Capacity of Single-Track Railway Lines with Short Sidings to Support Operation of Long Freight Trains

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Use of distributed-power locomotives in heavy-haul service has allowed for greater efficiencies through operation of longer freight trains. In North America, where the majority of main-line routes are single track, the potential economic and operational advantages offered by long trains are constrained by the inadequate length of many existing passing sidings. To implement longer trains, railroad operators may run long trains in a single direction or fleet trains or extend sidings enough to facilitate bidirectional operation of long trains. This research seeks to characterize the interaction between passing siding and train lengths and the subsequent effect on train delay. The operation of a single-track line is simulated under different combinations of freight throughput, percent of long sidings, percent of railcars in long trains, and directional distribution of long trains. The experiment design scenarios are simulated by using Rail Traffic Controller software. Results indicate that routes with roughly 50% of long sidings eliminate any delay-based consequences of running long trains on the route. Thus, to operate with a high percentage of long trains, only half of the sidings on a route need to be extended to maintain the baseline level of service. These results are expanded through discussion of their practical application in planning programs to either extend existing sidings or construct new longer-length sidings. The findings can streamline the decision-making process associated with capital expansion projects and further the understanding of relationships between siding and train lengths, thereby facilitating the sustainable expansion of existing rail corridors in anticipation of future demand.

Increasing train length provides economies of scale with respect to fuel consumption and operating crew costs and positively affects line capacity by reducing the number of train runs required to move a given freight volume (*1, 2*). In 1980 the average freight train in the western United States contained 68.9 railcars but by 2000 this length had only increased to 72.5 railcars. Over the past decade, increasing use of distributed-power locomotives and locomotives with alternating-current traction in North American heavy-haul service has allowed for greater efficiencies through operation of freight trains in excess of 125 railcars in length. In 2010 the average train had grown to 81.5 railcars and railroads had begun to operate 150-car trains on selected corridors (*3*). Thus, longer freight trains are still a relatively new phenomenon within the rail industry.

The implementation of long freight trains on existing routes is contingent on the physical capacity of the existing route infrastructure to handle them. The railway infrastructure in North America is primarily composed of single-track main lines with passing sidings whose lengths were sized for the shorter 100-car trains prevalent at the time of construction. Thus, these passing sidings are inadequate for staging meets between new, longer freight trains that exceed 100 cars in length. This operating constraint reduces flexibility and potentially introduces congestion and delay, which may partially offset the efficiencies afforded by long trains. As a result, freight infrastructure owners must adopt capital expansion programs that focus on the extension of existing passing sidings or the construction of new longer-length passing sidings to provide the physical capacity required to serve longer freight trains.

The analyses that follow aim to characterize the relationship between the lengths of rail corridor passing sidings and the operation of long freight trains from the perspective of line capacity (for which train delay serves as a metric). The research presented here considers the historical context of the problem of mismatched siding and train lengths and uses archetypal infrastructure and train characteristics to create an experiment to quantify the relationship between the number of long sidings and the practical number of long trains that can operate on a route. Although there are many factors to consider in the planning stages of rail infrastructure expansion, the results of this study can streamline the decision-making process by establishing general guidelines for the types of passing-siding extension and construction projects with the highest potential for significant return on investment.

BACKGROUND

Interest in operating long freight trains in heavy-haul service, as well as their economical and operational efficiency, has been well covered in the existing literature, from both a numerical and a qualitative perspective. Newman et al. described the economic and operational benefits of increasing the length of unit trains on one Class I railroad (*4*). Operational advantages of longer freight trains are discussed by Barton and McWha, who cited the need for lengthened passing sidings in response to the use of longer freight trains up to 12,000 ft in length by several North American Class I railroads (*5*). The sentiment for siding extension programs was shared by Martland, who elaborated on the insufficiency of existing passing sidings to handle long-train operations by indicating that two-thirds of unit trains

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Transportation Research Record: Journal of the Transportation Research Board, No. 2475, Transportation Research Board, Washington, D.C., 2015, pp. 95–101.
DOI: 10.3141/2475-12

in operation are "length-limited" by passing sidings and that this estimate was conservative (*6*). The ability for siding length to dictate the maximum practical length of trains on a particular corridor is further echoed by Dick and Clayton, who demonstrated that at the time of writing, in 2001, most sidings on the Canadian Pacific Railway and the Canadian National Railway were of insufficient length to adequately support long-train operations (*7*). To overcome its siding-length disadvantage relative to the Canadian Pacific Railway, its competitor, the Canadian National Railway, began to run 150-car trains (9,000 ft long) in a single direction to avoid the problem of meets between long trains (*7*). For perspective, typical sidings range in length from 6,000 to 7,500 ft, or from 100 to 125 railcars.

Validation of the efficiency of longer freight trains, as well as their interaction with relatively shorter sidings, was researched from a more analytical perspective by Jaumard et al., who used a dynamic management algorithm and optimization model for the purpose of simulating long-train–short-train interactions along a shared line (*8*). Kraft also used analytical tools to discuss fleeting techniques for long trains and to analyze the capacity-related benefit of running longer trains on a representative route with a mixture of short and long sidings (*9*).

The research presented in subsequent sections aims at expanding on the aforementioned research on long-train operability. This goal is accomplished by conducting a detailed simulation experiment design that quantifies the specific relationship between the number of long sidings on a route and the number of long freight trains that can be operated at a given level of service.

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. The RTC software is used by a wide range of public and private organizations, including most Class I railroads, Amtrak, and Bay Area Rapid Transit, in San Francisco, California. Specially developed for the North American railway operating environment, RTC software emulates dispatcher decisions in simulating the movement of trains over rail lines subject to specific route characteristics.

Inputs for the simulations run in RTC include factors such as track layout and signaling, speed limits, and train consists (*10*). Outputs include train delay reports, dwells, siding usage, and train energy consumption. With RTC, the 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 routes with varying fractions of short and long passing sidings) and freight train parameters were variable inputs, and train delay was the desired output.

METHODOLOGY

This study involved the simulation of an experimental design matrix on a representative route whose general characteristics, along with the properties of the freight trains, are outlined in Table 1. The experimental design matrix itself is composed of four main variable factors: total freight throughput, percent long sidings, percent railcars in long trains, and the directional distribution of long trains operating on the route.

TABLE 1 Simulated Route and Freight Train Characteristics

Route Characteristic	Value
Length	240 mi
Siding spacing	10 mi
Number of sidings	23
Siding lengths	2 mi (long), 1.25 mi (short)
Traffic composition	100% freight
Locomotives	SD70 (×2 or ×3)
Number of cars	100 (short train), 150 (long train)
Length of cars	5,500 ft (short train), 8,250 ft (long train)
Max. freight speed	50 mph (45 mph through siding)
Traffic control system	2-block, 3-aspect CTC

NOTE: Max. = maximum; CTC = centralized traffic control.

Total freight throughput is the number of railcars per day moved across the representative subdivision. To provide a constant level of transportation productivity, the total number of railcars moved during a single day by short and long trains must equal the specified total freight throughput. Percent long sidings is the fraction of total sidings on the route longer than the length of the long trains, in this case 150 railcars. Percent railcars in long trains is the fraction of total railcars on the route moving in long trains. For example, if the baseline traffic of 3,600 railcars per day consists of 36 short trains, each 100 cars long, the case of 50% railcars in long trains is composed of 18 short, 100-car trains and 12 long, 150-car trains. The directional distribution specifies how many of the long trains are operating in each direction. A 50-50 directional distribution is the bidirectional case with an equal number of long trains in each direction. A 100-0 directional distribution runs all of the long trains in the same direction to create a unidirectional case. For higher percent railcars in long trains where the number of long trains exceeds half the total traffic volume, the 100-0 directional distribution case exhibits strong directional preference by running as many long trains as possible in one direction with a smaller number returning in the opposite direction as required to provide an even flow of railcars.

Each of these four factors has a specific number of associated values, or levels. For example, the factor percent railcars in long trains was assigned four levels: 0%, 25%, 50%, and 75%. A summary of each of the factors and their respective range of values is provided in Table 2. The analyses performed in this study are based on simulated factorial combinations of these different values.

Within the context of simulations, it is important to note the strategy that was used when the long sidings were distributed

TABLE 2 Experiment Design Factors and Levels

Experiment Design Factor	Number of Levels	Level Specification
Percent long sidings	14	0, 4, 9, 13, 22, 30, 48, 52, 70, 78, 87, 91, 96, 100
Percentage of railcars in long trains	4	0, 25, 50, 75
Directional distribution	2	50-50 (bidirectional), 100-0 (unidirectional)
Freight throughput	2	3,600 cars and 2,400 cars

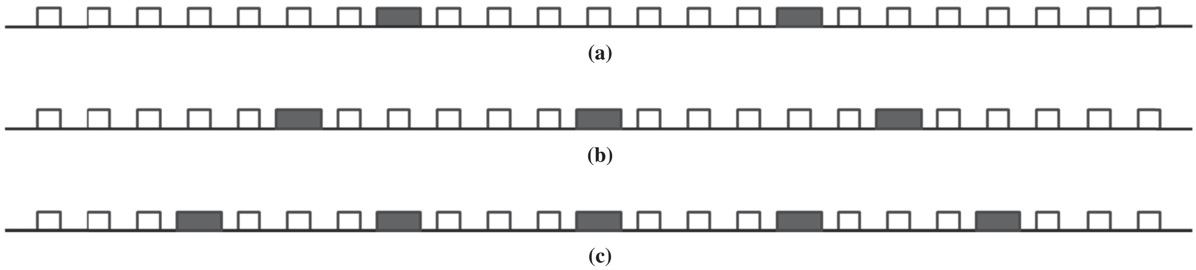

FIGURE 1 Balanced route distribution of long sidings for three example levels: (*a*) two, (*b*) three, and (*c*) five.

across the 240-mi route. An idealized approach was considered in which the factor-level number of long sidings was distributed evenly along the route. An example of this concept is presented in Figure 1, which shows the spatial distribution in the case of two, three, and five long sidings. A drawback of this distribution approach is that the pattern of long sidings does not represent, in all cases, a true progression of siding extensions that can be phased in over time. For example, the locations of long sidings in the case of two and three long sidings in Figure 1 cannot be built sequentially. A railroad cannot extend the first two long sidings and then later add a third and arrive at the same pattern of three evenly distributed long sidings. They could, however, extend one long siding in the middle of the route initially and eventually extend two more (for a total of three) and still maintain a balanced route. Thus, a railroad needs to first determine the total long sidings they will require and then build out accordingly.

To control for any difference in acceleration performance between short and long trains, the number of locomotives was increased for the long trains to maintain a constant horsepower-to-ton ratio. Thus the short 100-car trains operate with two locomotives and the long 150-car trains operate with three locomotives.

The results described in the following sections are based on a total of 196 simulated cases. The data points acquired for each of these 196 cases are based on five simulation days and include five replications. Thus, each data point is based on an average of 25 days of simulated train operations. Each replication represents a distinct freight train operating pattern in which each train departs randomly from its respective terminal within a 24-h window. Long trains and short trains are distributed randomly within this pattern according to a uniform probability distribution.

RESULTS

After simulations are run for the varying route and train characteristics described in the previous section, delay data are imported from RTC and used to characterize the relationship between short sidings and long-train operation. The results are divided into separate discussions for the simulation results pertaining to bidirectional (50-50) long-train distribution and unidirectional (100-0) long-train distribution. The results for each operating pattern are eventually merged into a comprehensive discussion of their combined implications.

Bidirectional Long-Train Operation

The results of simulating all cases with bidirectional long-train operations are illustrated for the 2,400-car throughput in Figure 2*a* and for the 3,600-car throughput in Figure 2*b*. Delay is plotted per 100 train miles along the vertical axis and percent of long sidings along the horizontal axis, with different curves representing each level of percent railcars in long trains. The delay curves in both figures exhibit three zones of observation: one at a low percent of long sidings (between 0 and 40%), one near the middle range of the percent of long sidings (40% to 70%), and one at a high percent of long sidings (between 70% and 100%).

Beginning on routes with a low percent of long sidings, a relatively steady downward trend in delay, almost exponential in nature, dominates the space. The exception lies with the curves for routes containing 50% or 75% railcars in long trains, in which larger data point variability leads to a slight fluctuation in the data. As the number of long trains being operated on the route increases, the train delay for a given level of percent of long sidings increases. In situations in which there is a high percentage of long trains and a low percentage of long sidings, the lack of locations where long trains can meet creates a dispatching phenomenon in which long trains are fleeted across the entire route successively. This form of fleeting leads to excessive delay as long trains are held in terminals until several long trains are ready to depart in rapid succession. These fleets also disrupt short-train movements on the line, since the short trains stop for longer periods of time in passing sidings to meet multiple long trains. The result is an inconsistency in the operating pattern that in turn causes high variability in delay data. This fluctuation, however, is short-lived and delay reduction declines to a single, critical point.

For both throughput volumes, the delay trends converge when slightly less than 50% of the passing sidings are extended to long sidings. At this point, delay for the 25%, 50%, and 75% railcars in long-train scenarios is equal to the zero percent railcars in the long-train base case. It may be recalled that for the base case, all trains are short and can therefore use any passing siding for a meet. This point of convergence may be the most critical piece of information to planners and engineers in charge of siding extension and construction programs. The implication is that routes with roughly half of their sidings extended to handle long trains will avoid any delay-based consequences of operating long trains on the route. This statement, from a different perspective, suggests that to operate with a high percentage of long trains, only half of the sidings on a route need to be extended in order to maintain the baseline level of service. These results are solely based on the balanced siding distribution presented earlier, and the results might change if a different build-out pattern were employed.

Past this critical point, the data between roughly 70% and 100% long sidings also exhibit an interesting trend. As larger numbers of passing sidings on the route become suitable for long-train operation, delay becomes almost entirely linear, and there is little or no

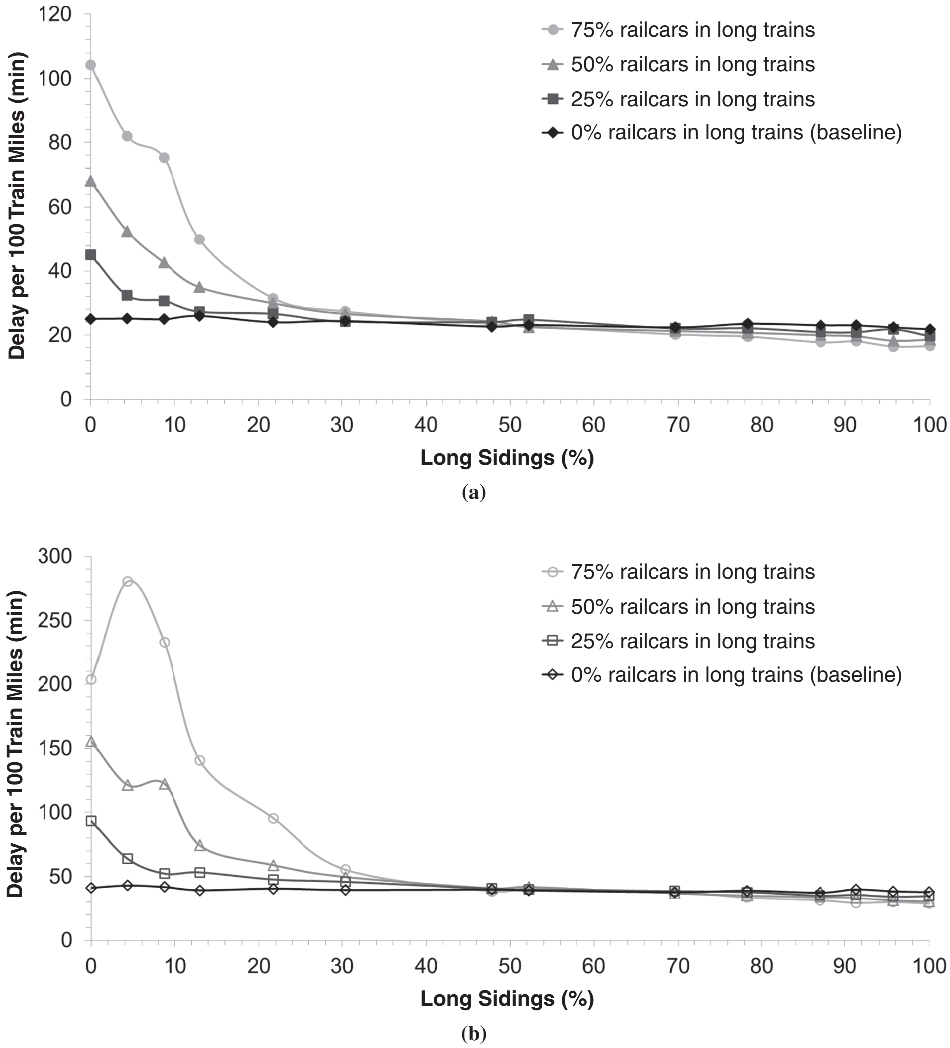

FIGURE 2 Delay as a function of percentage of long sidings and percentage of railcars in long trains: (*a*) 2,400-car throughput and (*b*) 3,600-car throughput.

negative effect of long-train operation on route delay. Delay for the case of 75% railcars in long trains is actually the lowest, whereas delay for the base case with all short trains is the highest. Over this range, the more long trains operating on the line, the lower the simulated delays along the route. This result is likely because as more long trains are operated with total throughput held constant, the total number of trains on the route decreases. With a smaller train count, there is an expectation of reduced delay, as observed in the right-hand tails of Figure 2, *a* and *b*. In this range, the efficiencies afforded by the operation of fewer, longer freight trains are fully realized. For the sake of comparison, the delay curves for the two throughput levels are superimposed in Figure 3; this comparison emphasizes the consistency in delay patterns for the two different freight throughput volumes and corresponding combinations of short and long trains.

To explain the trends seen in Figure 3, the delay variance for the same simulations is plotted in Figure 4. Observation of Figure 3 indicates a large variance for delay values obtained at a percentage of long sidings of less than 20%. This finding corresponds to the region of delay data variability on the left side of Figure 3, as was discussed previously. Although the shape of each delay variance curve is erratic and somewhat inconsistent, the primary finding is that all variances converge to small values at roughly 20% long sidings. This convergence is particularly interesting when related to the delays illustrated in Figure 3. In particular, the convergence of variance indicates that at any point after the 20% long siding mark of Figure 3, the simulations are very consistent and inspire confidence in the magnitude of the delay estimates. This finding also means that small differences in delay values at higher levels of percent of long sidings are more significant, since the delay variance is small across this region.

Unidirectional Long-Train Operation

The previous section suggests that bidirectional operation of long trains can be supported with minimal delay impact if 50% of the sidings on a route are extended to handle long trains; this finding is dependent on an even distribution of long sidings throughout the route. Although half of the existing passing sidings do not need to

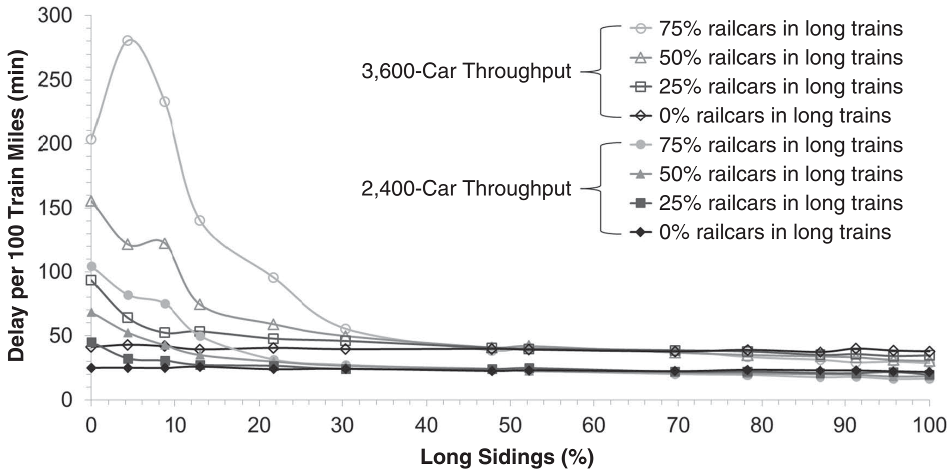

FIGURE 3 Delay as a function of percentage of long sidings and percentage of railcars in long trains overlaid by 3,600-car and 2,400-car throughputs.

be altered, building the required siding extensions still represents a sizable capital investment. Also, there may be environmental, engineering, or construction constraints that prevent the extension of certain passing sidings; this constraint would potentially disrupt the even distribution of long sidings. Although the effect of an uneven long-siding distribution is the subject of future study, such a scenario could cause additional delay and require extra siding extensions to match the original all-short-train base case.

To avoid this investment, railroads may elect to operate long trains in a single direction to avoid any meets between long trains (*7*). Since a long train on the main track can pass a short train in any existing siding, long trains operating in one direction do not require any additional passing siding infrastructure. However, operation of long trains in a single direction does introduce some complications. Since the number of trains operating in each direction is unequal, different numbers of crews are required in each direction. This unevenness introduces the expense of extended layovers or deadheading crews back to the origin terminal to match the uneven train flow. Similarly, on certain routes, the required number of locomotives for the short and long trains may be such that there is an imbalance in locomotive demand in each direction. This problem will decrease locomotive utilization and increase the number of nonrevenue locomotive deadhead miles required to reposition equipment. Running a long train in one direction without a corresponding long train in the other direction can also complicate train planning and block-to-train assignment. It also means that unit and shuttle trains, which benefit most from the efficiency of long trains, cannot operate as long trains for both legs of their round-trip journey. Instead, the long unit trains must be broken up and recombined at either end of the trip. Finally, unidirectional operation of long trains dictates that at most only 50% of traffic (i.e., all of the traffic moving in one direction) can move in long trains. Conversion of additional traffic to long trains will require some of the returning trains to also be operated as long trains.

Despite these complications, there are obvious economic and productivity benefits to implementing unidirectional long-train operation. The simulation results for unidirectional cases indicate that operating less than 50% of total traffic as long trains in a single direction has no

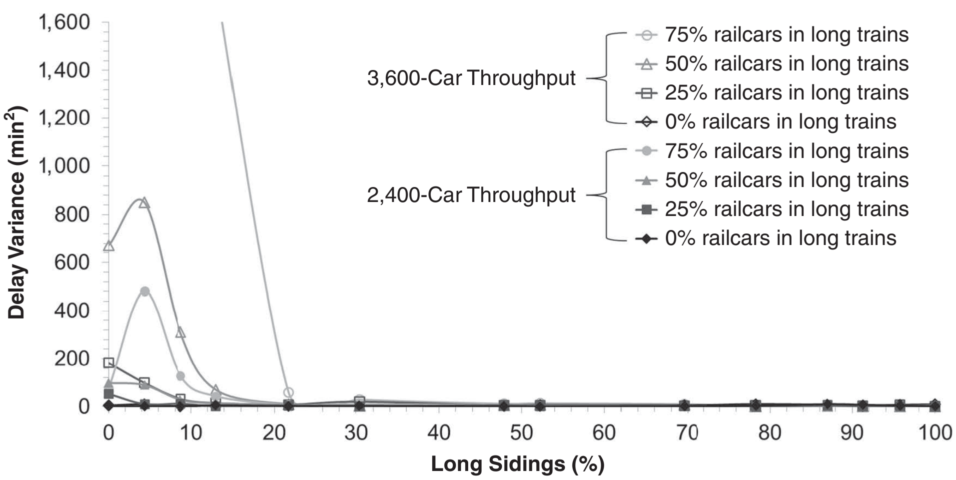

FIGURE 4 Delay variance as a function of percentage of long sidings and percentage of railcars in long trains with 3,600-car and 2,400-car throughputs.

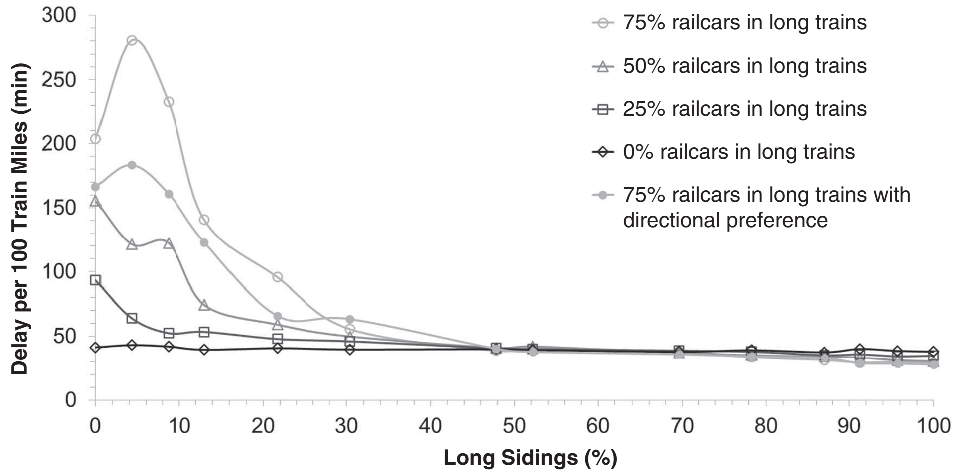

FIGURE 5 Delay as a function of percentage of long sidings and percentage of railcars in long trains: directional preference compared with bidirectional operation, 3,600-car throughput.

impact on train delay. Since the long trains travel in a single direction, there are no long-train meets and the delay for these cases matches that of the 100% short-train base case.

However, if additional long trains are run in the return direction, the results echo those obtained for the bidirectional scenario presented earlier. This is no longer a fully unidirectional case, but rather one with a directional preference. Figure 5 presents the resulting delay for long-train directional preference at 75% railcars in long trains and 3,600 railcars per day superimposed on the equivalent bidirectional results shown previously in Figure 2*b*.

The directional preference curve shows the familiar three-stage delay behavior. This result is not unexpected since this case involves the operation of long trains in both directions but with an imbalance (6 in one direction, 12 in the other). Most notably, however, this new delay curve converges to roughly the same 50% long siding mark observed in the true bidirectional data. This result indicates that this critical point of reference is independent of the exact directional distribution of long trains.

In Figure 5, at a low percent of long sidings, the delay curve for the case of long-train directional preference lies below that of its bidirectional equivalent. This result is intuitive since the bidirectional case, with nine long trains operating in each direction, has the potential for a maximum of 81 (9×9) long-train conflicts. The case with directional preference, with 6 long trains in one direction and 12 in the other, only has the potential for a maximum of 72 (6×12) long-train conflicts. Thus, consideration should be given to running a majority of long freight trains in one direction until a sufficient number of long sidings can be constructed to operate long trains equally in both directions.

CONCLUSIONS AND FUTURE WORK

The operational landscape of North American railways has experienced a dramatic shift with the advent of distributed-power locomotives, spurring increased use of longer freight trains to transport cargo along existing rail corridors. However, the economical and operational efficiencies that longer freight trains provide are constrained by the inadequate length of many existing passing sidings. This study presents a simulation approach to evaluate operations on a representative single-track line under various combinations of freight throughput, percent of railcars in long trains, percent of long sidings, and the directional distribution of long trains operating on the route. Results indicate that routes with roughly 50% long sidings exhibit no delay-based consequences of running long trains. This finding suggests that to operate with a high percentage of long trains, only half of the sidings on a route need to be extended in order to maintain the baseline level of service (which consists of operating all short trains). On routes with more than 50% long sidings, total train count takes precedence over the ratio of long to short trains in determining train delay. Results also indicate a similarity in delay-reduction patterns regardless of whether long trains operate with a 50-50 directional distribution or with directional preference. This finding does, however, also highlight the improved delay characteristics associated with running a majority of long trains in one direction as opposed to 50-50 bidirectional operations. When fewer long freight trains are run, unidirectional operation has no adverse effects on train delay and simultaneously minimizes infrastructure investment. These findings can serve as general guidelines for developing siding extension and construction programs while simultaneously facilitating the efficient operation of long freight trains.

Future work will investigate a broader range of total freight throughput values and ratios of long to short train lengths to determine whether the free-flow point of 50% long sidings varies or is a fundamental property of single-track lines. The investigated routes are idealized and, as with other delay and capacity relationships, the trends between percent railcars in long trains and percent long sidings may not hold for routes with uneven siding spacing (*11*). This research also considered only routes with homogeneous freight traffic. It has been shown previously that introducing traffic heterogeneity can alter capacity relationships (*12*), so the introduction of heterogeneity to the simulations in the form of passenger trains may alter the results. Future simulation experiments will include these and other factors to investigate these possibilities.

Finally, this analysis assumes that all yards, terminals, and loading–unloading facilities have the capacity to handle long 150-car trains. Just like passing sidings, yard and terminal tracks have been constructed to match the shorter trains of previous eras, and balloon loops at bulk freight transload facilities are designed for a particular design train length (*13, 14*). Without adequate infrastructure, long trains may affect the delay and capacity of these facilities with an overall negative effect on network performance that offsets gains from reduced train counts. These effects on terminals may also be worthy of future investigation.

ACKNOWLEDGMENTS

This research was supported by the Association of American Railroads and Rail Transportation and Engineering Center, Department of Civil and Environmental Engineering, University of Illinois at Urbana–Champaign. The authors thank Eric Wilson of Berkeley Simulation Software, LLC, for providing Rail Traffic Controller, as well as Mei-Cheng Shih of the University of Illinois at Urbana–Champaign for his support in developing this study.

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The Standing Committee on Freight Rail Transportation peer-reviewed this paper.