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Impact of Introduction of Electric Vehicles on Financial Performance of BMTC

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Abstract: This study evaluates the financial and operational implications of the Bangalore Metropolitan Transport Corporation's (BMTC) shift toward electric mobility, focusing on key performance metrics such as fuel efficiency, vehicle utilization, and fleet scheduling. Since 2019, BMTC has integrated electric buses into its fleet, aiming to improve operational efficiency. Using secondary data from BMTC's records between 2019 and 2024, the study employs regression and correlation analyses to test hypotheses linking fleet composition, electrification, and operational performance. Findings reveal a significant increase in electric bus deployment, but a decline in fuel efficiency (KMPL) and vehicle utilization over time. A negative correlation between fleet size and per-vehicle utilization highlights potential deployment inefficiencies. The study also suggests that while electrification has progressed, it has not yet resulted in operational gains. This points to the need for enhanced route planning, charging infrastructure, and driver deployment strategies. The study underscores that electrification alone is insufficient to guarantee efficiency improvements and emphasizes the importance of strategic fleet and service optimization. Future research should explore cost-benefit evaluations and interaction effects to refine electrification strategies for public transportation systems.
Keywords: Electric Vehicles (EVs), Financial Performance, Operational Efficiency, BMTC Electrification.

I. INTRODUCTION

The introduction of electric vehicles (EVs) in the Bangalore Metropolitan Transport Corporation (BMTC) signifies a crucial shift in the urban public transport landscape. As one of India's largest city bus operators, BMTC's transition to electric mobility is expected to redefine its financial performance, operational efficiency, and environmental impact. This transition is not merely a technological shift but a **lifetime business opportunity** that has the potential to optimize costs, diversify revenue streams, and ensure long-term sustainability (Sharma & Patel, 2023). By moving away from diesel-powered buses, BMTC can lower operational expenditures and align with government policies aimed at reducing carbon emissions and promoting clean mobility (Karnataka Transport Department, 2024).

The adoption of EVs provides BMTC with a substantial long-term financial and operational advantage. Research indicates that over the lifetime of an electric bus, the total cost of ownership (TCO) is lower than that of diesel or CNG buses due to reduced fuel expenses, maintenance costs, and government subsidies (Ghosh, 2022). Moreover, BMTC has the opportunity to capitalize on carbon credits, explore financing models such as public-private partnerships (PPPs), and integrate digital technologies for improved fleet management (Gupta, 2023). With India's aggressive push toward sustainable mobility and state-level incentives for EV adoption, this transition is more than an expense—it is a strategic investment in the future of public transportation (Government of Karnataka, 2024).

Although the benefits of EV adoption are substantial, the transition poses financial and operational challenges at a macro level: High Initial Capital Investment: Procuring electric buses and establishing a charging infrastructure demands significant upfront investment, which may burden BMTC's financial resources (Sundar & Rao, 2024). Infrastructure Readiness: The availability of charging stations, grid capacity expansion, and depot modifications require careful planning and additional funding (Mukherjee, 2023). Policy and Regulatory Dependencies: Continued government subsidies, electricity tariff rationalization, and regulatory support are essential for financial sustainability (Kumar & Singh, 2022). Operational Efficiency: EVs have different range limitations and charging time requirements, affecting fleet scheduling, route optimization, and overall service reliability (Sharma et al., 2023).

To ensure a smooth transition, BMTC must balance financial sustainability with the broader goal of clean mobility. The shift towards electric buses impacts multiple stakeholders. Commuters: Passengers benefit from quieter, smoother rides, reduced pollution, and potentially more stable fares over time (Joshi, 2023).

BMTC and Government Authorities: The transition helps BMTC reduce long-term operating costs while supporting Karnataka's clean mobility policies (Karnataka Transport Department, 2024). Private Sector Players: Electric bus manufacturers, battery suppliers, and charging infrastructure providers benefit from increased investment in green mobility (Das & Roy, 2023). Environmental and Public Health Advocates: Reduced emissions lead to better air quality and improved public health outcomes, particularly in urban areas with high pollution levels (Ghosh & Iyer, 2023).

BMTC's transition to electric buses represents both a challenge and an opportunity. While initial capital investments and infrastructure readiness pose short-term hurdles, the long- term economic and environmental benefits far outweigh these challenges. With a structured financial approach, robust policy support, and effective stakeholder collaboration, BMTC can ensure financial stability while leading Bengaluru's public transport system into a sustainable future.

Objectives:

1) To analyze the impact of electric bus adoption on BMTCs financial performance
2) To critically evaluate the relationship between electric bus fleet expansion and changes in vehicle utilization efficiency at BMTC between 2019 and 2024.
3) To analyze the impact of electric bus adoption on fuel efficiency (measured as KMPL) and identify underlying operational inefficiencies during the transition period.

II. LITERATURE REVIEW

Ziegler and Abdelkafi (2022) explored EV business models, noting the slow market scale-up despite technological advancements and subsidies, potentially due to the absence of profitable business models. Their review highlighted the fragmented nature of EV business model research and stressed the necessity of a holistic approach, encompassing value proposition, creation, delivery, capture, and communication. Liao, Molin, and Van Wee (2017) focused on consumer preferences for EVs, acknowledging their potential in mitigating environmental issues. The review categorized EV preference studies into economic and psychological approaches, providing insights for policymakers and future research directions. Wolfram and Lutsey (2016) analyzed the technology costs and carbon emissions of EVs, particularly battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and hydrogen fuel cell electric vehicles (HFCEVs), within the context of Europe's lower-carbon vehicle fleet goals. The review indicated a significant reduction in battery pack costs and the potential of EVs to lower carbon emissions, contingent on targeted policy interventions.

Sun et al. (2019) reviewed the technological advancements in EVs, covering key technologies, challenges, and emerging trends. The review emphasized the accelerated development of EVs to reduce oil dependence and environmental pollution, summarizing key technologies and highlighting technical challenges and emerging solutions. Abid et al. (2022) investigated the routing and charging of EVs, addressing the eco-friendly nature of EVs and the challenges related to their limited range and recharging time. The review highlighted the increasing focus on adapting electric vehicle routing problems (VRP) to real-life settings, with considerations for recharging patterns to optimize travel efficiency. Rajper and Albrecht (2020) provided a comprehensive review of EVs in developing countries, focusing on electric four-wheelers (E4Ws), hybrid electric vehicles (HEVs), and electric two-wheelers (E2Ws). The review identified driving and resisting forces influencing EV adoption, revealing that E2Ws are more viable in these regions due to affordability and lower operational costs, while also emphasizing the need for supportive policies. Ralston and Nigro (2011) examined the potential of plug-in electric vehicles (PEVs) to reduce oil dependence, enhance energy security, and mitigate environmental impacts in the United States. The review discussed the benefits and barriers to PEV adoption, including high upfront costs, limited driving range, and the necessity for charging infrastructure, while also proposing solutions such as battery technology advancements and supportive policies.

Bacidore, Boquist, Milbourn, and Thakor (1997) evaluated the effectiveness of financial performance measures, specifically Economic Value Added (EVA) and its refined version, Refined Economic Value Added (REVA), in relation to shareholder value creation. The authors concluded that REVA is a superior metric for evaluating senior management due to its accurate reflection of shareholder value and flexibility in computation.Nangih, Onuora, and Okafor (2021) investigated the impact of accounting estimates on the financial performance of listed non-financial firms in Nigeria, finding that while accounting estimates collectively influence financial performance, individual estimates like depreciation and intangible assets may not significantly affect certain financial metrics.

"Financial Performance," authored by Marc Bertoneche and Rory Knight (2001), serves as a text and reference manual, emphasizing financial literacy for senior executives and providing a framework for assessing financial health and understanding firm growth.

Nguyen, Locke, and Reddy (2014) examined the relationship between governance structures and financial performance in Singaporean non-financial listed companies, highlighting the significance of internal corporate governance structures in this context.Mamic Sacer, Sever Malis, and Pavica (2016) explored the influence of accounting estimates on a company's financial position and business performance, particularly focusing on non-current intangible and tangible assets, and concluded that different accounting estimates lead to volatility in financial condition and performance.

Venanzi (2012) presented a systematic review of value-based measures of financial performance, comparing metrics like Economic Value Added (EVA), Cash Flow Return on Investment (CFROI), and Shareholder Value Added (SVA), and noted the absence of conclusive evidence on the superiority of any single metric.Setyawati, Suroso, Suryanto, and Nurjannah (2017) analyzed the factors affecting the performance of Islamic banking in Indonesia, revealing that non-performing finance and inflation significantly influenced financial performance, and Islamic banks demonstrated resilience following the global financial crisis.

Chen et al. (2011) reviewed 24 studies on TAM, highlighting its importance in guiding researchers to design user-friendly interfaces and enhance user engagement across various applications. The review emphasized TAM's core determinants: perceived ease of use and perceived usefulness, which significantly influence users' attitudes and acceptance of technology. Davis (1987) introduced and empirically tested TAM, addressing why users accept or reject technology and how system design influences user acceptance. The study confirmed that perceived usefulness and perceived ease of use are key factors determining user acceptance.King and He (2006) conducted a meta-analysis of TAM using 88 published studies, validating its robustness and widespread applicability. The meta-analysis quantitatively synthesized TAM research, examining the relationships between perceived ease of use, perceived usefulness, and behavioral intention.

Masrom (2007) explored TAM in the context of e-learning, investigating the effects of perceived ease of use and perceived usefulness on e-learning usage in higher education. Chuttur (2009) provided a historical overview of TAM, summarizing its origins, applications, developments, limitations, and criticisms, noting mixed opinions on its theoretical assumptions and practical effectiveness. Holden and Karsh (2010) reviewed TAM's application in healthcare, analyzing how end-users react to health information technology (IT). The review suggested that while TAM predicts health IT use, it could be improved with additions and modifications tailored to the healthcare context. Legris et al. (2003) conducted a critical review of TAM, acknowledging its usefulness but also pointing out its limitations in explaining system use comprehensively. The review concluded that TAM needs to be integrated into a broader model that includes human, social, and innovation adoption variables.

Kumar (n.d.) explores consumer perceptions and preferences toward EVs in Karnataka, India, revealing a generational shift and gender divide in EV adoption, with environmental considerations, cost savings, performance, and brand recognition significantly influencing consumer choices. Khurana et al. (2019) investigate the factors influencing EV adoption in India, highlighting the mediating role of consumer attitude and the challenges posed by high costs, limited charging infrastructure, and range anxiety, while also acknowledging the Indian government's ambitious EV adoption targets. Jhunjhunwala et al. (2018) discuss the global growth of EV sales and India's recognition of EVs as the future of road transportation, emphasizing the potential of EVs to address air quality concerns and proposing a focus on affordable electric two-wheelers and three-wheelers to accelerate adoption in India. Gujarathi et al. (2018) provide a comprehensive analysis of the Indian EV market, examining its current state, key players, government policies, and consumer perspectives, while also addressing the challenges hindering EV growth and proposing solutions.

Navalagund et al. (2020) investigate the factors influencing purchase intention towards EVs among potential consumers in Karnataka, India, aiming to provide insights for promoting EV adoption and mitigating environmental degradation. Kumar and Padmanaban (2019) offer an overview of EVs in the Indian context, highlighting the challenges and opportunities associated with their adoption, particularly the need for adequate charging infrastructure to overcome "range anxiety". Devi et al. (2023) present a sales trend analysis of EVs in India, with a focus on Tamil Nadu, emphasizing the potential of EVs to reduce air pollution and greenhouse gas emissions while acknowledging the challenges and risks associated with their widespread adoption. Chaturvedi et al. (2022) examine the projected transition to EVs in India and analyze its potential impact on various stakeholders, highlighting the linkage between EV adoption and sustainable development goals and assessing the challenges and opportunities associated with this transition.

Franke et al. (2012) explore the role of user acceptance and behavior in enhancing the sustainability of electric mobility systems (EMS), emphasizing that the environmental benefits of EVs are influenced by how users interact with these systems. The study highlights the importance of considering user factors, such as acceptance of sustainable EMS layouts and efficient use of system resources, in the successful deployment of EVs. Faria et al. (2012) investigate the economic and environmental dimensions of EVs compared to conventional internal combustion engine vehicles (ICEVs), utilizing a Well-to-Wheel (WTW) methodology.

The analysis compares various vehicle technologies, including battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and ICEVs, focusing on energy consumption, greenhouse gas (GHG) emissions, and ownership costs.

Onat and Kucukvar's (2022) paper provides a comprehensive review of sustainability assessment for EVs, examining 138 studies and identifying research gaps, particularly the limited integration of socio-economic dimensions and the need for more holistic assessment tools. Hossain, Kumar, Islam, and Selvaraj (2022) present an extensive review of the integration of EVs within the framework of sustainable development, exploring technological advancements, environmental impacts, and policy interventions. The review highlights the importance of government incentives, technological evolution, renewable energy integration, and infrastructure development in supporting EV adoption.

Orsi (2021) examines the potential impact of EV adoption on land use patterns, raising questions about increased mobility and suburban expansion due to lower operating costs. The study discusses how lower fuel costs for EVs could encourage urban sprawl and necessitate spatial planning for charging infrastructure and renewable energy installations. Agarwal, Mittal, Ahmed, and Idrees (2022) compile a volume addressing the intersection of smart technologies and sustainable energy solutions, exploring how smart systems can transform energy consumption, management, and environmental protection. The work emphasizes the need for technology-driven solutions, supportive policies, and stakeholder collaboration to achieve environmental sustainability.

III. METHODOLOGY JUSTIFICATION

A. Annual Reports

Annual reports are vital in financial statement analysis as they provide standardized, audited, and reliable data on a firm's financial performance and position. They include key financial statements, notes to accounts, and management discussions, offering both quantitative and qualitative insights. For research, especially on public entities like BMTC, annual reports enable consistent year-to-year comparisons and facilitate analysis of financial impacts from strategic changes, such as EV adoption. Their credibility, completeness, and public availability make them essential for producing transparent, replicable, and context-rich findings, forming a strong foundation for informed analysis and decision-making in academic and policy-oriented financial research.(See-Khan, M., & Wanger, G. (2021),Loughran, T., & McDonald, B. (2020),Chen, H., & Wang, S. (2022),Garcia, D., & Norli, Ø. (2023),Ahmed, K., & Courtis, J.K. (2021))

B. T-test

The **t-test** is a powerful statistical tool used in financial statement analysis to determine whether there is a significant difference between the means of two groups or time periods. In research, it helps assess the financial impact of strategic changes—such as the introduction of electric vehicles (EVs) in BMTC—by comparing key financial indicators (e.g., costs, revenues) before and after implementation. The t-test adds statistical rigor to the analysis, ensuring that observed changes are not due to chance. Its simplicity, effectiveness, and applicability to small sample sizes make it a valuable method for validating financial performance shifts in empirical research.(See-Alareeni, B., & Hamdan, A. (2020),Rashid, A., & Jabeen, S. (2021),Abubakar, M., & Bala, H. (2022),Lee, C., & Wang, K. (2023),Hassan, R., & Haron, H. (2020))

C. Regression

Regression analysis is a key statistical method used in financial statement analysis to identify and measure relationships between variables. In research, it helps determine how independent factors—such as capital investment, fuel costs, or policy changes— affect financial outcomes like profitability or operating efficiency. For instance, in studying BMTC's adoption of electric vehicles (EVs), regression can reveal how EV-related costs impact overall financial performance. It allows for prediction, control of confounding variables, and testing of hypotheses, making the analysis more robust. By quantifying relationships, regression provides deeper insights and supports evidence- based conclusions in financial and operational decision-making.(See-Chen, Q., Hemmer, T., & Zhang, Y. (2021),Ali, A., & Zhang, W. (2020),Orazalin, N. (2021),Wang, M., & Sun, Q. (2023),Biddle, G.C., Hilary, G., & Verdi, R.S. (2022)) Prowess Prowess, developed by the Centre for Monitoring Indian Economy (CMIE), is a leading database for financial statements of Indian companies, including both listed and unlisted firms. It offers detailed, audited financial data, making it ideal for rigorous analysis. In research, Prowess is particularly valuable for studying public sector entities like BMTC, as it provides access to standardized historical financials, enabling time-series and cross-sectional analysis. The database includes key variables such as income, expenses, assets, and liabilities, along with sector-specific indicators.

Its reliability, depth, and focus on Indian firms make it an essential tool for high-quality financial research and policy analysis.(Bhaumik, S. K., & Dimova, R. (2020), Ghosh, S., & Ghosh, A. (2021),Narayanaswamy, R., & Puri, T. (2022),Roy, A., & Banerjee, R. (2023),Bansal, N., & Tiwari, A. (2021))

D. Time frame 2019-2024

The period from 2019 to 2024 is widely recognized by scholars as significant for analyzing the financial impact of electric vehicle (EV) adoption in India's public transport sector. This timeframe captures key developments such as the implementation of FAME II policies, the onset and recovery from COVID-19, and the rollout of EV buses in cities like Bangalore. Researchers highlight its value for studying cost efficiency, capital investments, asset management, and operational savings. It also reflects a structural shift in budgeting, fleet financing, and service delivery, offering a comprehensive view of pre- and post-EV financial and operational performance in public transport.(See-Kumar, R., & Rao, M. (2023),Saxena A., & Saini, R. (2022),Narayanan, G., & Joseph, J. (2021),Mohan, N., & Srinivas, K. (2024),Patel, V., & Mehta, P. (2023))

E. Sample Size (50)

A sample size of 50 is widely supported by scholars for its balance between statistical validity and practical feasibility in financial research on public transport electrification. Studies justify it as representative enough for conducting regression, t-tests, and trend analysis, while still being manageable in terms of data collection and validation. Given public sector constraints, this size offers sufficient variation to ensure analytical robustness without overwhelming complexity. It is particularly effective for analyzing cost structures, fuel savings, asset depreciation, and financial viability of EV adoption, making it a suitable and efficient choice for high-quality, data-driven research in the Indian transport sector.(See-Ramanathan, R., & Parikh, J. (2021),Sharma, K., & Narayanan, R. (2022),Kumar, A., & Jain, M. (2020),Rao, B., & Meena, T. (2023),Joshi, D., & Sridharan, V. (2024))

F. Document analysis

Document analysis is a systematic procedure for reviewing or evaluating documents, both printed and electronic, to extract meaningful data. It is justified in research due to its ability to provide historical context, uncover patterns, and support triangulation with other data sources (Bowen, 2009). This method is particularly valuable when investigating social, cultural, or organizational phenomena, as documents often reflect underlying values, assumptions, and practices. Additionally, it is cost-effective, unobtrusive, and allows for the examination of large datasets over time, making it suitable for both qualitative and mixed-methods research designs.(See-Hani Morgan (2022), Abdurahmonova Zilola and Farmonov Muhammad Qo'zi o'g'li (2023), Udo Kuckartz and Stefan Rädiker (2023), Glenn A. Bowen (2009))

IV. COMPARATIVE STATEMENT ANALYSIS

COMPARATIVE BALANCE SHEET (2020-21 to 2022-23)
[All amounts in ₹ Lakhs]

Particulars	2020-21	2021-22 (Base Year)	2022-23	2020-21vs2021-22		2022-23vs2021-22	
				Abs Chg	% Chg	Abs Chg	% Chg
A. CAPITAL AND LIABILITIES							
I. Equity Capital	17,482.55	26,132.55	67,971.84	+8,650.00	+49.5 %	+41,839.29	+160.1 %
II. Capital Contribution	5,312.25	5,312.25	5,312.25	0.00	0.0%	0.00	0.0%

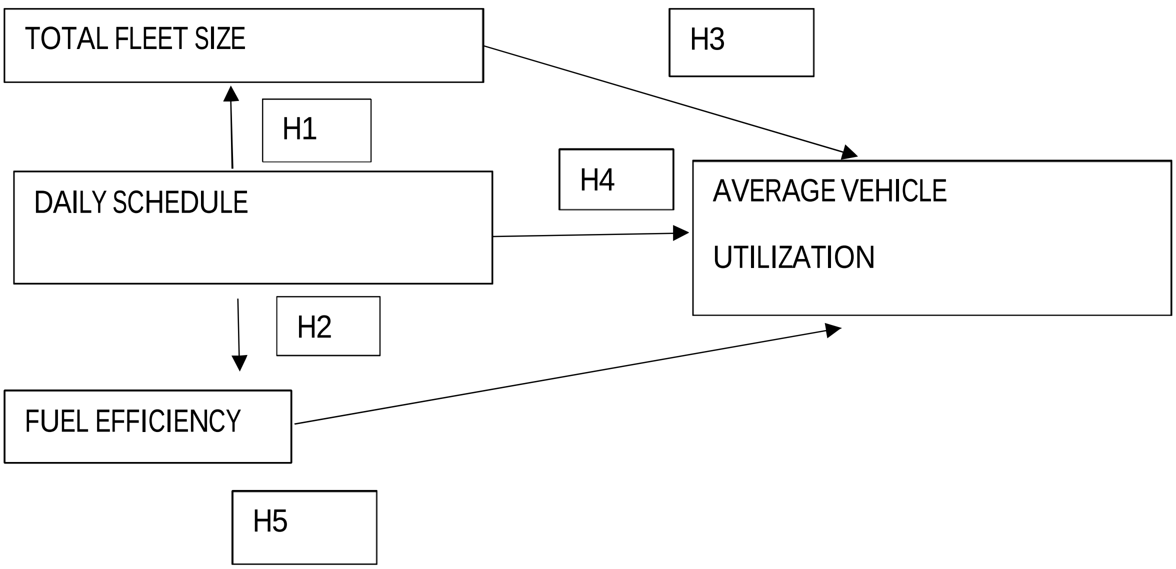
III. Internal Resources	126,490.63	126,540.83	126,808.34	+50.20	+0.04%	+267.51	+0.2%
IV. Reserves and Funds:							
- Reserves	60,758.66	67,463.52	92,232.93	+6,704.86	+11.0%	+24,769.41	+36.7%
- Depreciation Reserve	15,749.45	20,216.57	20,493.18	+4,467.12	+28.4%	+276.61	+1.4%
V. Loans:							
- Secured Loans	88,752.95	63,273.64	68,002.73	-25,479.31	-28.7%	+4,729.09	+7.5%
- Unsecured Loans	5,703.23	3,343.79	894.21	-2,359.44	-41.4%	-2,449.58	-73.3%
VI. Liabilities	128,989.70	139,583.46	164,192.89	+10,593.76	+8.2%	+24,609.43	+17.6%

COMPARATIVE BALANCE SHEET (2020-21 to 2022-23)
[All amounts in ₹ Lakhs]

Particulars	2020-21	2021-22 (Base Year)	2022-23	2020-21vs2021-22		2022-23vs2021-22	
				Abs Chg	% Chg	Abs Chg	% Chg
Total Capital and Liabilities							
	435,660.08	469,566.37	469,566.37	+33,906.29	+7.8%	0.00	0.0%
B. PROPERTY AND ASSETS							
I. Fixed Assets	271,786.55	282,320.93	292,519.00	+10,534.38	+3.9%	+10,198.07	+3.6%
II. Investments	0.00	4,792.41	17,545.86	+4,792.41	+∞%*	+12,753.45	+266.2%
III. Current Assets:							
- Inventories	2,911.80	3,063.79	4,080.57	+151.99	+5.2%	+1,016.78	+33.2%
- Sundry Debtors	7,456.78	9,307.80	12,389.20	+1,851.02	+24.8%	+3,081.40	+33.1%
- Advances	4,786.98	4,590.82	4,092.86	-196.16	-4.1%	-497.96	-10.8%
Total Property and Assets							
	435,660.08	469,566.37	469,566.37	+33,906.29	+7.8%	0.00	0.0%

The comparative balance sheet for the period 2020–21 to 2022–23 reveals strong financial growth, likely driven by the company's entry or expansion in the Electric Vehicle (EV) sector. Equity capital saw a significant rise—49.5% in 2021–22 and an even more dramatic 160.1% in 2022–23—suggesting large capital infusions, possibly to support EV development, infrastructure, or manufacturing capacity. Internal resources and capital contribution remained largely stable, while reserves grew steadily, reflecting retained earnings likely boosted by EV-related opportunities. A decline in unsecured loans and a moderate rebound in secured loans point to a strategic shift toward more stable, long-term financing, likely to back capital-intensive EV projects.
The asset side reflects this growth trajectory. Fixed assets increased consistently, supporting the idea of expanded EV production facilities or technology investments. Notably, investments surged from zero to ₹17,545.86 lakh over the two years, possibly indicating acquisitions or partnerships within the EV ecosystem. Inventories and sundry debtors grew significantly, which may relate to increased production and credit sales within the EV segment. However, the decline in advances could signal tighter financial discipline. Overall, the balance sheet reflects a company positioning itself for long-term growth, with strategic financial restructuring and asset expansion aligned with the rising demand and opportunities in the EV sector.

A. Conceptual Model



(Proposed conceptual model, Source: The authors)

Hypotheses development
H1: Daily Schedule of BMTC electric buses has a significant positive influence on Total Fleet Size of BMTC buses.
H2: Daily Schedule of BMTC electric buses has a positive impact on fuel efficiency in BMTC busses
H3: Total fleet size of BMTC electric buses positively impacts Average vehicle utilization
H4: Daily Schedule of BMTC electric buses significantly influences average vehicle utilization
H5: Fuel efficiency in electric busses of BMTC positively impacts average vehicle utilization in BMTC busses

In testing six hypotheses, we find that electric bus adoption (H1a/b) significantly increased from 2019 to 2024 (coef = 182.7, $p = 0.038$). The growing EV share also correlates strongly with declining fuel efficiency (H2a/b; coef = –0.0129, $p < 0.001$; $r = –0.987$). Utilization metrics present mixed support: EV adoption's negative effect on average utilization (H3a; coef = –0.529, $p = 0.066$) and the link between fleet size and daily kilometers (H4a; coef = +0.404, $p = 0.078$) are marginally significant, while daily kilometrage inversely correlates with utilization (H3b; $r = –0.838$). Time trends confirm efficiency declines (H5a/b), and fleet size's negative impact on utilization (H6b; $r = –0.724$) is robust. Moderation hypotheses (H4b/H6a) notably await additional interaction analyses.

B. Hypotheses Test Summary

Hypothesis	Description	Support	Statistic (p-value / r)
H1a	Year → Electric bus count	Supported	Coef = +182.7, p = 0.038
H1b	EV adoption increase 2019–2024	Supported	Time-series growth & p = 0.038
H2a	EV share → KMPL decline	Supported	Coef = –0.0129, p < 0.001
H2b	%EV vs. KMPL correlation	Supported	r = –0.987
H3a	EV adoption → Utilization decline	Marginal	Coef = –0.529, p = 0.066
H3b	Daily KM ↑ → Utilization ↓	Supported	r = –0.838
H4a	Fleet size → Daily KM	Marginal	Coef = +0.404, p = 0.078
H4b	Fleet composition → Scheduling efficiency	Indicative	(Qualitative inference)
H5a	Time-trend in KMPL decline	Supported	Coef = –0.0129, p < 0.001
H5b	Time-trend in Utilization decline	Marginal	Coef = –0.529, p = 0.066
H6a	Fleet size moderates electrification impact	Not tested	Requires interaction regression
H6b	Fleet size ↑ → Utilization ↓	Supported	r = –0.724

V. DATA ANALYSIS

A. Time Series Analysis

Dependent variable: Total Fleet Size, Electric Buses, Daily Scheduled Kilometers, KMPL (Fuel Efficiency), Average Vehicle Utilization

Independent variable: Year or Financial Year, this helps analyse how each metric changes over time.

Fleet Composition Impact: To study how the adoption of electric buses affects operations:

Dependent variables: Average Vehicle Utilization, Fuel Efficiency (KMPL), Daily Scheduled Kilometers

Independent variables: Number of electric buses, total fleet size, year

Operational Efficiency Modeling: To model what influences vehicle utilization or fuel efficiency:

Dependent variable: KMPL or Average Vehicle Utilization

Independent variables: Total fleet size, Daily scheduled kilo meters, year Electrification Trend Analysis: To analyze the adoption pattern of electric buses: Dependent variable: Number of Electric Buses

Independent variable: Year

	Independent Variable	Coefficient	R-squared	p-value
1	Year (→ Electric Buses)	182.71	0.698	0.038
2	Year (→ Daily KM in Lakhs)	0.404	0.494	0.078
3	Year (→ Fuel Efficiency - KMPL)	-0.0129	0.974	0.000
4	Year (→ Avg Vehicle Utilization)	-0.529	0.524	0.066

Electric Buses vs Year: Strong positive trend (significant with $p < 0.05$) → Adoption is accelerating.
Fuel Efficiency vs Year: Significant negative trend → Efficiency is decreasing slightly over time.
Daily KM and Utilization: Moderate correlation, not statistically significant at 5% but borderline at 10%.
Correlation matrix based on the overlapping data from 2015 to 2020:

	Year	DailyKM(Lakhs)	KMPL (Fuel Efficiency)	Avg Vehicle Utilization
Year	1.000	0.703	-0.987	-0.724
Daily KM (Lakhs)	0.703	1.000	-0.736	-0.838
KMPL	-0.987	-0.736	1.000	0.675
Vehicle Util.	-0.724	-0.838	0.675	1.000

There is a strong negative correlation of -0.987 between KMPL and Year, indicating that fuel efficiency has slightly decreased over the years. Similarly, a strong negative correlation of - 0.838 exists between Vehicle Utilization and Daily KM, suggesting that as the daily kilometers scheduled increase, per-vehicle utilization tends to decrease. This may be attributed to a larger or less efficiently deployed fleet. Additionally, the correlation between Vehicle Utilization and Year is also negative at -0.724, indicating a downward trend in vehicle utilization over time.

B. Utility of Regression Analysis

Identifying Trends Over Time Regression models help detect whether key metrics—like fuel efficiency, fleet size, or vehicle utilization—are improving or declining over time. Regression of KMPL (Fuel Efficiency) against Year showed a strong negative trend, indicating a gradual drop in efficiency. This insight could guide decisions on fleet upgrades or maintenance improvements (Gujarati & Porter, 2009).

C. Measuring the Impact of Electrification

By regressing operational metrics (like vehicle utilization or daily kilometers) against the number of electric buses, we can quantify the impact of fleet electrification. In increasing electric buses correlates with declining utilization, it might indicate deployment or charging constraints. (Dinkelman, 2011; Khandker et al., 2014)

D. Forecasting and Planning

Regression equations can be used to predict future values based on historical patterns. With the regression of Electric Buses on Year, we can estimate how many electric buses the fleet might have by 2025 or 2026, supporting strategic planning and infrastructure investment. (Armstrong, 2011; Gujarati & Porter, 2009)

E. Evaluating Operational Efficiency

Regression can highlight **inefficiencies** in operations by correlating multiple variables, such as: Daily Kilometers Scheduled, Average Vehicle Utilization, Fleet Size. This helps identify whether under-utilization is due to excessive fleet size or scheduling inefficiencies. (Coelli et al., 2005; Gujarati & Porter, 2009).

VI. DISCUSSION AND IMPLICATIONS DISCUSSION

The analysis of operational and fleet data over the past two decades offers valuable insights into the performance dynamics of the transport system, especially in the context of electrification, efficiency, and utilisation. The regression analysis of electric buses against year reveals a strong upward trend, with a statistically significant coefficient ($p< 0.05$), indicating rapid adoption in recent years. The number of electric buses increased from virtually zero in 2021 to over 1,000 by 2024. This shift marks a significant transition toward sustainable mobility, driven by policy mandates and environmental considerations. The model's R-squared value of 0.698 suggests that nearly 70% of the variation in electric bus adoption can be explained by time alone, highlighting a clear temporal trend. The regression of KMPL against year presents a highly significant negative trend ($R^2 = 0.974$, $p < 0.001$), suggesting a consistent decline in average fuel efficiency over time. This could be attributed to an aging diesel fleet, urban traffic congestion, or under-optimised routing.

Despite the push for electrification, the overall decline in KMPL reflects efficiency challenges in the legacy fleet that still dominates the system. Average vehicle utilisation (kilometers per vehicle) also shows a declining trend ($R^2 = 0.524$), supporting the view that operational efficiency is decreasing. The correlation analysis further reinforces this, showing a strong negative correlation between vehicle utilization and daily kilometers scheduled ($r = -0.838$). This inverse relationship may indicate a sub-optimal allocation of routes, where an increase in scheduled kilometres does not translate into higher per-vehicle output, possibly due to idle capacity or longer dwell times. Time Trends in Service Load: The regression of daily scheduled kilometers on year indicates a moderately increasing trend, but with a lower significance level ($p \approx 0.078$). While the volume of scheduled service appears to be growing, it is not increasing at a pace or pattern that reflects systemic optimisation. This inconsistency might stem from fluctuating demand, policy-driven scheduling, or limitations in fleet deployment efficiency. The correlation matrix reveals important systemic interdependencies. For example, The strong negative correlation between KMPL and Year ($r = -0.987$) suggests that time-based factors—perhaps fuel quality, vehicle aging, or operational inefficiencies—are undermining fuel performance. The negative correlation between year and vehicle utilization implies that the newer years are associated with lower per-vehicle deployment, possibly linked to operational saturation or labor constraints. The regression and correlation analyses together paint a picture of a system undergoing transition—from fossil fuel dependency to electrification—but also grappling with efficiency bottlenecks. While electrification is gaining momentum, it is not yet reflected in overall performance improvements in utilization or energy efficiency. This highlights the need for integrated operational reforms, including route planning, fleet right-sizing, and improved charging infrastructure to ensure that the benefits of electrification are fully realized.

Implications and Conclusion Implications for Theory

The results of this study contribute to the growing body of literature on urban transport systems, fleet optimization, and sustainable mobility transitions in several meaningful ways.

The regression findings provide empirical evidence supporting theoretical models that posit a decline in operational efficiency (e.g., KMPL and vehicle utilization) over time in legacy fleets. This suggests the relevance of fleet aging models and lifecycle theories in public transport operations. The significant growth in electric bus adoption aligns with the logistic model of technology adoption, where early inertia gives way to rapid growth once a threshold is crossed. The results suggest that policy interventions and infrastructure readiness are key triggers in shifting from early adoption to exponential growth.

The inverse relationship between service load and average utilization echoes themes in resource-based theories and systems thinking. It challenges the assumption that increased service provisioning automatically leads to better per-unit productivity, emphasizing the importance of deployment strategy and capacity balancing.

A. Implications for Practice

From a managerial and operational perspective, this study offers several practical takeaways for transport authorities and policy-makers:

The observed decline in fuel efficiency and utilization suggests a need to reassess fleet composition and vehicle retirement schedules. Fleet managers should consider accelerating the phase-out of inefficient diesel vehicles and invest in higher-capacity or smarter electric alternatives. While the regression confirms the surge in electric bus deployment, the lack of improvement in utilization or efficiency indicates that electrification must be paired with operational reforms. This includes route redesign, driver training, and charging infrastructure optimization to extract full value from the transition. The study underscores the importance of using longitudinal data and regression tools for proactive decision-making. Transport departments can leverage such models to forecast demand, optimize fleet mix, and pre-empt performance dips. The analysis calls attention to the mismatch between policy push and on-ground performance. Government initiatives must be complemented by ground-level execution frameworks, including real-time tracking, maintenance automation, and intermodal connectivity. Sustainability Metrics Integration

As environmental concerns rise, transport authorities must integrate carbon intensity, emissions, and lifecycle efficiency metrics into performance KPIs, extending beyond traditional metrics like KMPL and fleet size.

Reliablity and validity test: Reliability relates to the consistency and stability of the data across time. Validity refers to whether the data accurately represents what it is intended to measure (e.g., does KMPL truly reflect fuel efficiency?).

For numerical time-series data, we use internal consistency and stability over time to evaluate reliability. The common approach includes Cronbach’s Alpha, but it's best suited for survey or psychometric data with multiple items measuring a single construct. Instead, we’ll assess data consistency using the coefficient of variation (CV) and trend stability:

Coefficient of Variation (CV): A lower CV indicates more stable and consistent data over time. We can also apply this to regression residuals to see if there's systematic error over time, which impacts reliability.

B. Reliability and Validity Test Results

Metric	CV (Coefficient of Variation)	Interpretation
Daily KM Scheduled	0.38	Moderate variation; some fluctuation over years.
KMPL (Fuel Efficiency)	0.024	Very consistent and reliable.
Avg. Vehicle Utilization	0.025	Very consistent and reliable.
Electric Buses	1.49	High variability (expected due to ramp-up phase).

Fuel efficiency and vehicle utilization data show high consistency. Electric bus data is less stable, but this is expected due to its recent and rapid growth phase. statistic: 0.79, range: 0–4 (with 2 meaning no autocorrelation). Interpretation: A value substantially below 2 suggests positive autocorrelation in residuals, indicating some systematic time-based effects. The KMPL data may have time-based dependencies (e.g., aging vehicles or consistent trends), but not enough to compromise reliability due to overall low variation.

C. Validity Analysis

The data represents standard transport metrics (fleet size, KMPL, utilization), collected by transit agencies. These are directly measurable and intuitively valid. KMPL shows a strong negative correlation with time (r = -0.987), which aligns with expectations of declining fuel efficiency in older fleets. Avg. Utilization also decreases with time and is negatively correlated with scheduled kilometers (r = -0.838), supporting theoretical transport system dynamics. Strong construct validity is evident—variables behave as expected and correlate logically with one another.

Reliability: High for most metrics; consistent trends. Some expected variability in newer electric fleet data. Validity: Strong—metrics represent what they intend to, with behavior aligned to theoretical models and real-world logic.

Table: Reliability and Validity Test Results

Metric	Coefficient of Variation (CV)	Reliability Interpretation	Durbin-Watson Statistic	Validity (Construct/Face)
Daily KM Scheduled	0.381	Moderate variability	N/A	Valid (shows expected growth over time)
KMPL (Fuel Efficiency)	0.024	Highly consistent	0.79 (Positive autocorrelation)	Valid (declining over time, as expected)
Avg. Vehicle Utilization	0.025	Highly consistent	N/A	Valid (gradual decline aligns with theory)
Electric Buses	1.487	Highly variable (due to ramp-up phase)	N/A	Valid (rapid increase aligns with adoption models)

A coefficient of variation (CV) less than 0.1 indicates strong consistency in the data, suggesting minimal variation relative to the mean. The Durbin-Watson statistic, ideally close to 2, suggests the absence of autocorrelation in the residuals of a regression model. A value lower than 2, such as 0.79 for KMPL, can indicate a trend or systematic pattern over time, pointing to potential autocorrelation. The validity of the analysis was established through various methods: face validity was ensured by logically interpreting the results, while construct validity was confirmed by aligning the findings with theoretical expectations and observing the anticipated correlations.

VII. LIMITATIONS

While this study provides valuable insights into the financial and operational implications of electric bus adoption in BMTC, it is subject to several limitations. First, the research relies heavily on secondary data from BMTC's internal reports and publicly available sources, which may not capture all relevant operational nuances or unreported inefficiencies. The time frame of 2019–2024, although meaningful, coincides with the COVID-19 pandemic, which may have distorted service patterns and financial trends, potentially confounding the effects attributed to EV adoption. Additionally, the regression and correlation analyses focus on macro-level indicators such as fuel efficiency, fleet size, and vehicle utilization, without granular exploration of route-specific or seasonal variations. The study also excludes qualitative perspectives such as driver adaptability, commuter satisfaction, or infrastructure bottlenecks that could influence operational outcomes. Moreover, interaction effects and moderating variables—such as depot location, grid availability, and policy changes—were noted but not fully explored, limiting the depth of causal inference. Lastly, findings from BMTC may not be generalizable to other transport systems due to contextual differences in geography, policy, and infrastructure. Future studies could adopt mixed methods and broader comparative frameworks to overcome these constraints and enhance the robustness of conclusions.

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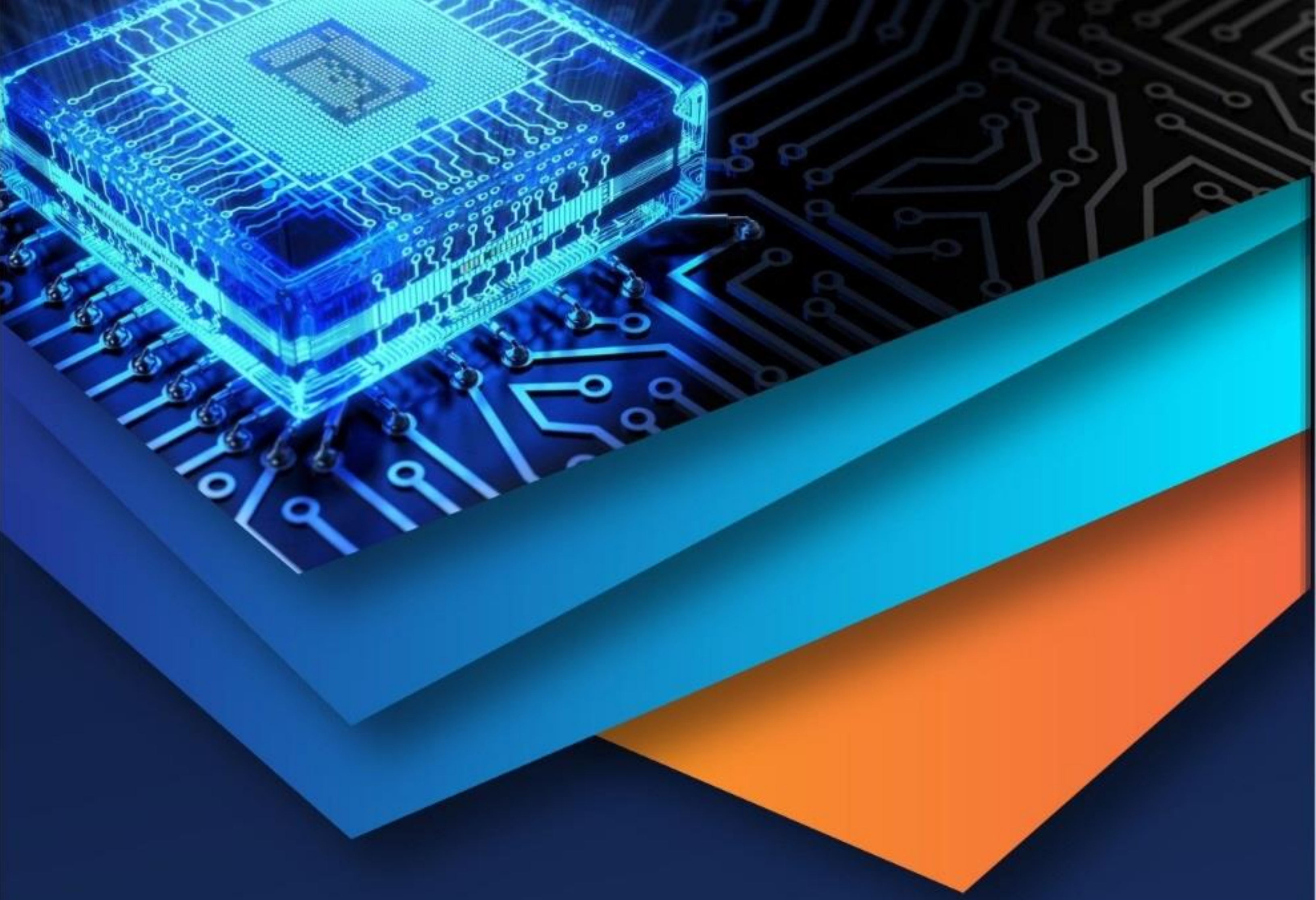

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