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**SIDING SPACING AND THE INCREMENTAL CAPACITY OF THE TRANSITION
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. Increased interest in expanded passenger service on shared rail corridors will also create additional capacity demand. However, the nation’s rail lines are still predominantly single track with passing sidings, making double track installation a vital capacity upgrade measure to sustain future volumes. Since increasing capacity through double track installation requires significant capital investment, the second main track must be allocated along a line in an optimal manner to provide maximum return on investment. An approach of investing in the least costly segments first may yield good results, but only if the benefits for each segment are equal. This research seeks to identify if the benefit of double track varies between bottleneck segments, and if there are compounding benefits of double track between adjacent passing sidings. Previous research has explored the allocation of double track on an idealized line with evenly spaced passing sidings. Due to numerous physical and engineering constraints, existing lines often exhibit a mixture of siding spacing with single-track bottleneck sections of varying length. To investigate the incremental capacity of adding double-track segments to a route with variable siding spacing, several build-out strategies are tested on a representative subdivision under random, mixed freight and passenger traffic via Rail Traffic Controller simulation software. The presented results highlight the most effective method, based on train delay, of incremental single to double track expansion and the potential differences in benefit between strategies. The linear delay reduction characteristics of single-to-double track mainlines vary based on the initial spatial arrangement of passing sidings and amount of second main track installed. These results further the understanding of relationships between infrastructure location and freight delay, thereby serving as a guideline for the sustainable expansion of existing rail corridors in anticipation

of future demands. While railroads must consider many factors in selecting capital expansion projects, these guidelines can streamline the decision process by helping to quickly identify the projects with the most potential for more detailed engineering evaluation. The methodology presented can eventually be incorporated into analyzing the progressions from double to triple track lines.

INTRODUCTION

The railway infrastructure in the United States is primarily composed of single-track mainlines with limited flexibility for routing conflicting train movements, causing these particular freight corridors to be much more prone to reduced levels of service as traffic grows. With ever-increasing demands for freight and passenger services, and at times combined along a shared corridor, it becomes necessary to expand rail infrastructure to accommodate the increases in traffic. While the methodology for dealing with such strains on rail corridors is varied, the primary actions in regards to infrastructure expansion typically involve the extension of existing sidings (e.g. a “super siding”), or altogether new construction of additional sidings along a particular corridor. However, while these steps may provide initial, or temporary, solutions to the problem, it may become necessary to look towards installation of double track as a sustainable upgrade measure to ensure the accommodation of future volumes.

The analyses that follow aim to characterize the incremental double-tracking delay benefits (with delay serving as a simultaneous measure of capacity and level of service) for corridors with varying initial siding spacing. To compliment previous research results pertaining to idealized lines with evenly spaced passing sidings, the objective of this research is to present a siding connection strategy for a more realistic scenario with a mixture of siding spacing within a corridor (which is the result of real-world physical and engineering constraints). While there are many factors to consider in

planning for additional railway infrastructure, the development of this double-track build-out strategy is meant to serve as a guideline for a more streamlined decision-making process, helping to identify the types of projects with the highest potential for benefit realization. These strategies should be taken into consideration along with other delay-inducing factors such as local switching work, yard locations, and grades that may make double track more attractive on one mainline segment than another. 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.

BACKGROUND

The delay characteristics for single-track mainlines have been well-covered in existing literature, and such research has been extended into studies on the delay benefits of double-track installation. The subsequent analyses provided in this research study are an extension of results obtained via the work developed by Sogin et al., where it was discovered that for idealized corridors with an even 10-mile siding spacing, double-track installation provided a linear reduction in train delay, measured in minutes, for differing levels of freight traffic [1]. The reductions in delay resulting from double-track installation are in keeping with the notion that train meets are the primary causes of delay, due to the fact that double track allows a larger proportion of trains to avoid meets altogether [2].

The research conducted by Sogin et al. involved Rail Traffic Controller (RTC) simulation of different strategies for transitioning from single to double track. The optimal build-out strategy from that research that will be used in the analysis that follows is an *alternating* strategy that is graphically represented in Figure 1 below:



Figure 1: Alternating build-out strategy in which (not necessarily) four midpoints are chosen along the corridor, and second mainline track is built out in each direction

The alternating strategy involves the specification of four to six points along the length of the route from which second mainline track would be built out in both directions.

A part of the analysis presented in the following sections is an effort to supplement and verify the conclusion of linear delay reduction of the Sogin et al. 10-mile siding spacing scenarios, in that this research observes the delay response when the initial route consists of sidings that are evenly spaced at a lengthier 16 miles apart. Conclusions drawn from this analysis are then extended further by application into more realistic scenarios where initial siding spacing is non-uniform.

RAIL TRAFFIC CONTROLLER

Rail Traffic Controller (RTC) is the industry-leading rail traffic simulation software in the United States, and is used by a wide range of public and private organizations, including most Class I railroads, Amtrak, and Bay Area Rapid Transit (BART). With the sophistication of the software increasing continuously throughout the years, users are provided with a very robust modeling software that captures a plethora of the most influential train operation characteristics and specifications.

Inputs for the simulations run in RTC are very diverse, and can range from factors such as track layout and signaling, to speed limits and train consists [3]. Output is similarly diverse, and can include reports that outline train delay, dwell, siding usage counts, and train energy consumption. Results are aggregated over a specified number of simulation days, and a specified number of “seeds” (i.e. simulation repetitions). For the analyses that follow, train delay was the desired output, and the only difference between simulations was the infrastructure additions in the form of double track segments.

METHODOLOGY

Different methodologies were employed for the two separate studies that were conducted: one for the study of delay characteristics of routes with 16-mile siding spacing, and one for the study of the optimal double-track installation strategy for a route with variable siding spacing. These methodologies are detailed separately below. It should be noted that 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, as will be described in the following sections, the maximum track speed on all sections of the hypothetical line is equal and the grade is also uniform, resulting in the same operating speed. Thus, the distance between passing siding centers can be used as a direct proxy for the running time between sidings.

Impact of Initial Siding Spacing

In order to identify how increasing the initial distance between evenly-spaced sidings affects the benefits of double-track installation, two models were specified and simulated in RTC to generate comparative delay characteristics. A summary of the details of each model is provided in Table 1.

Table 1: Model parameters for two routes with differing initial siding spacing

Route Characteristics	Model 1	Model 2
Siding Spacing	10 miles	16 miles
Min. % Double Track	~ 19%	~ 12%
Max. % Double Track	100%	100%
Trains Per Day Range	8-60 (8 Levels)	8-64 (10 Levels)
Traffic Composition	100% Freight	100% Freight
Locomotives	SD70 (x3)	SD70 (x3)
No. of Cars	115 Hoppers	115 Hoppers
Length	6,325 feet	6,325 feet
Mass	16,445 tons	16,445 tons

Both models in the table above are built up from an identical, 240-mile route, differing only in the initial arrangement of the sidings (i.e. the spacing between them). The sidings in each model were then incrementally connected via the alternating strategy (Figure 1) until the entire 240-mile route was composed of a two-track mainline with universal crossovers at one end of each former siding location.

Model 1 was simulated by Sogin et al., whose results were documented and, as mentioned previously, showed a linear reduction in train delay as a function of percent double track [1]. Model 2 is constructed as a means of identifying the difference in delay patterns for a route that has longer bottleneck sections (i.e. single track sections), due to sidings being spaced farther apart initially. The term “Levels” in the table above is used to differentiate the exact number of differing train volumes considered; for example, ten levels between 8 and 64 trains per day indicates that there were ten distinct train volumes modeled within that range.

The siding spacing is the only significant difference in the two models: the difference in “Min. % Double Track” is a mathematical result of the fixed route length and the increased siding spacing resulting in fewer sidings initially, while the jump to ten levels in Model 2 as opposed to eight levels in Model 1 is used solely for improved detail in the results. Both models were run for five “simulation days”, and included five repetitions at each combination of traffic level and double track percentage. Each repetition specifies a distinct train schedule where each train departs randomly from its respective yard within a 24-hour window. Thus, each data point is based on an average of 25 days of simulated train operations.

Variable Siding Spacing and Connection Strategy

While the experiment specified in the previous section on siding arrangement provides a better understanding for the delay characteristics of routes with closely spaced sidings as opposed to a more sparse arrangement, the vast majority of single-track routes will not have such ideal, evenly spaced sidings due to a variety of engineering, operational, environmental, geographic, land use and historical considerations. In order to investigate a double track installation strategy for corridors that would have a more non-uniform siding arrangement (a scenario more representative of corridors found in today’s rail industry), a new set of model parameters were created for simulation by RTC.

In general, there are countless strategies that can be employed in selecting the order to connect existing sidings to create double track sections. The most intuitive strategy, taking local variation in construction cost momentarily out of consideration, would be 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 delay. This strategy has not been proven, however, and so the goal of the following experiment is to determine what sort of strategy is, in fact, the optimal strategy in train delay reduction. To provide the greatest potential contrast in delay response, the two build-out

strategies that will be tested are a *short-to-long* strategy, where the shortest siding spacings are connected first, and the intuitive *long-to-short* strategy mentioned above, where the longest siding spacings are connected first. These build-out strategies are illustrated for a simple toy problem in Figure 2.

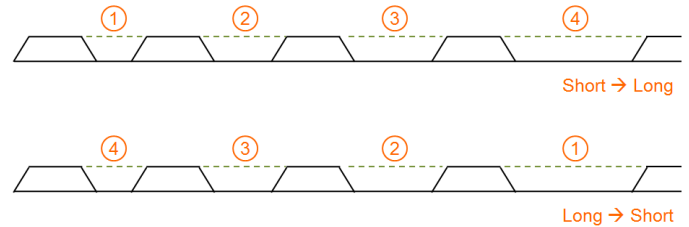


Figure 2: Generalized route with short-to-long and long-to-short build-out strategies. Circled numbers represent the order in which a siding connection is made.

These two build-out strategies will be realized on the route layout shown in Figure 3 below. The numbers in Figure 3 represent the spacing, in miles, between adjacent sidings and will follow a particular connection pattern.

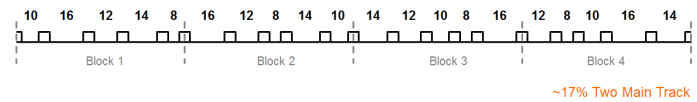


Figure 3: Initial 240-mile route layout for variable siding spacing and connection strategy experiment. Numbers represent the spacing (in miles) between adjacent sidings, which are represented by squares.

For further clarification, and as an example, consider the case of the *short-to-long* connection strategy. Initially, the sidings spaced at 8 miles in Block 1 and Block 3 will be connected simultaneously, followed by the sidings spaced at 8 miles in Blocks 2 and 4. This eliminates all of the bottlenecks between sidings spaced at 8 miles, leaving the shortest single-track sections as those between sidings spaced at 10 miles. The bottlenecks between sidings spaced at 10 miles in Block 1 and Block 3 will then be connected simultaneously, followed by the single-track segments between sidings spaced at 10 miles in Blocks 2 and 4. This pattern will repeat itself incrementally 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 exact same procedure will be 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 to isolate the effects of each build-out strategy by bringing order to the experiment. If the alternating pattern of building in Blocks 1 and 3, and then 2 and 4, is not followed and a more random approach is taken, the route may end up unbalanced in the sense that one side of the route might be disproportionately double-tracked, while another segment remains sparsely connected. This would confound the results, distracting from the goal of the study to

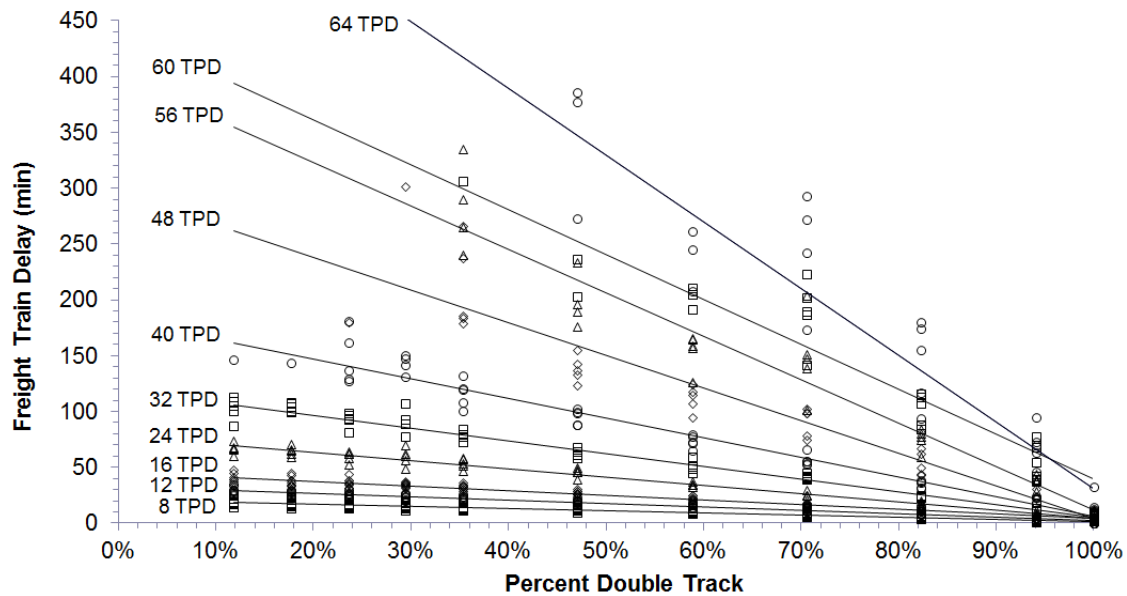


Figure 4: Train delay as a function of percent double track for a route with an initially even 16-mile siding spacing, with differing freight traffic volumes

determine how each build-out strategy fares in regards to train delay reduction.

RESULTS

After running the simulations for the two experiments described in the previous section, train delay data was imported from RTC and used to define improvements in line capacity due to double track installation. The results for each experiment are detailed in the following sections.

Impact of Initial Siding Spacing

RTC simulation of the two models presented in the methodology section provided detailed delay characteristics, with the delay patterns of Model 2 being summarized graphically in Figure 4.

Much like the results obtained by Sogin et al. (Model 1), there appears to be a linear response of train delay to additional sections of double track [1]. However, the delays, in absolute terms, are much higher in value than those obtained for Model 1, which included sidings spaced closer together (10 miles on-center as opposed to 16). This follows with intuition, since it is expected that for Model 2 above, there would be a greater level of train delay simply because there are longer bottleneck sections throughout the route than there were in Model 1 and the increased length of these single-track sections increases running time through the bottleneck.

The slopes of the lines in Figure 4 provide additional information: there is a greater reduction in train delay (i.e. a steeper negative slope) for routes with higher traffic volumes. This, again, is expected, since it is logical for routes that have a higher saturation of train traffic, and therefore more train meets,

to experience a higher level of congestion relief with the construction of additional sections of second-mainline track. Both of the results described here help to ensure the validity of the simulations.

It should be noted, however, that although a linear delay reduction characteristic is indicated by the graph in Figure 4, there is a larger variation in delay values for routes with higher train volumes and/or lower double track percentages. In fact, when these two factors are combined, data becomes either limited or nonexistent, as shown in the empty upper-left corner of the graph. This is a result of such high train delays that RTC actually ends the simulation process for those scenarios since the conflicts cannot be resolved reasonably. This is a problem that jeopardizes the linear relationship in that if data could be collected at these higher volumes/lower double track percentages, it might be realized that the relationship is not linear but rather follows some other trend altogether.

A more detailed comparison of the results of Model 1 and Model 2 are presented in Figure 5. The blue lines in Figure 5 represent the results from Model 1, while the red lines represent the results from Model 2. It is important to note how the patterns in Figure 5 highlight the significance of traffic volume in the delay reduction benefits of double-track installation. In the case of 24 trains per day (TPD), the lines almost overlap, indicating that double-tracking has a relatively equal benefit in terms of delay regardless of initial siding spacing. However, in the case of 48 TPD, the lines are much farther apart and the gap between the two (indicated by the orange arrows) is disproportionately large in comparison to the gap for 24 TPD. More specifically, the gap between the two 48 TPD lines is more than double the gap for the 24 TPD lines, even though the traffic volume is only twice as large. This indicates that siding

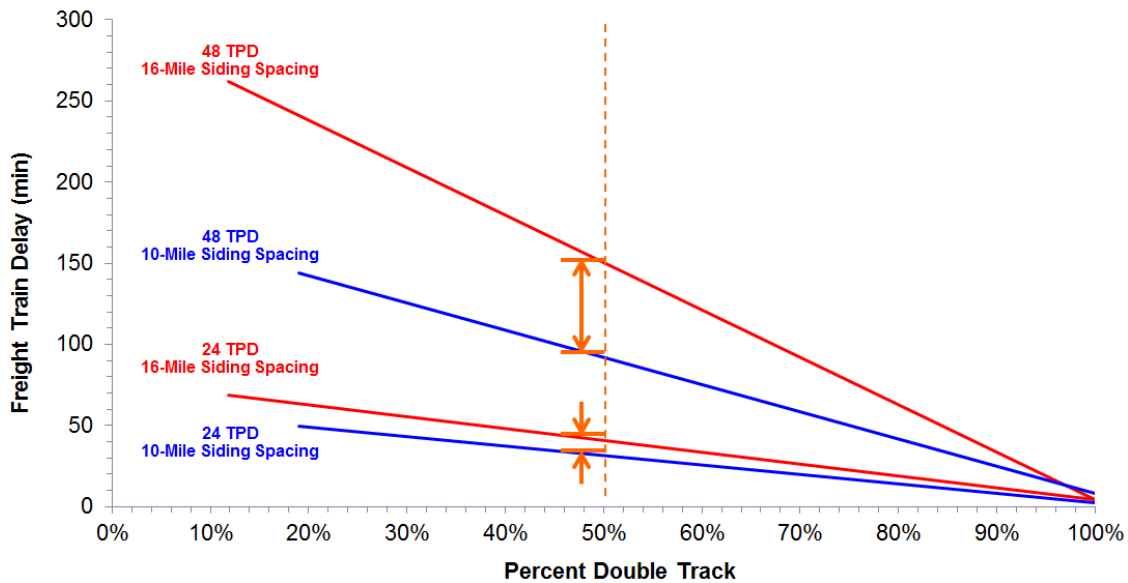


Figure 5: Train delay as a function of double track percentage for two freight traffic volumes and two different initial siding arrangements

spacing has a disproportionately larger impact on delay for lines with higher traffic volume than those with lower traffic volume. The relative slopes of the lines at 48 trains per day also indicate that for the same high traffic volume, double track has a disproportionately larger benefit on lines with larger initial siding spacing. This difference in delay response observed from connecting sidings at different spacing under the same traffic volume provides additional motivation for the investigation of variable siding spacing conducted as the second part of this research. It also suggests that a *long-to-short* strategy might yield the best delay reduction response.

Variable Siding Spacing and Connection Strategy

Running the variable siding spacing simulations under the methodology described previously, the comparison of delay as a function of double track percentage for the two build-out strategies (*short-to-long* and *long-to-short*) is shown in Figure 6. It was previously mentioned that, intuitively, it would seem logical that the *long-to-short* siding build-out strategy would provide the highest incremental delay benefits since this strategy takes care of eliminating the longest bottleneck sections first. However, inspection of the graph in Figure 6 indicates that this is not so; in fact, the lines for each build out strategy at equal train volumes almost entirely overlap one another. On the surface, what this result indicates is that it does not matter whether or not longer-spaced sidings are connected first or if those that are closer together are connected first instead.

A more detailed look at the incremental double tracking benefits of each build-out strategy is provided in Table 2 for the *short-to-long* strategy and in Table 3 for the *long-to-short* strategy. The incremental benefit of each individual step in the

double track construction process is calculated by taking the corresponding reduction in minutes of delay (per 100 train miles) and dividing by the length of double track installed in that segment (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. By assigning specific dollar amounts to the cost of delay and cost of double-track installation per mile, this rate of return could be transformed into a benefit-cost ratio. In Tables 2 and 3, the benefit is averaged over all steps that involve connecting sidings spaced at the same distance.

Table 2: Incremental delay benefits for the *short-to-long* siding connection strategy

Connection	Delay Reduction (minutes per % DT)	
	24 TPD	48 TPD
8-Mile Siding Spacing	-0.26	-0.31
10-Mile Siding Spacing	-0.24	-1.87
12-Mile Siding Spacing	-0.29	-1.88
14-Mile Siding Spacing	-0.29	-0.77
16-Mile Siding Spacing	-0.28	-0.83

Table 3: Incremental delay benefits for the *long-to-short* siding connection strategy

Connection	Delay Reduction (minutes per % DT)	
	24 TPD	48 TPD
16-Mile Siding Spacing	-0.32	-1.11
14-Mile Siding Spacing	-0.29	-1.26
12-Mile Siding Spacing	-0.24	-0.72
10-Mile Siding Spacing	-0.26	-0.89
8-Mile Siding Spacing	-0.28	-0.94

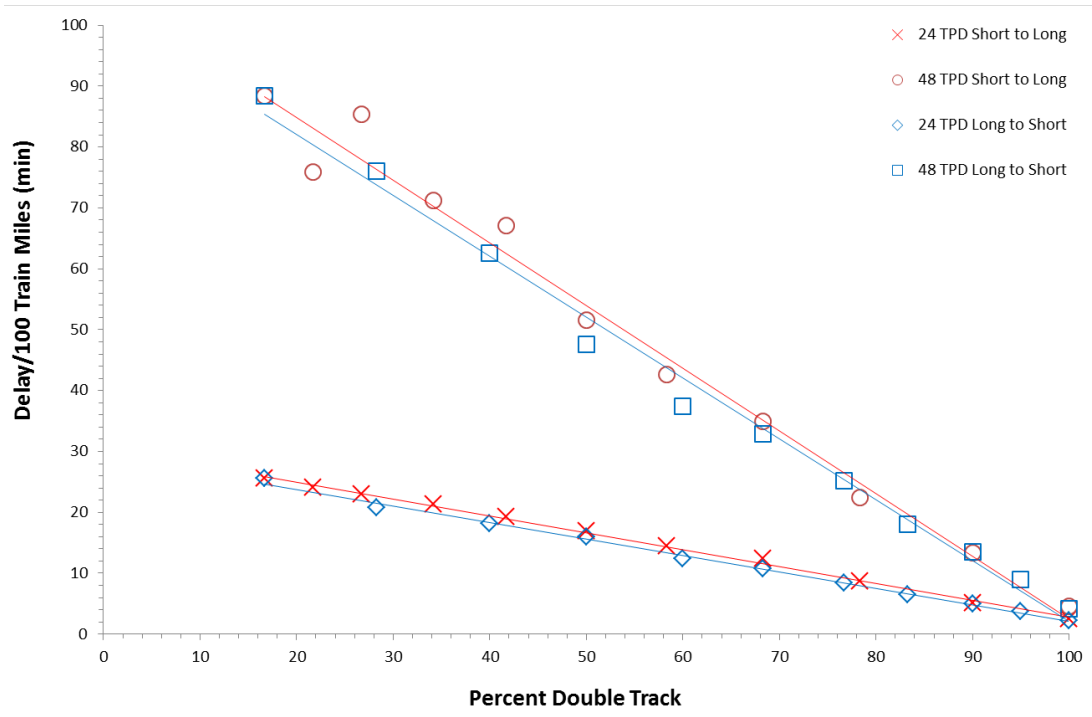


Figure 6: Delay per 100 train miles as a function of percent double track for two freight volumes (24 TPD and 48 TPD) under two different build-out strategies

While the two tables appear very similar at first glance, further inspection reveals differences. For example, at 48 TPD and an 8-mile spacing, only 0.31 minutes per %DT are saved when these particular sections are connected first (i.e. *short-to-long* strategy), while 0.94 minutes per %DT are saved when they are connected last (i.e. *long-to-short* strategy). A reverse relationship in delay reduction rates is apparent for the 16-mile siding spacing segments, reaffirming the intuitive notion that connecting the longest bottleneck sections first yields a greater return on investment than connecting them last. Thus, the higher cost of eliminating longer bottleneck segments may be more easily justified if they are constructed earlier in the transition when their rates of return tend to be higher.

A railroad starting the process of installing double track on this corridor would most likely just simulate the first set of connections and then evaluate the benefit-cost ratio of the different alternatives to select the first project. In this case for a traffic volume of 48 trains per day, the rate of return for the 16-mile connections is 3.5 times the rate of return for the 8-mile connections. Thus, the *long-to-short* strategy will be adopted and the 16-mile connections are likely to be built first. However, if the entire set of connections is simulated incrementally, connecting the 8-mile segments first via the *short-to-long* strategy allows the 10 and 12-mile segments to have a greater return than when they are used to make later connections in the *long-to-short* strategy. Thus, the incremental benefit of a double-track connection between sidings as measured by delay reduction per unit of double track

installed is not purely a function of the length of the bottleneck segment. The rate of return for any individual incremental connection is heavily influenced by the size and number of different bottlenecks that have been previously eliminated and remain to be connected.

An example of this is the role of the 12-mile siding connection. This connection is more important in the scenario where the longest bottleneck sections have not yet been double tracked (i.e. *short-to-long* strategy), as opposed to when they have been previously (i.e. *long-to-short* strategy). This is further illustrated by comparing the rate of return for segments in the uniform siding spacing cases to the rate of return for the same-length segments in the variable siding spacing cases. At the higher traffic volumes of 48 TPD, the delay reduction for the even 16-mile siding spacing model presented in Figure 4 is roughly -1.22 minutes per %DT, compared to the -0.83 minutes per %DT and -1.11 minutes per %DT shown in the variable spacing models in Tables 2 and 3. This indicates that these long, 16-mile connections have a larger delay benefit when part of an even, idealized line of many widely-spaced sidings than for routes with variable siding spacing and shorter bottleneck segments.

CONCLUSIONS

Highly-congested rail corridors in the United States with large traffic volumes have historically been improved with infrastructure expansion in the form of siding extensions or

additions. However, the continued strain and projected growth on particular corridors has called attention to the installation of double track as a vital capacity upgrade measure in anticipation of future volumes. It was determined in this study that routes with sidings spaced farther apart initially receive larger reductions in train delay (i.e. more congestion relief) via double track installation than routes with sidings spaced closer together. Further comparisons revealed that siding spacing has a disproportionately larger impact on delay for lines with higher traffic volumes than those with relatively lower volumes, indicating that double track installation is disproportionately more beneficial on busy lines with a larger initial siding spacing.

In regards to variable siding spacing and connection strategies, the results showed, counter-intuitively, that when the entire progression is considered, there appears to be no significant difference in double tracking larger bottleneck sections first, as opposed to double tracking shorter-spaced sidings first. While the results themselves are unexpected, the implication for railway applications might be significant in that it suggests that the lowest-cost option (likely to be the connection of shorter-spaced sidings) should be the preferred option regardless of infrastructure locations. Support for the intuitive results, however, was garnered via Tables 2 and 3, where it was determined that connecting the longest bottleneck sections in a route first leads to the greatest initial return on investment in terms of reduction in train delay per unit of double track installed. However, these results are far from definitive, and lead to more involved questions regarding double track installation strategies. These questions will be addressed via the future work described in the following section.

FUTURE WORK

Based on the sparse data obtained via RTC for scenarios in which relatively high freight traffic volumes were combined with low double track percentages, the linear relationship between delay and percent double track may not be the true relationship at all traffic volumes. If this missing high-delay data was included in Figure 4, the linear trends might be disproven, and an entirely new curvilinear relationship between delay and percent double track might present itself for traffic volumes at or above 40 trains per day.

As for variable siding spacing and connection strategies, the results that stand in contrast to expectation could be clarified via experimentation in which the number of siding lengths considered in the route in Figure 3 are decreased from five to just two. More specifically, if only 8- and 16-mile siding spacings were considered and the intermediate spacings eliminated to focus solely on the two extremes, the results may provide a sharper contrast between the *short-to-long* and *long-to-short* siding connection strategies. Additionally, a zonal demand model could be used instead of the two existing strategies presented in this study. The zonal demand model would not follow a predetermined order of connection projects;

rather, it would incorporate a check of cumulative delay at each point in the route for each simulation. The delay in each zone would then be used to determine where along the route train delays are concentrated, and installing double track in those particular sections would become the next incremental expansion projects selected for implementation. This process would iterate itself after every route simulation in RTC, and would therefore represent an evolving, real-time decision strategy for double track installation, as opposed to the two predetermined strategies used in this study. This strategy could then be compared against the others in order to determine an optimal, streamlined process for identifying the projects with the most potential for further engineering evaluation.

Finally, the results in this paper were obtained for the case of homogenous freight traffic. A mixed-use corridor with freight and passenger trains operating at different speeds that create the need for train overtakes may benefit more from sections of double track than a homogeneous freight line. Potentially this may create a starker contrast between the *short-to-long* and *long-to-short* siding connection strategies on lines with variable siding spacing.

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