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Extended Abstract Submission

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A Method to Increase Line Capacity at Peak Hour with Limited Platform Capacity

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This work addresses the following topic(s) from the Call for Contributions:
(Please check at least one box)

☐ Placemaking to integrate urban spaces and mobility
☐ Promoting sustainable mobility choices in metropolitan regions
☐ Governing responsible mobility innovations
☐ Shaping the transition towards mobility justice
☒ System analysis, design, and evaluation
☐ other: ________________________

Extended Abstract

Problem statement

The number of public transportation users has been growing as urban population increases. From 2012 to 2017, annual metro ridership grew by 8,716 million passengers worldwide, which is a 19.5% increase. (UITP, 2018). Even after the pandemic, train occupancy in mega cities is around 120~150% compared to original design capacity. (Seoul News, 2023; MLIT, 2022; Sohu, 2021). To alleviate the stress of peak hour trips, there are requests indicating that platforms and vehicles should expand to provide more space for the passengers, since driver shortages may prohibit higher train frequencies or in other cases, the headway might be at the limit of safe operation. Expanding railway infrastructure is not as straightforward as it is with buses due to various operational constraints. Expanding the number or size of tunnels, redesigning the connection between platform, toll gate and ground level, sometimes the connections between the railways, can be extremely costly. Therefore, we would like to look for a method to keep the construction cost at the minimum but increase the capacity of train operation, which is proposed as additional cars per train with door control in this paper.

Research objectives

The method proposed is to increase the number of cars per train in operation, but control the number of cars that open their door at each stations. There should be three sets of cars on a given train. Doors of cars at one end of the train will open only at certain set of stations, named as red stations. Cars in the middle part of the train open doors at every station, and a few cars at the other end of the train only open doors at stations that are not red stations, here called green stations. Passengers traveling from a red station to another red station have the option to use red cars or grey cars. It is assumed that passengers cannot move between cars inside the train. This method effectively increases the capacity of each train during peak hours, without huge investment compared to the other options available, and the length of trains as well as required platform capacity is illustrated as in Figure 1. Moreover, it offers flexibility since operators can remove or add connected cars during off-peak times, theoretically enhancing efficiency. However, how efficient can this operation be, and what can be done to improve its efficiency? This paper aims to find out the best solution and how much it mitigates the problem.

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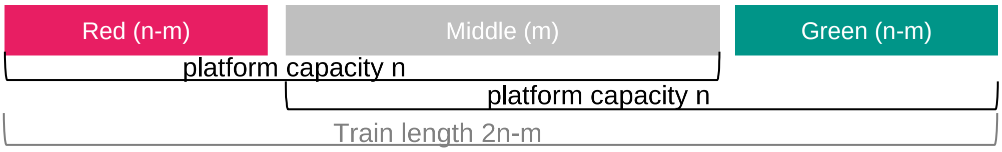

Figure 1. Platform capacity and train length in the method

Methodological approach

In this paper, data from BART in the San Francisco Metropolitan Area in 2019 serve as a case study to investigate and compare different operational scenarios. The research employs three primary approaches to identify the optimal operation scenario. First one is the enumeration approach. This approach involves exhaustively considering all possible scenarios within the given system conditions. It aims to determine the most effective station settings and the optimal number of flexible cars. By systematically exploring all feasible options, researchers seek to find the best configurations. The second one is a heuristics approach. We try to establish rules that find a reasonable station setting so that less time is needed to find an efficient solution. This approach is particularly valuable when dealing with more complex transportation systems, where exhaustive enumeration may become impractical. Attempts to use optimization packages to find the best strategy is also part of the research, but in this paper, we limit the result section with the results from the enumeration approach.

Results

First of all, below are some notations used in this study as in Table 1.

Table 1: Notations

Notation	Definition
n	Platform capacity for cars
m	Number of middle cars that open the doors at every station
s	Nnumber of stations
α	Rratio of passengers who take the cars that only open door at limited stations
R	Red stations, where red cars and middle cars open the doors
G	Green stations, where green cars and middle cars open the doors

We define the number of middle car and station setting that minimizes the maximum number of passengers per car in the line as the optimal operational strategy. With an enumeration approach, which tries out every possible number of middle cars and station settings, we can find out the optimal operational strategy with specific car and station settings.

This optimal operational strategy is dependent on the level of α, the ratio of passengers who take the red or green cars. It indicates that the preference of passenger affects the optimal number of middle cars (m_{opt}) in one train and the station settings. Starting from the number of cars in a train, as α increases, the optimal number of cars decreases, as shown in Figure 2. Furthermore, the original condition that we have only n = 8 cars that stops every station is compared with proposed method. When α is close to 0, the method appears to be not so effective while when it gets close to 1, the maximum number of passengers per car decreases, implying that the method has a larger impact. Therefore, this can be interpreted as an increase in α results in middle car load reduction, and when the load of middle car gets close to the other cars, a decrease in the number of middle cars is expected to even out the loads in different types of cars, which keeps the maximum load per car low.

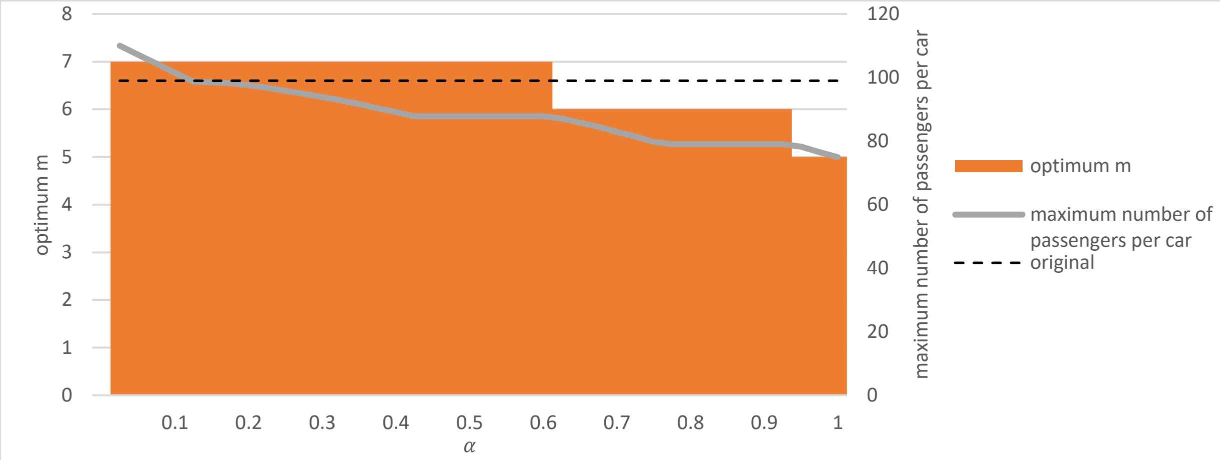

Figure 2: Optimum m and maximum load per car at different α

Figure 3 shows the load per car for different types of cars after alighting at each station under an optimal operational strategy. At the same α, the middle cars always are the most crowded ones. As α increases, the maximum number of passengers per car of red and green car increases.

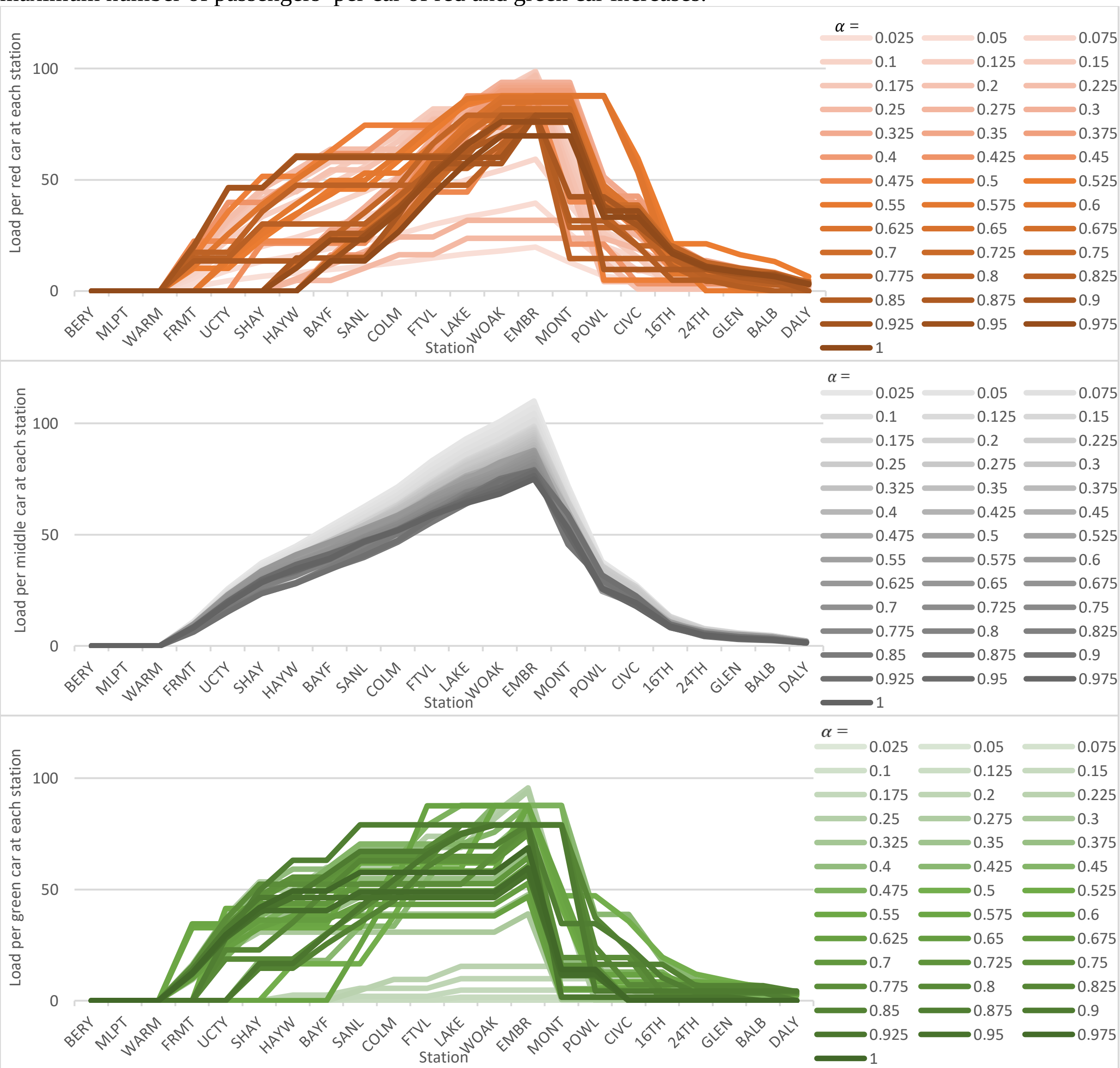

Figure 2: Load per car for red, grey and green cars at each station with optimal operational strategy at different α

Through above enumeration results, it is obvious that with this method, the overcrowding during peak hours could be greatly alleviated, as long as α is not too small. In particular, when the value of α approaches 1, it becomes a reasonable strategy to increase the number of both red and green cars during peak hours. In summary, the research findings suggest that a careful and balanced number of red and green cars, and station settings, with α values that are sufficiently high, can be a successful strategy for tackling peak-hour crowding and enhancing the overall performance of the railway system.

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