Comparison of Capacity of Single- and Double-Track Rail Lines

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Federal, state, and regional transportation authorities have shown an increased interest in adding or increasing passenger rail service between many city pairs. The most commonly proposed approach has been to operate passenger trains on existing freight railroad infrastructure. However, operation of passenger and freight trains on the same infrastructure poses a variety of challenges because of their different performance characteristics. In addition, track configuration—single versus double track—can significantly influence the interaction effects between trains. The maximum speed of passenger trains has little impact on the performance of freight trains on single-track lines. However, in double-track configurations, the speed of the passenger train has a major impact on freight train delays. Single-track operation can show an asymmetrical delay distribution centered on an average run time, with very few trains arriving close to the minimum run time. A double-track configuration can result in a delay distribution shaped similarly to an exponential distribution with many trains maintaining their minimum run times. In both single- and double-track operations, a higher passenger train maximum speed can lead to a greater range of possible travel times. These analyses can help transportation authorities further understand the interactions between passenger and freight trains for current and future shared-corridor operations.

Long-term freight demand is projected to increase substantially, and new passenger services are being proposed to operate over portions of the freight infrastructure (*1*). Passenger and freight trains have different characteristics in terms of power, weight, braking performance, top speed, priority, and on-time arrival performance. The unique characteristics of each train type place different demands on railroad infrastructure. Operating multiple train types on one line can introduce higher delays than operating a single train type. U.S. freight railroads traditionally host passenger trains operating at a maximum speed of 79 mph. Speeds faster than this may introduce new challenges to managing the existing capacity of a railroad. The objective of this study is to compare the simultaneous operations of passenger and freight trains in single- and double-track configurations taking into account increased maximum passenger train speeds. The simulation software called Rail Traffic Controller (RTC) was used to evaluate effects of homogeneous and heterogeneous operations (*2*).

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Single-track line capacity is limited by the need for trains to decelerate, stop, and accelerate out of sidings to allow other trains to use the intermediate single-track sections. Meeting at these sidings is the largest cause of train-interference delays on single tracks (*3*). Double-track configurations largely eliminate this dynamic and allow the line to operate at a significantly higher capacity. Because of these inherent efficiencies, double-track lines can run more trains at higher average speeds than a single-track configuration. In the absence of meetings, passing conflicts and train spacing become key capacity constraints for a double-track line.

For both single- and double-track configurations, previous research has determined that simultaneous operation of different train types consumes more capacity than homogeneous operations. Vromans et al. used simulation to investigate options to improve passenger operations (*4*). Leilich and Dingler et al. used simulation analysis to determine the delay caused by the interaction of unit trains and intermodal trains and found a capacity loss due to heterogeneous operations (*5, 6*). Harrod used integer programming to show that it can be feasible to run higher-speed trains in a single-track freight network provided there is a lane available (*7*). Petersen and Taylor used simulation analysis of where to locate sidings in single track to accommodate higher-speed trains (*8*). Sogin et al. used simulation analyses to show that there is a larger increase in delay to freight trains by adding a passenger train instead of a freight train in both single- (*9*) and double-track networks (*10*).

METHODOLOGY

Four key factors (Table 1) were considered in the simulation experiments. The different permutations of Table 1 can represent various shared-corridor conditions. Traffic volume is defined as the total number of trains per day (TPD). Traffic mixture (heterogeneity) is the percentage of these that are freight trains and describes the train-type heterogeneity of the corridor. The parameters of total TPD and percent freight are also described interchangeably by number of passenger trains and number of freight trains per day. The subsequent analyses use both pairs of parameters. The maximum speed of the passenger train was analyzed at 79 and 110 mph with intermediate speeds used in a correlation analysis. The fourth factor was the number of main tracks on the line.

The full factorial of Table 1 was simulated. Each simulation run featured a unique combination of the four factors described in Table 1. RTC was used to simulate a dispatcher making decisions regarding the train movements across a particular line. RTC is commonly used by railroad capacity planners in North America to simulate train traffic. Each simulation outputs the performance of trains over a 3-day period. This simulation was then repeated four times

TABLE 1 Experiment Factors

Factor	Level
Number of tracks	1, 2
Traffic volume (trains per day)[a]	0–80 (increments of 4)
Maximum passenger train speed (mph)	79, 110
Traffic mixture (% freight trains)[a]	0–100 (even increments of 4 trains)

[a]Traffic volume and traffic mixture can also be replaced by two parameters: number of freight trains and number of passenger trains per day.

to yield 12 days of total simulated traffic. The replication allowed the dispatching algorithm to make different decisions for any given traffic mixture. For example, one simulation has 40 freight and 24 passenger trains that operate at a maximum speed of 79 mph. This simulation was repeated four times to yield performance metrics for 768 trains. The single-track configuration was expected to have a lower capacity than the double-track route and will not be able to operate as efficiently at higher traffic volumes.

The routes used in the analysis represent idealized freight lines. The line was simplified to facilitate comparisons between the key variables described earlier. The single-track and double-track lines are described in Table 2. Each route featured one origin–destination pair with 0% grade and zero degrees of curvature. In addition, all the trains on the line were one of the train types identified in Table 3. The single-track line featured passing sidings every 15 mi between siding centers where trains can meet and overtake each other. The double-track line featured 45 mph universal crossovers every 15 mi where trains can change tracks. Because the double-track route has higher capacity, it will operate with less delay than the single-track route. The routes were compared to each other at traffic levels where both routes are considered congested. Traffic mixtures between 0% and 25% freight trains, such as those in the Amtrak Northeast Corridor, are considered passenger-dominated corridors. Mixtures between 75% and 100% freight trains, such as those in the Amtrak Cascades Corridor, are freight-dominated corridors. The single track is considered congested at 36 trains per day and the double-track route at 64 trains per day.

Train slots were scheduled evenly throughout the day. So for 24 TPD, there would be a train leaving each of the two terminals every 2 h. The departure times between the eastern and western terminal would be offset by 1 h in this case. Passenger trains were given preference to operate in the slots between 6:00 a.m. and 8:00 p.m. to reflect the short-haul daytime passenger schedules common to most existing and planned North American shared

TABLE 2 Route Characteristics

Parameter	Single Track	Double Track
Length (mi)	265	265
Interlocking spacing (mi)	15 between sidings	15 between universal crossovers
Siding length (ft)	7,920	na
Diverging route speed (mph)	45	45

NOTE: Traffic control system was 2-block, 3-aspect bidirectional centralized control. Average signal spacing was 2.2 mi between intermediate signals.

TABLE 3 Train Characteristics

Characteristic	Unit Freight Train	Passenger Train
Locomotives	×3 SD70	×2 P42
Number of cars	115 hopper cars	11 articulated Talgo cars
Length (ft)	6,325	500
Weight (tons)	16,445	500
hp/TT	0.78	15.4
Maximum speed (mph)	50	50–110
Minimum run time (min)	355	356–196
Unique characteristics	±20 min departure time	32.4 mi between stops

NOTE: hp/TT = horsepower per trailing ton.

corridors. In high-percentage freight corridors, the slots between 6:00 a.m. and 8:00 p.m. were allocated to both passenger and freight trains. In lower-percentage freight mixtures, the schedule was similar to temporal separation; passenger trains operated during the day and freight at night.

Individual train types vary in length, power, and weight. Each train in the simulation was based on the characteristics specified in Table 3. Although there are many different classes of freight trains, a single type was used to facilitate comparison of the key variables in Table 1. The freight train characteristics were based on the *National Rail Freight Infrastructure Capacity and Investment Study* conducted for the Association of American Railroads (*11*). Freight car tonnages and lengths were based on averages for each car type. The power-to-weight (horsepower per trailing ton) ratios were based on expert opinion and information from the 2002 Transportation Research Board Workshop on Railroad Capacity and Corridor Planning (*12*). Freight train departure times deviated from their prescribed departure times by ±20 min in a random uniform distribution.

The passenger train was based on the existing Amtrak Cascades service in the Pacific Northwest and the proposed consist used for planning the 110-mph service between Madison and Milwaukee, Wisconsin (*12*). The passenger train stops were spaced at 32.4-mi intervals based on the current Amtrak average station spacing on routes in California, Illinois, Washington State, and Wisconsin. The maximum speeds used were 79 mph and 110 mph. FRA limits trains to a maximum speed of 79 mph without advanced signaling and highway–rail grade crossing technologies. Illinois and Michigan have increased, or soon will increase, the track speed to 110 mph in certain locations (*6, 9, 10*). All passenger trains have higher dispatching priority than freight trains.

Freight train performance was measured by delay minutes per 100 train miles. Delay is defined as the difference between minimum run time (MRT) and the actual run time of a particular train. The maximum speed of the freight trains was held constant in all simulations at 50 mph. Passenger train speed is an experimental design variable that varies, so the MRTs also change. This feature means that the delay to a 110 mph train is different from the delay to a 79 mph train. A minute of delay to a 110 mph passenger train has a higher distance cost than a minute of delay to a 79 mph passenger train. A 5-min stop delay for a 79 mph train costs 6.6 mi of travel, and a 5-min stop delay for a 110 mph train costs 9.2 mi of travel. Because of this difference in distance cost, passenger train performance was evaluated by the comparison of actual run times normalized by 100 route miles.

Trains with higher maximum speeds will tend to have faster travel times. The variation in the time to travel 100 mi is also of interest in the evaluation of the reliability of passenger trains.

ANALYSIS

The delay-response surface for single track is shown in Figure 1*a*. The color intensity represents the average freight train delay per 100 train miles for various combinations of 110 mph passenger and 50 mph freight trains. The contours are generated from a four-train-unit grid based on all combinations of 110 mph passenger trains and freight trains. The contours are in increments of 15 min per 100 train miles. The linear density of these contours is sparse at low traffic volumes and high at increased traffic volumes. This representation is consistent with delay–volume curves used to describe train delay (*6, 9, 13–18*). A combination of 4 freight and 24 passenger trains per day has similar freight train delay to that of a homogeneous freight line with 36 trains per day. Assuming pareto efficiency with regard to freight train delay, this mixed operation translates into a capacity loss of 8 trains per day (from 36 to 28 trains per day). The contours are linear with an average slope less than 1, indicating that there is a consistent capacity loss as a result of heterogeneous operations.

The delay-response surface for double track is shown in Figure 1*b* (the scale is different from that in Figure 1*a*). Unlike single track, the contours are nonlinear. These contours are concave; this feature indicates a significant increase in train delays as the line transitions from a freight-dominated network to a passenger-dominated network. As the line approaches capacity, the contours are no longer parallel. This finding indicates that there are cases with higher traffic levels and lower freight train delays. In a capacity-constrained network, the delays may be sensitive to the management of the train interactions once traffic levels as well as the traffic density are high. The noise in the contours is probably due to the scheduling assumptions of the trains; certain schedules have different frequencies for how often a passenger train is scheduled after a freight train. When this schedule occurs, a passenger train is likely to catch up to a freight train and cause an overtake conflict that may delay trains traveling in the opposite direction.

On single track, much of the delay is attributed to meetings with other trains (*3*). In the homogeneous case, an individual freight train can be expected to be favored 50% of the time in meetings with opposing trains. In heterogeneous traffic mixtures, priority will influence which trains will be favored in a meeting. In a 50:50 heterogeneous traffic mixture, the freight trains may only be favored for 25% of the conflicts and take the siding in 75% of the meetings. The higher-priority passenger train has this effect on freight trains and it occurs regardless of the maximum speed of the passenger train. Figure 2*a* shows minor differences in freight delay between 79 and 110 mph passenger trains in a congested network at various traffic mixtures. In single-track and double-track scenarios, freight trains perform best in freight-dominated networks and experience substantial delays in a passenger-dominated network (Figure 2*a*). This trend is more pronounced on double track than on single track because removing the passenger trains removes the major source of train interference and trains no longer have to overtake each other (Figure 2*b*). In double track, 110-mph passenger trains cause more interference to freight trains than 79-mph passenger trains because of the greater speed differential.

An important goal in passenger operations is to have run times very close to the MRT most, if not all, of the time. The average run times of passenger trains are plotted for single track and for double track in Figure 3, *a* and *b,* respectively. The distance between the MRT and average run time is the delay. In the single-track configuration, delays for 79- and 110-mph passenger trains are similar. Both trends show passenger trains performing best in passenger-dominated networks in the range of 0% to 45% freight trains. The passenger trains show the longest run times in the range of 45% to 75% freight trains. Within this range, there are delays caused by trailing behind freight trains as well as by stopping for meetings at sidings to let other high-priority passenger trains go by. In the range of 60% to 100% freight trains, the run times of passenger trains start to decrease slightly because there is less heterogeneity and fewer higher-priority trains to conflict with the passenger train.

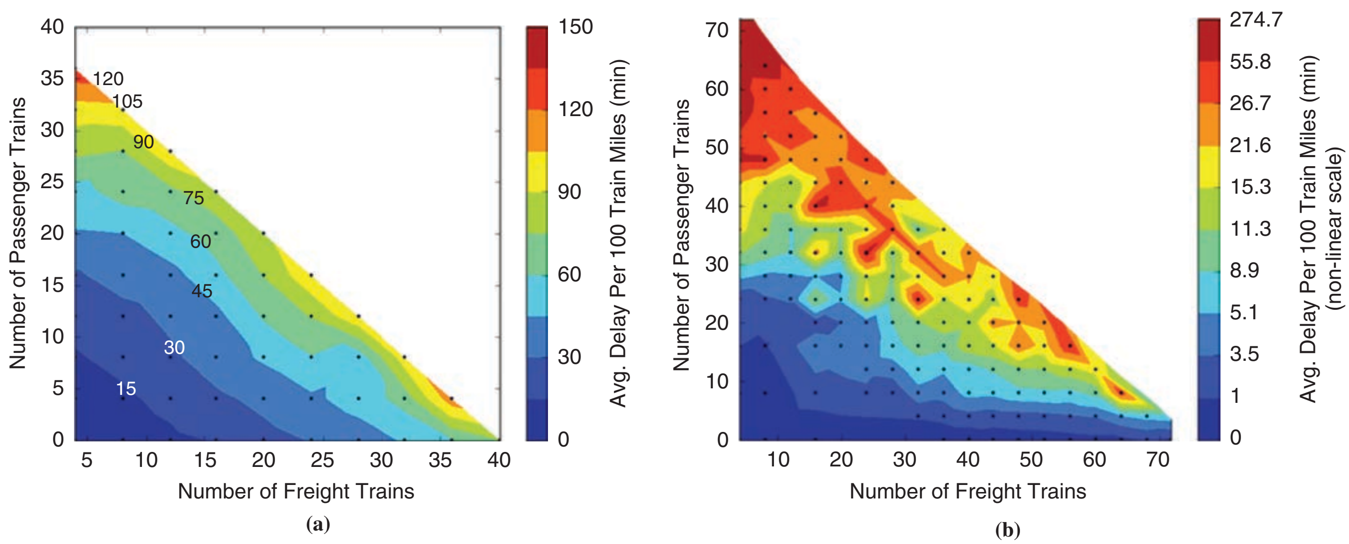
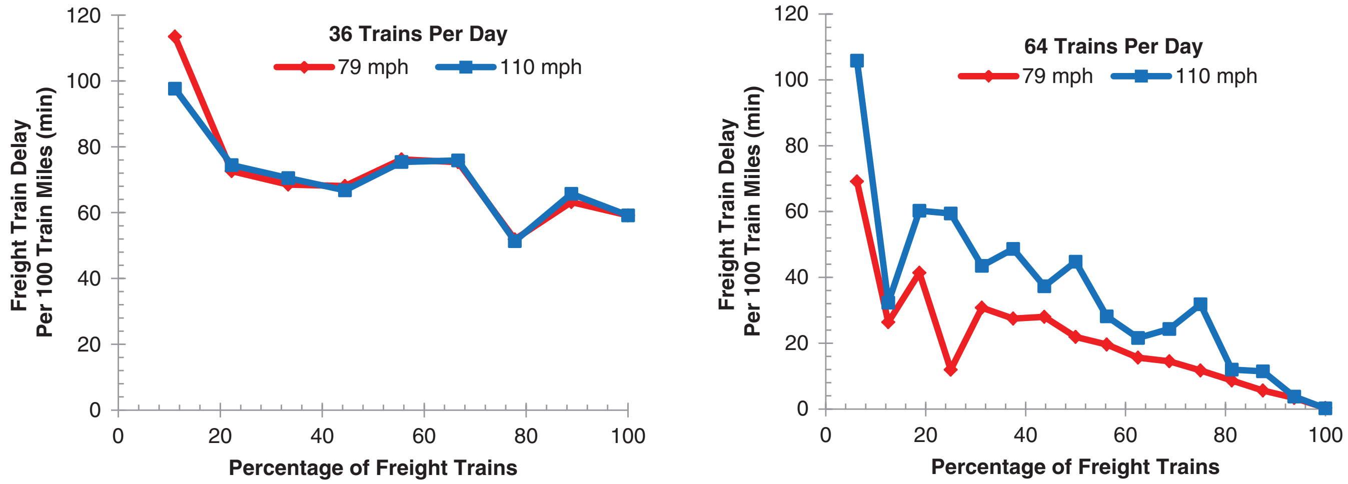


FIGURE 1 Freight train delay surface at various traffic mixtures of 110 mph passenger and 50 mph freight trains: (*a*) single-track configuration and (*b*) double-track configuration [delay measured as average delay minutes per 100 train miles; *x*-axis starts at 4 TPD and scale is different in (*b*) to show greater contour definition at low levels of traffic; avg. = average].



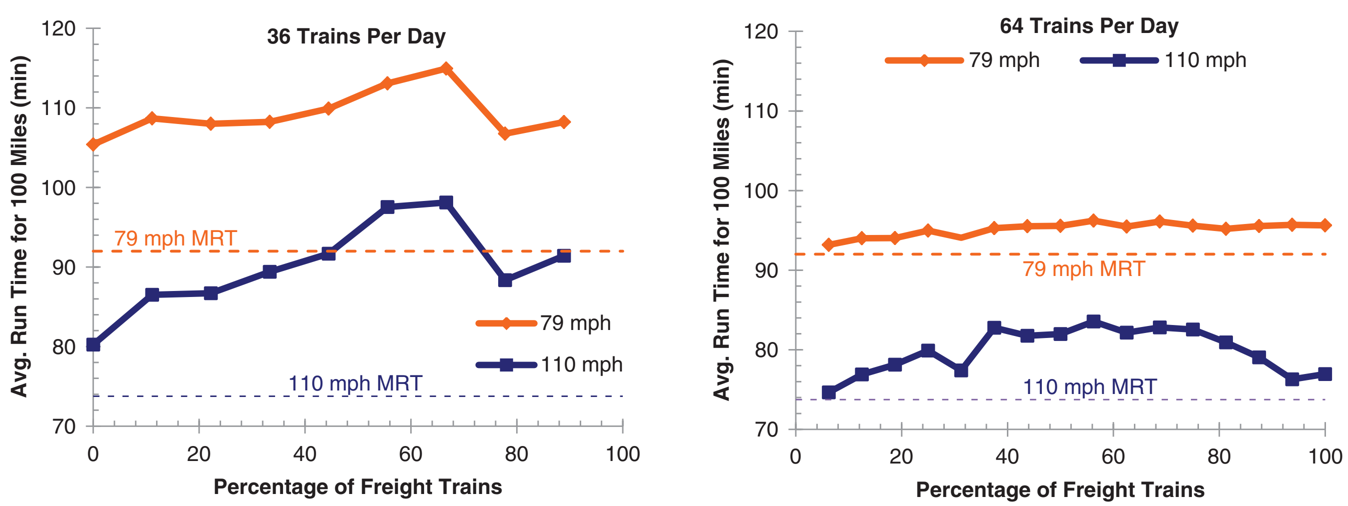
(a) (b)

FIGURE 2 Freight train delay in different traffic mixtures and different speed of passenger trains: (*a*) single track and (*b*) double track.

On double track, the 110 mph passenger trains are delayed more than the 79 mph passenger trains. Because of a greater speed differential, a 110 mph passenger train is more likely to catch up to a 50 mph freight train than to a 79 mph passenger train. In addition, a 110 mph passenger train will also lose more time when trailing behind a freight train compared with a 79 mph passenger train. With a lower speed differential, the 79 mph passenger trains show little sensitivity to operating in heterogeneous conditions on double track. Similar to the trend on single track, the 110 mph passenger trains on double track experience higher run times in heterogeneous conditions between 45% and 75% freight trains. This finding may be caused by the combination of frequent passing conflicts with freight trains and the greater likelihood that an opposing train is a high-priority passenger train.

Another implication of running passenger trains on the freight network is the increase in variation introduced into the freight network. Figure 4*a* and *b,* shows similar distributions of freight train delay in 10% bands as passenger trains are added to a single-track freight operation. The more passenger trains operated, the greater the variation in freight-train delay, and the more skewed the distribution will be. The performance of the worst 10% of freight trains is particularly important because these trains are the most likely to exceed a train crew's hours-of-service limit. Federal law prohibits train crews from being on duty for more than 12 h before a relief crew must take over (*19*). Therefore, increased variation in performance means that more relief crews are needed to maintain operations. Variation in freight service also affects time-sensitive goods, connections at terminals, customer satisfaction, and equipment utilization.

On single track, there are two counteracting factors that might explain why 79 and 110 mph passenger trains conflict with freight trains in a similar manner. The negative factor is that a faster passenger train will be more likely to cause a passing conflict with a lower-priority freight train. The positive factor is that the faster passenger train will be on the freight corridor for a shorter time. Freight trains will experience less stop delay waiting in sidings for faster passenger trains to go by.



(a) (b)

FIGURE 3 Passenger train run time at different speeds and in different traffic mixtures: (*a*) single track and (*b*) double track.

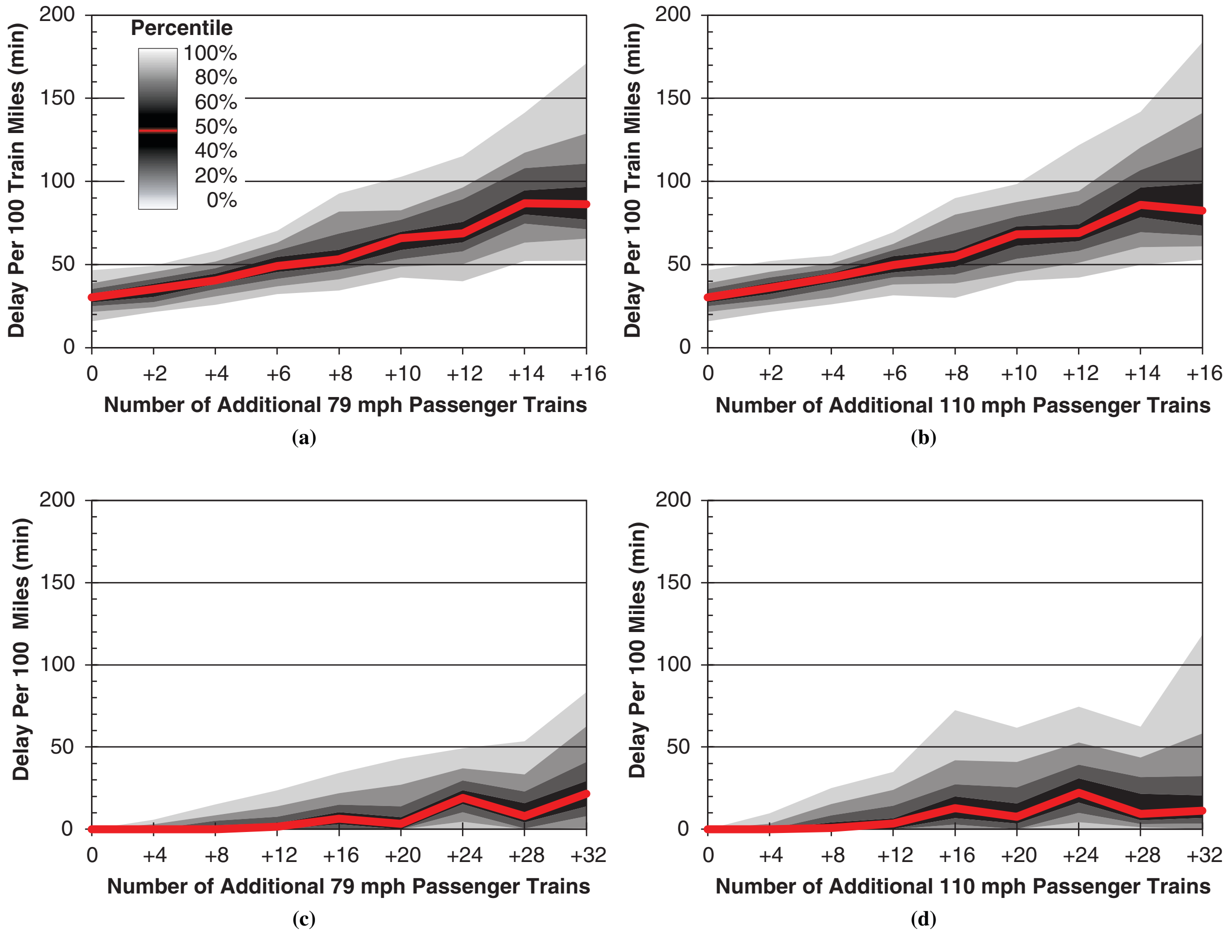


FIGURE 4 Distribution of freight train delay when (*a*) 79 mph and (*b*) 110 mph passenger trains are added to base of 24 freight trains in single-track configuration and (*c*) 79 mph and (*d*) 110 mph passenger trains are added to base of 48 freight trains per day in double-track configuration.

In a double-track configuration, the addition of passenger trains causes the median freight train delay to increase. Figure 4, *c* and *d,* shows the distributions of freight delay in 10% bands. The more passenger trains operated, the greater the variation in the delay of the freight trains, and the more skewed the distribution. The 110-mph passenger trains added more delay and variability to the arrival times of the freight trains (Figure 4*d*) than the 79 mph passenger trains (Figure 4*c*). The major increase in delay starts at a lower traffic level for 110 mph passenger trains than for 79 mph passenger trains.

The cumulative frequency distributions of freight train delay between two saturated single- and double-track configurations are shown in Figure 5. The double-track distributions are similar to the shape of an exponential distribution. The single-track shape is similar to a lognormal distribution with data skewed to the right. On double track, 15% of the freight trains will maintain the MRT with 79 mph passenger train interference. With 110 mph passenger train interference, only 7% of the trains maintain the MRT. The median of the double-track 110 mph distribution increases from 18.7 to 30.0 min per 100 train miles as passenger train speed increases from 79 to 110 mph. The single-track distributions for both 79 and 110 mph trains are similar, and freight trains did not maintain the MRT in either case. The median delays for both single-track distributions are similar.

As expected, passenger train run times per 100 mi are generally faster with 110 mph trains than with 79 mph trains (Figure 6). The MRTs are denoted by the 0th percentile and are 73.9 min (*X*) at 110 mph and 92.2 min (*Y*) at 79 mph train speeds on double track. A steep slope from the MRT point indicates better reliability. If the data within the 5th percentile and 95th percentile are considered likely to occur, then 90% of the times to travel 100 mi are within 62.9 min for 110-mph track speed on double track. At a 79 mph track speed, 90% of the data are within 22.3 min. The 79 mph passenger train operates more consistently at the MRT than does the 110 mph passenger train. Although 110 mph can offer faster travel times, the train suffers more time loss in delay events; these situations cause lower reliability (*10*). On single track, none of the trains perform at the MRT. Delays at sidings reduce the performance of passenger trains. More than 50% of 79 mph passenger trains on double track have faster run times than the 110 mph passenger trains in the single-track configurations (*Z*).

CORRELATION ANALYSIS

A Spearman rank correlation test was performed on the data from both saturated single- and double-track networks. This measurement differs from a standard Pearson correlation coefficient in which a value of

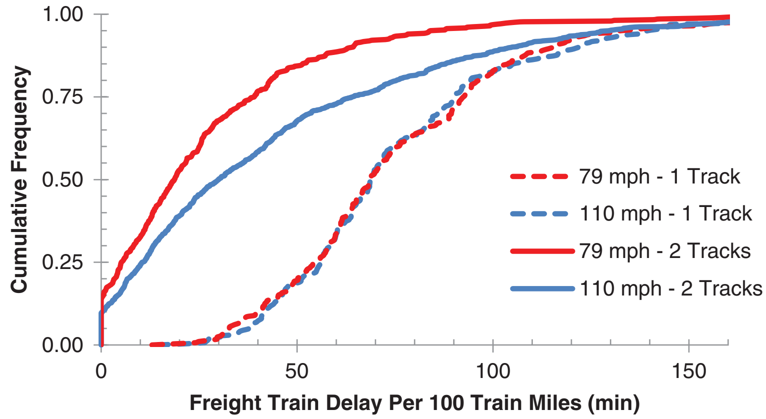


FIGURE 5 Cumulative frequency of freight train delay on single and double track with interference by 79 and 110 mph passenger trains on single-track network featuring 28 freight + 8 passenger trains per day and double-track network featuring 40 freight + 24 passenger trains per day.

+1 indicates a monotonic relationship between train performance and train speed. More data were generated to complement the previous analysis in order to increase confidence in the relationship between train performance and passenger train speed. Thirteen speeds between 50 and 110 mph were tested at 36 TPD for single track and 64 TPD for double track. Seven different traffic mixtures were considered.

Figure 7*a* shows seven different traffic mixtures and the corresponding Spearman correlation coefficient in both single- and double-track scenarios. Each bar in Figure 7*a* corresponds to a scatterplot similar to those in Figure 7*c*, and each bar in Figure 7*b* corresponds to a scatterplot similar to those in Figure 7*d*. The single-track coefficients did not show positive correlations between passenger train speed and freight train delay. There is a moderate positive correlation between passenger train speed and freight train delay on double track for the seven different traffic mixtures. The freight trains on double track are more sensitive to a large speed differential than those on single track.

The previous analyses used run time to summarize the performance of passenger trains. Correlating run time with various passenger train speeds is trivial. Instead of using run time, the analysis focused on investigating a possible correlation between reliability and passenger train speed. The reliability of the passenger trains is measured by the standard deviation of run times in a single simulation replication of a traffic mixture. Figure 7*d* shows an example scatterplot for maximum passenger speed and standard deviation of passenger train run time. There are fewer data points in the passenger train correlations than in the freight data because the standard deviation is a sample statistic instead of an individual train statistic. Consequently, this particular statistic varies less over four replicates than delays of individual trains. On single track, the results are mixed when compared with double track. In single-track, passenger-dominated networks, where passenger train delay is primarily from meetings with other passenger trains, the faster train speed showed a tendency to reduce the standard deviation of run times and to increase reliability. Presumably this finding is because each faster passenger train is on the network for a shorter time (and creating fewer meetings) and there are fewer freight trains to overtake, leading to fewer sources of variation in run times. In freight-dominated single-track networks, where passenger train delay is primarily from meeting and passing freight trains, which occur regardless of passenger train speed, increased passenger train speeds did not show a significant correlation with variability in the passenger train

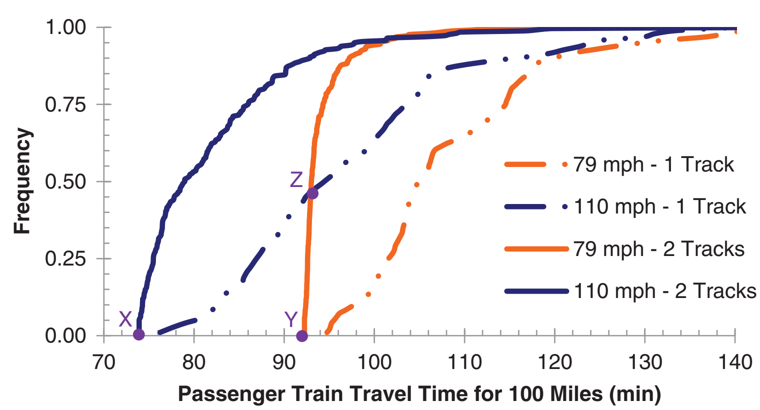


FIGURE 6 Cumulative frequency distribution of travel times of 79 and 110 mph passenger trains on single-track network featuring 28 freight + 8 passenger trains per day and double-track network featuring 40 freight + passenger 24 trains per day.

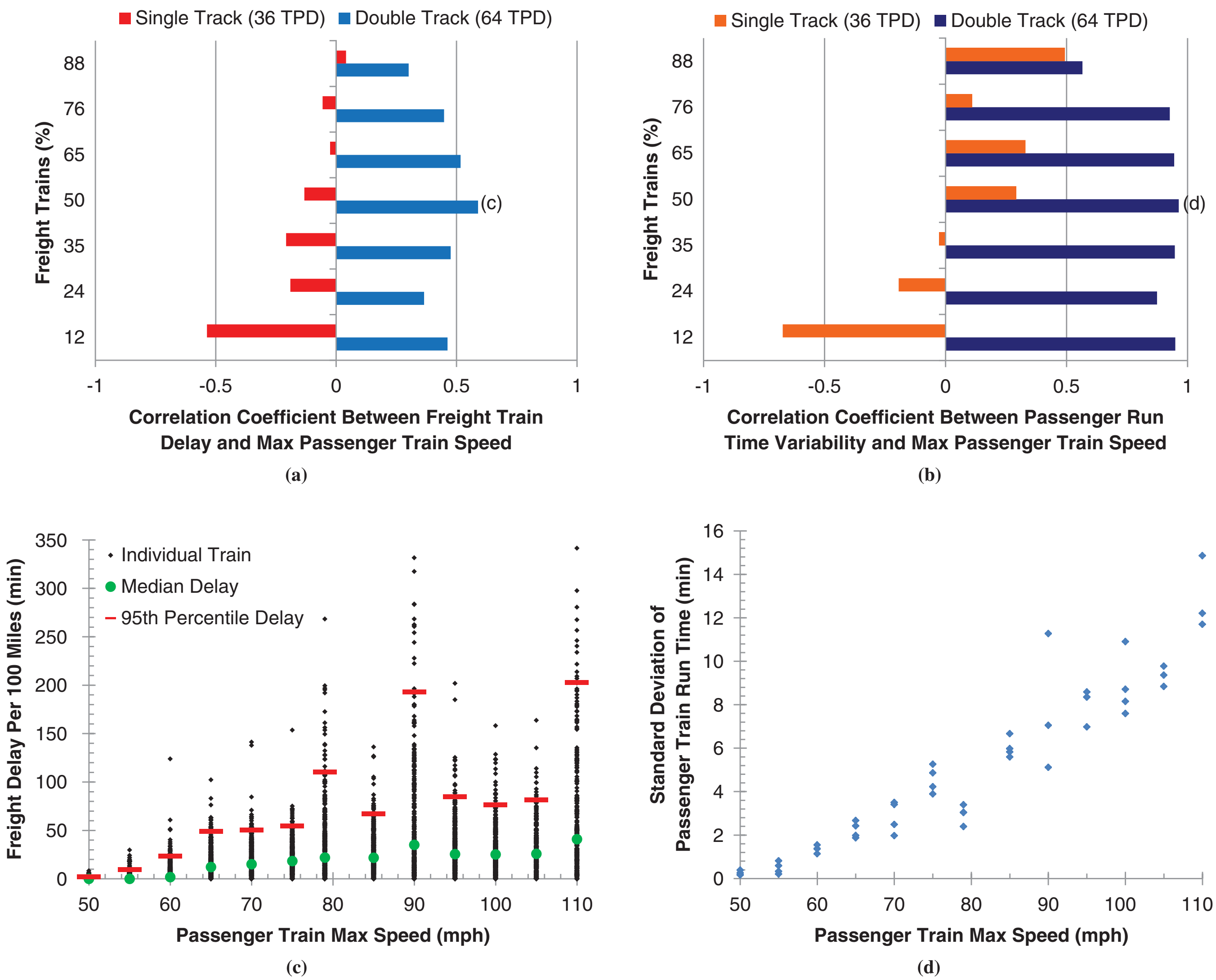


FIGURE 7 Spearman correlations between (*a*) maximum passenger train speed and freight train delay and (*b*) maximum passenger train speed and passenger train standard deviation of run time [statistically insignificant values ($P \geq .05$) are crosshatched; each bar in (*a*) and (*b*) corresponds to a scatterplot] and examples for (*c*) freight train delay and (*d*) passenger train reliability (on double track with 32 freight and 32 passenger trains per day).

arrival times. On double track, where passenger train delay is primarily from trailing behind and overtaking freight trains, increased passenger train speeds led to greater variability in the run times of the passenger trains across the seven traffic mixtures. With a greater speed differential, faster passenger trains are more likely to catch up to one or more freight trains and will experience a greater time penalty for each instance of trailing and overtaking; this occurrence leads to additional sources of variance of greater magnitude compared with those for slower passenger trains.

CONCLUSION

Sharing tracks with higher-speed intercity passenger trains and freight trains is a challenge. In all studied cases, the addition of passenger trains to a corridor increased delay to freight trains but the mechanisms differ between single- and double-track configurations, freight- and passenger-dominated lines, and passenger train speed. On single track, the greatest impact to freight trains is due to the higher priority of the passenger train rather than its speed. The passenger train has difficulty maintaining its MRT in a saturated network because it is delayed primarily for meetings with other passenger trains and for overtaking freight trains. In a double-track configuration, the meeting delay is mostly eliminated and subsequently a higher speed differential between train types causes more overtake conflicts. Increasing the passenger train speed reduces the travel time but may also decrease reliability.

In planning shared-corridor infrastructure and operations, the differing characteristics of single and double track should be carefully considered. On single track, an incremental upgrade of passenger train speed from 79 mph to 110 mph may have only a modest effect on freight train delay. However, to take full advantage of the decreased run time afforded by higher speeds, planners should investigate schedules and operational strategies such as fleeting that may reduce the number of meetings between passenger trains and freight trains to be overtaken. Alternatively, the addition of double-track segments to create hybrid track configurations may also mitigate the variability in run times created by these meetings and overtakings. On double track, an incremental upgrade from 79 mph to 110 mph may increase freight train delay and also may increase the variability in passenger train run time. Operational strategies and track configurations, such as optimized crossover spacing, that minimize or reduce the impact of overtaking should be investigated to counteract these trends when operational plans and infrastructure designs for shared trackage are developed.

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REFERENCES

1. *Transportation: Invest in Our Future—America's Freight Challenge.* American Association of State Highway and Transportation Officials, Washington, D.C., 2007.
2. Willson, E. *Rail Traffic Controller (RTC).* Berkeley Simulation Software, Berkeley, Calif., 2012.
3. Dingler, M., A. Koenig, S. L. Sogin, and C. P. L. Barkan. Determining the Causes of Train Delay. Presented at 2010 Annual Conference of the American Railway Engineering and Maintenance-of-Way Association, Orlando, Fla., 2010.
4. Vromans, M. J. C. M., R. Dekker, and L. G. Kroon. Reliability and Heterogeneity of Railway Services. *European Journal of Operational Research,* Vol. 172, No. 2, 2006, pp. 647–665.
5. Leilich, R. H. Application of Simulation Models in Capacity Constrained Rail Corridors. In *WSC '98: Proceedings of the 30th Conference on Winter Simulation,* Washington, D.C., IEEE Computer Society Press, Los Alamitos, Calif., 1998, pp. 1125–1133.
6. Dingler, M. H., Y.-C. Lai, and C. P. L. Barkan. Impact of Train Type Heterogeneity on Single-Track Railway Capacity. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2117,* Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 41–49.
7. Harrod, S. Capacity Factors of a Mixed Speed Railway Network. *Transportation Research Part E,* Vol. 45, No. 5, 2009, pp. 830–841.
8. Petersen, E., and A. Taylor. Design of Single-Track Rail Line for High-Speed Trains. *Transportation Research Part A,* Vol. 21, No. 1, 1987.
9. Sogin, S. L., C. P. L. Barkan, and M. R. Saat. Simulating the Effects of Higher Speed Passenger Trains in Single Track Freight Networks. In *Proceedings of the 2011 Winter Simulation Conference,* Phoenix, Ariz., IEEE Computer Society Press, Los Alamitos, Calif., 2011, pp. 3679–3687.
10. Sogin, S. L., C. P. L. Barkan, Y.-C. Lai, and M. R. Saat. Impact of Passenger Trains in Double Track Networks. *Proc., 2012 Joint Rail Conference,* Philadelphia, Pa., American Society of Mechanical Engineers, New York, 2012.
11. Cambridge Systematics. *National Rail Freight Infrastructure Capacity and Investment Study.* Association of American Railroads, Washington, D.C., 2007.
12. Galloway, D. Train Performance Characteristics. Presented at 81st Annual Meeting of the Transportation Research Board (Workshop on Railroad Capacity and Corridor Planning), Washington, D.C., 2002.
13. Abril, M., F. Barber, L. Ingolotti, and M. Salido. An Assessment of Railway Capacity. *Transportation Research Part E,* Vol. 44, No. 5, 2008, pp. 774–806.
14. Krueger, H. Parametric Modeling in Rail Capacity Planning. In *Proceedings of the 2011 Winter Simulation Conference,* Phoenix, Ariz., IEEE Computer Society Press, Los Alamitos, Calif., 1999, pp. 1194–1200.
15. Pachl, J. *Railway Operation and Control.* VTD Rail Publishing, Mountlake Terrace, Washington, 2009.
16. Schlake, B. W., C. P. L. Barkan, and J. R. Edwards. Train Delay and Economic Impact of In-Service Failures of Railroad Rolling Stock. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2261,* Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 124–133.
17. Lai, Y.-C., and Y.-A. Huang. Estimation of Single and Double-Track Capacity with Parametric Models. Presented at 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 2012.
18. Lai, Y.-C., Y.-H. Liu, and T.-Y. Lin. Development of Base Train Equivalents to Standardize Trains for Capacity Analysis. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2289,* Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 119–125.
19. Federal Railroad Administration, U.S. Department of Transportation. 49 CFR, Part 228: *Hour of Service of Railroad Employees,* 2009.

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