Review of Optimized Feeder Vehicle Systems in Developing Countries

H Sachithra Gayashani
Department of Interdisciplinary Studies
Faculty of Engineering
University of Sri Jayewardenepura
Colombo,Sri Lanka
hsgayashani@gmail.com

A H T Shyam Kularathna
Department of Interdisciplinary Studies
Faculty of Engineering
University of Sri Jayewardenepura
Colombo,Sri Lanka
shyamkularathna@sjp.ac.lk

Nadika Jayasooriya
Department of Interdisciplinary Studies
Faculty of Engineering
University of Sri Jayewardenepura
Colombo,Sri Lanka
nadika@sjp.ac.lk

***Abstract*— With the population growth and changes in travel patterns, transportation demand in urban cities continue to increase rapidly. Since it is a cause for higher traffic densities, poor parking facilities, air pollution and road accidents, transport planners have to provide a system, which can ensure safe and comfortable mobility to all users as well as suppliers' perspectives. Therefore, developing an affordable and efficient public transportation network is a critical goal for developing countries seeking to address urban mobility challenges. Feeder vehicle systems, which provide the first and last mile connectivity to the passengers, offers an opportunity for creating a system capable of meeting multiple needs of users and operators. It is an effective public transportation system that already operates in developed countries. It offers immense potential for improving accessibility and reducing congestion. However, the implementation of effective feeder system in developing countries is fraught with challenges due to uncoordinated transit networks, infrastructure limitations, and budget constraints. This paper presents a critical review of recent planning methodologies and selected decision support systems for optimizing feeder transport services.**

Keywords—Public Transportation, Feeder Service, Optimization, First and Last mile connectivity

I. INTRODUCTION

Transportation is an essential human need, and to fulfill this requirement, an effective and efficient transportation system is required. Having a well-planned transportation system has a direct impact on the economic development of a country [1], [2]. Public transport is a critical element of an urban transport system that is available for mobilizing people as it is less costly than private transport [1], [3], [4]. In addition, it can cater to the simultaneous movement of a large number of people at the same time [2], [5]. The most popular public transit (also called mass transit) systems in use can be classified as: Road-based transportation and Rail-based transportation. A well-functioning and effective mass transit system is indispensable for facilitating movement within a city [6], [7].

A. *Public transportation in developing and developed countries*

The public transport system of a city partly defines the consolidation of its spatial form and urban structure. The role of public transport systems in developing-world cities, however, often shows a much less clear-cut relationship with the city's structure than in developed-world cities [1]. In the present day, because of inadequate mass transit infrastructure, many cities in developing countries cannot offer comfortable and convenient services to commuters [8], [9]. This is because of the slow progress of economic development, low budgets, and lack of proper coordination and integration between transit modes [5], [10]. In many developing countries also, mixed-used activity centers (cities, workplaces, and houses), transit stations such as railway stations, highway hubs, and crowded recreational centers are constructed. However, a significant issue arises as these developments are often situated beyond convenient walking distances from transit stations. Consequently, there are deficiencies in the available public transportation modes, hindering people's access to these essential places [11]. In such cases, passengers have to use private vehicles, taxis, or walk, and it can cause long travel times and high costs [7], [12]. This has led to a huge increase in the use of private vehicles [1], [6], [7], [11]. It can be a cause for several negative outcomes, including huge traffic congestion, increased emissions, delays at workplaces, adverse effects on the ecosystem, and more [13], [14]. Therefore, the problem known as the "first and last mile problem" is a key barrier to better public transit utilization [11], [12], [15].

B. *Feeder Service for first and last mile problem*

In developed countries, the transportation network has undergone significant enhancements, resulting in reduced transportation costs and innovative solutions to the aforementioned challenges [16]. A real-time transit service called Feeder Services (FS) is an effective transit service that is used in developed countries [2], [11], [12], [17]. It is a service employing ridesharing vehicles like mini buses to transport passengers from their current transit stations to designated drop-off points known as service stops. This innovative approach aims to minimize the walking distance to their ultimate destinations and reduce the use of private vehicles [7], [17]. Feeders use only flexible vehicles without incurring high costs [2]. As well as the feeder is a development trend tailored for first and last-mile trips with a ring route starting from a high or lower-demand station [8], [18] featuring dynamic departure times and data-driven stops. Therefore, FS differs from usual taxicabs and regular bus services [11].

On one hand, optimized FS appears to offer numerous benefits for the passenger side because it is more efficient, reliable, and cost-effective [19], [20]. On the other hand, it is beneficial for the government. By fine-tuning routing and scheduling, FS can significantly reduce operational costs, minimize environmental impacts, and make the economy better [11], [21]. So in developing countries, the implementation of an effective, optimized feeder service can address several inconveniences that occur in the current transportation connectivity [8].

This study provides a detailed review of the literature on feeder services with the following objectives: 1) Identifying the key factors and recent planning methodologies for influencing optimized FS, 2) Identifying current mathematical models for FS, and 3) Highlighting the primary gaps in current research. Although several previous studies have provided an overview of the FS in a particular country, none have conducted a detailed review of the FS. In addition, the concept of FS is rather different between developed and developing countries. Therefore, the first two objectives of this paper are to identify the suitable key factors and recent planning methodologies for optimized FS in both developed and developing contexts.

The rest of this paper is organized as follows: Section 2 presents the methodology for this review. Section 3 summarizes the existing research on FS, and Section 4 concludes.

II. Approach

A critical literature search was conducted, utilizing academic databases, Google Scholar, and IEEE Xplore focusing on research papers published from 1970 to 2023. Only studies published in peer-reviewed journals and conference proceedings were considered. The first phase of the search used the keywords “first and last mile problem”, “feeder vehicle service”, “optimizing”, “modeling”, “feeder vehicle characteristics” and “public transportation” resulting in 310 retrieved articles. Subsequently, a second search was conducted using the keywords “optimized feeder vehicle characteristics”, and “mathematical modeling” yielding 45 results. Among the initially identified articles, not all were directly aligned with the primary objective of discerning the necessity for an optimized feeder service. Some articles merely incorporated the specified keywords in their title, abstract, or content without substantively addressing the target focus. To ascertain relevance, a preliminary review of abstracts and, when required, the content of these articles was systematically undertaken. After this filtering process, 50 articles were considered relevant and suitable for further analysis. Information from the chosen papers was systematically gathered, and structured to create a coherent overview of the current state of feeder service, and primary research gaps in the field were determined..

III. Previous Studies

In the early stages, various studies have tried to optimize transit systems with numerical rather than analytical approaches [22], [23], [24]. Newell [25] minimized the total waiting time of passengers and found the important concept that the optimal arrival rate of vehicles is approximately proportional to the square root of the arrival rate of passengers. As an extended work of this, Salzborn [26] determined the bus departure rate by setting a primary objective of minimizing fleet size and a secondary objective of minimizing passenger waiting time. Many researchers used, modified, and developed that concept for models of optimizing feeders [27].

At the beginning of the early 1980s, researchers developed analytical and network approaches for feeder vehicle service problems. Analytical models were created to derive optimum relations among various characteristics of the FS process [3], [28]. In this approach, these models formulated the design objective with a set of continuous design variables, and optimal solutions were obtained using the optimal conditions outlined by the objective function. Commonly considered design variables include the feeder route, service frequency, headway, and bus stops. This approach is applicable for small or regularly shaped networks, and it is context-dependent and requires the shape of the street geometry to be prespecified [3]. Further studies [29], [30], [31] in this direction were conducted to refine and extend these analytical models. In contrast, network approaches were developed that did not require pre-specified street geometry, making them context-free and applicable to more complex networks. Some of the network approaches were developed by [10], [28], [32], [33], [34]. These approaches enabled the analysis and optimization of feeder vehicle service in a wide range of urban settings.

Many studies focused on optimizing the feeder route and bus stop spacing [32], [35], [36]. Kuah and Perl [32], as the first developers of the network approach, defined the feeder bus network design problem to access the existing rail system using a mathematical programming model. The model optimized the route with the objective function of minimizing the user and operator costs under many-to-one and many-to-many demand patterns.

In public transportation, there may be instances where a few buses arrive after a long time and load unevenly. This could be unpleasant for passengers and would cause other problems too. So in FSDP (Feeder Service Design Problems), headway and vehicle capacity are also important decision variables that should pay attention to. In the late 80s, there were several studies on optimizing feeder vehicle headway and frequency, but fewer studies about vehicle size optimization [4], [14], [37], [38], [39]. Kwan [40] studied headway integration with the objectives of achieving smooth joint headways on roads and minimizing the number of buses required. A successive substitution solution algorithm is adapted to obtain an optimal solution.

Oldfield and Bly [41] considered vehicle size decision variables and pointed out that the use of smaller buses offered passengers a better service frequency, but it cost more. Hence, they described a mathematical model that can be solved analytically to provide an explicit relationship between optimal bus size and factors like operating cost, level of demand, and demand elasticities. For that, different bus seats were considered.

To solve FSDP, numerous studies have been carried out using mathematical, heuristic, metaheuristic, and hybrid methods. Few studies have been conducted on modeling feeder bus network design through a mathematical approach [11], [32], [42]. Mathematical optimization approaches typically provide more robust problem statements and a strong theoretical foundation in comparison to alternative design methods. Heuristic methods are developed to expedite problem-solving in cases where classical approaches prove excessively slow or fail to yield precise solutions. These methods aim to hasten the resolution time of the problem or identify an approximate solution. Due to their flexible characteristics, most studies have been done using the heuristic method [8], [14], [42]. Shrivastav and Dhingra [10] developed a heuristic algorithm to integrate the feeder routes to suburban railway stations and determine optimal coordinated schedules of feeder bus services for the given schedules and suburban trains. They use Dijkstra’s algorithm for generating the initial route.

The metaheuristic approach includes a Genetic Algorithm (GA), simulated annealing, and tabu search. This method is more time-consuming than the early heuristics, but they are capable of consistently producing high-quality solutions. Using genetic algorithm, ant colony optimization, and other optimization techniques, the feeder system has been continuously optimized under several objective functions from the beginning of 2000 [2], [28], [43], [44]. However, in most of the cases, only one or two decision variables were considered without optimizing all the parameters together. Taplin et al. [45] considered the variables feeder bus route and bus stops to maximize the utility of bus stops and minimize route length using a genetic algorithm. Huang et al. [46] introduced a new type of vehicle dispatching method called Feeder Vehicle Routing Problem (FVRP) for customers in urban areas. The objective was to minimize the overall costs including fixed route as well as travel costs. For that, the researchers developed the ant colony optimization algorithm to determine the number of dispatching sub-fleets and optimal routes that minimize the total cost.

Later few studies were focused on hybrid methods that combine different computational techniques to solve complex problems [3]. Shrivastava and O'Mahony [47] have developed the hybrid feeder route generation algorithm. In that study, GAs and the heuristic approach are combined to find higher efficiency optimized feeder routes.

Furthermore, Dou and Meng [48] proposed a solution to the feeder bus timetabling problem by determining vehicle size and terminal departure time simultaneously. For this purpose, three types of buses, mini buses, standard buses, and articulated buses were considered. The problem is formulated as a mixed-integer non-linear programming model, and a hybrid artificial bee colony algorithm is used to solve the model. However, in optimizing vehicle size, most studies consider about two or three types of capacities for one particular vehicle type. The above works of literature indicate that most studies have focused on individual or two decision variables.

Since FS plays a significant role in public transportation, it should be sustainable and should consider user satisfaction. However, few studies focused on different constraints environment rather than cost minimization. Recently, Zhang et al. [49] demonstrated an integrated optimization feeder bus timetabling problem with consideration of the environmental impact, and Park et al. [50] proposed a novel approach to design feeder bus routes based on taxi movement patterns that can consider the transportation demand and the traffic conditions in a specific time period.

IV. Conclusion

The designing, planning, and assessment of the network of feeder systems have been thoroughly examined from a different perspective. Many researchers have attempted to design a more efficient feeder network service for public transportation. Existing literature illustrates different models for developing FS with various decision variables, constraints, and objective functions. Different methods, including mathematical, heuristic, metaheuristic, and hybrid methods, were used to develop and solve various models and algorithms.

However, there are still some limitations and gaps in previous studies. The majority of research has focused solely on developed cities or countries. The process of creating, organizing, and assessing feeder systems in developed cities or countries has varied from developing cities or countries due to various factors, including parking facilities, infrastructure, the number of people using public transportation, and others. Therefore, those developed models cannot apply to developing countries.

According to the past literature, the majority of research focused on route optimization. On the other hand, most researchers tried to optimize feeder vehicle characteristics with limited constraints and focused on optimizing individual or at most two variables together, neglecting the complexity of factors at play in real-world transportation scenarios. By overlooking the broader spectrum of variables that influence feeder vehicle system performance, the resulting optimization strategies may lack the comprehensiveness required to address the diverse challenges faced in developing countries. Therefore, it is essential to study feeder vehicle service systems with more decision variables under different constraints environment.

Another finding is the limited scope of most existing studies, which primarily focus on feeder buses while neglecting other essential vehicle types. To address the comprehensive needs of feeder vehicle systems, a more inclusive approach that encompasses their diverse vehicle types is imperative.

Therefore, these limitations should be addressed in future studies to determine proper mathematical models that are suitable for developing cities or countries that have different characteristics. By addressing the above issues and creating a well-functioning network for feeders, we can address problems like traffic congestion, pollution, the frequency of accidents, and numerous other issues in developing countries.

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