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IMPACT OF PASSENGER TRAINS IN DOUBLE TRACK 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. Simultaneous operation of heterogeneous traffic further increases delay relative to additional homogenous traffic. Additional passenger trains can cause more delays to freight trains than additional freight trains. Rail Traffic Controller (RTC) was used to run simulations with varying mixes of unit freight and passenger trains operating at various speeds on a double track configuration. Basic assumptions on the relative difference in priority between train types lead to drastically different results on the impact of adding higher priority trains. This assumption dictates whether the track in the opposing direction should be used for overtake maneuvers. Also, higher speed differentials between train types can result in higher delays as faster trains catch up to slower trains more quickly. These analyses will help planners improve their understanding of the tradeoff in capacity due to operation of different types of trains at different priorities and speeds.

INTRODUCTION

Long-term freight demand is projected to increase 84% by 2035 [1], 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. Operating multiple train types on one line can introduce higher delays than operating a single train type [2]. Higher speed passenger trains in shared corridors introduce new challenges in managing the existing capacity of the railroad. Simulation analysis has been used to analyze the delay caused by the interactions of unit trains and intermodal trains. Simulation techniques have also been used to study the interactions between passenger train speeds and bulk freight trains on single track [3]. The objective of this paper is to analyze the impact of adding passenger trains to double track freight railroad networks. We used simulation software called Rail Traffic Controller (RTC) to evaluate effects of homogeneous and heterogeneous operations [4].

Delay, measured in minutes per 100 train miles, is the main output from the simulation analyses. Delay is defined as the difference between the simulated actual run time and the simulated 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. This metric provides insight into the capacity of a line. All delay values presented in this analysis refer to the performance of the trains on a line and not the maximum number of trains that can be operated on the line.

Background

Double track lines can move more traffic than single track by removing the need for trains to start and stop at sidings to allow the other train to clear the bottleneck section. The largest component of delays for train interaction in single track is the meet delays at these sidings [5]. Subsequently, double track lines should have very small meet delays. Because of these inherent efficiencies, double track lines can be utilized to run more trains at higher average speeds than single track configuration.

When speed differentials are present in double track configurations, there are two options to resolve the conflict when a fast train catches up to the slower train. The first option is to delay the fast train and slow it down to the speed of the slower train. Another option is to preserve the on time performance of the faster train by using the 2nd track for an overtake maneuver. There are two methods of accomplishing this maneuver. The first is to have the slow train use a crossover to transfer to the 2nd track and allow the fast train to pass at its track speed. The slow train will then take the next available crossover to return to the original track. Another approach is to have the faster train change its speed to that of the crossover speed and transfer to the 2nd track. The faster train can then pass the slower train and use the next downstream crossover to transfer back to the original track. The latter option can cause more delays to the faster train but use the 2nd track for a shorter period of time. The consequence of the overtake maneuver is that the 2nd track is being utilized to pass trains to preserve on time performance instead of using the 2nd track to move trains in the opposite direction.

If there are large speed differentials between train types then there is a greater need for overtakes which consume capacity of train movements in the opposite direction. The assumption of whether or not to allow overtake maneuvers greatly influences the total number of trains per day that can be operated along the line. In a congested double track line, often a low priority train in the opposing direction stops before the crossover in order to let the overtake maneuver finish. This stopped train incurs the braking, accelerating and stopped delays. Alternatively in the no overtake scenario, the passenger train only has to slow down to a slower speed and then accelerate back to the track speed. The overtake decision indicates which trains will be delayed and the capacity of the line since there are greater delays with stopped trains than with trains that are travelling at a reduced speed. There could exist a fast enough train with such a high speed differential that the trailing delays of the fast train could equal the meet delay of the low priority slow train. Such a large speed differential would dictate the need for dedicated tracks. Additionally, these faster trains often have better operating characteristics in terms of braking and accelerating. This scenario is unlikely.

Methodology

The simulated route characteristics are shown Table 1. The route is simplified as much as possible to facilitate comparison of the effects of key variables regarding traffic composition, priority, 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 [6].

Table 1: Route Parameters Used In Simulation Model

Parameter	Value
Type	Double Track (1 O-D Pair)
Length	265 miles
Universal crossover spacing	15 miles
Siding length	7,920 feet
Traffic control system	2-Block, 3-Aspect ABS
Average signal spacing	2.0 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) [7]. 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 Transportation Research Board Workshop on Railroad Capacity and Corridor Planning (2002) [8]. 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 [9]. The speeds tested were 79 mph and 110 mph. Trains are limited to a maximum speed of 79 mph without advanced signaling and highway crossing technologies. Illinois and Michigan have proposed increase the track speed to 110 mph.

Table 2: Train Parameters for Simulation Model

	Unit Freight Train	Passenger Train
Locomotives	x3 SD70	x2 P42
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
Max Speed (MPH)	50	79,110
Unique Characteristics	± 20 minutes departure time	32.4 miles between stops

Train starts were balanced between the east and west end of the network with all train starts spaced evenly. The headways for all trains were held constant throughout the simulation. At 64 trains per day, there are 32 eastbound and 32 westbound with a train departing each origination yard every 45 minutes. Each simulation includes the performance of all the trains that operate within a 5-day period. Each particular traffic mix was repeated four times. Passenger trains were scheduled to start during daylight hours between 7:00 am and 8:00 pm. This process was repeated for different passenger speeds tested: 79 mph, and 110 mph.

The primary output from each simulation was the total delay for each train. This number was then normalized by the route length to determine delay minutes per 100 train miles. This metric was used to analyze the freight train performance because the track speed of the freight trains was held constant over all of the simulation models. An increase in passenger train speed increases the cost of a delay inducing event to the passenger trains. A 10 minute delay for a 79 mph train costs 13.2 miles of travel, and a 10 minute delay for a 110 mph train costa 18.3 miles of travel. Instead of delay per 100 train miles, passenger train performance is analyzed as the time to travel 100 miles [10].

There were two experiments conducted to examine the effects of train speed on freight traffic. The first experiment was designed to look at three factors: traffic composition, passenger train priority and maximum speed of passenger trains. The traffic level was held constant at 64 trains per day. The traffic composition starts with a homogenous freight line and then passenger trains replace a percentage of the freight trains to create a heterogeneous traffic composition. Eventually the line will transition to only homogeneous passenger traffic. There were 9 compositions studied. The traffic composition is measured by the heterogeneity level defined as the percentage of the total traffic that is freight trains.

Each traffic mix was analyzed under two scenarios where the passenger train was given high priority and where it had the same priority as a freight train. A high priority passenger train would require an overtake maneuver to pass a freight train while an equal priority passenger train would trail behind a freight train. The equal priority case can represent a lower bound on passenger train performance. A high priority passenger represents the upper bound on train performance. Freight railroads do give priority to passenger trains in their dispatching practices. Additionally, a minimum service agreement may be required to protect on time performance of passenger trains. In practice, the performance of the passenger train should be between these two bounds.

The second experiment was to analyze the impact of passenger trains to an existing freight network. Under this scenario the base traffic level was 40 freight trains per day. Increments of two roundtrip passenger trains were sequentially added to the base of 40 freight trains until the network reached a total of 68 trains per day. Experiment 2 considers the effect of compressed headways that are caused by additional passenger trains. Experiment 1 focuses more on traffic composition.

Both Experiments have a shared traffic mix of 40 freight and 24 passenger trains per day. This particular traffic mix will be analyzed in further depth.

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.

EXPERIMENT 1

All the delays present in this experiment are solely due to the heterogeneity in train type. Under homogenous traffic of all passenger or all freight trains, there are no delays. There is no speed differential between trains to cause a delay event. Any delays that incurred in the simulation were related to the terminals.

The freight trains are delayed significantly in 110 mph passenger dominated lines as show in Figure 1. These trains often have to stop frequently in order to allow for overtakes on the other track. Another source of delay is when a freight train has to wait to enter the mainline at a terminal in order to let the passenger train depart first. As the heterogeneity level increases, there are more freight trains present in the network and these types of delays decrease sharply. The degree of these delays is also dominated by the speed and priority of the faster trains. 79 mph passenger trains did not cause as much delays to the freight trains as the higher speed did. 79 mph passenger trains require fewer overtake maneuvers and also have an average speed closer to the freight trains. As the passenger trains stop at stations every 32.4 miles, the average speed between terminals decreases. Without any freight train interference, the 79 mph passenger trains average 65 mph.

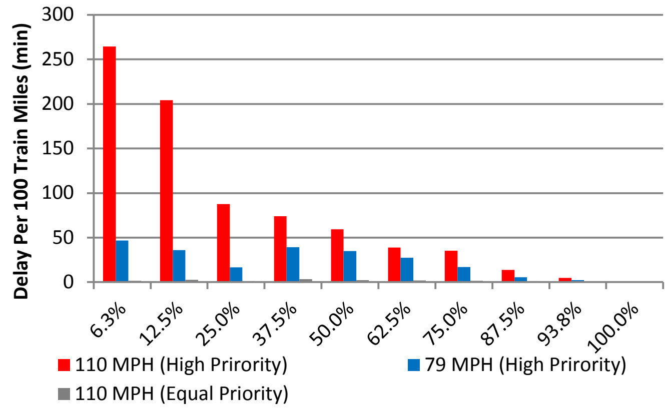

Figure 1: Induced freight train delays caused by speed differentials in train types

The travel time for passenger trains to cover 100 miles at various heterogeneity levels is shown in Figure 2. At 64 trains per day with no freight trains, passenger trains will not be delayed. The passenger trains maintain their minimum run times at 92.5 minutes per 100 miles with a track speed of 79 mph and 74.6 minutes per 100 miles with a track speed of 110 mph. Under heterogeneous conditions, passenger trains can catch up to a freight train and then experience trailing delays. These additional delays increase the time to travel 100 miles. The priority of the train can help mitigate this type of the delay. Figure 2 shows that high priority trains have faster travel times in heterogeneous traffic compositions than the equal priority condition, regardless of their speeds. The 110 mph high priority passenger trains are more sensitive to the heterogeneity traffic level. In heterogeneous conditions, the 79 mph high priority passenger train maintains travel times close to its MRT.

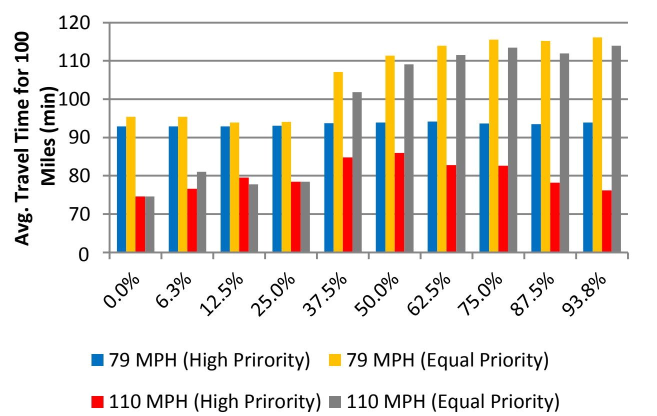

Figure 2: Induced passenger train delays caused by speed differentials in train types

Under the equal priority scenario, the passenger trains incur most of the delays within the network. The travel times can be maintained within heterogeneity levels of 13% and 25%.

With heterogeneity levels within 38%-88% range, the MRT is not be maintained and these trains receive significantly higher delays. At the 50%-88% range, the travel of the 110 mph and 79 mph train is within 4 minutes per 100 train miles. In freight dominated lines with low priority passenger trains, the benefit of speed can be negated.

EXPERIMENT 2

The addition of passenger trains causes the median freight train delay to increase in an exponential manner. Another implication of running passenger trains on the freight network is the increase in the amount of additional variation in delay introduced to the freight network. Figure 3 and Figure 4 show the distribution of freight delay in 10% bands. The higher number of passenger trains operated, the higher the variation in the delay of the unit trains, and the more skewed the distribution is. 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. Higher variation results in more relief crews are needed. Variation in freight service also affects time sensitive goods, connections at terminals, and customer satisfaction [3,10]. In both adding 79 mph and 110 mph trains to the base of 40 freight trains per day, the median delay of the freight trains increased. The 110 mph passenger trains added more delay and variability to the arrival times of the freight trains shown in Figure 4 than the 79 mph passenger trains as shown in Figure 3.

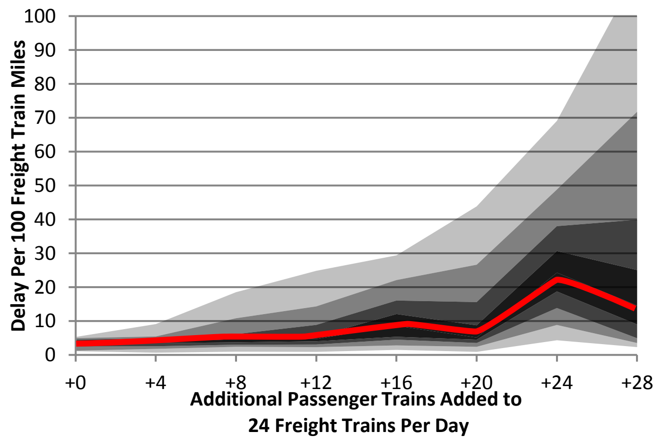

Figure 3: Distribution of freight delays when 79 mph passenger trains are added to a base of 24 freight trains

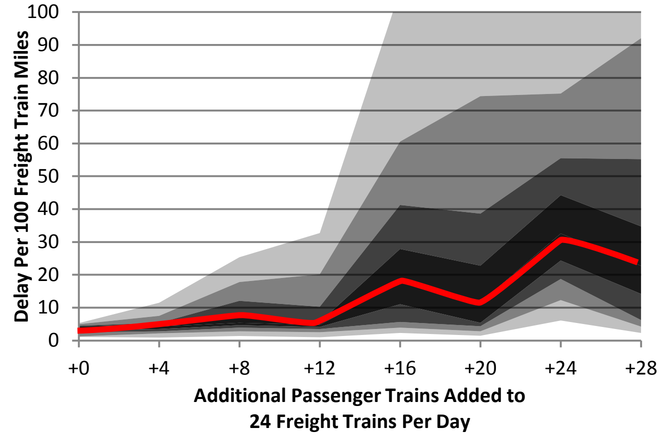

Figure 4: Distribution of freight delays when 110 mph passenger trains are added to a base of 24 freight trains

40 FREIGHT TRAINS + 24 PASSENGER TRAINS

The subsequent analysis will focus on the mix that was present in both Experiment 1 and Experiment 2 where 24 passenger trains operate alongside 40 freight trains.

The distribution of delays to the freight trains is positively skewed to the right with 79 mph and 110 mph passenger train speeds as shown in Figure 5. The peak of the distribution is more pronounced under the 79 mph scenario than with the 110 mph scenario. The amount of data in the right tail of the distribution is higher in the 110 mph cases. The higher speed of the passenger train resulted in a shift in the cumulative frequency diagram as shown in Figure 6. Higher delays are more frequent with 110 mph service. The median value of delays caused by 110 mph service is 34% higher than 79 mph. The 95th percentile is also 40% higher with 110 mph interference than with 79 mph interference.

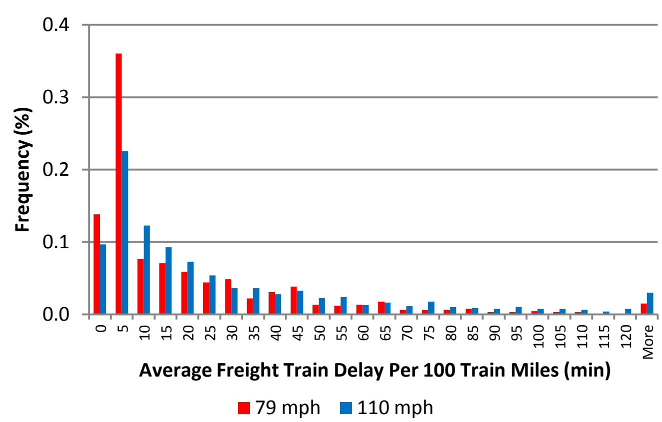

Figure 5: Freight train delay distribution with 79 mph & 110 mph passenger train interference

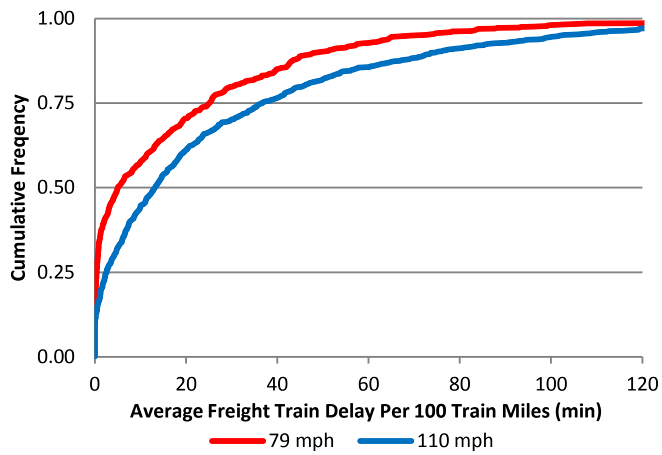

Figure 6: Cumulative distribution of freight train delays with 79 mph & 110 mph passenger train interference

Passenger run times to cover 100 miles in a high priority low capacity settings are mostly faster with 110 mph trains than with 79 mph trains as shown in Figure 7. The minimum run times are denoted by the 0th percentile and are 73.9 minutes (B) at 110 mph and 92.2 minutes (A) for 79 mph train speeds. A steep slope from the MRT point indicates better reliability. If the data within the 5th percentile and 95th percentile is considered likely to occur, than 90% of the travel times to travel 100 miles are within 62.9 minute for 110 mph track speed. At a 79 mph track speed, 90% of the data is within 22.3 minutes. The 79 mph passenger train speeds operates more consistently to the MRT than the 110 mph passenger trains. While 110 mph can offer faster travel times, the train suffers more time loss in a delay event and cause lower reliability.

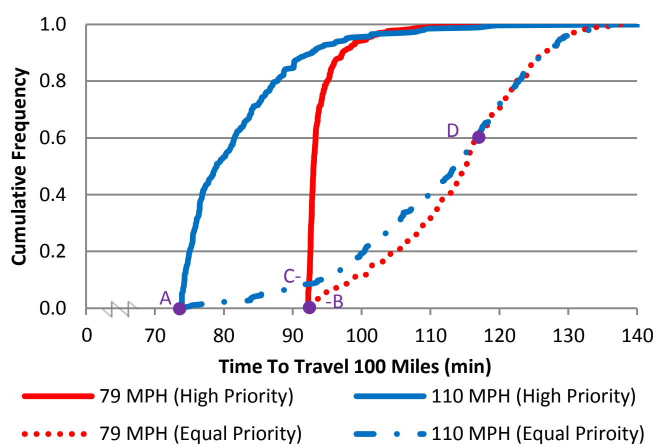

Figure 7: Cumulative frequency of travel times for passenger trains at various speeds and priority

When the element of priority between passenger trains and freight trains is removed, their performance decreases compared to when these trains operated at a higher priority. The best performing train are still similar to that of the best performing train (A&B) in the high priority scenario. However, when a fast train catches up to a slow train, a delay event occurs and causes the faster train to slow down. At the 10th percentile of the equal priority 110 mph case, the train performance has already deteriorated to the speed of a 79 high priority passenger train (C). At the 60th percentile, the distributions of the equal priority 79 mph and 110 mph trains converge (D). After this percentile, there are enough delay events to these worse performing trains that the benefit of operating at higher passenger train speed is negated.

The distribution of the worse performing 110 mph and 79 mph high priority trains are shown in Figure 8. The 110 mph distribution crosses the 79 mph distribution at the 97th percentile. After this point, there is an increased probability that there will be a slower travel time for a 110 mph train than with a 79 mph train. This is likely due to the additional disturbance to the freight trains that a high priority 110 mph train causes to the freight traffic.

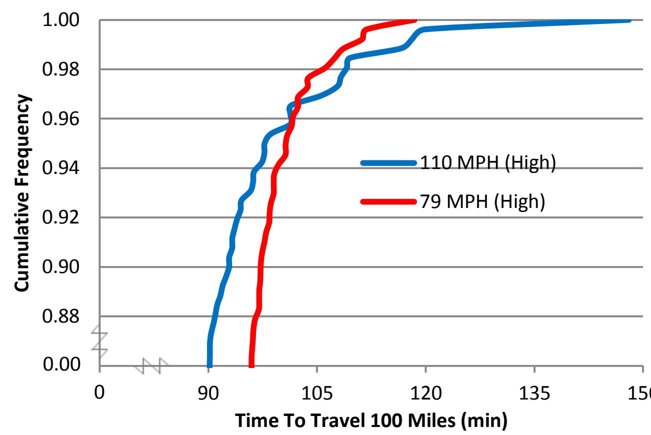

Figure 8: Cumulative distribution of the 10% worse performing Trains

CONCLUSION

Double track configurations can handle a significantly large amount of traffic under homogeneous conditions. Speed differentials in traffic introduce delays to the system and decrease the capacity of the line. Larger speed differentials cause larger delays and greater variability to the traffic on the line. Having a fast high priority train requires overtake maneuvers that uses capacity of the 2nd track. This overtake maneuver prevents the 2nd track from moving trains in the opposite direction. An equal priority scenario can move more trains through the network. The priority of the trains dictates which train types will receive the delays. Under the equal priority scenario there are less total delays.

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REFERENCES

[1] American Association of State Highway and Transportation Officials (AASHTO), "Transportation - Invest in Our Future: America's Freight Challenge," AASHTO, Washington D.C., 2007.

[2] M. H. Dingler, C. P. Barkan and Y.-C. Lai, "Impact of Operating Heterogeneity on Railway Capacity," *Transportation Research-Journal of Transportation Research Board*, no. 2117, pp. 41-49, 2009.

[3] S. L. Sogin, "Simulating the Effects of Higher Speed Passenger Trains in Single Track Freight Networks," in *Winter Simulation Conference*, Phoenix, 2011.

[4] E. Wilson, *Rail Traffic Controller,* 2.70 L61Q: Berkeley Simulation Software, 2011.

[5] M. Dingler, A. Koenig and S. Sogin, "Determining the Causes of Train Delay," in *AREMA*, Orlando, 2010.

[6] J. Pachl, Railroad Operation and Control, Mountlake Terrace, WA: VTD Rail Publishing, 2002.

[7] Cambridge Systematics, "National Rail Freight Infrastrucutre Capacity and Investment Study," Cambridge Systematics, Cambridge, 2007.

[8] "Workshop On Railroad Capacity and Corridor Planning," in *Transportation Research Board (TRB)*, Washington, 2002.

[9] J. D. Coran, "Why Talgo is Key to How America Moves," in *National Association of American Passengers*, Los Angeles, 2010.

[10] T. A. White, "Examination of Use of Delay as Standard Measurement of Railroad Capacity and Operation," in *Transportation Research Board*, Washington D.C., 2006.