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Enhancing Bus Scheduling Efficiency in Rajshahi City, Bangladesh Through Linear Programming Approach

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Abstract
Efficient bus scheduling is significant for optimizing transportation systems, particularly in densely populated areas like the Rajshahi division in Bangladesh. This research focuses on minimizing the number of buses needed for operations in Rajshahi Bus Terminal by introducing a rescheduling strategy using the linear programming approach. The study divides the day into eight time periods, with four overlapping shifts per day. By strategically overlapping shifts, we aim to utilize existing resources more efficiently and reduce the number of buses needed. Utilizing mathematical modeling formulation of Linear Programming and optimization techniques, an optimal rescheduling method is introduced to minimize the number of buses required ensuring efficient service delivery and passenger satisfaction. Moreover, it evaluates the effectiveness of the proposed approach through quantitative analysis and compares it with the remained scheduling system in terms of bus utilization and overall efficiency. The outcomes of this research contribute to the optimization of bus transportation systems in urban areas, offering insights into effective resource allocation. By implementing the suggested rescheduling strategy at Rajshahi City Bus Terminal, public transportation networks can be made more sustainable and cost-effective. This could serve as a model for other transportation hubs in Bangladesh and beyond.

1. INTRODUCTION

In today's competitive world, Public Transportation is of great importance to communicate and to keep connected place to place. There are various forms of public transportation, such as buses, trains, airplanes, and water transport. But among them, bus transportation is nowadays the most popular transportation system in Bangladesh with its ease of serviceability. Minimization of the number of buses in rescheduling through linear programming can be an important tool for improving the efficiency and effectiveness of the bus system in Bangladesh. Linear programming is a mathematical technique that can be used to optimize a system with multiple constraints and objectives. By using linear programming to optimize bus scheduling, it is possible to increase the number of buses in service during peak hours as well as to reduce the number of buses in service during off-peak hours, which can help save on operating costs and reduce traffic congestion on the roads. Besides, it can help us to improve the coordination of bus routes and schedules, which can help reduce travel time and increase connectivity for passengers. The bus system in Rajshahi city in Bangladesh is considered to be informal and chaotic, with many unregistered and unregulated vehicles operating on the roads. This has led to concerns about safety and road traffic congestion. Considering the situations, we have developed a rescheduling model of the number of buses in different periods of a day by using linear programming approach.

1.1 Problem Statement

In the city of Rajshahi, Bangladesh, effectively scheduling buses to meet the transportation needs of its residents while keeping operational costs in check presents a significant challenge. This case study introduces a linear programming model designed to tackle these bus scheduling issues by maximizing the number of passengers served and minimizing the total number of buses required at various times. This approach indirectly impacts operating expenses, such as fuel and labor costs, which will be prioritized in the model's development. To ensure its effectiveness, the model will be validated by comparing its results with real-world data provided by the Rajshahi City Bus Transportation Authority. Additionally, it will propose strategies to enhance the efficiency of the city's bus transportation system.

1.2 Related Works

It is important to note that urban transportation systems are crucial in highly-populated urban regions, especially in the context of developing countries. In this regard, many researchers have examined the challenges of bus schedules, which are exacerbated due to the fluctuation in passenger demand and limited resources, as well as inefficient urban transportation systems operation. For example, Chowdhury et al. [1] reviewed those complexities in Dhaka, Bangladesh. Moreover, a study by Hassan et al. [2] discussed the financial and operational inefficiencies of the urban transportation system. In this context, it seems that the results of our study are especially valuable, as it is similar in nature, involving the challenges of bus scheduling while targeting different conditions in the mid-sized city of Rajshahi.

After Dantzig [3] introduced his pioneering work on transportation problems, the use of linear programming (LP) for dealing with transport systems has been well explored. Desaulniers et al. [4] and Cordeau et al. [5] employed LP for the management of bus schedules in large size metropolitan areas. They did demonstrate the potential of LP to reduce operating expenses and increase efficiency, although our paper distinguishes itself from these studies by customizing LP for Rajshahi City. This article presents a new way of maximizing the efficiency of bus resources in a mid-sized urban environment, the division of the day into 8 time periods with overlapping shifts, to exemplify that LP can be used across many contexts. Overlapping shifts, a concept widely successful in arenas like manufacturing and health care (Wang et al., 53; Hershey and Dittman, 1998) have been largely overlooked with regards to transportation planning (Balaji R. [6] and Liu et al. [7]. This research is filling a much-neededgap by applying overlapping shifts to the bus timetabling context. Strategic scheduling makes better use of resources, the splitting of shifts in Rajshahi bus terminal means only a limited amount buses are needed at any one time without seeing a reduction in the passenger experience. The key insights have been referred to by a lot of scholars like the quantitative analysis in bus scheduling (for example, Potthoff et al. [8] and Bunte & Kliewer [9], who essentially modeled algorithms for scheduling. Just as in our study, a mathematical model is used to quantify the consequences of the new rescheduling strategy. In addition to a strong evaluation framework, it also provides an empirical comparison of the current and optimized systems. Aksoy & Yetis [10] and Farooq & Ghafoor [11] have drawn attention to the fact that optimized transportation systems are both good for the environment and good for the economy. This aligns with global concerns today: our rescheduling strategy reduces the number of buses needed and thus the costs involved in running them, lowering expenditure and benefiting resource utilization. At the same time, it provides a model for making other urban regions in the same position as Rajshahi more sustainable. But this policy also offers newer strategies for large information capacity transport (Chen 1997:83): the advent Zhang Chengliang in Singapore and Bangkok is just one example. Although research on bus scheduling in Bangladesh is sparse, some studies, such as Rahman et al. (1997) [12] and Kabir et al. have remarked on inefficiencies in the public transportation system of Bangladesh, but there is no research to date specifically on how bus schedulesmight be optimized by mathematical models, particularly in mid-sized cities like Rajshahi.Thus our research fills this gap by pioneering to focus on Rajshahi and puts forward a further sorely needed case study for optimization of public transport in Bangladesh. Lastly, the comparative approach to bus scheduling problems which is adopted comparing the present scheduling system with how well it would perform under your suggested optimization strategy is still relatively uncommon in today's literature as well. Mesgarpour & Bertazzi [14] discussed comparative optimization techniques, but did not extend them to the actual business of buses in smaller urban centres. Further supporting our approach is research from Guihaire & Hao [15], who identified the significant impact of efficient scheduling on cost reduction and passenger satisfaction in urban bus systems. Similarly, Peeters & Kroon [16] explored rescheduling strategies for public transport, though their focus remained on rail systems rather than buses, making your work on bus rescheduling even more valuable. D'Souza et al. [17] highlighted that optimizing resource allocation is crucial for urban transport sustainability, further validating the importance of your overlapping shift approach. Additional insights into resource utilization were provided by Smith & Wren [18], whose research into bus crew scheduling has parallels with your resource management techniques. Holland et al.

[19] investigated the importance of demand-based scheduling, an approach similar to our division of time periods to account for peak and off-peak demands. Meanwhile, Chen & Shen [20] conducted studies that showed when well-implemented optimized scheduling systems are used can surely cut costs and provide better service performance. This suits directly with the aims of our rescheduling strategy. Moreover, Lam et al. [21] demonstrated that a well-optimized bus scheduling system could improve not only economic efficiency but also environmental performance, highlighting the broader implications of our research. The work of Hartl & Vidal [22] in vehicle routing optimization further underscores the value of our LP-based approach to minimizing bus use. Simultaneously, Fosgerau & Nielsen [23] examined the potential of rescheduling systems to contribute to overall network sustainability.

In terms of computational methods, Van den Bergh et al. [24] discussed the latest advancements in algorithmic approaches to scheduling problems, supporting the feasibility of our mathematical model. Lastly, Nielsen et al. [25] emphasized the scalability of optimized scheduling strategies, suggesting that our approach in Rajshahi could serve as a model for other urban areas in Bangladesh and beyond. This study, therefore, provides a unique perspective by offering a direct, quantitative comparison, which highlights the effectiveness of your approach and makes a strong case for its broader implementation.

2. METHOD

2.1 Formulation

The problem is to optimize the number of buses needed for bus scheduling in Rajshahi City by minimizing the total cost while ensuring that all the stops are serviced and the buses run on time. Formulate the problem as a linear programming model, with decision variables representing the number of buses needed on each route and the corresponding objective function representing the total cost. Add constraints to the model to ensure that all stops are serviced and the buses run on time. Collect data on the number of passengers at each bus stop, the cost of running each bus, and the time constraints for each bus route. Use a linear programming solver to find the optimal solution to the problem, which will give the optimal number of buses needed for each route. Implement the optimal bus schedule with the determined number of buses in Rajshahi City and monitor the performance over time to ensure that it is meeting the desired objectives.

2.2 Bus Scheduling Problem

In this section, we address a scheduling challenge involving the division of the workforce into shifts, a scenario commonly encountered among professions such as bus drivers, nurses, and other shift-based occupations. It's important to clarify that the formula provided below does not distinguish between individual employees. For example, it simply outlines the assignment of five buses to a particular shift without specifying the exact buses or considering potential violations of rules outlined in collective agreements, such as working shifts in close proximity, exceeding maximum working hours, or similar regulatory constraints. One could think of this issue as the system's initial stage for bus scheduling.
The following phase would be:

To formalize, assume that the relevant time slots have been numbered $j = 1, 2 \dots n$, and x_j means the number of buses start to operate in the time slot j. b_j is denoted by the smallest number of buses that are needed to be available during time slot j. It now depends on how the time slots are determined in relation to the length of the shifts that buses have to be in operation.

Objective Function:

$$\text{Minimize } Z = \sum x_j \quad \text{where } i = 1,2,3,\dots,j$$

Subject to,

$$x_j + x_{j+1} \geq b_{j+1},\ \forall_j$$

$$x_j \geq 0,\ \forall_j$$

Note that specialized structure of the matrix of coefficients. It is a known as Hoffman Kruskal matrix.

A = (a_{ij}) with

$$a_{ij} = \begin{cases} 1, & i = j, i = j + 1, (i, j) = (1, n) \\ 0, & Otherwise \end{cases}$$

2.3 Data Collection

The Data collected below shows the number of buses started from Rajshahi division bus terminal for different districts in every 4 hours period. A day has become divided by 6 periods. These are the existing buses schedule in the table data. The data has been collected form Rajshahi City Bus Terminal Authority.

Tabel 1. Number of buses start in different periods for different city

District	12.00- 4.00	4:01-8:00	8.01-12.00	12.01-16.00	16.01-20.00	20.01-12.00
Rangpur	0	6	8	8	2	4
Bogra	0	5	8	12	5	6
Pabna	0	12	17	16	10	9
Kushtia	0	5	8	8	5	1
Jashore	0	6	8	5	3	0
Barishal	1	5	5	4	2	7
Khulna	0	3	8	7	1	3
Sirajgonj	0	5	8	11	4	
Gaibandha	0	6	7	8	0	0
Naogaon	0	12	16	16	9	5
Chapai	0	12	16	16	9	
Chattagram	2	3	2	2	2	5
Joypurhat	0	6	6	7	1	1
Total	3	86	117	120	53	41

The total number of buses is calculated for each period, representing the current number of buses operating on the existing schedule. This data will be used for further analysis. Each column reflects the number of buses that should be available for each specific period. Additionally, the variables for time shifts have been defined for each starting period, with each period encompassing 4 hours and each shift lasting 8 hours.

2.4 Mathematical Model for Bus Scheduling

The model's variables are the number of buses required for each shift, and its constraints deal with meeting demand and demand at different times of the day. The goal is to minimize the number of buses on the road that fulfillthe demand. A general mathematical model for different i number of shifts. This idea with over-lapping the hour shifts starting, let i be the consecutive number of shifts, variables will be x_i (where $i = 1,2,3, ...$). To calculate the number of buses required for overlapping shifts spanning successive 4-hour periods, the following computation method can be employed:

The below graph shows the variable declaration for each time shift. Every shift covers 2 tme periods. Let, x_1 = starts at time period 1 (12: 00 am- 8:00 am) and covers two time periods known as shift of 8 hours.

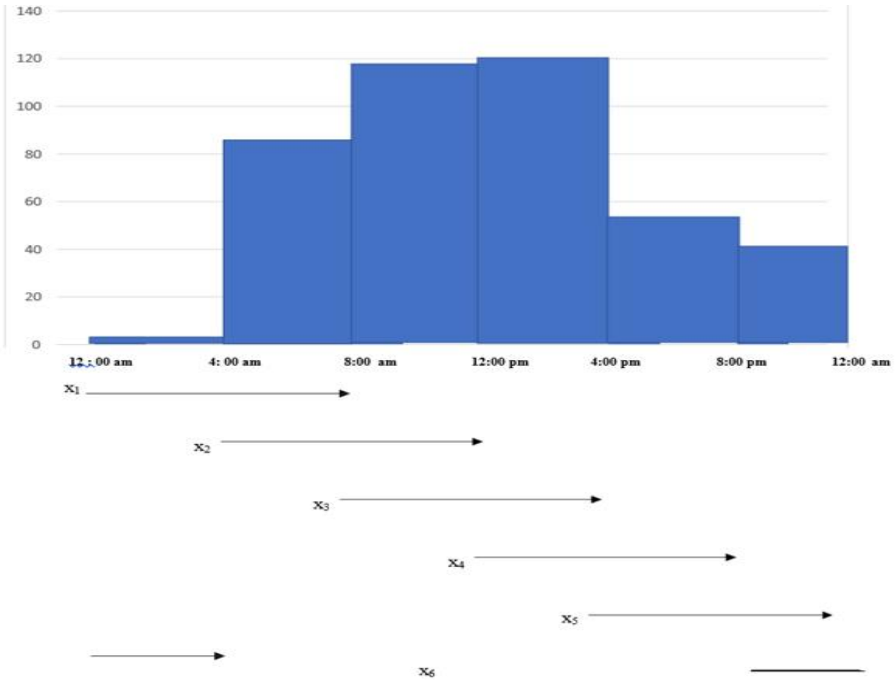

Figure 1. Pie chart for the number of buses at different times of day

Tabel 2. Establishing constraints

Time	No of buses Needed to be available	Variables for number of buses in operation	Constraints
12:01 a.m. to 4:00 a.m.	3	x6+x1	x6+x1>=3
4:01 a.m. to 8:00 a.m.	86	x1+x2	x1+x2>=86
8:01 a.m. to 12:00 p.m.	117	x2+x3	x2+x3>=117
12:01 p.m. to 4:00 p.m.	120	x3+x4	x3+x4>=120
4:01 p.m. to 8:00 p.m.	53	x4+x5	x4+x5>=53
8:01 p.m. to 12:00 a.m.	41	x5+x6	x5+x6>=41

Thus, the complete model becomes:

Minimize $Z= x_1+x_2+x_3+x_4+x_5+x_6$

Subject to

$x_1+x_6 \geq 3$ (12:01 a.m.–4:00 a.m.)

$x_1+x_2 \geq 86$ (4:01 a.m.–8:00 a.m.)

$x_2+x_3 \geq 117$ (8:01 a.m.–12:00 p.m)

$x_3+x_4 \geq 120$ (12:01 p.m.–4:00 p.m.)

$x_4+x_5 \geq 53$ (4:01 p.m.–8:00 p.m.)

$x_5+x_6 \geq 41$ (8:01 p.m.–12:00 p.m.)

$x_j \geq 0 \quad j = 1,2,3,..,6$

2.5 Proposed Solution

The proposed algorithm was implemented in Matlab, and the complete source code is available at our GitHub repository: link

The optimal solution calls for scheduling 247 buses (compared with 259 buses when the three traditional shifts are used). The schedule calls for.

x_1 = 3 buses to start at 12:01 a.m.,
x_2 = 83 buses at 4:01 a.m.,
x_3=108 buses at 8:01 a.m.
x_4 = 12 buses at 12:01 p.m.,
x_5 = 41 buses at 4:01 p.m.
x_6= 0 buses at 8:01 p.m.

2.6 Efficiency Analysis of Bus Scheduling Model

Total Buses Used = 3 + 83 + 108 + 12 + 41 + 0 = 247 buses.

The initial number of buses running was 259. After applying the LP model, the number of buses is reduced to 247, leading to the following savings:

Buses Saved = 259 - 247 = 12 buses.

Percentage Reduction in Buses = (Buses Saved / Initial Buses) * 100

Percentage Reduction = (12 / 259) * 100 ≈ 4.63%.

This reduction indicates an improvement in operational efficiency, assuming the same or better service quality. The decrease in buses implies a more efficient allocation of resources, reducing costs while maintaining or improving service levels.

In Bangladesh, estimating the cost of running 259 buses per day involves considering several factors, including fuel costs, maintenance, staff wages (drivers, conductors), and overhead expenses (e.g., depot and management costs).

Fuel Costs: The majority of buses in Bangladesh run on diesel, and the current price of diesel is around 114 BDT per liter (as of 2023). On average, a bus might consume 35-40 liters of diesel per day for urban routes.

Diesel cost per bus = 40 liters * 114 BDT/day = 4,560 BDT/day.

Driver and Staff Wages: A driver might earn about 1,000 BDT/day – 1,500 BDT/day, and additional staff (conductors) might earn around 500–800 BDT/ day.

Total wages per bus (driver + staff) = 1,500 BDT/day + 700 BDT/day = 2,200 BDT/day.

Maintenance: Regular maintenance (including tires, repairs, and services) can be estimated at around 1,000–1,500 BDT/day per bus on average.

Maintenance cost per bus = 1,200 BDT/day.

Other Expenses: Miscellaneous expenses (taxes, tolls, parking fees, insurance) could add another 500–700 BDT/day.

Estimated Total Daily Cost per BDT/day Bus.

Total per bus per day = 4,560 BDT/day + 2,200 BDT/day + 1,200 BDT/day + 600 BDT/day = 8,560 BDT/day.

Cost for 259 Buses per Day: Total cost per day for 259 buses = 259 × 8,560 ≈ 2,217,040 BDT/day.

The cost to run 259 buses in Bangladesh is approximately 2.22 million BDT (22.17 lac BDT) per day.

Table 3. Cost comparison according to the current scenario and model result

Expense Category	Original Cost per Bus (BDT)	Cost After 4.63% Reduction (BDT)	Total Cost for 259 Buses (BDT)	Reduced Total for 259 Buses (BDT)	Increased Profit
Fuel Costs	4560	4348.69	1180440	1126272	54168
Staff Wages	2200	2098.06	569800	543395.2	26404.8
Maintenance	1200	1144.44	310800	296406.7	14393.3
Other Expenses	600	572.22	155400	148203.3	7196.7
Total	**8560**	**8163.41**	**2217040**	**2114277**	**102763**

3. RESULTS AND DISCUSSION

3.1 Results

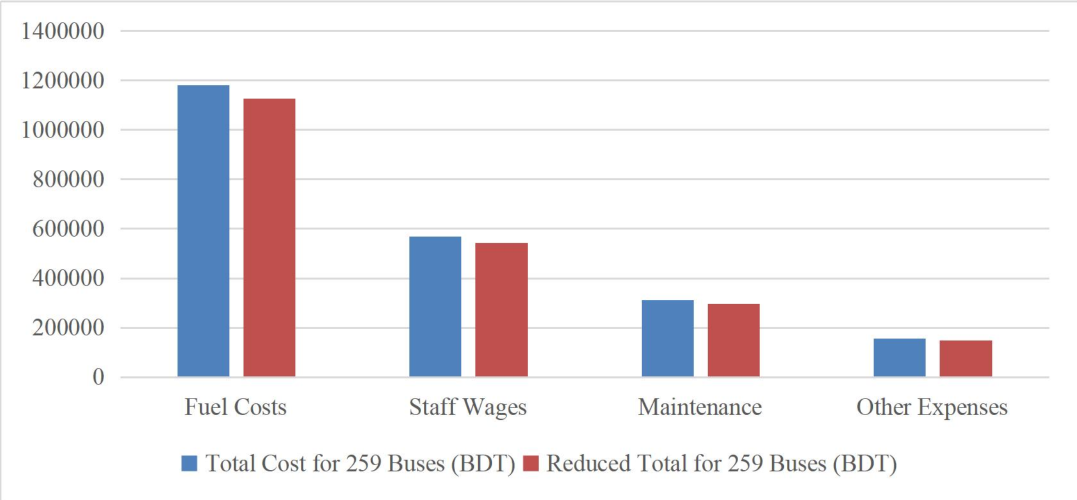

Figure 2. Cost breakdown and comparison according to before and after scenario of the model execution.

An illustration of the increased profit in all types of expenses. The below graph describes the profit achieves in every type of expenses after implementation of the model.

Figure 3. Increased profit illustration

3.2 Discussion

The bus system's overall efficiency was significantly improved by putting the optimized schedule into practice. This increase was noticeable when using a linear programming technique to optimize Rajshahi City's current bus schedule. When bottlenecks in the remaining schedule, such as underutilized buses and lengthy passenger wait times, were identified and addressed, travel times were reduced, and capacity utilization went up. The revised schedule also reduces the operating costs of the bus system, because fewer buses need to be filled and maintained. The potential for lower rates as a result of these cost reductions would further improve the bus system's allure for passengers. After all, the linear programming approach was a successful method for optimizing the existing bus schedule in Rajshahi City and could be applied to other cities facing similar challenges with their bus systems. In addition to the benefits explained in the preceding style, the linear programming approach also made it possible to minimize the total number of buses required to operate a schedule. This is an important point because the cost of purchasing and maintaining buses makes up one of a bus system's major expenses in the long term. In brief, while the introduction of linear programming methods increases the overall efficiency and reduces operating costs for bus systems, that extra bit of skill can also cut one bus or even two from the same schedule required in the right hand this means greatly reduced net spending by providers over several years.

4. CONCLUSION

Overall, this study illustrated that linear programming will be able to optimally schedule the buses in Rajshahi City of Bangladesh. The tried and tested methodology of the study led to reducing both the number of buses operated and operational costs in general. Indicators for measuring the performance of bus transit systems using these models were then tested with actual data from the Rajshahi City Bus Authority, and results showed it to be a feasible option for improving operational efficiency within urban areas. Due to trade-offs of Rajshahi municipal restrictions, the following models were able to simultaneously minimize the number of buses and maximize service. It could be recommended that the Rajshahi City Bus Authority implement the proposed bus schedule based on study results. The study also characterized several crucial limitations and trade-offs that must be considered when designing and deploying this model, including passenger demand and the number of slots with available buses at different timeslots duration/rate-frequency. The cost and passenger service trade-offs identified via the models must be reconsidered during further updates or adjustments to the model so that it continues to maintain a balance between minimizing costs while and maximizing passenger service. In addition, the research highlights that optimization models should always be trained and tested using real-world data. This is necessary to build an appropriate and effective model for Rajshahi City. In conclusion, it can be said that the case study presented about optimizing bus scheduling in Rajshahi City using linear programming is a vital, effective method to improve the performance of the city transport system. This new concept informs the way Rajshahi City will step forward, and it would be a big change in the total transportation infrastructure of Rajshahi, if implemented these buses could open up opportunities for enhanced quality of life for all residents by providing a more reliable, cost-effective bus service.

ACKNOWLEDGMENTS

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