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Capacity and Energy Optimisation of Metro Network: A case study on the Bangalore Metro

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Abstract

To meet the rapid rise in demand, service enhancement of the Bangalore metro network became a necessity. This paper demonstrates that line capacity, energy efficiency, operational reliability and passenger comfort can be improved by effective optimisation of the service, without huge investments in infrastructural modifications and crippling traffic restrictions. To achieve this objective, benchmark studies from metro systems around the world has been carried out to understand efficient platform designs for crowd management and efficient crossover placements for quick turnback manoeuvres at terminals. The existing and planned infrastructure, rolling stocks, operational scenarios, and traffic forecasts has been analysed and simulation models were created based on available data. The results of the simulations exhibit improvements across all key performance indicators. Such optimisations can be replicated around the world, increasing the attractiveness of metro rail transport.

Keywords: capacity, optimisation, energy, simulation.

1 Introduction

Operational optimisation of an existing railway network while challenging, becomes inevitable for keeping up with current requirements. The aim of this study is to increase the capacity of lines in the network, render it more energy efficient and increase the level of reliability and passenger comfort by identifying the possible ways to optimize the currently available system with minimal disruption of regular service.

Bangalore is one of the most cosmopolitan city in India, one among the top ten High-Tech cities of the world and one of the very successful commercial and industrial hubs of the Indian Sub-Continent. The city which was originally developed as a Garden City has over the years, slowly transformed into an industrial and software hub of India. This has led to an exponential growth of population as workers migrated from all over the country and beyond. There has been a phenomenal growth in the population of vehicles as well, especially the two and four wheelers in this period due to rising household incomes consequent to IT (Information Technology) sector boom in the region.

As a result, the city's attention is focused on the possible ways to improve the public transport system through the provision of new lines and optimization of existing ones.

The Metro Rail of Bangalore is the second longest operational metro network in India after the Delhi Metro and is being built in phases. The Bangalore Metro phase 1 network consists of two lines and operates with a fixed block "dynamic distance-to-go" signalling system based on ATP (Automatic Train Protection) and ATO (Automatic Train Operation), with fixed 27 meters of safety margin. Currently, the ATO is enabled only during peak hours of service and the trains run with ATP during non-peak hours. The fleet consists of a mix of 3-car and 6-car train configurations, always running at 99.8% performance level. The phase 1 lines gained popularity with commuters, however with the increase in footfall crowd management is posing a big challenge which also affects the level of service. The phase 2, 2A and 2B lines consisting of 3 new lines and extensions of the two phase 1 lines are being designed and constructed, which will operate on a CBTC (Communications Based Train Control) signalling system with 6-car train configuration. The operator has set up operational scenarios for every 10 years of service starting from 2021 up to 2041 with progressively shorter headways for each lines.

2 Methods

Metro systems which are similar to the one in Bangalore are used as Benchmarks in terms of infrastructure and operational plans. Crossover locations and incident statistics are analysed to predict optimal locations across multiple metro projects. Different station layouts are studied for optimal passenger movement and crowd control. A study [1] related to dwell times with respect to passenger flows is analysed for the future lines.

For the operational optimisation of the network, the current infrastructure and operational scenario is studied, and simulation models of the lines are created using OpenTrack, a simulation tool, to calculate the potential operational limit of the lines considering the current or planned line alignments, train characteristics, the signalling infrastructure and its logic. A list of KPIs (Key Performance Indicators) has been defined which includes the minimum mainline headway, minimum turn-back headway, the total trip time and the energy consumption. This aids in comparing the current and the simulated scenario and highlights the area of possible improvements.

The simulations are performed considering the worst-case scenarios with full capacity trains running at peak hour conditions. For the phase 1 lines, a performance comparison between passenger service with ATP and ATO has been developed. For the future lines where complete infrastructural or operational characteristics like CBTC safety margins and station dwell times are not yet available, multiple values are assumed and simulated. Moreover, trains running with reduced performance levels were simulated to understand whether energy can be conserved during non-peak hour operations.

3 Results

From the simulation outcomes, for the existing phase 1 lines the current infrastructure allows to shorten the headways by more than 30% on average, and around 10% reduction in headways and trip times has been observed when ATO is enabled. For the future lines, simulations demonstrated that the peak headways could be reduced by around 40% and 30% for the planned peak headways of 2021 and 2041 respectively.

Some relocation of planned crossovers along the line were implemented in the simulation models for the future lines to reach an optimal synchronisation with other trains in the line for turnback headway reduction. Multiple simulations were performed with different turnback manoeuvres with various crossover configurations near the terminals to arrive at the most optimal route for each line. The reduction in the overall headways is possible by implementing a combination of optimal turnback operations coupled with efficient management of driver cabin swap after trips, by having another driver ready on the terminal platform at the tail-end of the train, thereby eliminating the need for the driver to walk the whole length of the train to reach the opposite cabin.

Based on the traffic forecast and the demand analysis for the network, short loops were also suggested and their minimum line and turnback headways were simulated. Moreover, the energy consumption of trips with reduced performance levels were calculated from the simulation outcomes to demonstrate the advantages in terms of energy savings with minimal impact in roundtrip times. Also, unforeseen delays can be recovered by increasing the train performance level when necessary. The following figures illustrates the reduction in energy consumption per trip and increase in trip time for 6-car configuration CBTC trains running at 95% and 90% performance level for each line.

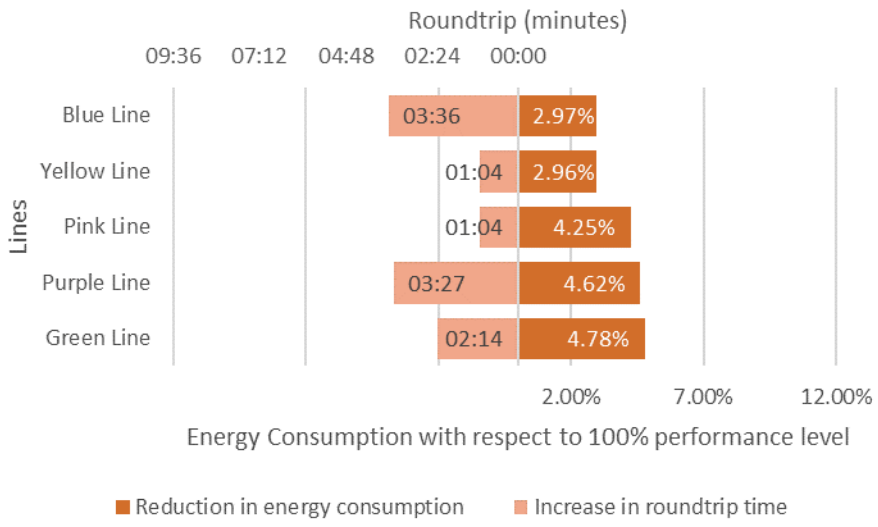

Figure 1: Reduction in energy consumptions and increase in roundtrip times for trains running at 95% performance.

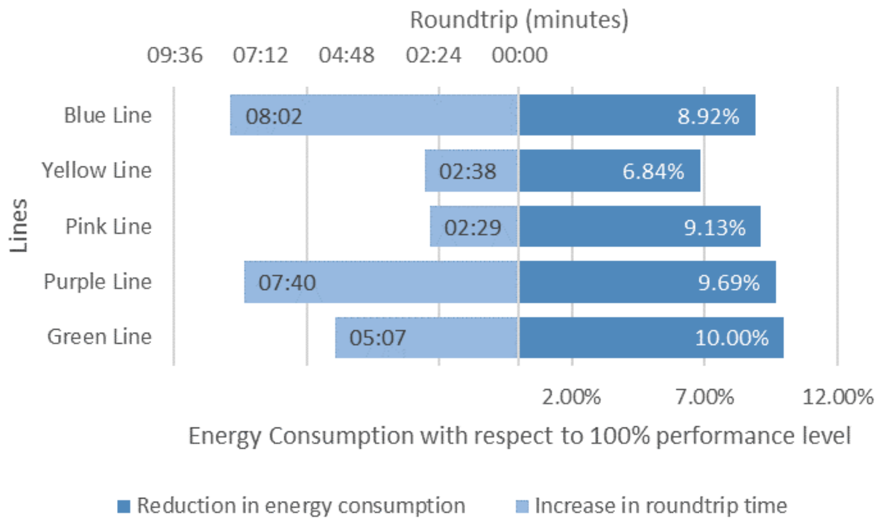

Figure 2: Reduction in energy consumptions and increase in roundtrip times for trains running at 90% performance.

The common purpose of traffic simulations on metro lines is to verify the performance requirements and thus the Operator expectations in terms of passenger capacity, headway, dwell time, or more specifically, the capacity of a sub-system (e.g. signalling, Rolling Stock). Differently from such usual approach, this research shows that an effectively optimised metro operation could result in not only increased passenger capacity and comfort, but also a more energy efficient and attractive mode of transport.

4 Conclusions and Contributions

The outcome of this study impacts not only the existing lines of the Bangalore Metro, but also the future lines using the lessons learnt from the current operation and the simulations performed. An efficient metro system has the potential to move large number of passengers without straining the transport infrastructure of the city. The decrease in headways and smoother speed curves with ATO makes the Bangalore metro system an attractive mode of transport, potentially reducing roadway congestion and private vehicle usage by improving the network capacity. Running the trains at dynamic performance levels as required instead of a fixed performance can assist in delay recovery, resulting in a more reliable service. The ripple effect of a well-planned and optimised metro system results in a win-win situation for the operator, passengers, and the city.

With rapidly growing cities and increasingly larger worker migrations, infrastructural augmentation to an existing metro system often involves huge investments and restricting traffic in sections of the line. This is especially challenging in Indian cities, where any disruption of service can quickly create chaos. This could affect the transport system of the whole city, which are often already stretched to their limits. In these conditions, operators can investigate ways of optimising their current system to improve network capacity, reliability of service and decrease energy costs. This model could be further expanded with dedicated energy consumption studies and periodic traffic demand forecasting for better accuracy of the simulation models. Based on the experience of the research, this exercise can be replicated in other metro systems throughout the world, where operators can choose how and where improvements can be brought in their current or planned network with minimal disruption of regular service.

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