Influence of Siding Connection Length, Position, and Order on the Incremental Capacity of Transitioning from Single to Double Track

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ABSTRACT

The North American freight railroad network is projected to experience rising transportation demand in the coming decades, leading to increased congestion along many rail corridors – an effect further strained by increased interest in expanded passenger service on shared rail corridors. However, rail lines in the United States are still predominantly single track with passing sidings, making double track installation a vital capacity upgrade measure. Previous research has explored the allocation of double track on idealized lines with evenly spaced passing sidings. Due to numerous constraints, existing lines often exhibit a mixture of siding spacing with single-track bottleneck sections of varying length. This research seeks to identify the optimal double-tracking strategy for lines with a more realistic variability in siding spacing, and determine if the result supports long-held practitioner heuristics for locating double track. This is accomplished by testing several build-out strategies on a representative subdivision under mixed freight and passenger traffic with Rail Traffic Controller simulation software. Results suggest the prioritization of connecting longer bottleneck sections first, as opposed to shorter connections first. Analyses also determined the delay-based influence of connection position along a route, as well as the time order of connections within the full progression from single to double track. While railroads must consider many factors in selecting capital expansion projects, this paper suggests that heuristics involving connection length, position and order have the potential to capture relationships between infrastructure and train delay, streamlining the decision process and facilitating the economic expansion of existing rail corridors.

INTRODUCTION

The railway infrastructure in the United States is primarily composed of single-track mainlines with limited capacity to maintain required levels of service as traffic volumes grow *(1)*. Increasing demand for freight and passenger services can have a compounding effect where both operations share track infrastructure owned by the freight railroads *(2,3)*. On these shared rail corridors, it quickly becomes necessary to expand rail infrastructure to avoid congestion and mitigate delay to freight and passenger trains. While there are many approaches to increasing rail line capacity, the primary infrastructure expansion strategies typically involve the extension of existing passing sidings to accommodate meets between three trains or new construction of additional passing sidings along a corridor *(4)*. While these steps may provide initial solutions to the problem, it will eventually become necessary to consider installation of double-track segments to ensure capacity for future rail traffic volumes *(5)*.

Network-level models can help railroad practitioners quickly identify the routes where installation of double-track segments will be required to increase capacity (6). However, capital program planners are still faced with the complex task of selecting between dozens of possible candidate segments for installation of double track on each critical route. While obvious engineering obstacles such as tunnels and large bridges can quickly eliminate some possible locations, and local switching work, yard locations, and grades may make double track more attractive on certain segments, planners are still faced with the daunting task of selecting between a large numbers of project alternatives. Detailed simulation and engineering investigation to establish the cost and benefit of all options is largely impractical due to time and resource constraints. Thus, railroad planners often use simple heuristics to screen the alternatives and select a smaller subset of double-track projects for detailed evaluation. In discussion with Class 1 railroad planners, examples of double-track heuristics developed through experience include:

- Make longer double-track connections first, followed by shorter connections
- Double track offers the greatest return on segments approaching terminals
- Locations corresponding to the natural return grid for the average train interval between terminals are ideal candidates for double track
- Initial double track segments offer little return until they are connected by additional segments and the benefits compound; thus it is better to continue adding double-track segments along a route, as opposed to installing the first segment on a different route

Overall, these heuristics suggest that connection length, route position, and order can serve as quick indicators of the potential incremental capacity offered by installation of double track between a pair of existing passing sidings.

The analyses that follow aim to determine if the incremental delay benefits of installing segments of double track on single-track corridors exhibit trends in connection length, route position, and order that correspond to the above heuristics. If distinct trends are discovered that support the above heuristics, or entirely different rules, the results can serve as a guideline for a more streamlined decision-making process by helping to quickly identify the types of projects with the highest potential benefit. With a smaller number of project alternatives prioritized based on general guidelines, railroads can better utilize their modeling, planning and engineering resources in conducting a more detailed analysis to make a final selection between the few remaining options.

In the context of this paper, delay serves as both a measure of level of service and a proxy for line capacity, as is common practice in North America *(7)*. To compliment previous research results pertaining to idealized lines with evenly-spaced passing sidings, and to investigate the connection-length heuristic, this research explores siding connection strategies for lines with a mixture of distances between existing passing sidings. This scenario captures the more realistic range of siding spacing found within rail corridors due to real-world physical and engineering constraints.

BACKGROUND

Measurement of rail capacity and delay characteristics for single-track mainlines has been well-covered in existing literature, and such research has been extended into studies on the delay benefits of double-track installation. Mitra et al. introduced parametric methods for the estimation of single-track railway capacity *(8)*. Lindfeldt broadened the physical scope of single track analysis to consider and analyze the operational dynamics inherent to a double-track rail corridor configuration *(9)*. Gussow and Welch analyzed the capacity of partial double-track lines, and the effect of track infrastructure distribution on system performance *(10)*. The subsequent analyses conducted for this research, however, are rooted in results obtained through work developed previously by the authors and that of Sogin et al., where it was discovered that for idealized corridors with even 10- and 16-mile siding spacing, double-track installation provided a linear reduction in train delay for differing levels of freight traffic *(11,12)*. Graphical representations of excerpted train-delay characteristics from both works are shown in Figure 1. The reduction in delay resulting from double-track installation is consistent with previous findings that identified train meets as primary causes of delay, with double track allowing for a larger proportion of trains to avoid meets altogether *(13)*.

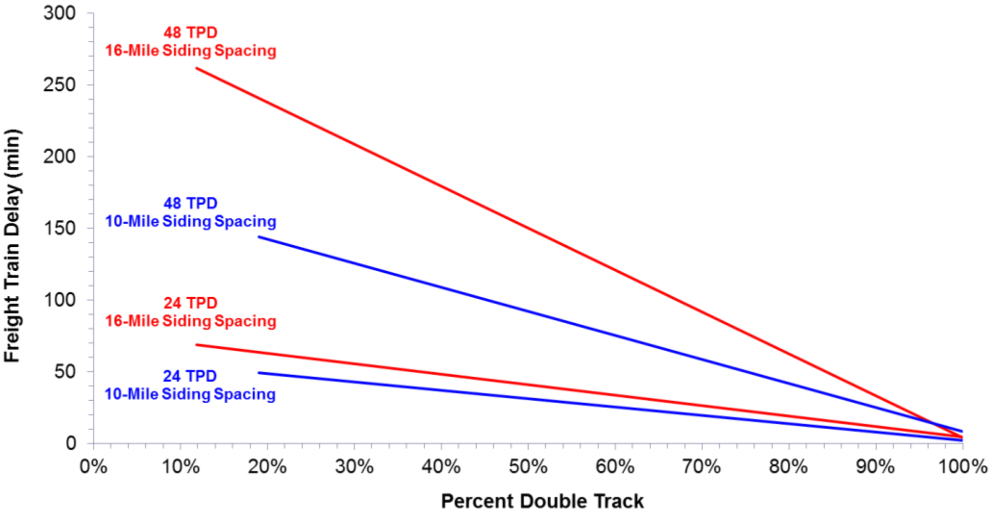

FIGURE 1 Train delay as a function of double track percentage for two freight traffic volumes and two initial siding arrangements *(10)*.

While linearity and general trends in delay-reduction are similar across the two traffic and initial infrastructure conditions presented in Figure 1, it is important to note, however, that they do differ in magnitude. More specifically, the slopes of lines for the 16-mile study (which represent minutes of delay reduction per percent double track installed) are steeper than their corresponding slope in the 10-mile study. On a macro scale, this phenomenon suggests that, given a particular traffic volume on a line with variable siding spacing, the connection of longer-spaced sidings (or elimination of the longest single-track bottlenecks) should reduce delay by an amount greater than that achievable via connection of shorter-spaced sidings (or elimination of the shortest single-track bottlenecks). This theoretical effect is visualized in Figure 2, where two contrasting delay responses are presented for an arbitrary route consisting of non-uniform siding spacing. The lower trajectory depicts a scenario where longer-spaced sidings are connected first. Train delay should theoretically exhibit an initially sharp decline followed by a reduction in incremental benefit resulting from the connection of remaining shorter-spaced sidings. The upper trajectory is a mirrored response of the former, representing the inverse scenario where shorter siding connections are given initial priority and increasing returns are observed as the final long connections are made.

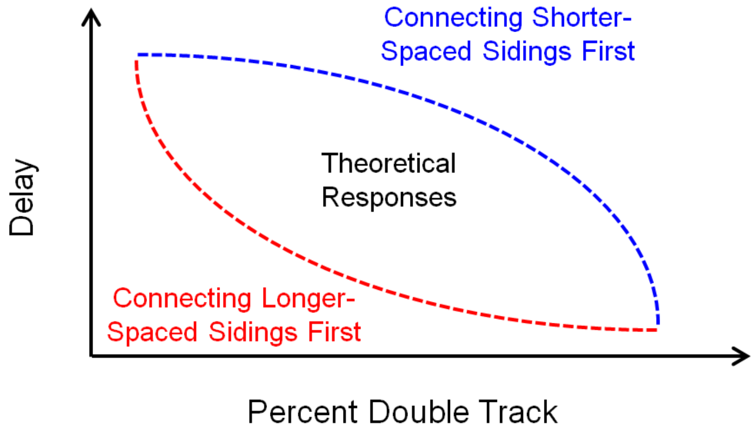

FIGURE 2 Theoretical delay response curves for two different siding connection strategies.

The theoretical response presented in Figure 2 follows conventional industry practice. The head of service design at one Class I railroad in the United States favors an incremental approach of gradually adding double track between sidings, beginning with the longest and proceeding to shorter sections of single track *(14)*. This research investigates the sensitivity of incremental line-capacity to different double-tracking strategies on lines with a mixture of siding spacing to aid railroads in better determining when there are capacity benefits to be gained by deviating from this standard “long-to-short” heuristic.

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 and Amtrak. 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, signaling, speed limits, and train consists *(15)*. Output includes train delay, dwell, siding usage and train energy consumption. In using RTC, results are aggregated over a specified number of simulation days and a specified number of simulation repetitions.

For the analyses that follow, infrastructure (in the form of double track segments) and train parameters are variable inputs, while train delay is the desired output. Each track arrangement described in the methodology section is run for five simulation days and includes five repetitions. Each repetition specifies a different train operating pattern where each train departs randomly from its respective terminal within a 24-hour window. Thus, each simulation data point is based on an average of 25 days of simulated train operations.

METHODOLOGY

While inputs to the simulation model were varied throughout the study, one consistent, overarching methodology was used to isolate the response of train delay to double-tracking strategies. In practice, it is the running time between sidings and not the siding spacing distance that can control the capacity of a single-track line. However, for this study, the maximum track speed on all sections of the hypothetical line is equal and the grade is also uniform, resulting in uniform operating speeds along the route (50mph freight trains, and 110mph passenger trains). Thus, the distance between passing siding centers can be used as a direct proxy for the running time between sidings. It should also be noted that, for the sake of completeness, the first part of the following methodology is carried over from previous work of the authors, since it forms the basis for subsequent steps *(11)*.

There are numerous strategies that can be employed when selecting the order of existing sidings to connect into double-track sections on a route with non-uniform siding spacing. Conventional industry practice, taking local variation in construction cost out of consideration, is to connect sidings that are the farthest apart first. Such a strategy ensures that the longest bottleneck sections are immediately removed from the route, presumably leading to the highest potential reduction in train delay. The goal of the following experiment is to determine the relative optimality of this practice relative to other connection strategies. To provide the greatest potential contrast in delay response, the two tested build-out strategies are a *short-to-long* strategy, where the shortest-spaced sidings are connected first, and the intuitive *long-to-short* strategy mentioned above, where the longest-spaced sidings are connected first. These build-out strategies are illustrated for a simple toy problem in Figure 3.

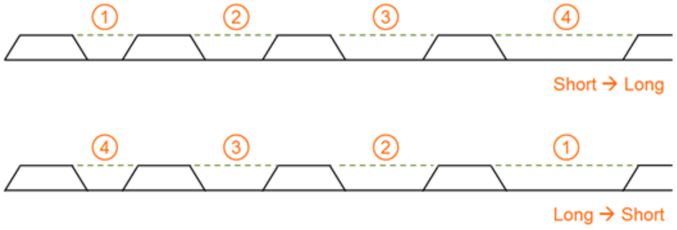

FIGURE 3 Generalized route with short-to-long and long-to-short build-out strategies. Circled numbers represent the order in which a siding connection is made.

The two build-out strategies are implemented on the 240-mile route layout shown in Figure 4. The numbers in Figure 4 represent the spacing, in miles, between adjacent sidings and lead to particular connection patterns on the *base*, *simplified* and *inverse simplified* layouts.

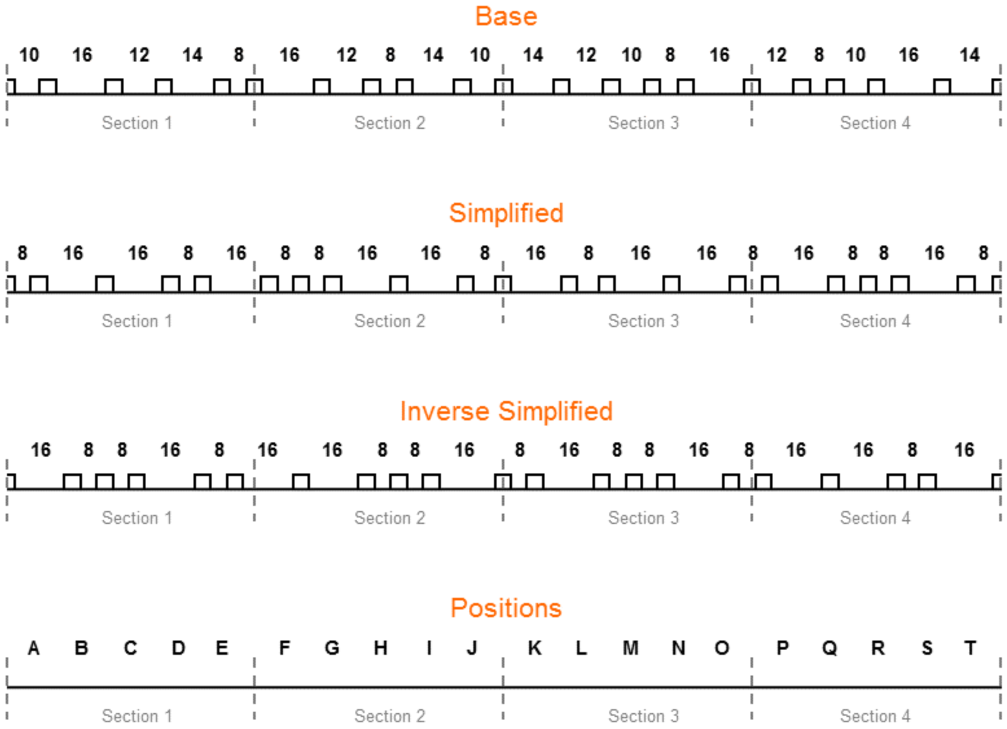

FIGURE 4 Initial siding arrangements for the 240-mile route. Numbers represent the spacing (in miles) between adjacent sidings, which are represented by squares. Bottom graphic depicts the naming convention for relative siding locations.

To illustrate the connection patterns, consider the case of the *short-to-long* connection strategy for the *base* arrangement. Initially, the sidings spaced at 8 miles in Section 1 and Section 3 are connected simultaneously, followed by the sidings spaced at 8 miles in Sections 2 and 4. This eliminates all of the bottlenecks between sidings spaced at 8 miles. At this point, the shortest remaining single-track sections are those between sidings spaced at 10 miles. The bottlenecks between sidings spaced at 10 miles in Section 1 and Section 3 are then connected simultaneously, followed by the single-track segments between sidings spaced at 10 miles in Sections 2 and 4. This pattern is repeated until the longest single-track segments between sidings spaced at 16 miles are connected, and the entire route is composed of two-mainline track. The same procedure is followed for the *long-to-short* strategy, only differing in that the single track between sidings spaced at 16 miles will be connected first, followed by 14, 12, etc.

The pattern described here helps isolate the effects of each build-out strategy by balancing the experiment. If a more random approach is taken, the route may end up unbalanced in the sense that one half of the route might have disproportionately more double-track compared to the other half. This situation could potentially confound the results.

To create the *simplified* layout in Figure 4, the *base* arrangement is adjusted to include only two distinct siding spacings (8 and 16 miles), as opposed to the original five. The purpose of focusing on these two extreme siding lengths is to potentially show a sharper contrast between the delay response of the two connection lengths and connection-order strategies. In the *simplified* layout, however, siding connections are no longer made in pairs, but rather one-by-one to bring out more detail in the simulation results. It should be noted that even though connections are no longer paired, successive connections still follow the general pattern of connecting in Sections 1 and 3, followed by Sections 2 and 4.

The *inverse simplified* layout in Figure 4 is created to isolate the influence of route position, as opposed to connection length of the new double-track segment. More specifically, where 8 miles exist between sidings in the *simplified* model, 16 miles exist in the *inverse simplified* scenario, and vice versa. Simulation and observation of this *inverse simplified* scenario in comparison to the *simplified* layout can determine if the delay reduction observed for a particular connection is a function of the siding connection length, the position of the siding connection along the route (e.g. near the middle of the route, close to terminals, etc.), or some combination of both of these factors.

RESULTS

After running simulations on the three siding connection arrangements described in the previous section, delay data is imported from RTC and used to characterize the relationship between train delay and double-tracking strategy. The results for each experiment are detailed in the following sections.

Base Scenario with Range of Connection Lengths

Simulation of the *base* scenario route with its range of siding spacing distances is carried out for both homogeneous and heterogeneous traffic mixtures. The homogeneous freight traffic scenario was developed in the authors' previous work, *(11)* but is presented in Figure 5 for comparison to the new analysis of the same layout under a mixture of freight and passenger trains.

Compared to the theoretical delay response (Figure 2) characterized by curved, mirrored delay trajectories dependent on the type of connection strategy being employed, Figure 5 shows little difference between the *short-to-long* and *long-to-short* connection strategies. There is almost no difference in the overall linear trend of each connection strategy for the case of homogeneous freight traffic. In the heterogeneous case, the introduction of priority passenger trains causes some separation between the delay-response of the two strategies. While delay reductions for the *long-to-short* connection patterns at both traffic volumes in the heterogeneous case show a fairly linear trend, the *short-to-long* connections follow a different trend. More specifically, delay values remain relatively static for lower percentages of double track (i.e. when shorter double-track sections are being added), and only begin to drop off near 50% double track. This point corresponds to the time when longer siding spacings (12-or-more miles) begin to be connected by new double-track sections. This pattern of delay reduction is comparable to that of the upper theoretical curve in Figure 2.

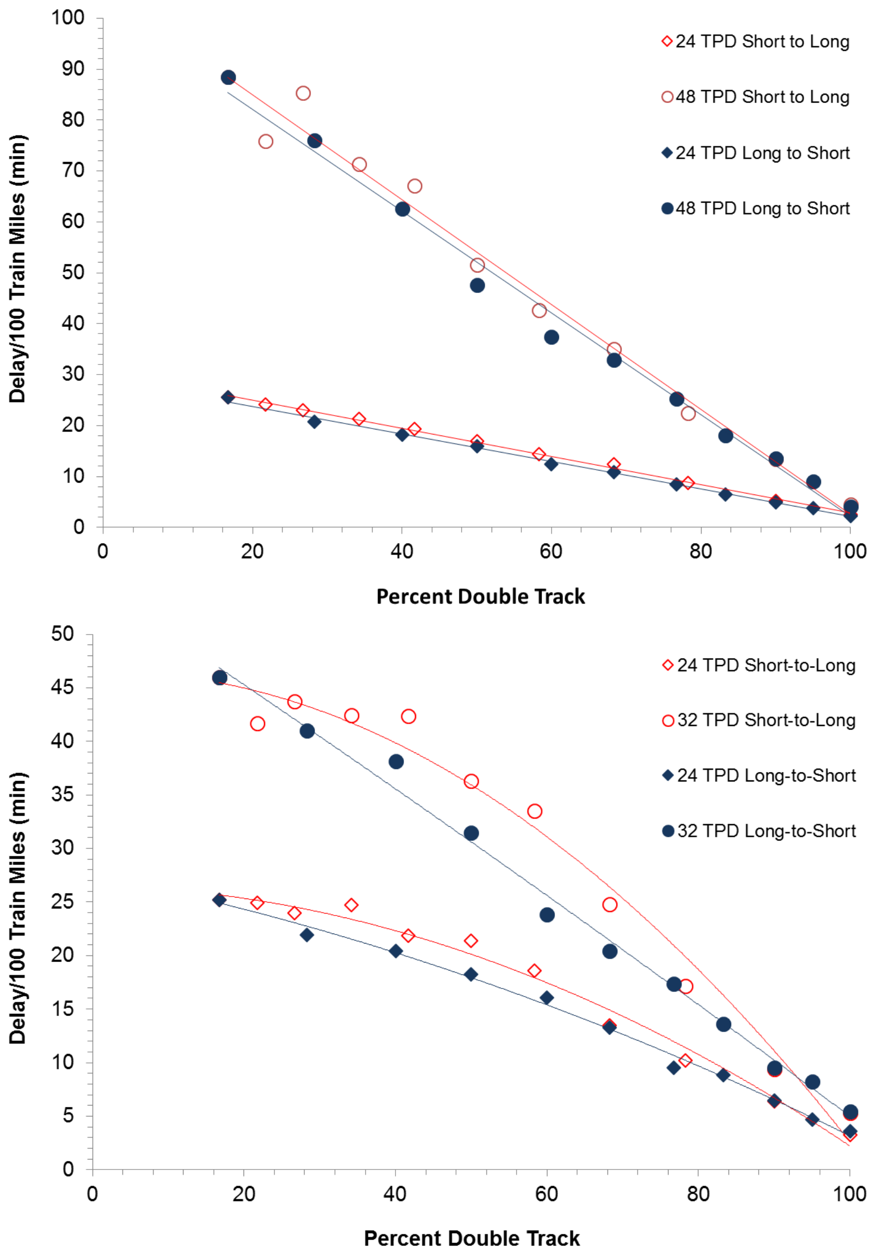

FIGURE 5 Delay as a function of percent double track for the homogeneous case (top) and heterogeneous case (bottom) of the Base scenario. Heterogeneous case includes 75% FRT, 25% PAX.

In the case of homogeneous freight traffic at 24 and 48 trains per day (TPD), Figure 5 indicates no substantial benefit to connecting longer bottleneck sections first when the entire progression is considered. This suggests that the lowest cost option (likely to be the connection of shorter-spaced sidings) should be preferred regardless of infrastructure location *(4)*. Inspection of the trends in the heterogeneous case, however, suggest there is an increased delay benefit to connecting longer bottlenecks first. In particular, connecting shorter bottlenecks first does little to reduce delay until sizable amounts of double track have already been installed and longer connections are made. These trends parallel some of the simple heuristics described earlier in the paper.

Simplified Scenarios with 8- and 16-Mile Connections

A potential limitation of the *base* scenario is that it involves a range of siding spacing distances. Thus, for connections made during the middle of each build-out progression, there are only small differences in the length of connections being made at each step when the *short-to-long* and *long-to-short* strategies are compared. This could be a possible explanation for the lack of separation in the delay response observed in Figure 5. To provide greater contrast in the lengths of connections being made by the *long-to-short* and *short-to-long* strategies at all double-track levels, the experiment was repeated for heterogeneous traffic on the *simplified* and *inverse simplified* layouts. As mentioned previously, the *simplified* and *inverse simplified* scenarios drop three of the intermediate siding connection lengths (10, 12, and 14 miles), leaving only the two "extremes" of 8 and 16 miles.

The delay response of the *short-to-long* and *long-to-short* strategies on the routes with only 8 and 16-mile connections is displayed graphically in Figure 6. For clarity, the response for the *simplified* and *inverse simplified* routes are presented on separate axes. It is immediately apparent that the actual response does not resemble the theoretical response predicted earlier. On both routes, the *short-to-long* and *long-to-short* curves overlay and even intertwine as the transition to full second-mainline track progresses. The *inverse simplified* scenario does exhibit a slight separation between the *long-to-short* and *short-to-long* curves but the effect is small. These results, at least in the graphical form in which they are presented, do not support the simple heuristic that connecting longer sections first will obtain greater benefits than connecting shorter sections first.

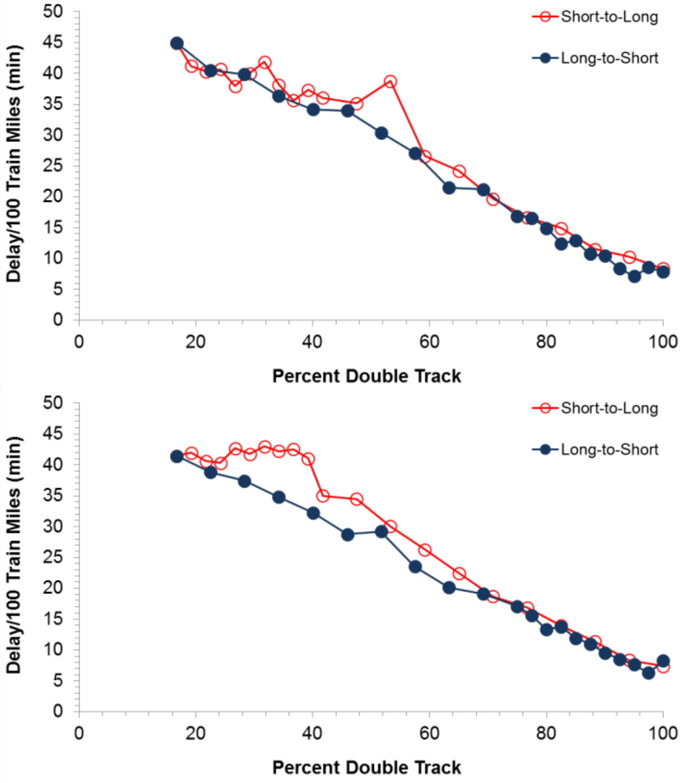

FIGURE 6 Delay as a function of percent double track for the Simplified (top) and Inverse Simplified (bottom) scenarios. Results shown are for 32 TPD, 75% FRT and 25% PAX.

Effect of Siding Connection Location

For a given route location, the four combinations of the *simplified* and *inverse simplified* routes and the *long-to-short* and *short-to-long* connection orders provide results for four distinct connection project circumstances:

1. The segment is short (8 miles) and connected early in the progression to double track
2. The segment is short and connected late in the progression
3. The segment is long (16 miles) and connected early in the progression
4. The segment is long and connected late in the progression

These four different results are summarized graphically for each route position in Figure 7. For the sake of comparability between different connection lengths, the delay values are normalized by the length of double track installed to make each siding connection. This process takes the corresponding reduction in minutes of delay per 100 train miles for each new double track segment, and divides by the length of the double track installed for that connection (expressed as a percent). The result is a measure of the rate of return on investment expressed in the units of minutes of delay reduction per percent of double track installed, or minutes per %DT.

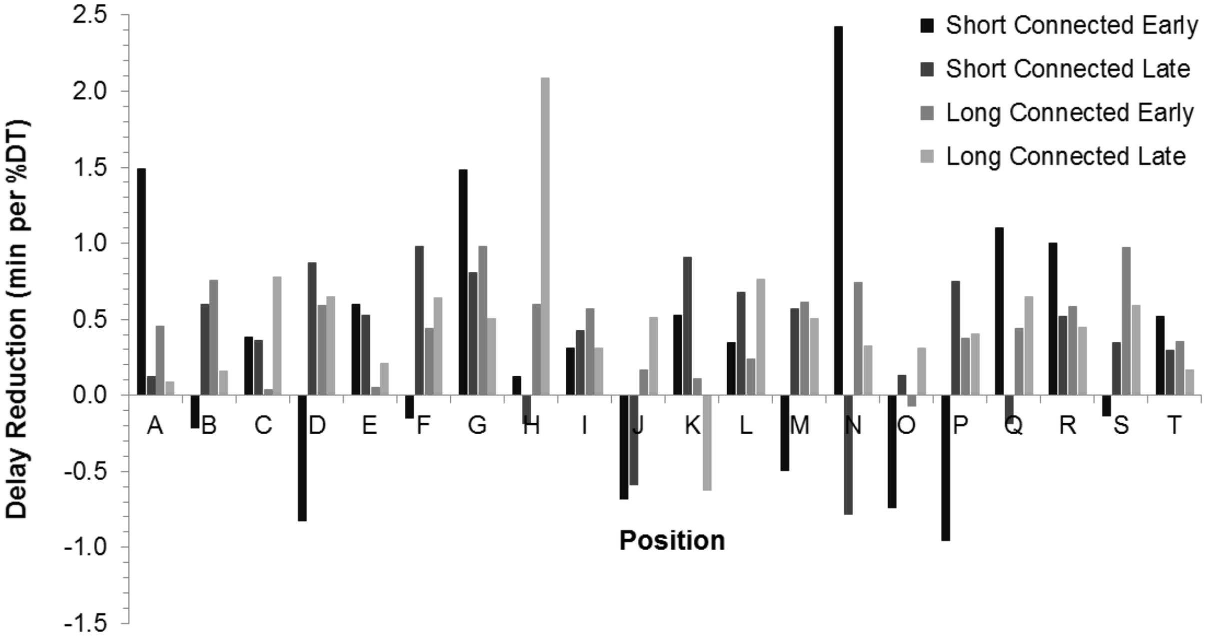

FIGURE 7 Average delay reduction for each combination of siding connection position, arrangement (i.e. Simplified and Inverse Simplified), and connection type. Results are for 32 TPD, 75% FRT and 25% PAX

If the heuristic of making long connections first is to hold true, the middle pair of bars at each position should show the largest delay reduction. It is apparent from Figure 7 that this is only the case for a small number of route positions and is not a general trend.

If it is to be assumed that siding connection position does not play a role in delay reduction trends, then the average value of each group of four bars associated with a particular position in Figure 7 should all, theoretically, be at or around the same height across all positions. The average magnitude of the bars, however, shows variation across positions. Certain route locations provide a larger delay reduction than others, regardless of their relative length or order within the progression to double track. Although there are positions that consistently provide larger delay reductions, there is no obvious structure to this response that easily ties these segments to specific route features. Thus position may not be the most useful heuristic on its own and that there is an interaction between position, connection length and order.

This finding is further supported by examining the relative delay reduction of the four different circumstances at each particular position. Although some positions have relatively consistent delay response across the four circumstances, most show wide variation for different combinations of connection length and order at a particular position. Overall, this comparison suggests the length of the single-track bottleneck segment should not be the sole consideration in establishing connection order; certain route positions may offer a greater return on investment. This may also help explain why the results in Figures 5 and 6 do not reflect the hypothesized relationship of siding connection length.

Effect of Siding Connection Order

A further reorganization of the simulation data is used to investigate the role of siding connection order. Figure 8 shows the average delay reduction associated with the temporal order in which each double-track connection project was completed. Each data point is associated with the time order in which it was completed within the full progression to double track, regardless of siding connection length or position along the route (i.e. the delay of all projects completed as the fifth step in a progression are averaged together to create the data point for step five).

A 3-step moving average for each traffic volume is included in Figure 8 to bring order to the highly variable distribution of average delay values. Note that projects ordered in the latter half of the double-tracking progression typically show higher delay reduction values compared to projects completed near the beginning or very end of a progression. This finding suggests that there are some economies of scale to adding double-track connections in that later connections compound on the benefits of the previous connections. While this supports the initial order heuristic described earlier, the weak trend suggests that connection order is not a dominant decision factor. Thus, order should be factored into infrastructure expansion decision-making in conjunction with siding connection length and position.

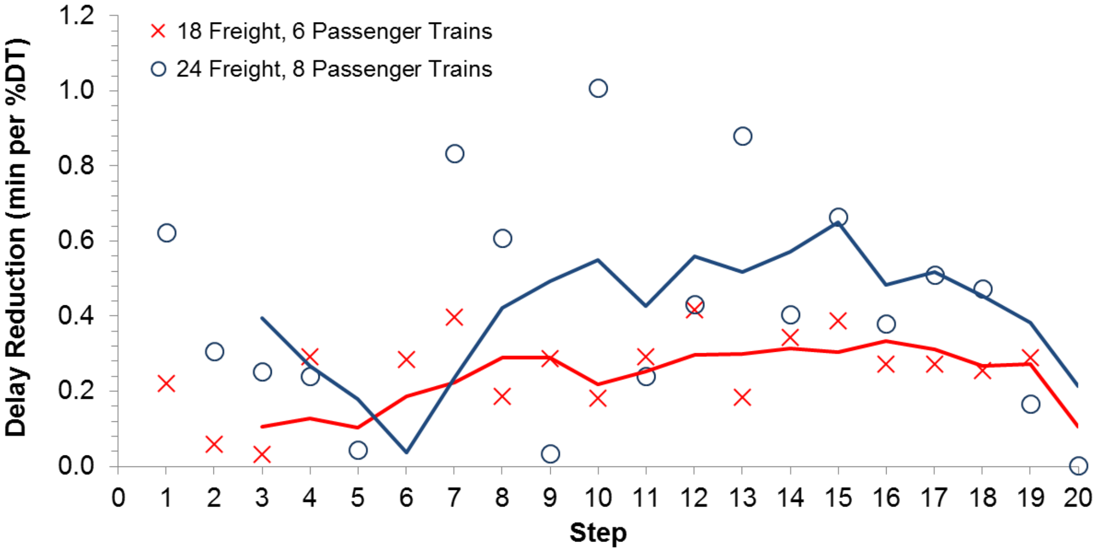

FIGURE 8 Delay reduction as a function of siding connection order (with 3-step moving average).

Comprehensive Results

A primary objective of this study is to determine if there is significant delay-benefit in connecting longer-spaced sidings first, as opposed to sidings with shorter spacing. By combining the simulated delay results across all three route layouts (*base, simplified,* and *inverse simplified*), Figure 9 serves as a summary of the effects of siding connection length on line capacity. Again, delay values are normalized by the length of double track installed, making for fair comparisons between the two siding connection lengths.

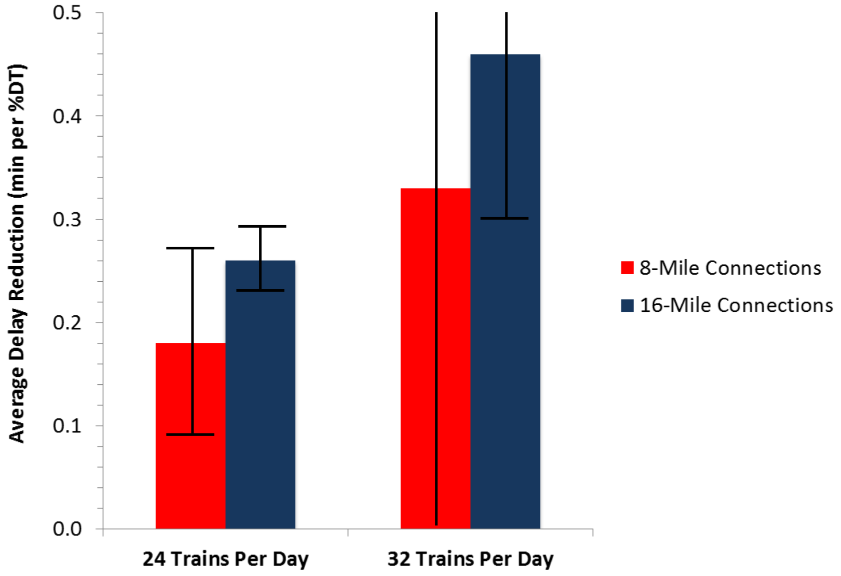

FIGURE 9 Summary of average delay reduction (with overlaid variance bars) for the connection of 8- and 16-mile siding spacings.

Figure 9 shows larger normalized average delay reduction values for 16-mile siding connections as opposed to 8-mile connections, supporting the heuristic of prioritizing longer bottleneck sections for initial double-tracking. The values presented here suggest that longer connections are approximately 50% more effective at reducing delay as opposed to shorter connections. It is important to note the substantially smaller delay variance values for 16-mile connection projects as compared to the 8-mile projects. The difference in variance indicates that the longer connections provide more consistent delay reduction, while short connections are more sensitive to the effects of route position and connection order.

CONCLUSIONS

Highly-congested rail corridors with high traffic volumes have historically been improved with infrastructure expansion in the form of siding extensions or additions. However, the continued growth on particular corridors requires the installation of double track to upgrade capacity. Initial double-track project alternatives are often identified using simple heuristic rules regarding connection length, position, and order. Analysis of different siding connection strategies on a corridor with different siding spacing did not clearly support any one of the heuristic approaches as the definitive rule for locating double track. The results demonstrate that the delay response of siding connection projects is influenced not only by the length of the connection being made, but its position along the route, as well as the order that these connections are made within the full progression from single to double track. In particular, double-tracking projects completed in the latter half of the entire progression from single to double track are expected to have a greater delay-based return on investment. While longer connections appear to provide more consistent delay reduction, shorter connections are more sensitive to the effects of route position and connection order, and can provide substantial delay reductions under the right conditions. These findings suggest a more holistic planning approach with more complex heuristics, requiring factor combinations of connection length, order, and position in order to properly support initial screening of double-track project alternatives. When developed, a more comprehensive set of heuristics will lend themselves to practitioner applications in the form of a streamlined decision process for capital expansion projects.

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