Determining the Causes of Train Delay

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ABSTRACT

Class 1 railroads are expected to face increasing capacity constraints due to long-term projections of growth in both freight and passenger traffic. To prepare for this growth and to strategically determine the best capacity expansion projects the Class 1 railroads make extensive use of a simulation tool known as Rail Traffic Controller (RTC). This tool can be used to estimate the capacity of existing or propose track and signal configurations. One of the primary outputs of these analyses are estimates of train delay. Delay is the extra time it takes a train to operate on a route due to conflicts with other traffic. Reduction in delay is often used by the railroads to calculate the benefit of a project or operational change. However the specific factors that cause these delays are not well understood. We used RTC to categorize and quantify the delay due to different types of conflicts and operational causes. The conflicts considered were meets, passes, mainline restrictions and entry delay. The operational causes considered were the delays due to acceleration, braking, reduced speed and dwell time. The results were studied for trends and offer a better understanding of the principal factors that contribute to train delay. With delay being used as the primary metric to select projects, understanding the leading causes of delay is important to plan capacity more effectively and economically. This work provides insight into the outputs railroads use for their decision making and potentially allows planners to more effectively choose specific alternatives that will provide the greatest benefit.

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INTRODUCTION

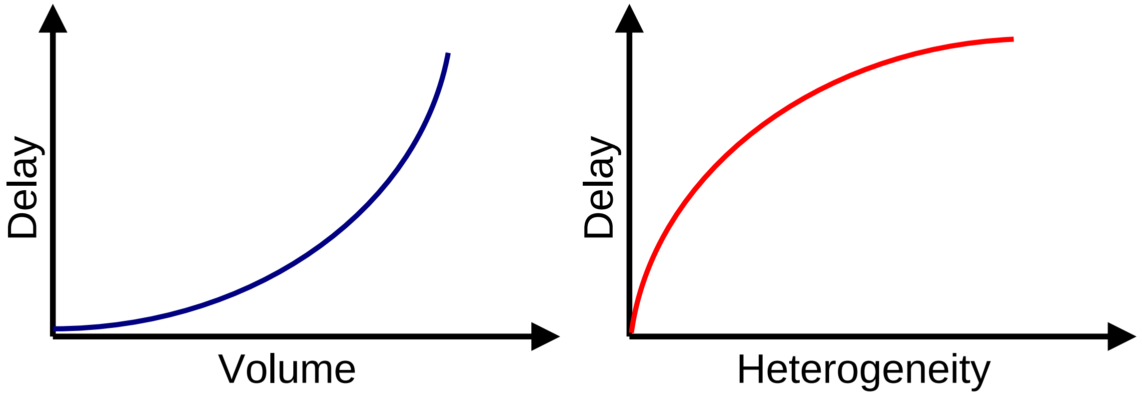
Class 1 railroads are expected to face increasing capacity constraints due to long-term projections of growth in both freight and passenger traffic *(1)*. In order to accommodate this new traffic railroads will need to modify operational practices and build additional infrastructure. Railroads are increasingly using simulation to plan these changes and projects. One of the primary outputs from these simulations used by railroads as a metric for capacity and efficiency is train delay. Delay is influenced by a number of factors and its relationship to capacity is indirect. Simulations of railroad operations were performed under a variety of volumes and traffic mixtures and the delays categorized by source and conflict. The results offer better insight into the different factors that contributing to train delay. Better understanding of this capacity metric will enable railroads to conduct more effective capacity planning by focusing on alternatives that will provide the greatest reduction in delay.

DELAY AS A CAPACITY METRIC

Delay is often used as a metric of capacity; however, delay is a measure of level of service, not capacity and the relationship between delay and capacity is complicated. Delay can be defined as either the difference between the minimum, or unopposed, travel time and the actual travel time or the difference between the scheduled and actual travel time. Using either definition, delay increases as the level of service offered decreases.

Trains can be delayed by both scheduled and unscheduled events. Scheduled delays are incorporated into the timetable as buffer time to allow for conflicts with other traffic. Unscheduled delays are stochastic and are a leading factor in unreliability and instability of a network. Unscheduled delays can be caused by numerous events including: mechanical failures, malfunctioning infrastructure, weather conditions, excessive boarding times of passengers, accidents at highway-railroad grade crossings and so on *(2,3)*. Delays to one train can lead to a cascading effect of delays to other trains. As a route nears its theoretical capacity the probability that a delay will lead to subsequent delays increases, while the ability to recover from these delays decreases *(4,5,6)*.

The amount of delay is related to the volume and type of traffic on a route (7). With more traffic the number of meets and passes increases, and headways are reduced, increasing the probability of a delay causing additional delays to other traffic. It is generally agreed upon that delays increase exponentially with volume (Figure 1a) *(4,7,8,9,10)*. However, the specific delay-volume relationship is dependent on the traffic mix on a route *(7,8,11)*. Different train types have different operating characteristics influencing the amount of delay that a train experiences. Heterogeneity in these train characteristics causes additional conflicts increasing delays (Figure 1b) *(7,12,13,14)*.



(a) (b)

FIGURE 1: The delay-volume (a) and delay-heterogeneity relationship (b)

The maximum capacity of a route is dependent on operational decisions by the railroad. When determining capacity each railroad determines the maximum tolerable delay based on the traffic mix, route geography and service requirements. Greater tolerable delays will increase the capacity of a route, but decrease the level of service and reliability (Figure 2) *(15)*.

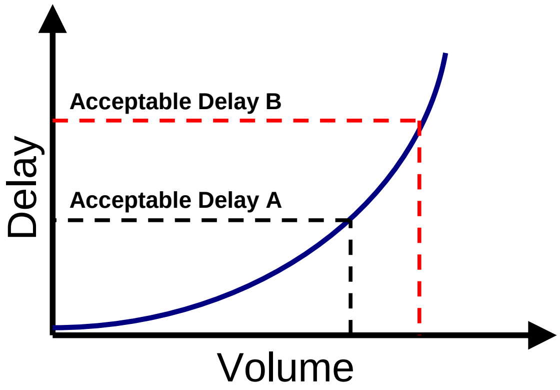


FIGURE 2: Maximum volume based on maximum allowable delay

DETERMINING THE SOURCES OF DELAY

There are numerous factors that cause train delays and there has been limited previous work investigating the magnitude of the various operational causes. One of the best analyses to date is by Gorman *(16)*. In his work he created a train run time model from empirical data for eight BNSF subdivisions. He used the data to statistically calculate the amount of delay caused by various factors including: meets, passes, headway, secondary effects, priority and HPT. He identified meets, passes and overtakes as the primary causes of delays. This work uses simulation instead of empirical data to determine the magnitude of delays caused by different operational factors.

Methodology

We used the simulation software Rail Traffic Controller (RTC) from Berkeley Simulation Software in order to calculate the impact of the various mechanisms that affect train delay. We used RTC because its flexibility permits rapid evaluation of different scenarios and because of its widespread acceptance and use by the North American railroad industry. For this analysis, delay was defined as the difference between the minimum, or unopposed, run time, and the actual run time required to traverse the route. Using RTC's Train Performance Calculator (TPC) the speed, position and acceleration data for each train were collected. The TPC data, along with time-distance diagrams were used to identify the conflicts that caused each delay. The delay was then divided between the delay accumulated while the train was braking, traveling at a constant speed below normal, stopped and accelerating.

The route and train characteristics used for this analysis were chosen to represent the characteristics of a typical route and train types. While specific characteristics of individual rail lines are unique, the rail line used for this analysis is intended to represent the characteristics of a typical midwestern North American single-track mainline subdivision. The train types used for this analysis are intended to match the attributes of intermodal and bulk trains. The attributes were chosen to approximate actual characteristics, but generally the "intermodal" trains represent freight trains with the highest maximum speeds, power to ton ratios and dispatching priorities, while the "bulk" trains represent those with the lowest speeds, power to ton ratios and dispatching priorities.

Simulations were performed using RTC over seven different levels of heterogeneity with a constant volume of 40 trains per day. For each configuration a series of five simulations were performed. In each simulation sixteen trains were analyzed, eight in each direction with the number of trains of each type corresponding to the percentage of that train type in the scenario.

Factors of Delay

The delays were categorized by conflict and source. Conflicts considered in this work are meets, passes and line restrictions (Table 1). Meets were classified as any delay due to conflicts with one or more trains traveling in the opposite direction. Passes were classified as any delay due to conflicts with one or more trains traveling in the same direction that result in one train overtaking another. When a conflict involved multiple meets and passes, the acceleration and braking delay were attributed to the first conflict while the extra dwell time required to accommodate the additional conflicts were attributed to each conflict accordingly. Line delays were classified as any delay due to one train being slowed down by a preceding train traveling in the same direction that does not result in an overtake.

For each conflict the specific operational source was identified. Sources of delay include the delays while a train is braking, accelerating, at a constant slower speed or stopped (Table 6.1). By splitting the delay up into conflicts and sources, it is possible to see which type of conflict has more delay, why that delay is occurring, and how it changes with changes in traffic composition.

TABLE 1: Categories of Delays

Conflicts	Sources
Meets	Accelerating
Passes	Braking
Line	Reduced Speed
	Stopped

Average Delays

The delays due to each conflict and source of delay are combined to determine the total delays for each traffic mix (Figure 3). The delays were greatest with heterogeneous traffic. However, the greatest amount of delay was not when heterogeneity was greatest but when the majority of traffic was bulk trains. The traffic composition that results in the greatest delays is dependent on the characteristics of the specific trains. In this example each bulk train experiences greater delays due to its poor operating characteristics, and therefore the combined effect of the larger number of these poor performing trains and the effects of heterogeneity are greatest when the traffic is 75% bulk trains.

FIGURE 3: Average Delays with Different Traffic Mixes

Conflicts that Cause Delays

When sorted by type of conflict most of the delay is accumulated during meets (Figure 4). The delays from meets are much larger than delays from line or pass delays. Each type of delay changes differently with changing traffic. The delays due to passes are the greatest at the highest levels of heterogeneity while mainline delays are the same with all levels of heterogeneity. The delays from meets closely follow the trend of the average delays. Consequently, the increased delays due to heterogeneity are primarily from increased meet delays.

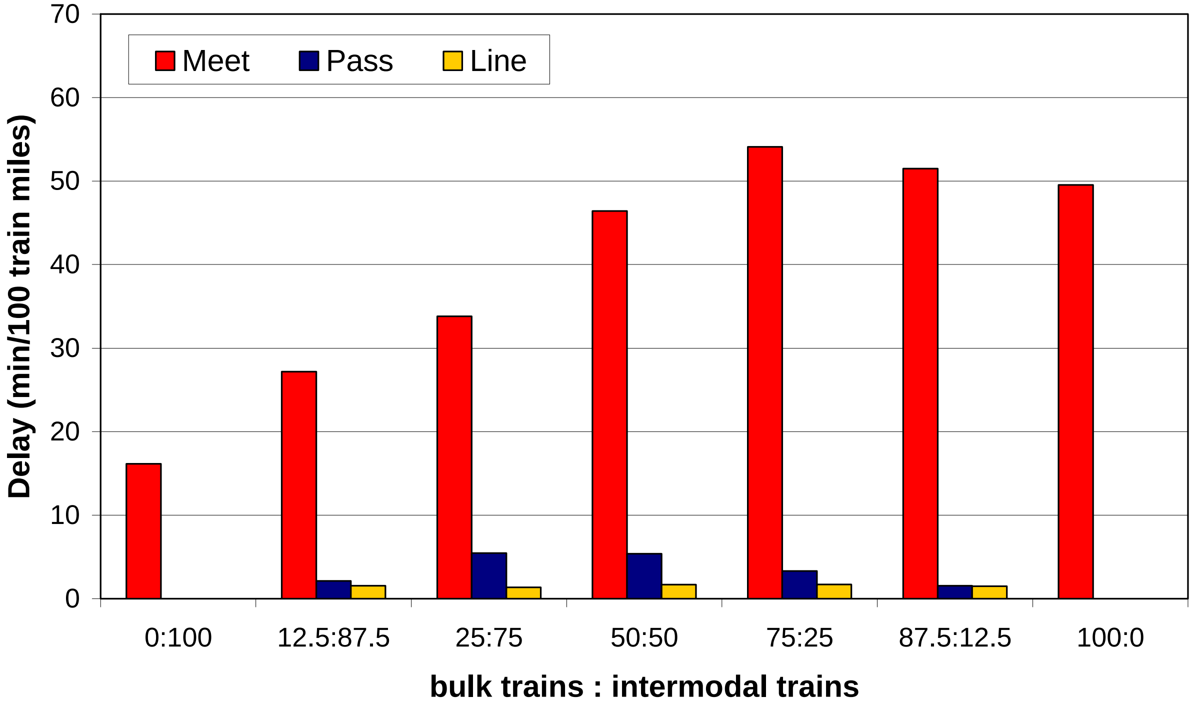


FIGURE 4: Average Delay by Conflict and Ratio of Bulk to Intermodal Trains

Sources that Cause Delays

Each source of delay has a different trend with regard to traffic mix (Figure 5). The delays while a train was traveling at a reduced speed were minor and relatively constant over all traffic mixes. The delays while a train is braking and accelerating increased with larger percentages of bulk trains. These delays are therefore due to changes in traffic and not increased heterogeneity. As the percentage of bulk trains increases the acceleration and braking delays increase accordingly.

The stopped delay is the only delay that increased with heterogeneity. Therefore, the increased delays with heterogeneity are due to a greater amount of time trains are stopped waiting in a siding. There are two possible explanations for this. First, at the higher levels of heterogeneity there is a greater likelihood two trains of different priorities will meet resulting in less efficient meets. These inefficient meets result in longer dwell times because a train will enter a siding earlier than it otherwise might. Secondly, higher heterogeneity results in more complex conflicts in which a train is met or passed by more than one train resulting in more time stopped.

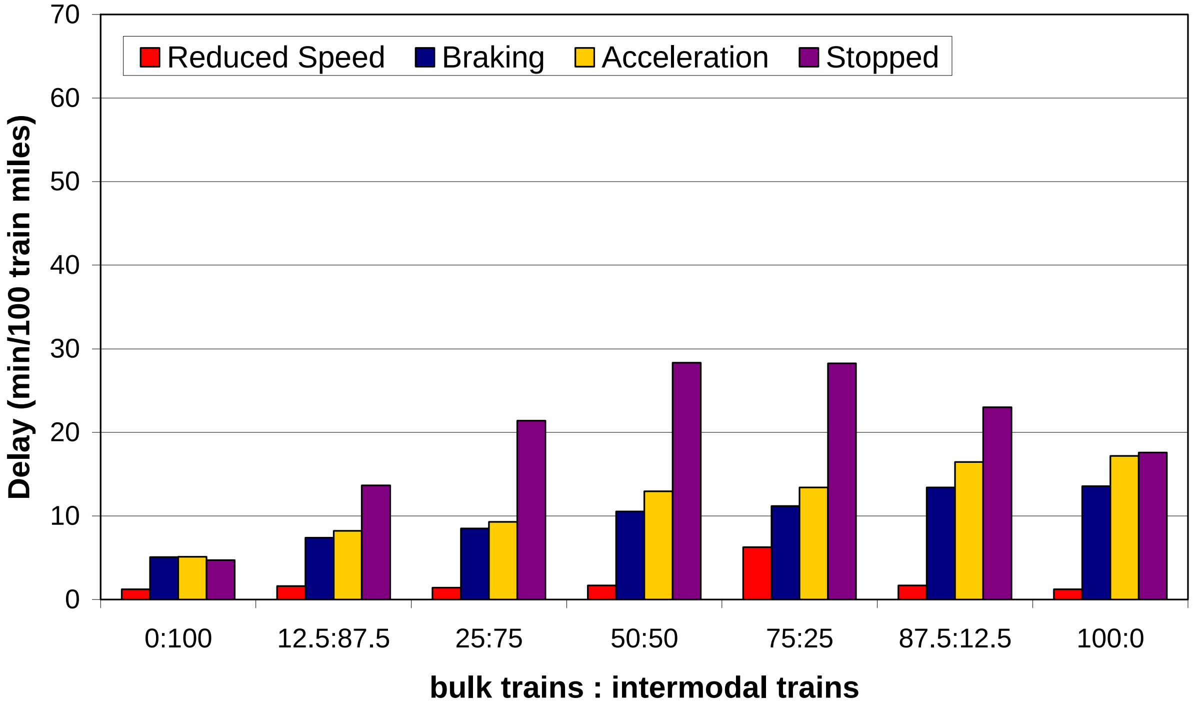


FIGURE 5: Average Delay by Source and Ratio of Bulk to Intermodal Trains

DISCUSSION

By categorizing delays the specific conflicts and sources that cause them can be identified. This work suggest that increased delays are the result of trains waiting longer in sidings to resolve additional and more complex meets at the highest levels of heterogeneity.   Passes were found not to be a major source of delay on single track indicating that speed difference alone is not a significant factor affecting train delay. Independent of heterogeneity in speed, higher average speeds will reduce dwell times and improve capacity on a single-track route.

Time spent stopped in sidings for meets was found to be the leading cause of delay and efforts to reduce train delay should focus on reducing this time. Possible methods of reducing this delay include increasing the speed of trains, reducing siding spacing, equalizing priorities, and adding a second track. Increasing speeds decreases the time it takes to resolve conflicts. Reducing siding spacing allows for trains to stop closer to the point of conflict thereby reducing waiting time. Removing priorities makes meets more efficient since the first train to arrive will enter the siding. Lastly, adding a second track eliminates delay time from meets.

CONCLUSIONS AND FUTURE WORK

Simulation is increasingly being used to plan for future growth and improve current operations. The primary output from the simulation software is train delay, with the reduction in delay often being used to determine the benefit of a project or operational change. However, the specific causes of the delay are not well understood. Using simulation software delays were categorized by conflict and source. The results showed that the source of delay that increased due to heterogeneity was the time a train spent stopped in a siding to resolve a meet. Using this information the best way to improve operations are changes that either reduce the number of meets or reduce the time a train is stopped while in a meet.

Additional work using this methodology will permit a better understanding of the impact of various operations. Future work should be completed that considers multiple volumes, no priorities, different infrastructure configurations and passenger traffic.

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