# EC601 Project One, Review of Literature: Optimizations for Public Transport via Light Rail as Developed in the MBTA Green Line

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2023.09.17

## I. INTRODUCTION

DESPITE public transport by rail offering the clearly greener transportation option in the face of an accelerating climate crisis [1], personal car usage in Boston remains the dominant mode of transport. Assuming the national average of 1.5 passengers per car holds, Boston sees roughly 804,000 people travel by car versus only 276,000 by the Massachusetts Bay Transportation Authority (MBTA) subway system every day [2].

From personal experience as a Boston resident and frequent passenger, the MBTA undoubtedly has room for betterment, and by improving the general public transport infrastructure to be the more desirable option than cars, not only would residents enjoy cheaper and more effective transportation, but so too would the climate benefit from the reduction in the emission of harmful pollutants and greenhouse gasses.

Although the expansion and implementation of longer, denser, more interconnected rail lines is imperative, such projects are expensive and a long time in the making, often requiring years of wading through red tape. Scheduling and route optimizations, however, offer simple, low-cost-to-implement solutions that could help make the MBTA more attractive and effective.

This project will be looking into specific scheduling and routing optimizations that could be made to improve the Boston Green Line as the third most used light rail system in the United States [3]. As a light rail system, it boasts a complicated, multibranched network populated by more than 200 modern streetcars and can offer a diverse playground to virtually experiment with possible scheduling and routing optimizations [4].

## II. CURRENT STATE OF RESEARCH

Most contemporary research on public transportation optimizations remains focused on improvements to the more flexible bus system. However, both buses and rail (including heavy and light rail) all follow the same approach to general planning, and as such there exists a significant overlap in the research.

### *A. Planning Steps: Service Requirements, Timetable Development, Vehicle Scheduling, & Crew Scheduling*

Currently, almost every major public transportation system follows the same 3-4 step process, starting with an analysis of what needs the system needs to meet. This process is beyond the scope of this review of literature, but it is also an area for which future improvements could be made as the entire process essentially consists of extrapolating broad generalizations and specific timing constraints, requirements, and goals from small, noisy sample sizes. Regardless, once the service characteristics have been defined, planners develop a timetable to fit the physical infrastructure and service requirements given. The calculation of this timetable results from a combination of design by hand as well as software assisted equation solving, and this is the step of the process wherein fine-tuned optimizations could be made. Once the schedule is in place, specific, physical vehicles and drivers and then assigned to populate the various routes [5].

### *B. Genetic Algorithms*

In a 2011 paper analyzing bus scheduling in China, the authors developed a genetic algorithm inspired by natural biological processes to solve for optimal bus departure intervals given a set of service requirements including route layouts and passenger travel data. Although this paper concerns itself solely in the domain of street buses, the routes of which are significantly more physically and geographically malleable than light rail, the paper does not use genetic algorithms to solve layout optimization problems, but it rather instead focuses on solving departure interval and scheduling problems. As such, it offers relevant insight as to how one could implement scheduling optimizations for light or even heavy rail [6].

By using an iterative generation and detection process, the authors were able to model passengers and bus companies as phenotypes and genotypes, which were then evolutionarily determined through virtual chromosome. These virtual scheduling organisms could then be tested by a fitness function designed to approximate by the efficacy of the proposed bus system. By introducing a random mutation operation, the model was able to explore a wide range of the possible solution space in a generational process mimicking evolution through natural selection [6].

### *C. Eigenmodel for Iterative Planning*

Although most planning systems generally follow the three steps outlined above in sequential order, a 2016 paper analyzing the German public light and heavy passenger rail infrastructure system proposed a more holistic approach to planning and attempted to solve the problems of line layouts/ scheduling, timetabling, and vehicle/driver scheduling in one unified model [7].

Despite having a much broader scope than the intent of this paper, the German paper's approach to handling multiple input variables in a large and sometimes unpredictable solution space could perhaps also be applied to already existing public infrastructure, such as the MBTA Green Line, without necessitating a total, physical redesign of the existing infrastructure layout, which would of course be wholly impracticable [7].

The authors described how they designed an integrated-approach Eigenmodel to tackle this problem by minimizing the cost functions of each of the three stages all at once. They constructed a feedback graph wherein each stage occurs multiple times and feeds into other stages iteratively; thus, by reducing the problem to its original bite sized pieces, the massive theoretical complexity of handling so many inputs at once is mitigated [7].

Although, like sequential planning, the algorithm also solves each iteration of each stage individually, it offers a comprehensive and interconnected process totally distinct to sequential planning, and the paper ultimately shows that such a model is able to successfully produce more efficient results with multiple simultaneously optimized cost functions [7].

### *D. Light Rail Scheduling Standard*

Published through the American Federal Government, the Transit Cooperative Research Program released a 2016 report as a scheduling manual for solving various public transit problems in the United States. Like much of the research examined for this paper, most of the report deals with timetabling and scheduling for bus systems, but the end of the book offers a coda for how such bus scheduling techniques could be applied to heavy and light passenger rail [8].

The chapter begins by highlighting the differences between buses and rail, specifically in how the latter is much less geographically and physically flexible compared to the former, in that railyards have concrete immutable routes for storing and activating trains whereas bus garages have free wheels on pavement. Nonetheless, this rigidity does offer a firm, discrete basis for any optimization algorithm, which results in significantly less expensive computations as an inherent aspect of the transportation medium [8].

The authors also lay out the various distinctions between heavy and light rail, and how planning approaches vary wildly between the two. However, for the purposes of this paper, we will be focusing in on the section for light rail, as the MBTA Green Line is mostly an above-ground light rail system with some mixed, but algorithmically interchangeable aspects for its underground portions. I.e., The portion of the Green Line that is not strictly light rail can still be effectively modeled as light rail for timetable and schedule simulation purposes [4, 8].

Regardless, in terms of the authors' advice for scheduling light rail, the scheduler needs to first consider the physical layout of passenger routes as well the tracks themselves, including station-by-station demand, track right-of-way, switchback locations, yard locations, and more. Once the physicality of the track has been determined, one-way and round-trip calculations are made for various levels of passenger demand at different times of day [8].

Branches are handled as individual lines, where overlapping stations can be conceptualized as a linear combination of the component branches. Additionally, the chapter explores how, unlike buses, light rail is more flexible in that the passenger capacity for a given train is variable based on how many cars and linked together. The chapter does not, however, examine possible implementations of express rail lines, which could be modeled as in-line branches, as solutions [8].

## III. PROPOSED NEXT STEPS

As such, this paper will propose a method for light rail optimization wherein multiple branches could be added in-line with existing lines such that each branch only intersects with a smaller subset of stations along the same physical rail by the use of nominally maintenance oriented, or perhaps minimally expensive additions, of bypass rails at each station.

### *A. Express Lines via In-Line Tracks*

Let us examine how a light rail system might currently handle weekday morning rush hour traffic: the most outbound fringes of the line will begin to collect passengers headed inbound for work. However, the smaller capacity light rail cars quickly fill up as the vast majority of passengers are destined for the same approximate location. Thus, stopping at each station becomes incredibly wasteful as people attempt to cram into full cars, thus causing traffic jams for additional trains farther outbound.

If, however, express lanes were set up such that the train visits only the first, say, three stops from the outbound terminal before riding nonstop to downtown, the entire system could be expedited. Additional express lanes could then service the fourth to sixth most outbound stops and so on. The flexibility afforded by having each train only service a subset of the total stations on the line, combined with the flexibility of car length determination as well as with bypass lanes and switchbacks offers several variables for which a significantly more complicated schedule could be optimized.

### *B. Target Users & Readability*

Regarding target users, there exist two main groups: the planners who could use such an algorithm to optimize the lines as well as the passengers would be interfacing with the determined schedule. For the former, the use case would start with an analysis of the current physical infrastructure available, including rail capacity, switchback and bypass locations, terminals, and passenger demands. The algorithm could then calculate proposed improvements or even whole new schedules based on dividing each physical line into smaller in-line express branches. A feedback process could then begin wherein planners can analyze how different physical additions to the system, such as more feedback or bypass options, could improve the ultimate result. Based on the available amount of money and resources, planners could offer efficiency improvements with only minor physical costs and a focus on scheduling optimization.

The use case for the individual passenger is different in that they are focused on concrete navigation. One of the advantages of having a train stop at every location along its route is that it is very simple to learn and navigate, and as such in-line express trains are not very common in the literature nor in real life. This issue, however, could be mitigated in a number of ways, most of which boil down to communication on behalf of the transit authority. For example, the Green Line branches are currently designated by letter, (B, C, D, & E). To distinguish between which in-line branch a passenger could take either in-bound or out-bout, one could simply add a B1 or B2 designation. The fine nuance of which stations are included in each express line is part of the optimization problem for the planners, as they need to balance flexibility and readability. In short, although a more optimized timetable may offer better final results, if the layout of the express lines feels arbitrary to a human, it will be difficult to navigate and use to those final results. As such, planners should opt to balance results and aesthetics, the latter of which passengers can use basic pattern recognition to understand the layout of the entire system more intuitively.

## IV. CHAT GPT ANALYSIS

As part of this review of literature, ChatGPT was consulted to examine how it might be able to effectively serve as a companion tool for further research. The prompt given was "write me a review of literature on the current state of public transport scheduling optimizations relating to light rail, specifically on how the MBTA green line in Boston could be improved."

### *A. Overall Form of First Output*

The output from ChatGPT was divided into seven sections, covering a wide array of suggestions for general improvements. Only one of the seven sections directly addressed scheduling, however, and what it offered was vague advice about using simulations with machine learning and AI techniques. Most of the output was instead concerned with data collection, information accessibility, and general rationale arguments. As the specific suggestion of this paper uses a custom term not found in the broader literature ("In-line Express Rail"), the initial prompt did not include such a parameter for fear of the model not understanding what was meant by it. However, as the first result offered little in the way of relevant information for this proposed project, a second attempt was made.

### *B. Second Attempt with Use of In-Line Express Rail*

Surprisingly enough, ChatGPT seemed to have a reasonable understanding of the core idea for this project after amending "with the use of in-line express systems" to the original prompt. Indeed, the first of seven sections successfully described the basic premise for this paper, offering a simple and concise rationale: "these express trains bypass certain stops to reduce travel time and congestion, offering passengers a faster and more convenient commuting option." It even went on to identify the critical issue of implementing such a system as founded in a multifaceted timetable coordination problem [9].

Additionally, ChatGPT offered several case studies to take inspiration from, such as the "RER system in Paris and tram-train systems in Germany," both of which are real systems, but neither of which are examples of the idea put forward by this paper; rather they are simple examples of highly efficient public transportation systems driven by combinations of light, heavy, and commuter rail infrastructure.

Unfortunately, ChatGPT offered little in the way of concrete suggestions. Perhaps with further refinement more specific recommendations could be coaxed from the model, but as it stands, it does offer a solid foundation for an abstract or rationale. For both attempts at generation, ChatGPT provided persuasive rationales for improving public infrastructure in general, from passenger-side and government-side arguments as well as broader climate-based arguments. Perhaps for analyzing the societal implications of this research, ChatGPT could easily serve as an invaluable assistance tool.

## REFERENCES

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