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A BUS ROUTE-EFFICIENCY ANALYSIS USING STOCHASTIC FRONTIER MODEL

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ABSTRACT - This research analyzes the efficiency of bus routes in Kandy, Sri Lanka, utilizing a Stochastic Frontier Model (SFM). The primary objective is to identify inefficiencies and provide recommendations for optimizing bus operations. The data collection was done through collecting relevant documents maintained at bus depots. These documents included records of revenue, number of buses, distance covered, fare structure, load factors, route length, and bus capacities. The analysis reveals that over 60% of routes cluster around a moderate efficiency range, indicating potential for improvement. Notably, a significant number of routes (potentially 24 or more) achieve efficiency scores exceeding 90%, serving as exemplars of efficiency. Conversely, some routes score as low as 10%, necessitating further investigation to address inefficiencies. The SFM results, with an R-squared value of 0.84, indicate the model explains approximately 84% of the variation in revenue per kilometer. Key recommendations include optimizing bus schedules to increase load factors, adjusting trip lengths to balance operational costs and passenger demand, and re-evaluating bus allocations to ensure resource efficiency. These findings provide actionable insights for enhancing the efficiency of bus routes in Kandy, contributing to improved public transportation services and resource allocation.

Keywords: Bus Transportation; Cost Efficiency; Stochastic Frontier Model; SFM; Route Characteristics

1. INTRODUCTION

The efficiency of public transportation systems is a crucial factor in urban planning and management, particularly in densely populated areas where transportation demand is high. The study focuses on the bus routes within Kandy, Sri Lanka, a region characterized by diverse geographic and demographic features. Kandy is a significant urban center with a rich cultural heritage and serves as a crucial node in Sri Lanka's transportation network. Bus route efficiency impacts not only the Several studies have examined the efficiency of public transportation systems using various methodologies. For instance, Gebeyehu and Takano [1] analyzed the efficiency of bus routes using Data Envelopment Analysis (DEA) and found that route length and passenger load significantly impact efficiency. Similarly, Deng and Yan [3] employed Stochastic Frontier Analysis (SFA) to evaluate the efficiency of bus routes in China, highlighting the importance of optimizing operational factors. Despite the existing literature, there is a lack of studies focusing on the efficiency of bus routes in the Sri Lankan context. Though bus transportation plays a significant role, the service quality (especially the supply) in some regions is not favorable for the demand, as noted by Lowe et al. [4]. In the city of Kandy, four major types of areas were identified depending on the service level and population density: High Scored – High Density areas, High Scored – Low Density areas, Low Scored – High Density areas, and Low Scored – Low Density areas. Figure 1 represents a graphical illustration of these areas.

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Figure 1. Areas Depending on the Service Level and Population Density.

The primary aim of this research is to evaluate the efficiency of bus routes managed by selected bus depots in the Kandy district and identify the key factors affecting their efficiency. Additionally, the study will estimate the efficiency of bus routes using a Stochastic Frontier Model (SFM) to measure the efficiency scores of different bus routes and identify the factors contributing to inefficiencies. By achieving these objectives, this study aims to provide valuable insights into the management of bus routes in Kandy, contributing to the broader literature on public transportation efficiency and offering practical solutions for improving the performance of bus depots in the region.

2. MATERIALS AND METHODS

The methodology for analyzing the operational efficiency of bus routes in Kandy, Sri Lanka, employs the Stochastic Frontier Model (SFM) to assess and model bus route performance. SFM was chosen over Data Envelopment Analysis (DEA) because it includes random shocks and noise in the analysis, providing a more nuanced picture of efficiency. It also estimates technical inefficiency, which measures the gap between actual performance and potential output given input resources, enabling targeted interventions to improve efficiency by addressing specific areas of underperformance. The study focuses on bus routes from two regions identified based on service level and population density: the high-low areas and the low-high areas covering a population of 725,290. A total of 163 bus routes were considered for this study. The model estimates the maximum possible output (revenue per kilometer) given the inputs (route length, bus fare, number of seats, number of buses, trip length, and load factor), and identifies how far each bus route deviates from this frontier. This approach allows for targeted analysis and identification of factors contributing to inefficiencies. The model aims to identify areas for improvement by evaluating the operational elements by providing a complete picture of cost efficiency that benefits both bus service providers and passengers.

3. RESULTS AND DISCUSSION

The maximum likelihood estimates of stochastic frontier model are made using Stata, and the result is presented in Table 1. The ordinary least square (OLS) coefficients provide a starting point for the maximum likelihood estimate process. The model's goodness of fit is indicated by an R-squared value of 0.8364, meaning it explains approximately 84% of the variation in revenue per kilometer. The remaining 16% could be due to unobserved factors or model limitations. According to the analysis results, the negative coefficients for trip length and bus numbers suggest that longer trips and more buses on a route decrease revenue per kilometer, likely due to increased costs or lower passenger loads per bus. Conversely, positive coefficients for higher load factors, bus fares, and longer routes indicate that these factors contribute positively to revenue per kilometer, highlighting their profitability-enhancing effects. As shown in Figure 2, most routes cluster around a moderate efficiency range. Specifically, greater than 60% (0.6) of the routes fall within this band. This indicates there's potential for improvement on many routes, but also that some are already functioning quite well. The table suggests a significant number of routes (potentially 24 or more, depending on how the ranges are grouped) achieve efficiency scores exceeding 90% (0.9-1.0 and >=1.0).

Table 1. Stochastic Frontier Estimations

Dependent variable: Revenue per km	Least squares		Half-normal SFM	
Independent Variables	**β**	**t-ratio**	**β**	**t-ratio**
Constant	-175.4886	-8.45	-175.4382	-6.93
Route Length	-4.485927	-9.80	-4.485927	-10.02
Bus Fare	0.7380315	7.42	0.7380315	7.58
No. of seats	3.426939	10.09	3.426939	10.32
Number of buses	3.04893	0.59	3.04893	0.60
Trip length	-0.0007312	-0.69	-0.0007312	-0.71
Load factor	3.248282	26.93	3.248282	27.52

These routes are likely exemplars of efficiency and could be studied to understand what factors contribute to their success. On the other hand, there are also routes with lower efficiency scores. The table might show a handful of routes scoring as low as 10% (less than 0.1). These underperforming routes warrant further investigation to pinpoint the reasons behind their inefficiency.

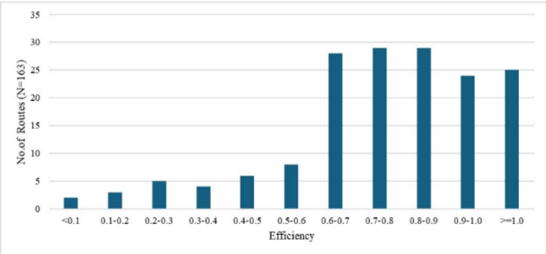

Figure 2. Efficiency Estimates of Bus Routes

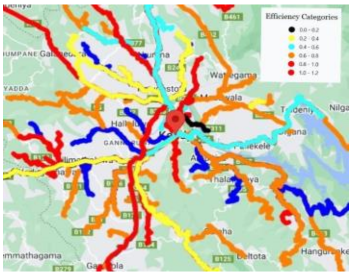

Figure 3. Efficiency Scores and Locations of Bus Routes

4. CONCLUSION

The study analyzed bus route performance using the half-normal Stochastic Frontier Model, finding a mean efficiency of 78.75%. This model effectively identified factors affecting route efficiency and provided a reliable efficiency analysis by accounting for random errors. The findings highlight the importance of addressing inefficiencies for service improvement and suggest further research to include additional variables and extend the methodology to other transit systems.

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