Comparison of Capacity Expansion Strategies for Single-Track Railway Lines with Sparse Sidings

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The North American railroad network is projected to experience increasingly constrained capacity. Growth in long-term demand for freight transportation combined with higher speeds and greater frequency of passenger trains operating on the same trackage will increase congestion at many locations. To accommodate this demand and maintain traffic fluidity, investment in projects to increase the capacity of many lines will be necessary. Recent changes in commodity flows, particularly related to rail transport of energy sources such as petroleum, alcohol, and coal, have led to growth on lines with historically lower traffic density and infrequent passing sidings that are too short for modern unit trains. This study aimed to find the most effective capacity expansion strategy for these single-track lines with sparse sidings. Rail Traffic Controller software was used to conduct experiments simulating traffic operation on such lines under several expansion alternatives, and the performance in terms of train delay and reliability was evaluated. The results suggest that for a single-track line with sparse sidings, the best strategy is first to construct new sidings between existing sidings in the middle of the corridor. Then these investments should be extended toward the two end terminals by constructing new sidings in successive gaps until the maximum number of sidings is reached. The results are also used to develop a relationship between the total length of the second main track and average freight train delay for use in planning capacity expansion on these lines.

The North American economic recovery has been marked by renewed growth in the demand for freight transport (*1, 2*). In addition, many government agencies are interested in expansion of intercity and commuter passenger rail operations with increased frequency and higher speeds on existing freight corridors. Both of these trends have a significant impact on rail line capacity (*3–5*). Consequently, the North American rail network is expected to face increasing capacity constraints that reduce efficiency and increase operating costs. Improving rail capacity to reduce this congestion is crucial to maintain the rail traffic fluidity and economic competitiveness of rail freight transportation.

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In general, rail capacity can be improved through changes in operational strategy or improvements to the infrastructure (*6–8*). Changes in operational strategies tend to have lower capital cost and can be implemented more quickly than infrastructure investment but will not be adequate to accommodate sustained growth in traffic. Given the projected increase in long-term demand for rail capacity, both infrastructure and operational strategies are needed.

North American railroads have been making infrastructure investments to increase capacity for more than 15 years, with a focus on adding multiple main tracks to key segments of core high-density rail corridors. However, recent changes in commodity flows and energy markets (primarily related to domestic production of ethanol and petroleum and exports of gas and coal) have changed this traffic pattern and resulted in growth on lines with historically lower traffic density and infrequent passing sidings of sufficient length to handle modern unit trains. To meet growing demand on these lines with sparse passing sidings, railroads have shifted capital to projects that increase capacity. For example, in 2011 and 2012, Canadian Pacific Railway invested US$97 million to renew and improve its network in the Bakken region of North Dakota to provide better service to the energy industry (*9*). Burlington Northern Santa Fe also initiated several siding projects related to energy industry development in 2012 (*10*). The Canadian National Railway was to spend US$68 million in 2013 to upgrade two of its branches in Wisconsin to cope with growth in "frac sand" transportation demand (*9*). Besides these examples, additional prospective projects are in the planning and engineering stages. Because of the large capital investment required for these infrastructure projects, understanding the relationship between infrastructure improvement and capacity increase on single-track lines with sparse sidings will help the railroads plan a more effective and efficient capacity expansion strategy.

Several previous studies relate to increased line capacity through infrastructure improvements. Petersen and Taylor used simulation analysis to find the best positions for longer sidings to accommodate passenger trains on freight lines (*11*). Pawar used analytical models to determine the length of long sidings required to reduce meet delays (*12*). These studies focused on only one specific type of capacity expansion alternative and are thus not general enough to cover all possible scenarios. Lindfeldt (*13*) utilized an analytical approach to find feasible strategies for a long-term, stepwise incremental process to increase capacity, and Sogin et al. used simulation methods to find the relationship between the length of a partial second main track and capacity of a rail corridor defined by train delay (*14, 15*). Both of these studies used more systematic methods to cover a wide range of expansion options but still had some limitations.

Lindfeldt analyzed a particular real-world line with specific existing characteristics, so the results do not easily lend themselves to generalization. The study by Sogin et al. was more general; it focused on the transition process from a single-track line with dense sidings (at the minimum practical siding spacing) to a full double-track line and examined the incremental impact of siding connection projects on capacity. However, the range of scenarios did not consider the transition from single-track lines with sparse sidings to single-track lines with dense sidings and higher capacity. The study also only looked at double-tracking projects, although there are several different capacity expansion options for lines with sparse sidings. Since these lines are common in North America and have been the subject of recent and planned infrastructure investment, a study investigating infrastructure improvement strategies for single-track lines with sparse sidings will enable better-informed investment decisions.

The objective of this research is to analyze the performance of possible alternative capacity expansion strategies for single-track lines with sparse sidings via simulation and identify the best strategy for particular conditions. The results can provide insight for railroad development of more effective capacity expansion programs. The following section introduces the methodology used to meet this objective, including the standard for evaluating traffic performance, the simulation tool, the parameters, and the experimental design. The analysis section presents how the best capacity expansion alternative was identified and how its relationship with line capacity was investigated.

METHODOLOGY

Standard for Performance Evaluation

Rail capacity can be measured in many different ways (*16–18*). Therefore, specific ways to evaluate rail capacity must be identified as the basis for measuring and comparing the performance of capacity expansion alternatives in this study. Two main approaches are frequently used to define capacity. The first way is by track occupation percentage. The compression method proposed by International Union of Railways 406 adopted this idea to represent capacity (*17*). The second approach is to use the average train delay and maximum allowable delay to define capacity. Krueger used this concept to obtain maximum throughput of traffic per unit of time (*3*). Since the flexible operating environment in North America does not fit into the strict schedule requirements of the first method, the concept of average train delay is adopted by this research to be the measurement of line capacity and traffic performance.

Rail Traffic Controller

The Rail Traffic Controller (RTC) software, developed by Berkeley Simulation Software, allows for detailed simulation of rail traffic performance on rail corridors in a stochastic operating environment. RTC takes both infrastructure and traffic properties into account, including maximum allowable track speed, curvature, grades, signal system, train departure time, and locomotive and rolling stock characteristics. On the basis of the input parameters, RTC makes train dispatching decisions to modify train paths and avoid conflicting movements. To resolve a conflict, RTC may delay or reschedule one or more trains on the basis of their priority to reflect the business objectives of the railroad. The emulation of dispatching decisions given train priority and various other attributes of the software have resulted in RTC's being adopted as the de facto standard for Class I railroads in North America.

Traffic Parameters and Infrastructure Properties

Krueger (*3*), Gorman (*19*), and Sogin et al. (*20*) identified several important traffic factors that affect capacity of a single-track line, and these parameters were incorporated into the experimental design for this study. These factors include traffic volume, maximum speed of freight trains, maximum speed of passenger trains, and traffic mixture. Traffic volume is defined as the total number of trains traversing the study route per day. The maximum speed values for freight and passenger trains are the highest authorized track speed for each group of trains under free-flow conditions. The actual traveling speed may often be constrained below these values because of the acceleration and braking required for different stopping patterns and to negotiate turnouts, the number and power of the locomotives assigned to the trains, and interference between train types. For purposes of generality, there are no curve speed restrictions on the route considered. Traffic mixture is expressed as the percentage of the total number of trains that are freight trains (*14, 15*). Varying the percentage of slow trains changes the level of interference caused by differences between train types; this process allows the study to consider both lines that are dominated by freight traffic and lines that are dominated by passenger traffic. For generality, the traffic on the study corridor includes only two train types: passenger and freight trains.

The two sets of train parameters are specified in Table 1. The freight trains represent typical bulk unit trains and were set according to a Cambridge Systematics study conducted for the Association of American Railroads (*2*). The passenger trains are based on train consists used for the regional intercity Amtrak Cascades service in the Pacific Northwest and are scheduled to make station stops every 30 mi. The car weight and length for both passenger and freight trains are the average values for each type of train. The trains described are simulated on a representative 240-mi single-track line with sparse sidings that is subject to various infrastructure improvements. The baseline corridor has passing sidings 2 mi long spaced every 20 mi. The baseline settings of these and other parameters are shown in Table 2. In addition to the train characteristics shown in Table 1, the

TABLE 1 Train Parameters and Characteristics for Simulation Model

Criterion	Freight Train	Passenger Train
Locomotive	3 EMD SD70	2 GE P42
Number of cars	115 hopper cars	7 articulated Talgo cars
Length (ft)	6,325	500
Weight (tons)	16,445	800
Ratio of horsepower to trailing tons	0.78	15.4
Scheduled stops	None	30-mi station spacing
Ideal total running time (h)	6.4–9.6	3.4–4.1
Ideal running time between adjacent sidings, 20-mi siding spacing (h)	0.4–0.8	0.2–0.3

TABLE 2 Route Parameters for Simulation Model

Parameter	Value
Total length of the line	240 mi
Initial siding spacing	20 mi
Initial percentage of two main track	9.50
Average signal spacing	2 mi
Diverging turnout speed	45 mph
Traffic control system	2-block, 3-aspect CTC

NOTE: CTC = centralized traffic control.

scheduled departure pattern also affects line capacity. In this study, train departure time is determined by using a random, uniform distribution over a 24-h period in order to obtain a stable average of traffic performance under a range of possible schedule scenarios.

The infrastructure improvements in the experimental design alter the percentage of a second main track according to a particular capacity expansion strategy. The second main track is the second track of a single track mainline. The percentage of a second main track is the ratio of total length of a second main track, including passing sidings, to the total length of the corridor, expressed as a percentage. The higher the percentage, the greater the length of the second main track present for trains to meet and pass. By this definition, the baseline corridor is 9.5% of two main tracks. Since passing sidings are counted as a part of a second main track in this study, increasing the number of sidings will increase the percentage of a second main track.

The alternative capacity expansion strategies selected for analysis are part of the larger transition processes from a single-track line with sparse sidings to a full two main track line (Figure 1). The dashed arrow indicates the transition strategy of connecting closely spaced sidings with double track, previously studied by Sogin et al. (*14, 15*). The bold terms beside the arrows in Figure 1 indicate the alternative processes considered in this study; the exact expansion strategies between 9.5% and 19% of a main track are shown in Figure 2. Alternatives 1a and 1b both consist of inserting new sidings between existing sidings to create a single-track line with dense siding spacing. However, 1a initiates new siding construction from the middle of the corridor, whereas 1b more evenly distributes the siding projects along the corridor. Alternative 2 is the siding connection process in which the existing sidings are connected to form one continuous portion of a second main track. This approach is considered because of research suggesting that the double-track resource has the greatest capacity benefit if installed in one group (*21*). Alternative 3 is the strategy of converting the existing passing sidings into "super sidings" by doubling their length and installing an intermediate universal crossover at the new supersiding midpoint. This strategy is used by at least one Class 1 railroad to reduce delay through greater flexibility in meets and overtakes between two or more trains at a single location (*22*). To emulate the transition process and capture intermediate differences between the four alternative strategies, three routes with different levels of percentage of a second main track were constructed for each alternative.

Partial Factorial Design

This study seeks to investigate the main effects and interactions of the selected factors on train delay so that the performance of the different capacity expansion alternatives can be evaluated. A traditional systematic method to construct experiments for effect and interaction analysis is a full factorial design and includes trials with all possible combinations of factors. Experiments with many factors can result in a large number of trials and redundancies in the experiment matrix. To solve this problem, a similar method called partial factorial design is used (*23*). The experimental matrix generated through partial factorial design is composed of a carefully chosen subset of the full factorial design in order to reduce redundancy while maintaining the characteristics of the response surface (*23*).

Table 3 displays the factor levels used by the partial factorial design. The highest traffic volume tested in this study is 24 trains per day because of the limited capacity of the initial single-track line with sparse sidings. Higher traffic volumes lead to failed RTC simulation runs and a lack of valid simulation results for inclusion in the response surface. The value of the percentage of slow trains ranges from 25% to 75% to capture the effect of heterogeneous traffic. The lowest

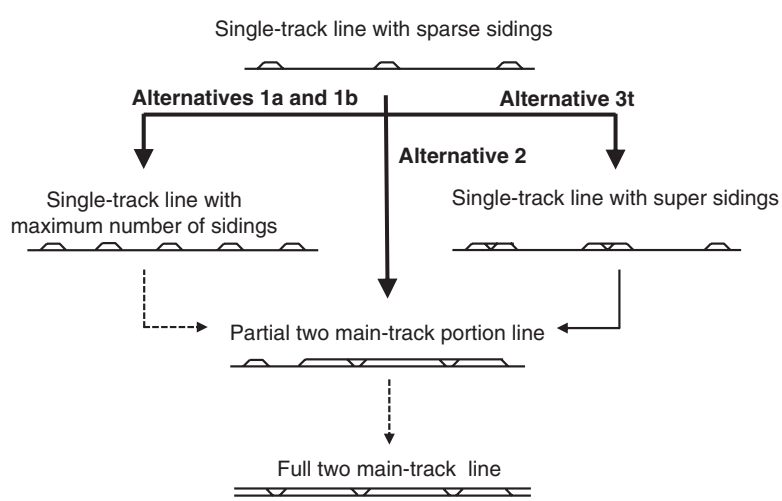

FIGURE 1 Transition process from single-track lines with sparse sidings to full two main track line.

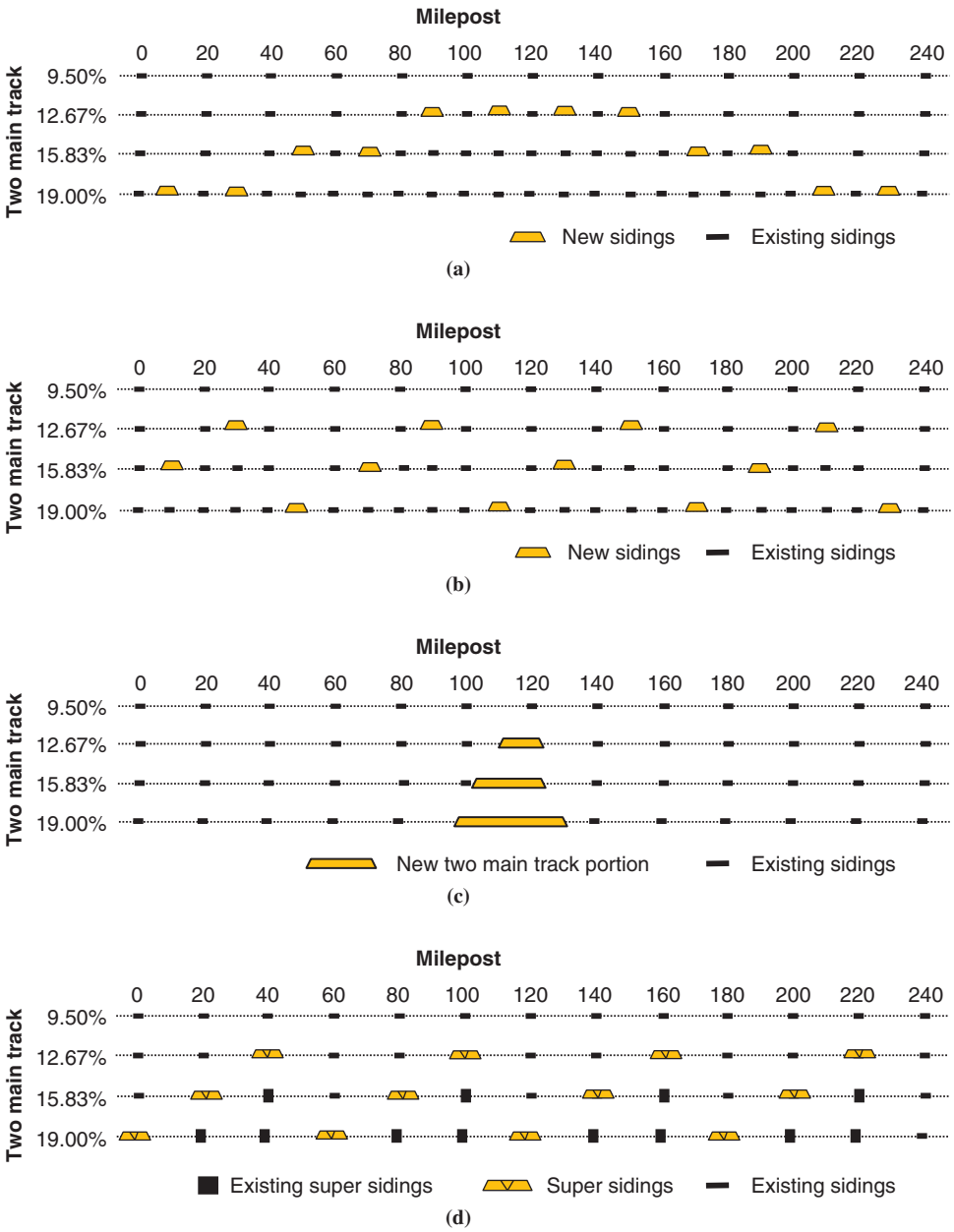

FIGURE 2 Capacity expansion alternative strategies for single-track lines with sparse sidings with different levels of percentages of second main tracks: (*a*) Alternative 1a, (*b*) Alternative 1b, (*c*) Alternative 2, and (*d*) Alternative 3.

TABLE 3 Numeric Factors Involved in Experiment

	Value		
Numeric Factor	Low	Medium	High
Traffic volume (trains per day)	8	16	24
Slow train (%)	25	50	75
Maximum passenger speed (mph)	79	95	110
Maximum freight speed (mph)	30	40	50
Two main track (%)	12.66	15.83	19.00

and highest value of maximum train speed are assigned according to typical North American operating practices, where 79 mph is the maximum speed for trains without cab signals and 110 mph is the maximum speed for higher-speed rail systems outside the Northeast Corridor. The percentage of two main tracks starts from 12.66% (the base scenario with four additional sidings) instead of 9.5% (the base scenario) because all of the alternatives start with the same single-track configuration with 9.5% two main track. The high level of 19% two main track reflects the scenario with the maximum number of sidings (or minimum siding spacing).

The partial factorial experiment matrix contains 172 scenarios (compared with 972 in the full factorial design). Each scenario was

simulated with RTC six times for 5 days each to develop train performance data from 30 days of operation. The repetition of each scenario generates enough traffic data from the different randomized schedules to support statistical analysis while providing realistic variation. The randomized simulation process involved in the repetitions also helps ensure that there is at least one feasible output from RTC for each scenario.

ANALYSIS

The results of the simulations were used to create a multivariate regression model to predict average freight train delay. The model was built from the results of all 172 scenarios (5,160 operating days in simulation) with an *R*-square equal to .934. Freight train delay per 100 train miles as predicted by the model was used to identify the best alternative capacity expansion strategy for single-track lines with sparse sidings and to develop the relationship between the average freight train delay and the percentage of two main tracks based on the selected alternative.

The comparison between alternative strategies includes both efficiency and reliability analyses. In the efficiency analysis, the average freight train delay per 100 train miles is used as the index for measuring the capacity of an alternative. The elasticity of each numeric factor to average freight train delay was first computed and the factors with comparatively high impacts on average delay were selected for the interaction tests. The interaction tests focused on the interactions between the identified factors and the alternatives under different operating environments. In the reliability analysis, the distribution of freight train delay per 100 train miles under a certain delay threshold was used to evaluate the performance of alternatives, with the preferred alternative strategy being that which had the highest proportion of on-time trains. The results from both analyses were used together to determine the best strategy for capacity expansion.

After the best strategy was identified, a more detailed experiment, termed the high-resolution experiment, was conducted to investigate the relationship between the percentage of two main tracks and the average freight train delay per 100 train miles under the preferred expansion strategy. The relationship between the percentage of a two main track and practical capacity was also plotted according to the average freight train delay and a maximum allowable delay standard (delay per 100 train miles).

Elasticity of Numeric Factors to Average Freight Train Delay

Elasticity, or point elasticity in the mathematical field, is an index used to measure the effect of an independent variable on a dependent variable. The equation to obtain elasticity is

$$e = \frac{\%\Delta Y}{\%\Delta X} \cdot \frac{X_o}{Y_o} \tag{1}$$

where

e = point elasticity,
ΔX, ΔY = independent and dependent variables, and
X_o, Y_o = baseline condition.

Elasticity is a dimensionless parameter, so this estimate is independent of the units of the two variables. Since the numerator and the denominator of elasticity are normalized, it is an appropriate index for this study, which compares the effect of factors with varying units and numeric ranges. The elasticity calculation used the average freight train delay per 100 train miles predicted by the regression model, with each of the capacity factors being varied ±25% from the initial baseline operating conditions. Figure 3 shows the resulting tornado chart for the numeric factors and the initial operating condition for the elasticity analysis. The positive and negative elasticities in Figure 3 are related to a 25% increase or decrease in the value of each numeric factor.

The magnitude of the calculated elasticity shows that the maximum speed of freight trains, traffic volume, and the percentage of two main track have the largest effects on train delay. The elasticity of the percentage two main track to train delay also shows the effectiveness of each alternative in improving capacity. From the elasticity analysis, Alternatives 1a and 1b are the most efficient methods for reducing

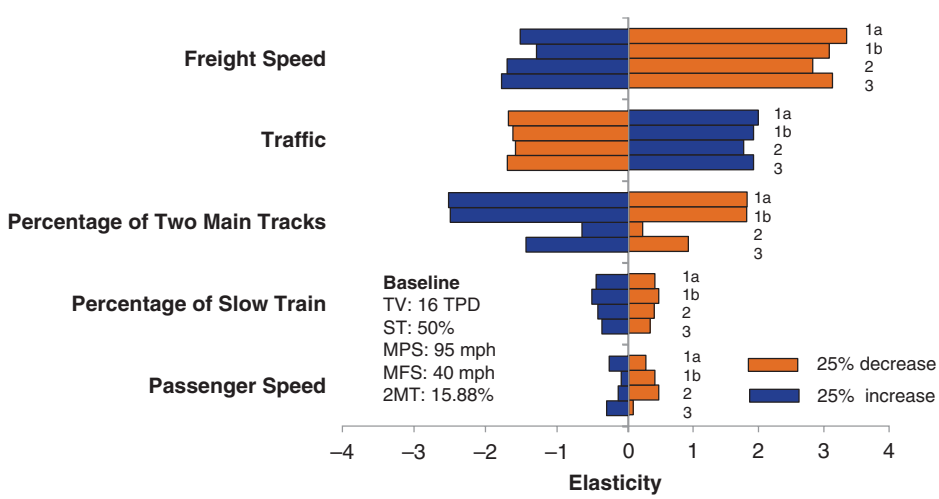

FIGURE 3 Elasticity of numeric factors (TV = traffic volume, ST = slow train, MPS = maximum speed of passenger train, MFS = maximum speed of freight train, 2MT = two main track).

delay, Alternative 3 is the second best, and Alternative 2 manages to reduce delay only slightly when its level of percentage two main tracks increases. The maximum speed of freight trains, traffic volume, and percentage of two main tracks were selected for the interaction analysis. Moreover, the elasticity of MFS suggests that increasing this parameter will increase capacity. This factor could be important on single-track lines with sparse sidings that are experiencing increasing traffic. The maximum speed of the passenger train has little effect, consistent with previous research regarding the operating behavior of single-track trains (*20*).

Interaction Analysis

To compare the performance of alternative strategies under different operating environments, the interactions between the major factors and alternatives were analyzed. Figure 4 shows the interactions between the numeric factors and the alternatives. According to the values of average freight train delay per 100 train miles shown, Alternatives 1a and 1b have the lowest average delay and the best performance compared with the other alternatives. Alternative 2, where a single long section of double track is created, consistently performs worse than the other alternatives.

If the maximum speed of freight trains increases, the delay reduction due to the incremental addition of two main track is reduced (Figure 5). This result implies that the higher the track class, the less effective additional sidings are at mitigating congestion.

Reliability Analysis

In the interaction analysis, Alternatives 1a and 1b were found to have the lowest average train delay, and both strategies appear to have nearly equal average values of freight train delay. However, equal average freight train delay does not always lead to equivalent performance, since this single value does not capture the variability in freight train delay. The distribution of freight train delay for each scenario was chosen as an index to measure the reliability of an alternative to handle traffic.

To allow for direct comparison of the reliability of each alternative strategy, the same set of baseline conditions (eighteen 50-mph freight trains and six 79 mph passenger trains) was simulated for 32 runs at each of four different percentage of two main track levels to obtain a series of train delay distributions for each alternative strategy. The number of runs was increased from 6 to 32 in order to both increase the randomness involved in the experiment and provide a wider test of the reliability of each alternative.

Figure 6 shows the freight train delay distributions for the different alternatives at each of the percentage of two main track levels. The *y*-axis is the cumulative percentage of trains that are delayed less than the corresponding delay on the *x*-axis. For example, 20% of the trains have less than 35 min of delay in the 9.5% two main track scenario. Since all of the alternatives start from the same sparse single-track network, they share the same delay distribution for 9.5% two main track. Also, Alternatives 1a and 1b lead to the same dense single-track line, so they share the same delay distribution at 19% two main track.

Overall, Alternative 1a has the best reliability because it consistently has the highest percentage of lower-delay trains compared with the other alternatives. Although Alternatives 1a and 1b begin and end with the same track configuration and delay distribution, the intermediate steps show different delay characteristics. More specifically, despite having equal average train delay values, Alternative 1b (where

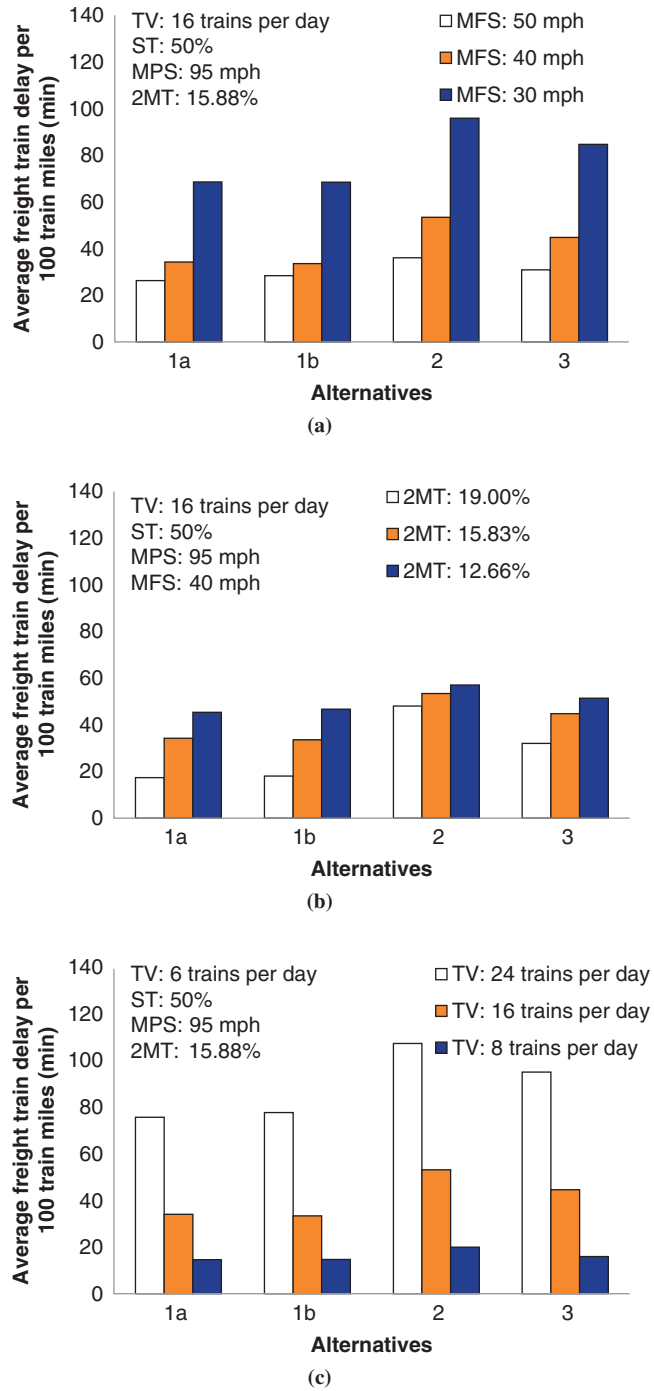

FIGURE 4 Interaction between alternative expansion strategies and (*a*) MFS, (*b*) percentage of two main track, and (*c*) traffic volume (2MT = two main track).

the new siding projects are distributed evenly over the route) consistently presents a larger percentage of high-delay trains as compared with Alternative 1a (in which the new sidings are grouped together toward the middle of the route). This finding suggests that the exact order and pattern of passing siding additions may influence the reliability of a rail corridor.

Alternative 1a has the best performance in terms of both efficiency and reliability; this finding suggests that it may be the pre-

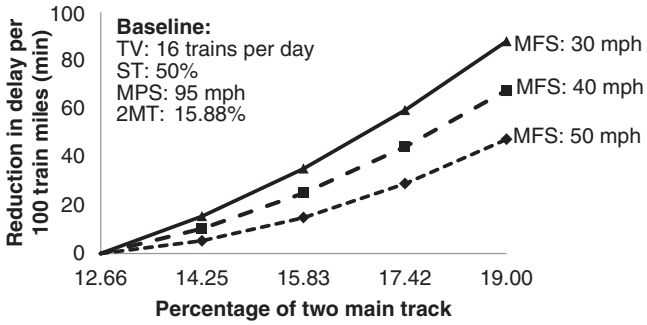

FIGURE 5 Relationship between reduction in delay per 100 train miles and percentage of two main track.

ferred capacity expansion strategy for single-track lines with sparse sidings.

Incremental Benefit of Second Main Track

Developing the relationship between the percentage of two main track and average freight train delay was the other objective of this research. This study covers the range of percentage of two main track between 9.5% and 19%, whereas the range of partial two main track examined by Sogin et al. was between 19% and 100% (*14, 15*). The two studies combined offer a wider understanding of the relationship between percentage of two main track and average freight delay per 100 train miles.

To develop this relationship, a high-resolution experiment was conducted containing seven different levels of percentage of two main track (9.50%, 11.08%, 12.66%, 14.25%, 15.83%, 17.42%, and 19.00%) and eight levels of homogeneous freight traffic volume (8, 12, 16, 20, 24, 28, 32, and 36 freight trains per day with a 50-mph maximum speed). Each combination of percentage of two main track and traffic volume was simulated according to the Alternative 1a expansion strategy with six replicates to obtain 30 days of traffic for each combination.

The simulation results were fit to both linear and polynomial regression values and an *R*-square test of both methods was used to select an appropriate regression model. The *R*-square value of the second-order polynomial model was better suited to the results than the value from the linear model, but the polynomial exhibited overfitting problems. Some polynomial regression lines are convex and inconsistent with other regression lines that curve downward when percentage of two main track is low. Moreover, the *R*-square values of the linear models range from .855 to .972. The precision of the linear model and overfitting characteristics of the polynomial model indicate that the linear function is a better method for describing the relationship between average train delay and percentage of two main track. This finding is consistent with the study by Sogin et al., where the relationship between percentage of two main track and delay was also linear in the range of 19% to 100% two main track (*14, 15*).

The slope of the resulting linear relationship between percentage of two main track and average freight train delay varies with traffic volume (Figure 7). This plot can be used by the practitioner to determine how much second main track needs to be added through siding projects to meet the required level of service. However, since this experiment involves homogeneous freight traffic, the base train equivalent method proposed by Lai et al. could be used to transform the homogeneous traffic into an equivalent number of freight and passenger trains (*24*).

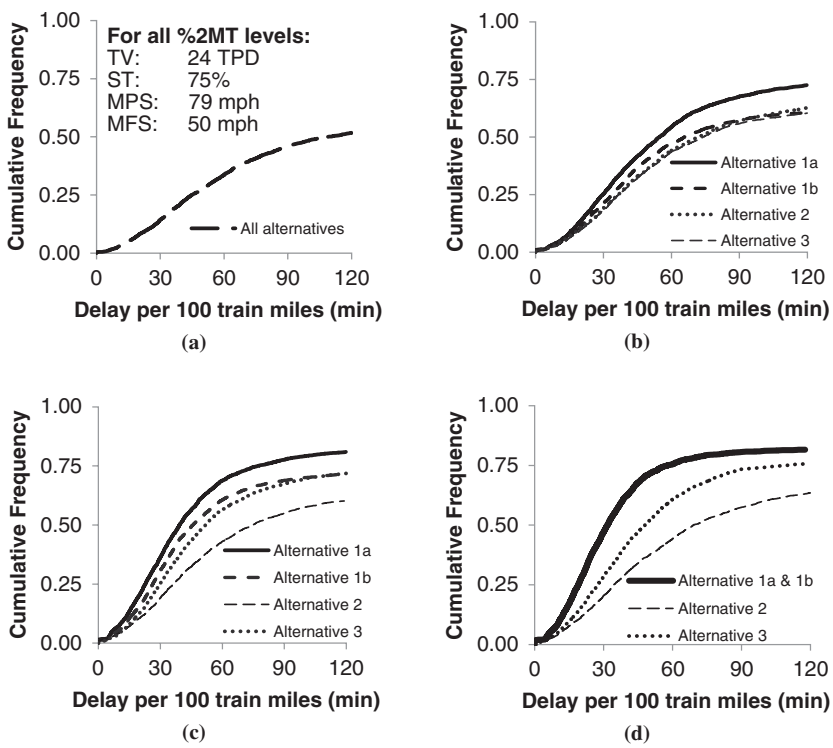

FIGURE 6 Freight train delay distributions for various percentages of two main track scenarios.

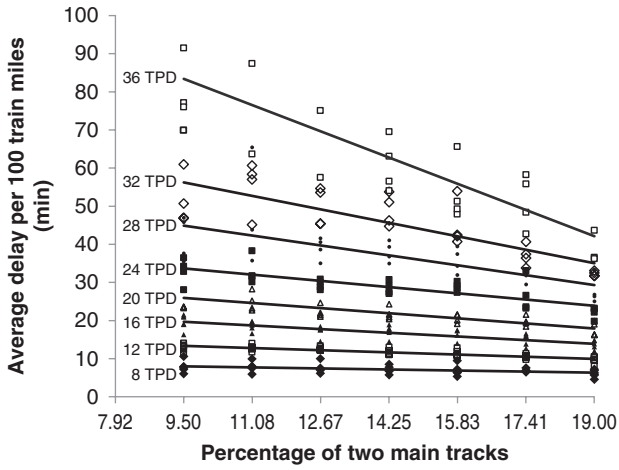

FIGURE 7 Relationship between average freight train delay, percentage of two main tracks, and traffic volume (TPD = trains per day).

Although average freight delay is a good index for evaluating capacity, translating this value into the maximum train throughput per day provides a more straightforward and communicable index for practical use. Sogin et al. proposed a method to transform average train delay into train throughput capacity (trains per day), and Figure 8 shows the results of this transformation (*15*). Figure 8 shows the trade-off between percentage of two main track and capacity under different levels of service defined by a maximum allowable delay standard per 100 train miles (D_{max}). The capacity contours are convex but very close to linear. Sogin et al. also showed that the capacity versus percentage of a two main track curve in the lower range of percentage of two main tracks above 19% is also close to linear. The relative magnitude and slope of the contours of this study compared with those of Sogin et al. show good agreement at the dense single-track network (19% two main track) interface common to both studies. The linear relationship between percentage of two main tracks and capacity implies that the bottleneck of single-track lines with sparse sidings, which requires a large investment to increase capacity, needs to be carefully considered to ensure the cost-effectiveness of the engineering option.

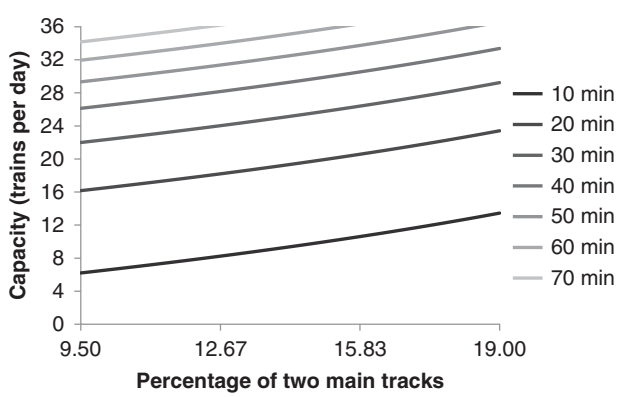

FIGURE 8 Relationship between capacity, percentage of two main tracks and maximum allowable delay per 100 train miles.

DISCUSSION AND CONCLUSION

This study aimed to find the best capacity expansion strategy for single-track lines with sparse sidings. To select the best alternative strategy, both efficiency and reliability analyses were used to evaluate the performance of alternatives according to RTC simulation data and resulting regression models. The two analyses determined that concentrating passing siding projects toward the middle of a sparse single-track corridor is the best-performing strategy to increase line capacity when the amount of a second main track is in the range of 9.5% to 19%. The relationship between average freight train delay (capacity) and the percentage of a two main track under this preferred alternative strategy was plotted according to the results of additional simulations. The final outputs can be used by practitioners to develop and evaluate the benefit of siding expansion programs on lines that are experiencing significant traffic growth. The output can also be used to understand the relationship between capital infrastructure investment and delay after the percentage of a two main track axis is converted to the construction cost appropriate for a particular line.

The results obtained from this study also expand the understanding of the transition process from a single-track line to a full double-track line. The results presented here and those of Sogin et al. (*14, 15*) combine to further demonstrate the linear relationship between percentage of two main track and average train delay.

The elasticity and interaction test in the efficiency analysis also indicates that both infrastructure improvements and operating strategies associated with increases in the maximum speed of freight trains can be used to increase line capacity. For example, investments to increase FRA track class or reduce curve speed restrictions on a single-track line may be investigated as feasible options for increasing line capacity without adding additional track. The economics of this trade-off on lines with low traffic levels and sparse sidings should be studied further.

Nevertheless, a number of questions related to the transition processes remain unanswered. According to Lindfeldt, adding new sidings is not the best alternative to increase line capacity under the scenario of hybrid lines that contain both passing sidings and longer segments of partial second main track (*21*). He found that extending the length of a second main track can provide more flexibility for various types of timetables and improves practical capacity more than additional sidings. Since the percentage of a second main track in Lindfeldt's study is higher than in all the cases used in this study, there might be a level of percentage of a second main track where the scenario of adding sidings is no longer the best alternative and extension of second main track becomes the best alternative. Knowing the particular conditions and levels of percentage of a second main track where siding projects perform better and where siding connection and double-track extension projects perform better should be the subject of further study. In addition, this study examines lines with regular, evenly spaced sidings and end terminals with essentially unlimited capacity. Lines with highly variable siding spacing or more constrained end terminals may have different optimal strategies for the placement and order of siding construction. This study employed randomized train operations. There may be particular train operating patterns that utilize fleeting techniques to increase capacity by taking better advantage of certain track layouts. The effect of such operating strategies will be the subject of further research. Finally, since changes in operational practices and infrastructure improvements have a cumulative effect on line capacity, the interaction between these changes (e.g., upgrading track warrant control to centralized traffic control) should be evaluated in a future study.

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