Operations Research in Metro Rails

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ABSTRACT

Over the years, Urban rail transit operations have changed from a single line slow train to a multiline modern network. The network operations have experienced quantitative as well as qualitative changes, and in this industry, operations management is facing internal and external changes at a rapid pace. Researchers and practitioners have applied many techniques in Transportation sector, for both tactical and operational issues. There still exists a tremendous scope for application of OR techniques to optimize the Metro Operations. By means of this Research paper we have aimed at determining the various techniques used in optimizing metro operations like time tabling and platform assignments. A quantitative approach using the simplex method was used. The resources that we have taken into account include, the unit costs of carrying tools, achieving infrastructure and achieving operation management.

Keywords: Metro, Timetabling, Platform assignment, Optimization, Transport.

INTRODUCTION

In the forthcoming decades, railway transport will be facing a significant growth of passenger traffic flows. The challenge is to accommodate them over the pre-existing infrastructures. Rail systems are progressively becoming the most desirable form of transportation infrastructure around the world due to its speed and efficiency. In India, Metro is the future of local railway system. With an increase in awareness about the environment and pollution, introduction of an efficient metro system is the way forward. There are several challenges faced by the metro industry. Some of them are increasing public travel demand leads to great challenges to operations and management, inaccurate travel demand forecasting causes insufficient supply, old management systems could not satisfy increased network-level operations. To avoid reduction of reliability and punctuality of transport services an increase of capacity utilization is needed. Furthermore, energy-efficient operations and multimodality opportunities are also topics of growing interest and concern (Liang, 2016). Intelligent railway operations management requires accurate modelling and simulation of train and pedestrian traffic flows and optimal management of key decisions at strategic, tactical, and operational levels. Our aim is to identify methods for improving the effectiveness along with efficiency of railway operations, which includes the development of advanced algorithmic techniques for timetabling, capacity management, infrastructure management, and traffic and passengers flow management.

OVERVIEW

Metro rails are rapid transit systems with a growing demand in the urban regions. There is a growing mobility need which can't be fulfilled by the existing means and other road transport system, thus giving more preference to metro. Metro rails are perceived to have higher levels of comfort, speed and efficiency, than other transit systems, making them more attractive to both policymakers and potential users of the system. Policymakers have launched and are proposing new metro rail projects to cater to the growing demands of the commuters. It's not only a step towards modernization but also towards environment conservation, which is the need of the hour. The emergence of metros in India has also boosted the construction and equipment industry and has helped in commencing metro coach industry in India. The first MRTS started from Kolkata and now has spread to many metro political cities such as Delhi, Mumbai, Jaipur, Hyderabad, Bengaluru and Chennai. Metro rails running at a speed of 30kmph has capacity to carry 60000-80000 passengers per hour in a single direction with comparatively higher frequency. These can operate either underground or at an elevation. However the construction cost of MRTS is 25-30 times more

than BRTS. India has 644 Km of operational metro tracks with 502 stations with nearly 500+ km of tracks being under
construction.

RESEARCH OBJECTIVES

1. To understand the application of Operations Research in metro.
2. To find the areas having potential for optimization in metros.
3. To elaborate Operations Research (OR) models and techniques that can be used for determining railway timetables, platform allocations and crew scheduling.
4. To outline different methodologies and techniques used to address the areas having potential for optimization.

RESEARCH METHODOLOGY

A qualitative approach was used to find answers to the research questions given in the paper. Past research papers were referred in order to study the application of OR in metro. An analysis was made based on secondary data from the various secondary sources. The secondary nature of our sources form the basis of this research paper and the findings have been derived through them.

LITERATURE REVIEW

Majority of the urban cities in India are facing an issue of traffic congestion and air pollution due to increasing number of travel demand. That's why in the past years' metro has been developed in various cities like Kolkata, Chennai and Delhi as these cities have the highest traffic congestion in the country. In Delhi, number of two wheelers and cars continue to rise. Despite construction of flyovers and roads, the roads continue to face congestion at peak hours that's why it is necessary to find an alternative way to travel that is metro which is a network consisting of underground, elevated and surface corridors which will help in reducing the traffic from roads at peak hours. This paper gives an evaluation of Delhi metro in terms of its capacity, travel time, accessibility and the commuters point of view (Mukti Advani).

The metro has become a symbol of infrastructural development of a nation thus it has become necessity to build metro rails. It not only caters to the demand of public transport by the commuters but also helps in reducing traffic and pollution levels in the urban regions. The metro involves a high capital construction cost which is further fuelled by other services to be provided and can be operated by the government or private players. The metro runs on LRT supported by a fully integrated network wide operational control system which is integrating communication and facilitating advanced operational management. The RTA bus service bridges the gap between metro rails and the rest of the city by covering maximum area and solving transportation problems in areas without metros. They provide safety and security to passengers by crowd control measures, increasing frequencies of rails along with provision for additional rails. They are continuously evolving with latest technology and innovations and offer excellent services to the metro passengers to provide a pleasant travelling experience (Niyazudeen Kamarudeen, 2018).
Researchers and practitioners have applied many techniques and models the in Transportation sector, for both tactical as well as operational issues. There still exists a tremendous scope for application of OR techniques to optimize the Metro Operations. Moreover, a number of areas in the Indian system have the potential for optimization. Rangaraj et al (2005) have identified areas in Indian Railways having potential for optimization;

1. Definition of capacity on railway section
2. Capturing congestion effects and broad scheduling strategies
3. Medium term capacity investments in signalling
4. Trade-off between throughput (number of trains) handled and transit time (average)
5. Strategic decisions (railways)
6. Robust capacity: capacity in the presence of failure
7. Signalling failures modelled and impact on train running quantified
8. Quantify the trade-off between achievable headway and service measures (such as

punctuality and average delays suffered by trains) under a given pattern of failure
9. Railways (capacity analysis)
1. Terminal capacity
2. Capability of handling trains at terminals
10. Routing possibilities: Look-ahead period and a routing algorithm applied on an appropriate time-space network
11. Timetabling
12. Master chart preparation tool for railway planning
13. Rake linking
14. Long distance trains
1. Coaching stock utilization (integrated with maintenance schedules at terminals)
2. Timetables as an input
15. Suburban trains
1. Integrated with timetables
2. Maintenance schedules as an input
16. Long distance rake linking
17. Terminal maintenance line charts (pit lines and washing lines – also considering constraints on line length and time for maintenance)
18. Rake link table (constraints on length of run between two maintenance points and rake compatibility)
19. Typical patterns of rake linking (self-linking, interchange of day trains)
20. Marketing and Pricing models
1. Network based models for pricing (based on second shortest distance)
2. Marketing and service planning
21. Containers/Trucking: Fleet utilization and locational imbalance based pricing model
22. Supply chain view of transport operations: Freight supply chains on Indian Railways (Kumar).

It was recognized within the railway world that the application of OR models and techniques for supporting the solution process of the problems may be beneficial along various dimensions. The application of such models and techniques may lead to better solutions, and simultaneously lead to a reduction in the time which will be involved in the planning processes.

The techniques used are Alternative Graph Model, Branch and Bound Algorithm, Mixed Integer Programming, Job Shop Scheduling Method, Heuristic Greedy Approach, Fix and Regenerate Algorithm, Genetic Algorithm, Artificial Neural Network. The striking areas requiring optimization was timetabling and platform assignment issues. In the following section we are exploring the application of operations research for the same. The objective here is to understand and evaluate Operations Research (OR) techniques and models to determine railway timetable. Many railways nowadays use cyclical timetabling. Cyclical timetabling means that the trains are operated in a cyclical pattern e.g. the trains run in every 30 or 60 minutes. Cyclical timetabling models are based on Periodic Event Scheduling Problem (PESP). The objective of PESP model cyclically scheduling a number of events.

When creating a timetable, it is important to see that the solution has minimum number of errors as possible. This is called **robust timetabling**. A robust timetable will lead to high punctuality in real life situations. Robust timetabling has many effects which has been discussed in the research paper further. In the research paper, we have also discussed the routing problem with significant diagrams and platform assignment issues. Through all this we can easily find a feasible solution. Overall we have discussed and analysed the most feasible solution to find the timetabling and routing of trains from different stations and locations.

Determining (cyclic) metro timetables

Various Operations Research (OR) models and techniques can be used for determining (cyclic) metro timetables. This means that each line of metro is operated in a cyclic pattern, for example the trains run in every 10, 20 or 30 minutes. This helps the public to easily keep in mind the time of departure of their train.

A railway timetable is constructed out of two elements: (i) the time of arrival and departure of the trains at the stations and other relevant locations such as junctions and bridges, and (ii) the assignment of each train

to an appropriate platform and corresponding inbound and outbound routes in every station. Preferably, the generation of the arrival and departure times and the selection of the routes through the stations are carried out simultaneously. However, when using a model based approach for generating a timetable, this would lead to models that are too large to be solved by the currently available technology for optimization. Therefore, in a model based approach the two steps are commonly split: the timetable is computed first, and then the routings through the stations for this particular timetable are determined. To get an overall feasible timetable, several iterations of this process may be necessary. Most cyclic timetabling models are constructed using the Periodic event scheduling problem (PESP) (Leo Kroon, 2007).

Platform assignment issues

The goal of routing trains through stations is, besides specifying the approach routes from and to the platforms, to assign the trains to the platforms themselves. The platform assignment has to satisfy a number of market requirements. For example, trains of the same line are to be assigned to the same platform, while trains departing towards the same destination are preferred to leave from the same platform. Then passengers can easily remember the departure platforms of their trains. Certain pairs of trains have so-called cross platform connections. These trains have short stops with overlapping time intervals, and are to be as signed to neighboring platforms. Then passengers can easily change from one of these trains to the other in that case. The platforms of large stations may have different preference values when being assigned to trains. For example, trains with many expected passengers are preferred to arrive at platforms that can accommodate long enough trains and that are located closer to the main station facilities (Leo Kroon D. H., 2007).

Crew scheduling was another striking feature which was addressed upon:

Crew scheduling

Crew scheduling is one of the most successful Operations Research applications in the transportation industry. After the introduction of OR in airline crew and bus driver scheduling, it has also been applied to the railways. Most major railway companies in Europe use crew scheduling software nowadays to make their operational schedules. A set of tasks, which can either be passenger train movements, empty train movements, or shunting activities, must be assigned to train drivers such that each task is covered and each train driver has a feasible duty. In this case, a duty is a sequence of tasks after each other thatcan be carried out by a single employee on a single day. A duty is feasible if a large set of constraints are fulfilled, e.g. the length of the duty does not exceed the maximum spread time, there is a meal break in a duty with a certain minimum length, and so on. Furthermore, for drivers there are extra requirements with respect to their knowledge about specific rolling stock types and routes. Moreover, there are requirements on the complete set of duties at each depot. Hereby, one can think of a maximum average working time for all drivers and a fair division of the work over the depots.

The number of variables to be considered is usually exponential in the input size. Therefore, column generation techniques are needed to solve the relaxation. Mostly, the LP-relaxation is solved, but also Lagrangian relaxation can be applied. To find the optimal integer solution, a Branch and Price algorithm is used where in each node of the Branch and Bound tree column generation is used (Dennis Huisman, 2005). Going around in railroad Systems are slowly getting to be a standout amongst the most attractive type of transportation around the globe, this is partly because of rail lines being more environmentally friendly compared to that of vehicles and airplanes. Many emerging countries such as India, Brazil, Fiji, China, South Africa, etc. have urban rail transport projects largely due to the increase in commercial transportation activities brought in by development of these emerging nations. This paper looks at the place of developing nations in this move of executing present day rail framework that will eventually enhance the realization of a low-carbon society. Network model, transportation model and linear programming algorithms are utilized to show the present urban rail transport framework in Nigeria, as a developing nation, keeping in mind the end goal to optimize it. Operational research techniques, including the simplex method and MODI, with the help of computer software (excel solver and LIP solver) were adopted to solve the subsequent models. The result shows that in any of the emerging countries, 3 factors that are Safety monitoring, Tractive Power Supply, and Transportation Organization Model classified under Carrying tools, Infrastructure and operational Management respectfully, are very critical in optimization of the urban rail transport system in the emerging counties:

i) carrying tool is a general term of various types of equipment required by the railway and urban transit transport; it consists of safety monitoring, facilities of maintenance and protection.

ii) Infrastructure is the basic device of rail transit transportation, and it mainly consists of public works engineering system, tractive power supply system, and communication signal system. The public works engineering consists of lines, stations and bridges and tunnels. The tractive power supply system consists of substation, overhead line system and electric power supply. Also the communication signal consists of two parts namely: the communication and signal parts.

iii) Operation management mainly refers to the operation organization and service management system organizing various transportation resources scientifically and reasonably, and provides high quality transportation services for passengers and owners of cargo based on the requirements on the transport of travellers and goods. This involves mainly: The passenger flow demand forecasting, demand rules analysis, Passenger transport path, transportation organization model, train operation plan, train graph, motor train unit application, train and station organization.

The outcomes demonstrated that optimization of rail transport systems won't just lessen carbon emission but also bring about economic development which is required for the eradication of prevalent poverty in these developing nations. (M. C. Agarana, Optimization of Urban Rail Transportation in Emerging Countries Using Operational Research Techniques, 2016)

The successively increasing scale of urban rail transit lines gives rise to quantitative and qualitative focus in operation management. According to an article referred the following three characteristics of operations are considered as network operation: Regional coverage, Station location, Percentage of urban rail transit use among all travel modes. It talks about the challenges of network operations including Increasing Public Travel Demand, Old Management Systems etc. The innovative solutions that can be used to approach these challenges can be establishing a front-end and back-end maintenance system, strengthening the management foundation, creating plans to promote operation capacity, overall planning and step-by-step implementation overall planning and step-by-step implementation etc. This research and these practices not only ensure the sustainable development of urban rail transit network operations, but also facilitate the qualitative leap for operations management (Lin He, 2016).

Findings

1) The potential of metros in the urban cities in the upcoming years along with the reasons for preference of metro over other modes of transport which were congestion, rising commuters, quality service provided by metros. Due to successive increase in the use of urban rail transit in India, the use of operation research has increased simultaneously on quantitative as well as qualitative basis.

2) In this paper, we identified the areas in Indian Railways having potential for optimization and how are Operations Research techniques and models applied to the same. Some of them include routing possibilities, timetabling, capturing congestion effects and broad scheduling strategies, Rake linking, robust capacities, platform assignment issues etc. Techniques like Alternative Graph Model, Branch and Bound Algorithm, Mixed Integer Programming have been used.

3) While constructing timetables for metros two elements are considered: time for arrival and departure and assignment of metros to appropriate platform with inbound and outbound routes. Cyclical timetabling models are based on Periodic Event Scheduling Problem (PESP). The objective of PESP model cyclically scheduling a number of events.

4) In crew scheduling a number of factors or variables like knowledge of the drivers, average working time of the employee etc are to be considered. This totals to be a very large number of variables and therefore a Branch and Price algorithm is used in many cases.

5) A number of operation research methods are used for the optimization of the urban rail transport system in emerging countries. Three major variables can be classified while optimization are: 1) carrying tools like safety monitoring, maintenance and protection, 2) Infrastructure including communication signal system, tractive power supply system, Public works engineering system, 3) Operation management including Passenger transport path, train operation plan etc. Moreover, optimization of these rail transport systems won't just lessen carbon emission but also bring economic development which is required for the eradication of poverty in these developing nations.

Conclusions

Due to successively increasing use of urban rail transit in India, the use of operation research has increased on quantitative as well as qualitative basis. Metro system has been planned to reduce congestion on the roads and hence there should be optimal utilization of cost for getting maximum benefits of the resources available. In this research paper, we found out different areas who have the potential of optimization, addressed the OR techniques used in time tabling, platform assignment issues and are scheduling using the PESP model, Branch and Price algorithm etc. Optimization of metros is considered on the basis of three variables; carrying tools, infrastructure and operation management. This study systematically proposes an effective management for the operations of the urban rail transits based on secondary data collected from various sources.

Limitations

1. The major drawback in using operations research for metros is finding the actual figures that will help in analysing the problem.
2. As the topic is vast, it is very difficult to find all the constraints and hence, it is difficult to calculate maximum safety.
3. Finding research papers that addressed to a particular optimization problem seemed difficult. Different research papers used different techniques.
4. The models used in research papers are difficult to update and comprehend. Comprehending the quantitative approaches given in various research papers seemed extremely difficult. The interpretation generally require experts, making it difficult for us to understand and include the said information.
5. Since secondary data was used, the authenticity of information on the internet is questionable.

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