COMPARATIVE ANALYSIS OF BUS SCHEDULING HEURISTICS FOR FLEET SIZE OPTIMIZATION IN THE NARAYANGANJ CITY CORPORATION

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ABSTRACT

Bus operators face difficulties in operation with fleet size due to limited financial issues and a manual scheduling system. This study focuses on this issue by comparing different approaches to bus scheduling under identical service conditions in Narayanganj City Corporation. The study evaluates three different scheduling methods on six routes for three different years (2029, 2034, 2044). The traditional First In First Out (FIFO) method is compared with the Earliest Compatible Trip Assignment (ECTA) and Dynamic Relocation with Deadhead Optimization (DRDO) method. The ECTA method minimizes the idle time by looking for the earliest available match, whereas the DRDO method allows deadhead trips as it reduces the fleet size. Selected routes show a lot of variations. The number of trips ranges from 1,434 to 2,559. Also, the passenger load ratio in opposite directions varies from perfectly balanced (1.0) to highly uneven (1.95). All the datasets were kept unchanged to ensure that the changes in optimization were caused by scheduling logic only. The results show that the routes where demand is highly imbalanced between directions achieved significant improvement. The ECTA method reduced the number of required buses by 11.7% to 68.0% compared to the FIFO method. The DRDO method achieved 1.0% to 79.5% reduction compared to the FIFO method. The number of buses in route C1 was reduced the most by 79.5%. B2 and D2 routes, where directional demand was balanced, showed very little change. This indicated that these methods work better when there is variation in passenger demand. The directional imbalance ratio is a valuable indicator. Required bus numbers in routes having a directional imbalance ratio value more than 1.5 were reduced by 40 to 80%. The DRDO method was better than the ECTA method in routes with demand imbalance but required around 4 to 20% deadhead trips. Deadhead trips percentage went up to 20% where the demand ratio was highly imbalanced. But even in the extreme cases, the revenue trips stayed above 80%, indicating the relocation with deadhead trips did not affect productivity. From the obtained results, ECTA can be applied in moderately imbalanced routes. DRDO is most suitable for routes with a high directional demand imbalance ratio. With these approaches, operators can increase efficiency without major investment.

Keywords: Bus scheduling, Fleet Size Optimization, Heuristic Scheduling Methods, Deadhead Reallocation, Trip Matching Strategies

1. INTRODUCTION

Bus operators in Bangladesh face a great number of challenges in maintaining proper service using a minimum number of buses. Increasing the number of buses results in increased investment, fuel charges, staff costs, and operational expenses. For bus operators with a limited budget, operational efficiency impacts the service expansion or contraction. In Narayanganj City Corporation buses serve a large number of passengers across multiple corridors. Operational efficiency with the optimum number of buses plays a vital role in sustainable public transit operations (Vuchic, 2005).

Most operators in Narayanganj run their service on a simple, experience-based scheduling method. The most common trend is to assign a bus in upcoming trips that has completed its previous trip early. This is similar to the First In First Out (FIFO) method (A. Ceder, 2007). It is easy to follow and maintain but it does not try to improve the trip connection considering idle time. As a result, some buses stand idle for a long period of time. Meanwhile some buses have to cover a larger number of trips. This imbalance causes a larger number of buses to maintain service quality. Resulting increase in operating cost and investment (Desaulniers & Hickman, 2007; Furth & Wilson, 1981)

The vehicle scheduling problem is a concerning matter in the field of transport planning and operations research. The issue is severe because as the service grows and becomes complex the computation process becomes more difficult (Lenstra & Kan, 1981; Toth et al., 2014). As a result, researchers have developed several scheduling methods that focus on effective solutions instead of being mathematically perfect (Desaulniers & Hickman, 2007). This study focuses on two methods that symbolize real-world situations. One method tries to minimize the idle time between two successive trips made by a bus whereas the other method uses deadhead trips to move the bus to other terminals when necessary.

The first method focuses on finding the most suitable bus for upcoming trips rather than simply selecting the first available option which is the core logic of the FIFO method. The main goal of this method is to minimize idle time between trips to utilize each bus efficiently (Huisman et al., 2004). This type of approach generally improves the bus schedule with reduced idle time and bus numbers (A. Ceder, 2007).

The second method does not follow the traditional rule of scheduling that a bus should never travel empty. Earlier studies have shown that with systematic deadhead trips the required number of buses can be reduced in routes having imbalanced demand in opposite directions (A. Ceder & Stern, 1981). Allowing deadhead trips to assign buses in the direction where passenger demand is high may result in a smaller number of required buses. Other studies have also found similar findings in different operational contexts (A. (Avi) Ceder, 2011; Cortés et al., 2011; Furth, 1985).

Both approaches have been individually validated but no study has directly compared idle time reduction with allowing deadheading trips under the same conditions. Previous studies compared each method individually with simple FIFO method. No comparison was done between them to find out which method reduces bus numbers most, on which demand patterns methods work best and how operational cost of deadhead trips is balanced against investment savings from lower bus numbers (Daganzo, 2009; Guihaire & Hao, 2008).

This study compared two strategies under the same conditions using Aimsun-based travel demand modeling data for Narayanganj City Corporation. Both methods were run in same routes in identical conditions to compare the performance. The Earliest Compatible Trip Assignment (ECTA) method optimizes bus scheduling focusing on reducing idle time between two trips. The Dynamic Relocation with Deadhead Optimization (DRDO) method allows deadhead trips in high demand directions. Analysing both methods in similar routes with same demand pattern this study measures their performance in terms of fleet size, average trips made per bus, workload distribution and ultimately operational efficiency

In Narayanganj the scheduling is done manually, maximum operators have limited budget and passenger loads on same routes often have high imbalance. All these make Narayanganj a suitable case for evaluating different scheduling methods. The city shows various types of demand patterns in some routes the passenger demand is balanced or almost similar whereas in some routes there is a huge difference between direction demand. These differences create ideal opportunities to evaluate the benefits of using different scheduling methods (Ibarra-Rojas et al., 2015; Tirachini et al., 2010).

This study contributes by comparing idle time minimization and allowing deadhead trip strategies for fleet size reduction. It provides proper evidence that can help to integrate theoretical knowledge with practical implementation. It also develops a framework for transit operators to choose the most suitable scheduling method depending upon route characteristics and demand patterns.

2. METHODOLOGY

2.1 Research Design

The study compared three different scheduling methods. Six bidirectional routes across Narayanganj City Corporation were chosen for the study. Same routes traffic demands of three different years were used to analyze the results. Demand data, vehicle capacity, total service hours and minimum frequency were all kept unchanged. This ensures that the difference in performance should be caused only by the logic of the methods.

2.2 Study Area and Route Selection

Narayanganj City Corporation is situated just beside Dhaka. It is a major commercial and industrial hub. The city's transport system is continuously dealing with high travel demand due to rapid urbanization and population growth. There is very limited funding available for the transport system as most of the private operators have limited budgets. Scheduling of vehicles is done manually. All these make it a suitable option for evaluating the improvement in transit operation by different scheduling methods.

Six different routes were selected with various travel demand patterns. Passenger loads in C2 and D1 routes from the year 2029, C1 and B2 routes from the year 2034 and A1 and D2 routes from the year 2044 were chosen. All these cover the majority of the city's transit network. The number of daily trips differs from 1,434 to 2,559 on the C2 and A1 routes, respectively. Travel demand patterns also vary among the six routes. Route B2 requires nearly an equal number of trips in both directions (ratio 1.00:1) to provide adequate service, whereas Route C1 has a high difference in total number of trips (ratio 1.53:1). These variations help to find which method is more suitable for which demand patterns.

2.3 Data Collection and Preparation

Passenger demand of all routes for different years was generated using Aimsun-based modeling. It was calibrated with available field survey data for Narayanganj. The input parameters of the modeling were land-use patterns, employment, population distribution, mode choice behaviour of people. Hourly boarding and alighting profiles were produced for each route and direction using those parameters.

The maximum hourly passenger load was used to determine the frequency. Travel time between the origin and destination terminals was taken from simulation results. Vehicle capacity was considered as 45 passengers to replicate the current vehicle's capacity that runs in the city. Service hours were set from 6:00 AM to 11:00 PM. These were kept unchanged for all scheduling approaches.

Timetables were developed using standard frequency determination practices used in transit operations (A. Ceder, 2007). Hourly frequency was calculated by dividing peak load by vehicle capacity. Headways were obtained by dividing 60 minutes by the hourly frequency. Complete sequential departures were created for both directions using the headways. Each trip was given a unique ID, departure and arrival time. All these datasets were used for every scheduling method to ensure a fair and unbiased comparison.

2.4 Fleet Scheduling Methods

All three methods were tested. All buses should complete their ongoing trip before starting a new one and the departure time of a trip must be later than the arrival time of the previous trip.

First In, First Out (FIFO): Majority of the operators are currently following this method. A new trip is assigned to a bus that has arrived at the departure terminal first. If no bus is available, then a new bus is assigned for the trip. This is the baseline because it is simple to use and does not optimize utilization.

Earliest Compatible Trip Assignment (ECTA): In this method before assigning a trip to a bus the algorithm checks the idle time between the previous trip and the new trip. If multiple buses are available, it chooses the bus that has waited the least amount of time. If no bus exists then a new bus is assigned. The main goal of this method is to reduce the idle time between two trips and only allow revenue trips.

Dynamic Reallocation with Deadhead Optimization (DRDO): DRDO method is similar to FIFO. The key difference is in DRDO method deadhead trips are allowed when more buses are required but no bus is available in that particular terminal. It also ensures that the bus reaches the terminal on time from opposite direction with a deadhead trip. And if no bus can reach the terminal after completing the deadhead trip, then a new bus is assigned.

2.5 Performance Evaluation

Several factors were considered to compare all three methods. The first priority was fleet size. It was chosen as the main priority because the main goal is to maintain service quality while using minimum number of buses. Fleet reduction percentage shows a clear improvement in operational efficiency achieved by the methods compared to FIFO. Average trips per bus show the workload balance and proper utilization of each bus. The dead head count and dead head trip percentage can be used to determine the operational cost due to deadhead trips and investment savings by reducing number of buses. Directional imbalance ratios were considered as the routes with balanced demand in both directions had little change. Routes having big differences in demand patterns had significant improvements.

3. RESULTS AND DISCUSSION

3.1 Fleet Size Comparison

Figure *1* compares fleet requirements for all three (FIFO, ECTA and DRDO) scheduling methods. The comparison covers six routes across different years (2029, 2034, and 2044). Results show that DRDO consistently requires fewer buses than both FIFO and ECTA across all routes analyzed.

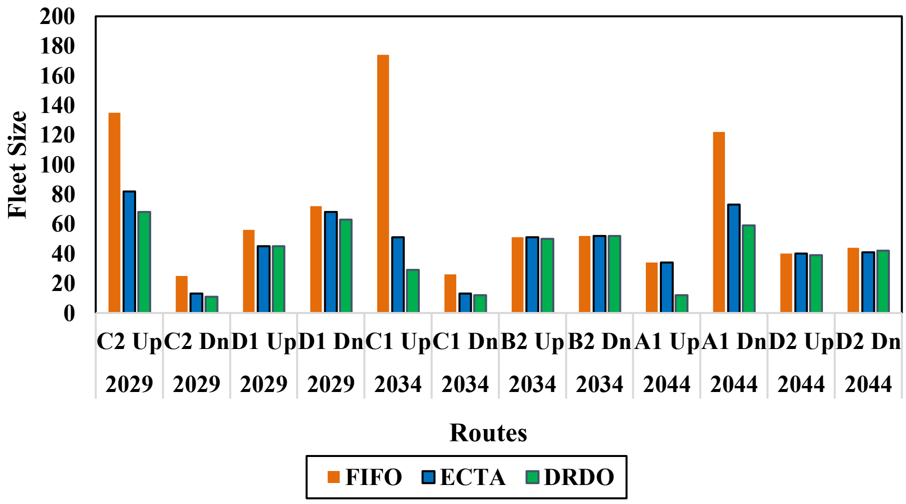

Figure 1: Fleet size Comparison among FIFO, ECTA, and DRDO

3.2 Fleet Reduction

Figure *2* shows the percentage reduction in fleet size achieved by ECTA and DRDO compared to FIFO. Results vary significantly across routes depending on the demand pattern. Route B2 with balanced demand patterns shows almost no improvement. Route C1 showed an improvement of 79.5%. This variation demonstrates that route characteristics, particularly directional demand imbalance, strongly influence optimization potential.

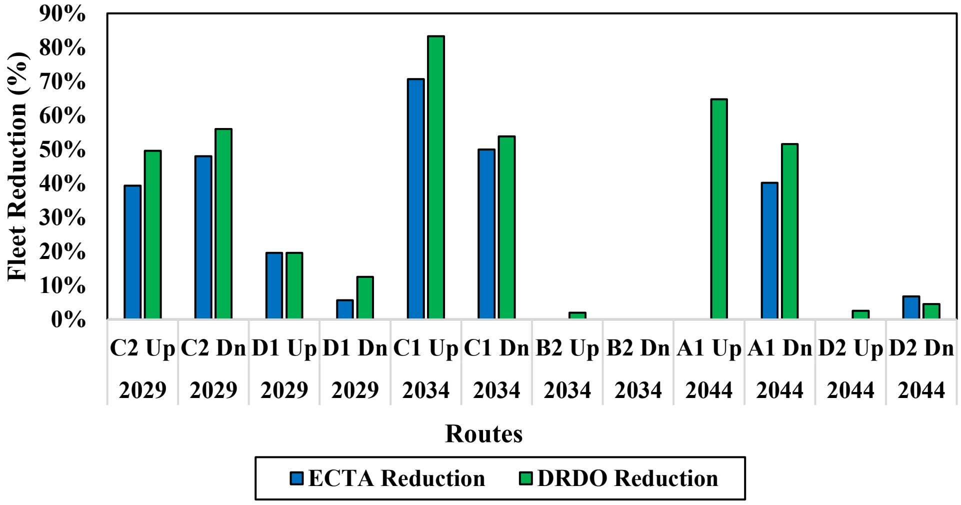

Figure 2: Fleet Reduction Percentage

3.3 Directional Demand Imbalance

Figure *3* shows directional demand imbalance for each route, measured as the ratio of high direction demand to low direction demand. Routes with higher directional imbalance ratios (C1 and C2) show greater potential for fleet reduction through deadheading. This finding confirms that demand imbalance is a key indicator of deadheading effectiveness.

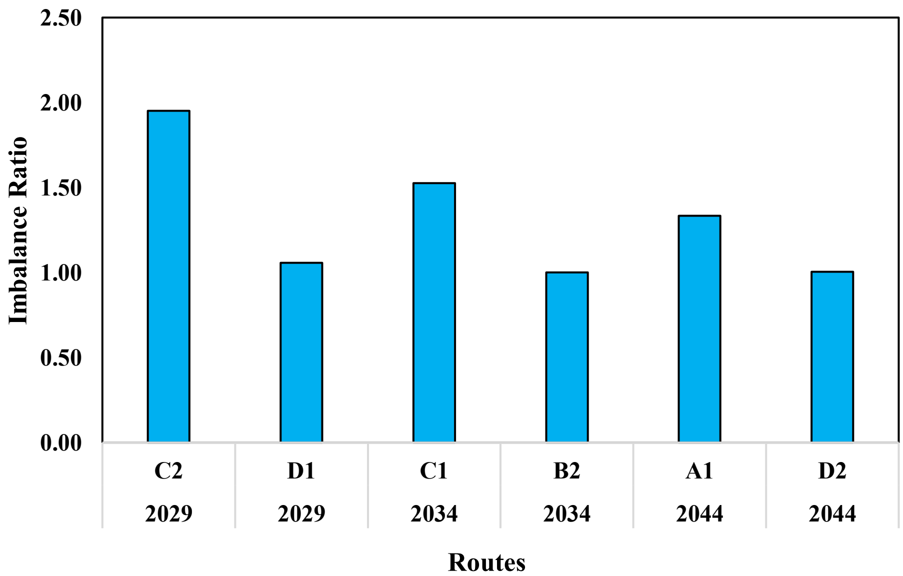

Figure 3: Route Wise Demand Imbalance

3.4 Overall Comparison of Different Methods

Table 1 provides a detailed quantitative comparison of fleet requirements across all evaluated routes and scheduling methods. The data encompasses trip frequencies, absolute fleet sizes under each methodology, and percentage reductions achieved by ECTA and DRDO relative to FIFO baseline. Several key observations emerge from this analysis:

The DRDO method consistently outperforms or equals ECTA performance across all routes, with particularly pronounced advantages on routes with significant directional imbalances. Route C1 (2034) demonstrates the most substantial optimization potential, achieving a 79.5% overall fleet reduction through DRDO implementation. Conversely, Route B2 (2034) exhibits minimal improvement (1.0%), indicating near-optimal balance in existing FIFO scheduling.

Table 1: Fleet Size Comparison of different Routes

Year	Route	Trips	FIFO Fleet No	ECTA Fleet No	DRDO Fleet No	ECTA Reduction (%)	DRDO Reduction (%)
2029	C2 Up	948	135	82	68	39.3%	49.6%
2029	C2 Down	486	25	13	11	48.0%	56.0%
2029	C2	1434	160	95	79	40.6%	50.6%
2029	D1 Up	1036	56	45	45	19.6%	19.6%
2029	D1 Down	1096	72	68	63	5.6%	12.5%
2029	D1	2132	128	113	108	11.7%	15.6%
2034	C1 Up	990	174	51	29	70.7%	83.3%
2034	C1 Down	649	26	13	12	50.0%	53.8%
2034	C1	1639	200	64	41	68.0%	79.5%
2034	B2 Up	994	51	51	50	0.0%	2.0%
2034	B2 Down	993	52	52	52	0.0%	0.0%
2034	B2	1987	103	103	102	0.0%	1.0%
2044	A1 Up	1096	34	34	12	0.0%	64.7%
2044	A1 Down	1463	122	73	59	40.2%	51.6%
2044	A1	2559	156	107	79	31.4%	49.4%
2044	D2 Up	1031	40	40	39	0.0%	2.5%
2044	D2 Down	1035	44	41	42	6.8%	4.5%
2044	D2	2066	84	81	81	3.6%	3.6%

Directional analysis reveals asymmetric optimization potential, with certain route directions (e.g., C1 upward: 83.3% reduction) offering substantially greater improvement opportunities than their counterparts (C1 downward: 53.8% reduction). This asymmetry reflects the underlying demand distribution patterns and suggests that bidirectional optimization strategies may require distinct approaches for each travel direction.

3.5 Deadheading Analysis:

Table 2 shows the deadheading patterns for DRDO across all routes. Deadhead percentages vary widely, from less than 1% on balanced routes like D2 to nearly 20% on Route C2 upstream. This variation reflects how much empty running each route needs to minimize its fleet.

Routes with imbalanced demand naturally require more deadheading. C2 upstream needs 19.59% deadhead trips, while its downstream direction only needs 4.14%. This shows that demand asymmetry between directions directly affects how much repositioning is necessary. In contrast, balanced routes like D2 need minimal deadheading (under 2%) because buses can efficiently cycle between directions without extra repositioning.

Despite these deadhead trips, productive ratios remain high across all routes. Most routes maintain ratios above 80%, and several exceed 95%. This means the majority of bus movements still carry passengers, even when using deadheading strategies. Routes D1 and D2 show particularly high productive ratios (above 96%), demonstrating that even small amounts of strategic repositioning can reduce fleet size while keeping operations efficient.

Table 2: Deadheading Analysis of DRDO

Year	Route	Revenue Trips	Deadhead Trips	Deadhead trip Percentage	Productive Ratio
2029	C2 Up	948	231	19.59%	80.41%
2029	C2 Down	486	21	4.14%	95.86%
2029	D1 Up	1,036	17	1.61%	98.39%
2029	D1 Down	1096	28	2.49%	97.51%
2034	C1 Up	990	98	9.01%	90.99%
2034	C1 Down	649	24	3.57%	96.43%
2034	B2 Up	994	11	1.09%	98.91%
2034	B2 Down	993	13	1.29%	98.71%
2044	A1 Up	1,096	95	7.98%	92.02%
2044	A1 Down	1,463	340	18.86%	81.14%
2044	D2 Up	1,031	10	0.96%	99.04%
2044	D2 Down	1,035	16	1.52%	98.48%

3.6 Fleet Utilization Comparison

Table 3 establishes the relationship between the directional demand imbalance ratio and achievable fleet reduction percentages. The data reveal a strong positive correlation between demand asymmetry and optimization potential. Routes with directional imbalance ratios exceeding 1.5 (C2: 1.95, C1: 1.53) consistently achieve fleet reductions exceeding 40% under both methods, while routes approaching perfect balance (B2: 1.01) demonstrate minimal improvement potential (≤1.0%).
This relationship provides transit planners with a practical heuristic for preliminary assessment: routes with directional imbalance ratios below 1.1 may derive limited benefit from deadheading optimization, suggesting that temporal scheduling adjustments (ECTA) offer near-optimal solutions. Conversely, routes with directional imbalance ratios exceeding 1.3 present substantial opportunities for fleet reduction through strategic vehicle repositioning, justifying the operational complexity and additional deadhead costs associated with DRDO implementation.

Table 3: Relation Between Directional Imbalance Ratio and Fleet Reduction

Year	Route	Directional imbalance	ECTA Reduction	DRDO Reduction	Recommended Method
2029	C2	1.95	40.60%	50.60%	DRDO (best output)
2029	D1	1.06	11.70%	15.60%	ECTA (good balance)
2034	C1	1.53	68.00%	79.50%	DRDO (best output)
2034	B2	1.00	0.00%	1.00%	FIFO (sufficient)
2044	A1	1.33	31.40%	49.40%	ECTA (good balance)
2044	D2	1.00	3.60%	3.60%	FIFO (sufficient)

4. CONCLUSIONS

Using the Aimsun-based travel demand modeling data for six different routes in Narayanganj this study compared the three different bus scheduling methods. The effectiveness of the methods depends upon the demand patterns of specific routes. Routes that have a big difference in trip numbers due to passenger demand showed significant improvement. DRDO method reduced the fleet size by 79.5%

and ECTA method reduced the fleet size by up to 68% compared to FIFO method. Routes with nearly the same demand patterns (B2 and D2) showed bare minimum improvement. This indicates that FIFO method can be used in this type of route as it is easy to apply and does not require complex calculation. Directional imbalance ratio provided a fruitful insight. Minimum improvement was achieved in those routes where the ratio is near 1.0. Major improvements were seen in routes having a directional imbalance ratio above 1.5. ECTA required fewer buses than FIFO without requiring any deadhead trips. DRDO method reduced more fleet size by allowing 4 to 20% deadhead trips on the routes with directional imbalance. These results can be very helpful for the private operators having limited budget for investment. ECTA method is suitable for routes with little imbalance where operators prefer to avoid deadhead trips. DRDO method is more suitable for routes with higher demand imbalance if deadhead trips are operationally feasible. Operators can choose FIFO method in those routes where the demand ratio is balanced and other methods on routes with imbalanced trips to optimize the operational efficiency most.

There are some limitations in this study. The travel time was assumed to be constant; traffic congestion delay was not considered. Economic analysis comparing deadhead operating costs with fleet investment savings was not conducted. These factors should be considered in future implementation studies.

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DECLARATION OF USE OF AI TOOLS

AI tools were used only for grammar checking and clarity improvement during manuscript preparation. No AI tool was used to generate research methodology, analysis, results or ideas presented in this paper. All research ideas, analytical procedures, calculations, and tables were entirely developed by the authors.

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