresponding replacement ratio) has already been proposed, a more streamlined estimation of the required number of siding extensions can be developed as part of a capital plan. It should be noted that since the relationship appears to be linear, there does not appear to be an optimal point of diminishing returns in this regard.

The idea of linearity can, however, be argued from a conceptual standpoint. For example, if the replacement ratio was 1.01 (101-car long trains, 100-car short trains), it can be expected that almost all of the sidings along a route would need to be extended in order to maintain the current level of service. Alternatively, for a hypothetical replacement ratio of 12 (1,200-car long trains, 100-car short trains), it might be such that no sidings need to be lengthened since only two trains would need to be run to achieve a 2,400-car throughput. These conceptual data points would not follow the linear relationship suggested in Figure 6. Linearity as shown in Figure 6 may therefore just be a function of the limited range of values tested, with extremities potentially highlighting a more complex relationship. In either case, observation of more scenarios that test a broader range of replacement ratios can test the validity of the relationship observed thus far. However, the current result covers the most practical long train replacement scenarios that would be considered by the industry in practice. Further data would just fine-tune the extremes of a result that can already help streamline siding extension/train lengthening programs in the railway industry.

CONCLUSION

The economic and operational merits afforded by long train operation are commonly constrained by historically inadequate passing sidings in North America. This problem necessitates the need for infrastructure expansion in the form of either siding extension programs, or altogether new construction of longer passing sidings. The research presented in this study used a simulation approach to analyse the relationship between replacement ratios (i.e. the ratio in the length of long trains on a route relative to short trains) and required investment in infrastructure expansion. Results show a declining linear relationship between train replacement ratio and the point at which infrastructure investment on a route finally allows the operational efficiency expected from running longer freight trains to be realized. More specifically, the larger the replacement ratio, the less infrastructure expansion is required to achieve the operational economies of scale intuitively expected from long train operation. These findings can streamline the planning process by providing foresight on the scope and magnitude of siding extension programs in anticipation of longer heavy-haul freight train operations and their desired return on investment.

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