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SIMULATING THE EFFECTS OF HIGHER SPEED PASSENGER TRAINS IN SINGLE TRACK FREIGHT NETWORKS

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ABSTRACT

North American freight railroads are expected to experience increasing capacity constraints across their networks. To help plan for this increased traffic, railroads use simulation software to analyze the benefits of capacity expansion projects. Delay increases exponentially with volume as individual lines and the network become more saturated with traffic. Simultaneous operation of heterogeneous traffic further increases delay relative to additional homogenous traffic. Running higher speed passenger trains with higher priorities amplifies heterogeneity. Rail Traffic Controller (RTC) was used to run simulations with varying mixes of unit freight and passenger trains operating at various speeds ranging from 50 to 110 mph. Additional passenger trains delay freight trains more than additional freight trains will. Higher speed trains also introduce more variation to the delay. These analyses will help planners improve their understanding of the tradeoff in capacity due to operation of trains at different priorities and speeds.

1 INTRODUCTION

1.1 Background

North American freight railroads are expected to experience increasing capacity constraints across their networks. Long-term freight demand is projected to increase 84% by 2035 (AASHTO 2007), and new passenger services are being proposed to operate over portions of the freight infrastructure. These train types have different characteristics in terms of acceleration, braking, top speed, priority and on-time performance. Their unique characteristics place different demands on the freight infrastructure. When multiple trains operate on the same line, different train types consume more capacity than homogenous operations (Vromans 2006). Simulation analysis has been used to analyze the delay caused by the interactions of unit trains and intermodal trains (Bronzini and Clarke 1984; Dingler 2009). Higher speed passenger trains on shared corridors will introduce new challenges in managing the existing capacity of the railroad. The objective of this paper is to analyze the impact of adding passenger trains to freight railroad networks. We used simulation software called Rail Traffic Controller (RTC) to evaluate effects of homogeneous and heterogeneous operations (Wilson 2011). We analyzed delays caused by introducing passenger trains to a single track freight network at different volumes.

Delay per 100 train miles is the main output from the simulation analyses that provides insight into the capacity of a line. Delay is defined as the difference between the actual run time and the minimum run time (MRT). The MRT is the fastest a particular train can traverse the network with no interfering traffic, slow-orders or other external factors that could cause the train to deviate from normal track speed. The delay includes time for meets and passes, and excludes time spent at scheduled stops. All delay values presented in this analysis refer to the performance of the trains and not the maximum number of trains that can be operated on the line (White 2006).

1.2 Methodology

The majority of the North American railroad network is single track with regular passing sidings. Trains must enter these sidings to allow other trains to meet and pass. Single track operation was chosen because of its prevalence in the network and because it is more sensitive to marginal increases in rail traffic than double track configurations. Single track represents a worst-case scenario because it becomes saturated with traffic more quickly. The simulated route characteristics are in Table 1. The route is simplified as much as possible to facilitate comparison of the effects of key variables regarding traffic composition and passenger train speed. The route is symmetrical to prevent any directional biases that could affect the average of an entire train group. Grade and curvature were eliminated from the model since these factors affect different train types differently. Freight trains are more sensitive to grade, while passenger trains are more restricted by degree of curvature (Pachl 2002).

Table 1: Hypothetic Route Used for Analysis

Parameter	Value
Type	Single Track (1 O-D Pair)
Length	265 miles
Distance between siding centers	15 miles
Siding Length	7,920 feet
Traffic Control System	CTC with 2-Block, 3-Aspect ABS
Average Signal Spacing	2.2 miles

Individual trains vary in length, power, and weight. Each train in the simulation is based on the characteristics specified in Table 2. The freight train characteristics are based on the Cambridge Systematics National Rail Freight Infrastructure Capacity and Investment Study (2007) conducted for the Association of American Railroads (AAR). Freight car tonnages and lengths were based on averages for each car type. The power-to-ton ratios were based on experience and information from the TRB Workshop on Railroad Capacity and Corridor Planning (2002). The unit freight trains were scheduled to depart ± 20 minutes from their scheduled departure time in a random, uniform distribution.

The passenger train was based on the Amtrak Cascades service in the Pacific Northwest and the expected consist that was used in the planning of the 110 mph service between Madison and Milwaukee Wisconsin. The passenger train stops were spaced at 32.4 mile intervals based on the current Amtrak station spacing on routes in California, Illinois, Washington State, and Wisconsin (Coran 2010).

Table 2: Train Characteristics

	Unit Freight Train	Passenger Train
Power	3 SD70 Locomotives	2 P42 Locomotives
No. 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
	± 20 minutes departure time	32.4 miles between stops

The base case for all comparisons is the homogeneous condition when the composition of total traffic is 100% unit freight trains. Simulations were run for 8 to 40 train starts per day on the network. Train starts were balanced between the west and east end of the network with all train starts spaced evenly. The locations of meets and passes were not planned in advance and were calculated by RTC. At 24 unit trains per day, there are 12 eastbound and 12 westbound with a train departing each origination yard every two hours. Each simulation includes the performance of all the trains that operate within 72 hour period. Each particular traffic mix was repeated four times.

Passenger trains were systematically added to the freight train base case starting with 2 additional passenger train starts per day up to 16 additional passenger train starts per day. Passenger trains were only added in pairs to maintain directional balance, and were scheduled to start during daylight hours between 7:30 am and 8:00 pm. The headways for all trains were held constant throughout the simulation. Adding 12 passenger trains to a base of 24 freight trains will change the headway from two hours to 90 minutes between train starts at each yard. This process was repeated for different passenger speeds tested: 50 mph, 79 mph, 90 mph, 110 mph. These speeds are typical operating speeds in North America. 79 mph is the maximum speed passenger trains usually travel on freight networks without advance signaling and highway crossing technology. 90 mph and 110 mph were chosen because they are the proposed speeds to run new higher speed passenger trains service. The host freight railroads are more acceptable to 90 mph over 110 mph. Amtrak passenger trains travel at 90 mph in sections of Michigan and 110 mph on the Northeast Corridor and on the line between New York and Albany. 50 mph was chosen to isolate the difference in speed between passenger trains and freight trains. When the speed of passenger trains and freight trains is the same, headways should be maintained.

The primary output from each simulation was the total delay for each train. This number was then normalized by the route length to yield delay per 100 train miles. Most of the analysis concentrated on the delay of the freight trains, because they are more sensitive to the addition of passenger traffic. Freight trains incurred larger delays compared to passenger traffic. Also, for most of the traffic mixes tested, the freight traffic comprised a higher percentage of the total traffic.

The results presented here are not intended to represent absolute predictive measurements for a particular set of conditions. Rather, they are meant to illustrate comparative effects under different conditions.

2 RESULTS

2.1 Homogenous Traffic

In the homogenous condition delay per train increases exponentially as the number of train starts increases in the network (Figure 1). The experiments ranged from 8 to 40 freight trains per day. Each point represents one train. The delay per train increases exponentially with the number of train starts and the variation in the delay also increases.

The number of replicates increases as more trains are scheduled to run in a 24-hour period. At 8 trains starts per day, there were 96 trains (8 trains per day x 3 days x 4 iterations). At 40 train starts per day, there were 480 trains (40 trains per day x 3 days x 4 iterations). The variation in delay also increases with the traffic density. The 95% confidence interval of the averages at each traffic level is roughly constant because of the positive correlation between the number of trains scheduled in a 24 hour period, variation, and number of replicates.

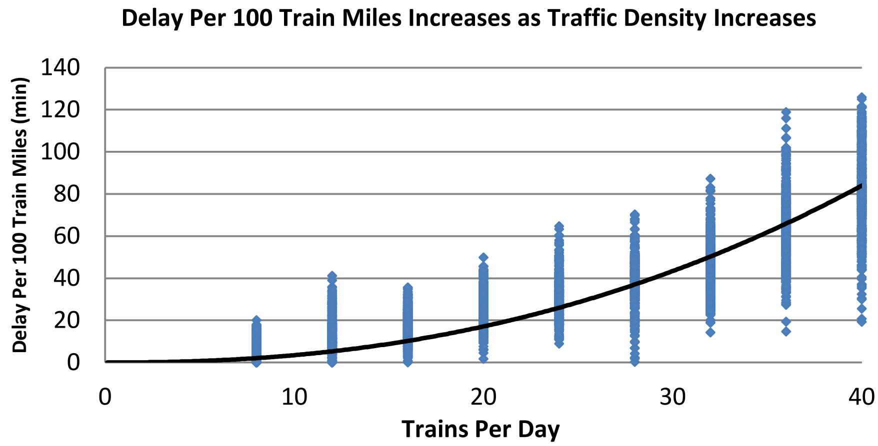

Figure 1: Homogenous Freight Traffic Delay at Various Densities

2.2 Adding High Priority 50 MPH Passenger Trains to the Homogenous Condition

The difference in priority is one of the major differentiating factors between a passenger train and a freight train. Passengers are more sensitive to delay than bulk materials. As a consequence, passenger trains have a higher priority than freight trains. In order to isolate this priority factor, passenger trains were constrained to operate at 50 mph. These slow passenger trains were introduced to each of the homogenous freight mixes in Figure 1. Adding higher priority traffic increases the delay over the initial homogenous traffic mix for all additional passenger trains (Table 3). When the total number of trains per day is held constant, the delay is higher for traffic that includes passenger trains compared to homogeneous freight traffic.

For example, consider the case with 24 freight and 8 additional passenger trains; the freight trains will average 63.7 minutes of delay per 100 freight train miles. For an equal traffic level of 32 freight trains per day, the delay will be 47.8 minutes per 100 freight train miles. Holding the number of trains per day constant, the delay increases with the percentage of passenger train traffic.

Table 3: Delay per 100 freight train miles of adding 50 MPH Passenger Trains to a Base Case of 100% Unit Freight Trains. (Cells of equal traffic densities are highlighted in the same color).

No. of Freight Trains→		8	12	16	20	24	28	32	36	40
Base: 100% Freight Trains		**7.9**	**12.4**	**17.7**	**27.1**	**31.8**	**38.0**	**47.8**	**63.5**	**80.4**
Additional Passenger Trains	+4	15.4	20.3	27.1	35.3	40.2	48.7	60.2	85.9	
	+8	20.4	30.0	42.4	46.7	63.7	54.6	105.0		
	+12	29.8	41.5	44.5	64.0	87.4	171.6			
	+16	50.6	43.6	55.9	101.9	145.2				

2.3 Varying Passenger Speeds

The effect of speed is small compared to the priority of the additional traffic. In Table 4, most of the traffic mixes studied, higher speeds correlated to higher freight train delays. A small minority of the traffic combinations experienced weak or negative correlations between passenger speed and freight delays. There is considerable variation that cannot be explained by speed alone. The start times of all the trains for each traffic mix are the same, so the different passenger train speeds cause meets and passes to occur at different locations. Certain speeds can lead to a schedule that better utilizes the fixed infrastructure.

Table 4: Adding Passenger Trains at Different Speeds to a Base Case of 100% Unit Freight Trains

Additional Passenger Trains ↓	No. of Freight Trains →	8	12	16	20	24	28	32	36	40
	Passenger Speed ↓ Base	**7.9**	**12.4**	**17.7**	**27.1**	**31.8**	**38.0**	**47.8**	**63.5**	**80.4**
+4	50 mph	15.4	20.3	27.1	35.3	40.2	48.7	60.2	85.9	
	79 mph	15.0	18.6	30.4	33.9	43.0	53.0	68.5	98.5	
	90 mph	14.7	19.4	30.4	37.3	45.4	57.0	76.5	120.9	
	110 mph	15.6	21.4	30.0	37.2	46.1	59.2	77.6	112.2	
+8	50 mph	20.4	30.0	42.4	46.7	63.7	54.6	105.0		
	79 mph	18.6	30.6	36.6	47.5	60.8	52.5	107.3		
	90 mph	20.0	31.2	39.7	51.0	70.0	60.6	152.7		
	110 mph	21.1	31.3	42.1	50.3	66.5	57.8	143.6		
+12	50 mph	29.8	41.5	44.5	64.0	87.4	171.6			
	79 mph	29.9	34.7	42.5	64.5	75.1	118.3			
	90 mph	28.7	38.3	49.3	67.5	88.6	147.1			
	110 mph	29.4	37.5	46.7	73.4	86.9	139.9			
+16	50 mph	50.6	43.6	55.9	101.9	145.2				
	79 mph	39.6	46.8	60.5	89.5	140.1				
	90 mph	42.1	46.0	58.1	88.7	133.2				
	110 mph	39.6	47.2	61.9	88.7	137.3				

Another implication of running passenger trains on the freight network is the increase in the amount of additional variation introduced to the freight network. Figure 2 shows the distribution of freight delay in 10% bands. The more passenger trains operated, the higher the variation in the delay of the unit trains, and the more skewed the distribution will be. The performance of the worst 10% of freight trains is particularly important because train crews can only be on duty for 12 hours before a relief crew must takeover. So more variation means that more relief crews are needed. Variation in freight service also affects time sensitive goods, connections at terminals, and customer satisfaction (White 2006).

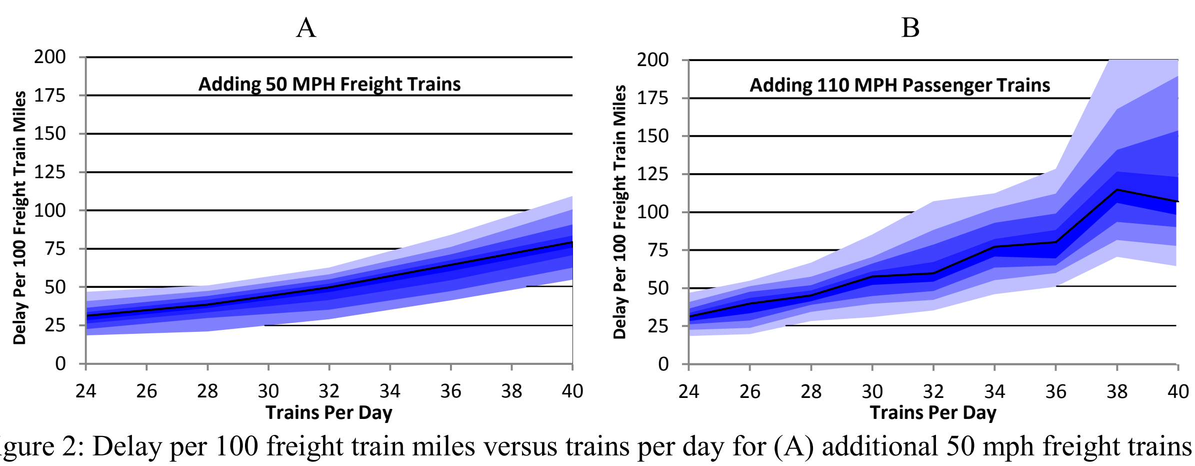

Figure 2: Delay per 100 freight train miles versus trains per day for (A) additional 50 mph freight trains and (B) additional 110 mph passenger trains. The base case is 24 freight trains per day.

3 DISCUSSION

3.1 Homogenous Traffic

The homogeneous condition is an idealized set of circumstances in which all the traffic consists of only unit trains. All trains have the same operating characteristics and maximum speed. There are no overtakes between trains and all meets tend to occur in predictable locations on the network at regular intervals. The priority of trains is solely dependent on each train's on-time-performance (late trains are given a higher priority), and which train arrives at a siding first. These conflicts only involve two trains in opposite directions of travel. This is considered the equilibrium condition of the network. As the number of trains per day increases, each train will encounter more trains traveling in the opposite direction. On average, each train will be the favored train in a conflict 50% of the time. With more conflicts, there will be more variation in the delay. Some trains will perform better than 50% while others will perform worse.

Our base case of only unit trains is not entirely representative of the equilibrium condition. We assumed a variation of ± 20 minutes for scheduled departures of freight trains. At higher traffic densities, the headway between trains is lower, and the variation leads to bunching of trains. Under these circumstances, conflict resolutions become more complex. For example one train may depart 20 minutes late and enter the second siding on the subdivision for a meet with a westbound train. Meanwhile, the next train departs the origination yard 20 minutes early and catches up to the first train. These two trains now form an eastbound "fleet" that will make all subsequent dispatching resolutions more complicated. Westbound trains will enter sidings in order to accommodate the fleet. This type of complex meet has greater delays compared to the equilibrium condition with simple two train meets. Under heterogeneous conditions, fleeting becomes much more prevalent as faster trains catch up to slower trains.

3.2 Prioritizing Traffic

Adding passenger trains to the base case of 100% freight trains has consequences regardless of the speed or number of additional passenger trains. The first is that the freight trains no longer encounter trains of equal priority. The passenger trains have higher priority and require freight trains to enter sidings to maintain on-time performance requirements. The result is that a freight train will be favored in conflicts less than 50% of the time. The second consequence of additional passenger trains is that the number of train starts on the line increases resulting in compressed headways between all trains. With reduced headways, trains are more likely to catch up to delayed trains and cause fleeting. Each train will encounter more trains on the network, irrespective of the type of train added. These two effects can be seen when comparing the addition of a 50 mph passenger train in Table 3. The impact of the heterogeneous delays caused by passenger trains is more pronounced at higher traffic densities. This trend is consistent with Dingler's (2009) work which found that heterogeneous delays between intermodal and unit trains are more pronounced at higher traffic densities.

3.3 The Impact of Speed on Freight Trains

Passenger train speed has two major counteracting factors that affect the performance of freight trains. The positive factor is that because of their higher speed, passenger trains spend less time on the network than freight trains. Because of this, they have fewer opportunities to conflict with freight traffic. The negative factor is that higher speeds disturb the equilibrium condition and introduce more complex dispatching resolutions. These complex resolutions cause more delays than simple meets between two trains. The data in Table 4 suggest that at higher traffic densities, higher passenger speeds will increase delays but eventually the network becomes disturbed enough that the marginal increase in speed has a diminishing effect on the delay of freight trains (Figure 3). Our data suggest this trend is occurring with additional variation. Testing additional speeds should follow the trends in Table 4 where there was additional variation due to other factors besides speed. While the effects of delay on 79 mph and 110 mph are small, there are other problems with running passenger trains beyond 79 mph such as liability assignment, grade crossings and infrastructure.

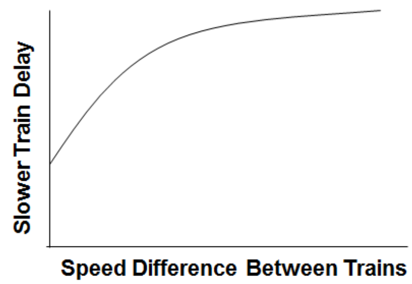

Figure 3: Proposed Relationship Between Speed and Delay

3.4 Implications of Temporal Separation of Trains

One approach that is sometimes used for shared freight and passenger corridors is to separate the two train types by time of day. Passenger trains would operate during the day and freight trains at night. In the schedule for the simulations, passenger trains ran between 7:30 am and 8:00 pm. In our simulations with passenger traffic consisting of 40% or more of the total traffic, we experience this type of temporal sharing.

A substantial portion of freight train delay in this situation is caused during homogenous conditions due to compressed headways at night. When the passenger trains push the freight operations to night hours, the density of the original freight traffic increases. For example, with an initial density of 16 freight trains per day, a train leaves each yard every 3 hours and averages 18 minutes of delay per 100 miles. When 16 passenger trains per day are operating during the daylight, the 16 freight trains operate at night leaving each yard every 90 minutes. The nocturnal operation of the freight trains is similar to operating 32 freight trains per day. In the shared corridor example, each freight train is delayed 62 minutes per 100 miles. Our analysis shows that 90 minute headways of only homogenous freight traffic results in 48 minutes of delay per 100 miles. Freight trains average 12 minutes more delay per 100 train miles in the shared corridor than in the homogenous operation. This is due to the heterogeneous delays to the freight trains as the line transitions from freight to passenger traffic. The additional delay due to the transition can be reduced by adding a time buffer between freight and passenger traffic. However, adding buffer time to prevent heterogeneous delays has the tradeoff of further compressing the headways of the freight operations at night. Sharing the corridor in this manner causes freight traffic to operate in a capacity constrained environment instead of a free flowing condition.

4 FUTURE WORK

The methodology presented here can be adapted to simulate shared corridors with multiple mainline tracks. While many proposals for higher speed passenger train service in the Midwest will be on single track, other regions of the country will use double track. Delays are more pronounced on single track lines than two-main tracks. Also, this study suggested some of the impacts to temporal sharing of corridors. The assumption of equal headways can be re-evaluated to look at compressed headways to provide a buffer time between train types to allow the line to transition from one type of operations to another. This compression of headways does not need to be 100% and does not have to be shared equally between train types. Lastly, it will be interesting to correlate train performance to the crew delays and determine the total number of relief crews needed to operate a shared corridor. Lastly, a universal method can be developed to equate the capacity impact of a passenger trains to a freight train.

5 CONCLUSION

There is a tradeoff between on-time-performance and the number of trains scheduled over a network. Additional trains result in more delay. Adding passenger trains instead of a similar type of freight train will make this tradeoff more severe. The additional passenger trains increased the mean and variation of freight delay more than additional freight trains of similar type. The greater the speed differential in train types, the more freight delay will occur at passenger train speeds up to 90 mph. Beyond this, the marginal effect of speed starts to decrease.

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