TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering

Vol. 68, Issue II, June, 2025

RESEARCH ON THE RELATIONSHIP BETWEEN PASSENGER VOLUME AND THE ENERGY EFFICIENCY OF ELECTRIC BUSES

Alexandru Constantin OPRICA, Ilie DUMITRU, Laurențiu RACILĂ, Augustin CONSTANTINESC

Abstract: *When it comes to public transportation in cities, battery-electric buses offer a practical and adaptable option that may lessen traffic congestion and noise pollution. Plus, they're more compatible with preexisting transportation networks and can run in places without trolleybus service. Also, battery-electric buses are much quieter than hybrid or diesel buses, so they're great for routes that go past parks or other places where noise is a problem. These cars are more cost-effective for public transportation systems in the long run because to their reduced maintenance costs compared to those fuelled by fossil fuels. Using data collected over the course of three weeks, this study examines the relationship between energy use and passenger traffic along a major route in the Craiova municipality.*

Key words: *electric busses, energy consumption, passenger volumes.*

1. INTRODUCTION

Battery-electric buses have the ability to outperform conventional buses in terms of acceleration and noise level [1]. Additionally, they have the potential to completely eliminate emissions. In addition, these systems offer the flexibility to modify routes without any impact on the existing infrastructure, which sets them apart from trolleybuses. Furthermore, they eliminate the requirement for a constant connection to the network [2].

Therefore, battery-electric buses provide a practical and versatile solution for urban areas, resulting in a quieter and cleaner city environment. In addition, they have greater compatibility with existing transportation networks and can operate in areas where trolleybus service is not available. Due to these factors, battery-electric buses are rapidly gaining popularity among environmentally conscious cities worldwide [3, 4].

In addition, battery-electric buses offer a significant advantage over hybrid or diesel buses as they operate much more quietly. This makes them an ideal choice for routes that pass-through parks or other areas with noise limitations. These cars are a more economical choice for public transportation systems in the long term due to their lower maintenance costs compared to vehicles powered by fossil fuels.

Switching to battery-electric buses offers both environmental and financial benefits, contributing to the creation of greener and more sustainable cities [5]. In addition, battery-electric buses have a positive impact on the environment as they do not release dangerous air particles or greenhouse gas emissions [3, 6, 7]. These vehicles contribute to the improvement of city air quality and the reduction of pollution, which has positive implications for people's health [8, 9]. Electric buses offer a promising solution for combating climate change and reducing our dependence on fossil fuels, paving the way for a more environmentally friendly and efficient transportation system in the long run.

2. THEORETICAL CONSIDERATION

It is important to understand that in order to assess the energy saving and emission reduction impacts of battery electric buses using life cycle energy consumption simulation/modelling, one must consider the energy used during operation in real life traffic usage with dynamic flux of passengers [4, 10].

Received: 07.04.25; **Similarities**: 29.05.25: **Reviewed**: 07.04./ 07.04.25: **Accepted**:18.06.25.

Through a comprehensive examination of the bus's entire life cycle, we can precisely assess the positive impact on the environment that comes with the shift to electric vehicles [11]. In order to gain a comprehensive understanding of the emissions reduction impact of electric buses, it is important to consider additional factors such as the source of electricity used for charging the batteries and the materials utilized in the manufacturing process.

In the "Conversion Methods for Energy Consumption of Electric Vehicles" [1] you can find the calculation of the fuel consumption equivalent used throughout the fuel life cycles, specifically in relation to energy consumption.

$$D_{comsumption} = f_c \times f_{energ} \times f_{prod} \qquad (1)$$

where:

- $D_{comsumption}$ is the equivalent diesel consumption in liters/100 km
- f_c is the fuel consumption in kWh/100 km, liters/100 km or m^3/100 km
- f_{energ} is the fuel energy factor
- f_{prod} is the fuel productive efficiency factor

The calculation for the power efficiency factor is as follows [1, 2]:

$$PF_{efic} = \frac{1}{c_{efic}(1 - l_{los})}\left(\frac{\varphi}{s_{efic}} + 1 - \varphi\right) r_{efic} t_{efic} \qquad (2)$$

where:

- PF_{efic} is the power efficiency factor
- c_{efic} is the charge efficiency
- l_{los} is the line loss rate [%]
- φ is the thermal power ratio [%]
- s_{efic} is the power supply efficiency [%]
- r_{efic} is the refining efficiency [%]
- t_{efic} is the transport efficiency [%]

Considering the equation 1 and 2 provided above and the relevant factors, a typical battery electric bus that consumes approximately 114 kWh/100km has an equivalent fuel consumption of 25 litters/100km [2].

3. PUBLIC TRANSPORT LINE ANALYSIS

3.1 Public transport line 9

The 9th line, which stretches for 24.6 km between Station 30 and High-Tech Industry Park, is located in Craiova. In addition, examining the frequency data depicted in the figure below can offer valuable insights into usage patterns and community requirements, thereby aiding in the enhancement of services and infrastructure. Through a careful analysis of this information, organizations can enhance their decision-making process and adapt their strategies to effectively cater to user demands. Therefore, the use of frequency data is essential for maximizing resources and enhancing the overall quality of life across various sectors of society.

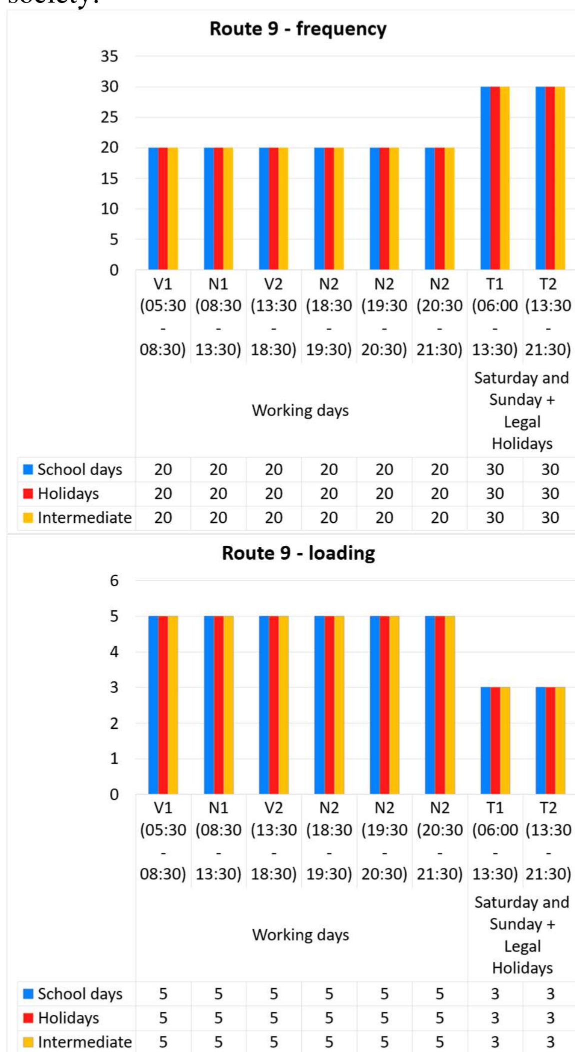

Fig. 1. Time table and frequency for line 9.

Line 9 also links the Craiovița Nouă neighborhood, Centru, and the Metro Area. Below is a table that displays the route and stations utilized by these lines:

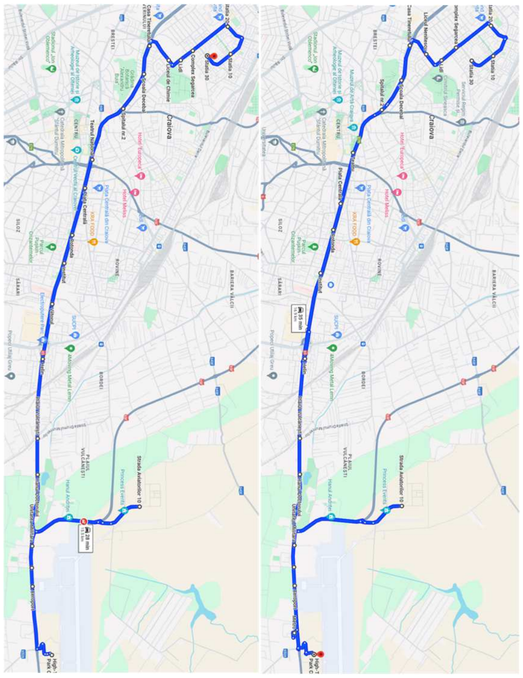

Fig. 2. Line 9 route (tour/retour).

High-Tech Industry Park Craiova S.A., Cal	Statia 30, Craiova
Aeroport, Craiova	Statia 10, Bulevardul Oltenia, Craiova
Blocuri, Craiova	Statia 20, Craiova
Unitatea Militara, Craiova	Complex Segarcea, Craiova
Strada Aviatorilor 10, Craiova 207280	Lidl, Craiova
Hanul Doctorului, Craiova	Liceul Nenitescu, Craiova
Plaiul Vulcănești, Craiova	Casa Tineretului, Craiova
Helin, Craiova	Şcoala Decebal, Bulevardul Nicolae Titul
Viitorul, Craiova	Spitalul nr.2, Craiova
Institut, Calea București, Craiova	Teatru, Craiova
Rotonda, Craiova	Piata Centrala, Craiova
Piața Centrală, Craiova	Rotonda, Craiova
Teatrul Național, Craiova	Institut, Calea București, Craiova
Spitalul nr.2, Craiova	Helin, Craiova
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Lidl, Craiova	Unitatea Militara, Craiova
Complex Segarcea, Craiova	Blocuri, Craiova
Statia 20, Craiova	Aeroport, Craiova
Statia 10, Craiova	Metro
Statia 30, Craiova	High-Tech Industry Park Craiova S.A., Cal

Fig. 3. Line 9 stations (tour/return).

Upon thorough examination of the data obtained from traffic analysis and surveys conducted in 2024 by the University of Craiova – Faculty of Mechanics, along with the insights provided by R.A.T. SRL, we have successfully established the daily passenger volumes for this particular route. Below, you will find graphs that showcase the usage of public transport at various stations, along with the fluctuations in passenger numbers during boarding and alighting.

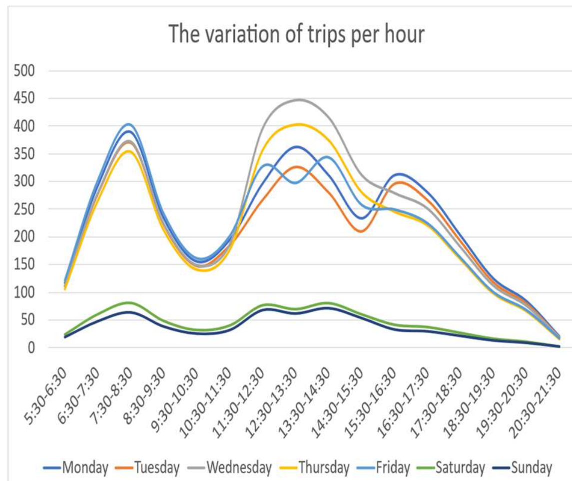


Fig. 4. Fluctuations in passenger numbers throughout the day.

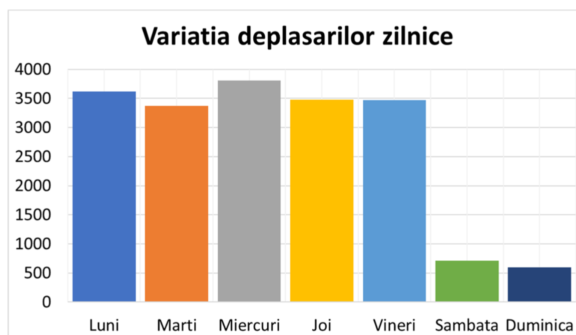


Fig. 5. The variation of movements throughout a day.

Based on the data collected on this route, there are multiple high points in passenger numbers. These peaks of passengers are a result of various reasons, including business travel, school commutes, personal trips, and other activities. During the time frame of 8.30 to 12.30, there is a decrease in the number of passengers due to a reduction in work commutes and student travel, while there is an increase in the number of pensioners and individuals engaged in other activities (figure 4).

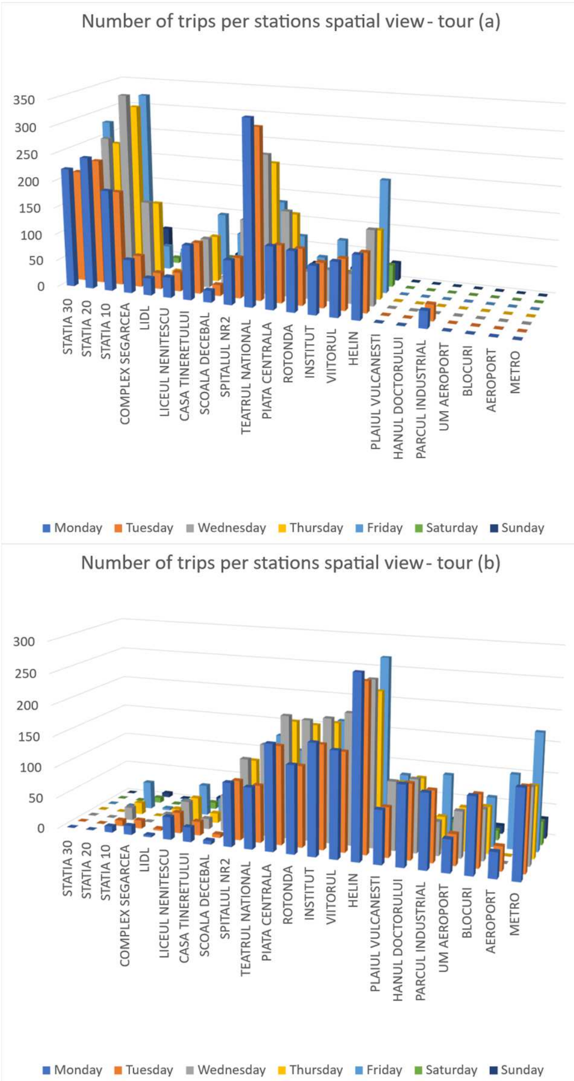
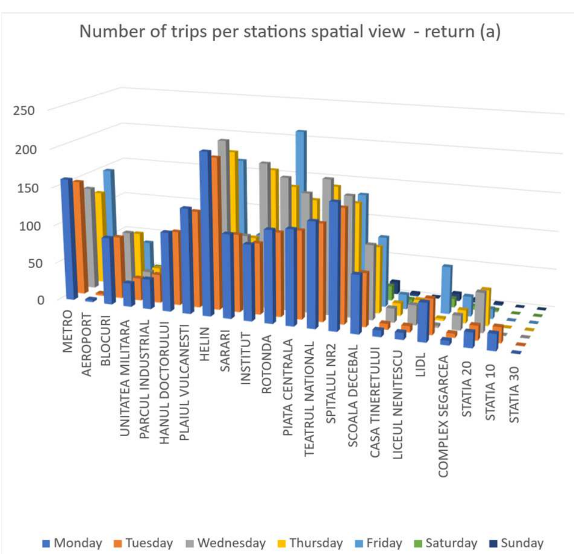


Fig. 6. Variation of displacements throughout a day at stations (tour), a – passengers get-on, b – passengers get-off



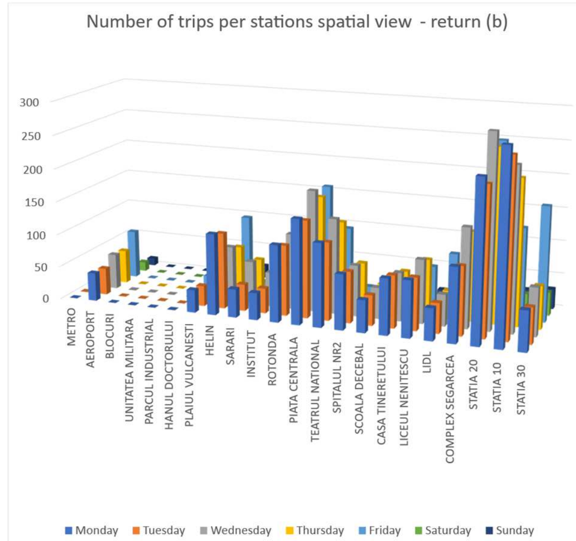


Fig. 7. Variation of displacements throughout a day at stations (return), a – passengers get-on, b – passengers get-off

From 5:30 PM to 9:30 PM, there is a steady decline in the passenger count.

On Wednesdays, there is an approximate maximum of 3800 passengers. On weekends, there tends to be a decrease in the number of travelers, which is primarily influenced by sporadic events such as matches or cultural happenings (figure 5).

Line 9 conveniently connects the Craiovița Noua neighborhood, Centru, and the Metro Area. There is a noticeable difference in passenger density at the stations in the Craiovița Noua neighborhood, Piața Mare, and Spital Nr.2 during the round trip (figure 6 and 7).

3.2 Battery electric buses on line 9

RAT SRL utilizes two types of electric buses.

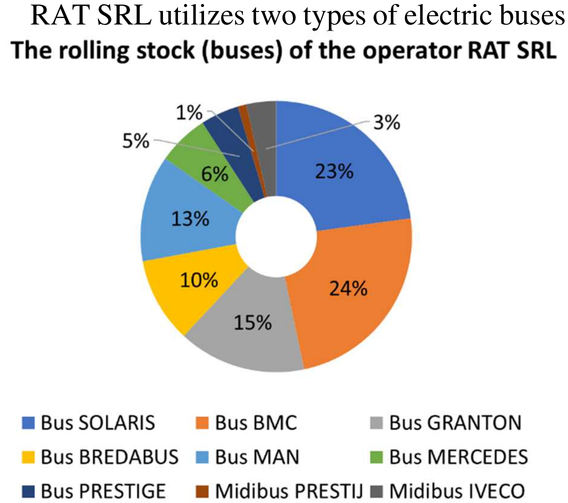


Fig. 8. Rolling stock – RAT SRL

The buses Granton and Solaris, for the routes in Craiova, make up 38% of the total rolling stock (figure 8).

For line 9, the electric buses used are specifically the SOLARIS ones, namely the Urbino 12 (figure 9).

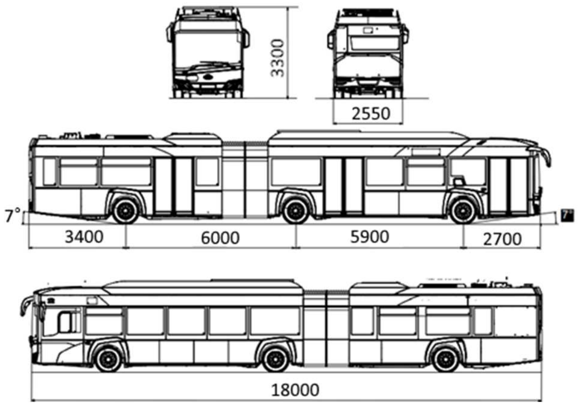


Fig. 9. Bus – Urbino 12.

Figure 10 provides a general overview of the buses technical characteristics operating on line 9.

Tipul motorului	Motor asincron TSA	
Puterea maximă	160/240 kW	
Baterii de tracțiune / capacitatea	Baterie High Energy	160 - 240 kWh
Baterii de tracțiune / capacitatea	Baterie High Energy +	317 - 554 kWh
Baterii de tracțiune / capacitatea	Baterie High Power	87 - 145 kWh

Fig. 10. General characteristics – Urbino 12.

4. RESEARCH RESULTS

Figure 1 displays the composition of bus line 9, operated by RAT SRL. This line boasts a maximum of 5 buses, ensuring a frequency of 20 minutes during peak hours. The buses are marked with the numbers 30, 31, 32, 33, and 40.

These buses play a crucial role in meeting the heightened transportation needs during busy periods and are vital for ensuring smooth and efficient passenger mobility. The frequent 20-minute intervals ensure convenient access to public transportation, minimizing the inconvenience of large crowds and delays. The various bus signs facilitate easy identification and provide clear guidance to passengers, ensuring they reach their intended destination.

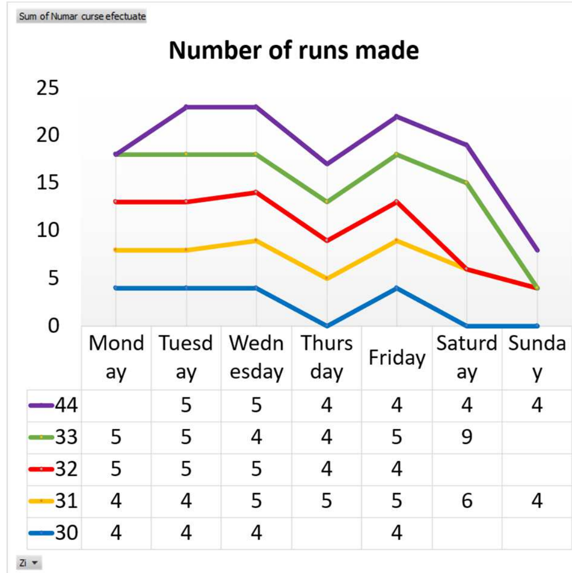


Fig. 11. Number of trips made by each bus.

Figure 11 presents a graph that depicts the weekly number of trips made for the 5 bus codes, spanning from Monday to Sunday.

There is a noticeable weekly pattern in the number of trips made, with a peak occurring in the middle of the week, particularly on Tuesdays and Fridays, and a minimum on Mondays and Sundays. It can be inferred that racing activity reaches its peak during weekdays, particularly in the middle of the week.

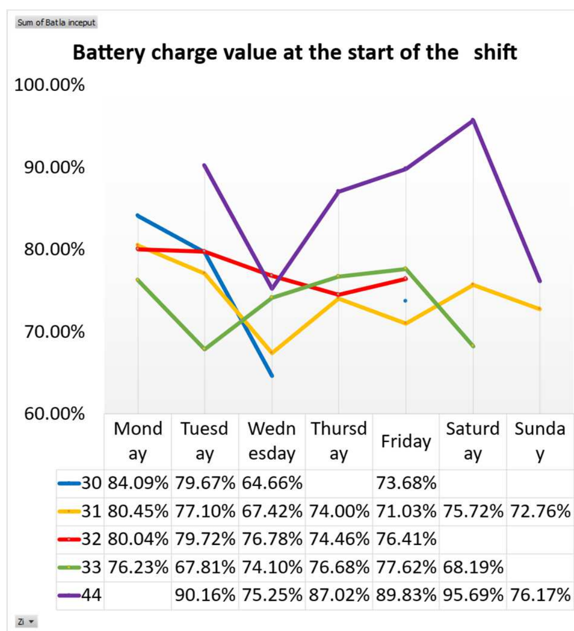
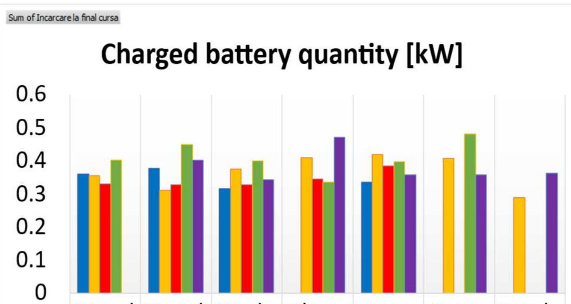


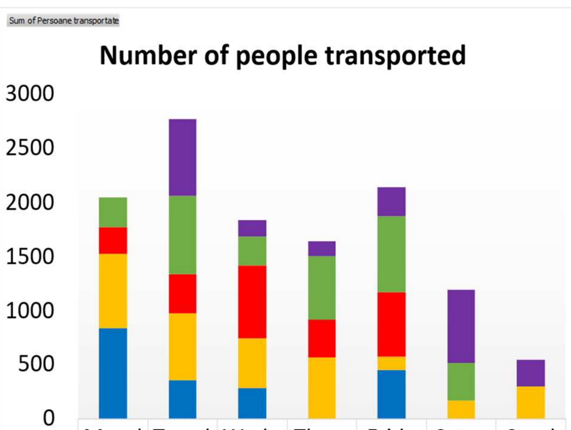
Fig. 12. Battery charge percentage at the start of the day.

The battery charge value at the start of the race (Figure 12) varies throughout the week, with a tendency to rise during the middle days of the week (Tuesday and Wednesday) and reaching significant peaks on Tuesdays and Sundays. Category 44 consistently exhibits the highest charge values, indicating a potentially optimized charging strategy or more conservative battery usage for this bus.



	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
30	0.361	0.377	0.317		0.337		
31	0.355	0.311	0.374	0.41	0.42	0.407	0.288
32	0.33	0.327	0.328	0.345	0.384		
33	0.402	0.448	0.401	0.337	0.396	0.482	
44		0.402	0.343	0.47	0.358	0.357	0.362

Fig. 13. Quantum of energy stored in the battery daily.

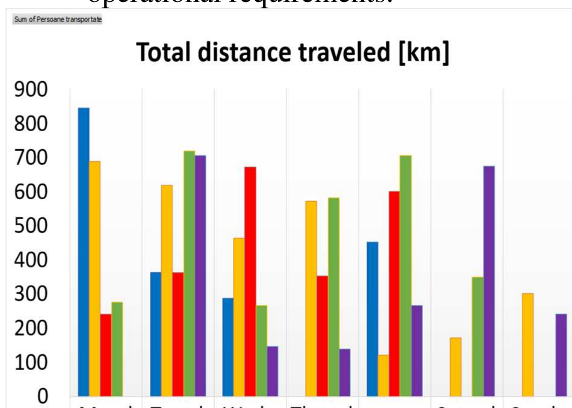


	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
44		706	146	139	266	674	242
33	277	718	267	581	705	349	
32	241	363	672	353	601		
31	688	619	464	571	121	171	302
30	845	363	288		452		

Fig. 14. Number of people transported.

The battery's energy level (Figure 13) varies throughout the week, showing significant spikes on Thursdays and Saturdays. Typically, there is a noticeable increase in values during the weekdays, with a decline occurring on weekends, particularly on Sundays. This pattern highlights two primary directions:

- Each bus requires a unique loading strategy.
- Each bus or transport line has unique operational requirements.



	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
30	845	363	288		452		
31	688	619	464	571	121	171	302
32	241	363	672	353	601		
33	277	718	267	581	705	349	
44		706	146	139	266	674	242

Fig. 15. Number of kilometers traveled by day.

5. CONCLUSION

There is a noticeable trend in the level of activity throughout the week, with higher levels on Tuesday and Friday, and lower levels on Mondays and Sundays.

During days with a greater number of races (specifically Tuesday and Friday), the battery charge tends to be higher at the beginning of the race. This suggests a strategic approach to preparation for busier days.

The battery's energy levels are noticeably higher on Thursdays and Saturdays, indicating a readiness for the upcoming busy days or a replenishment after Wednesdays and Fridays. There seems to be a correlation between lower energy levels on Mondays and Sundays and a decrease in the number of trips.

It can be seen from the graphical results that RAT establish a well-structured routine that optimizes productivity on days filled with numerous tasks, ensuring that energy levels are fully replenished. Conversely, on less demanding days, a more moderate amount of energy is needed.

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CERCETĂRI PRIVIND RELAȚIA DINTRE VOLUMUL DE PASAGERI ȘI EFICIENȚA ENERGETICĂ A AUTOBUZELOR ELECTRICE

Când vine vorba de transportul public în orașe, autobuzele electrice cu baterii oferă o opțiune practică și adaptabilă care poate reduce aglomerația traficului și poluarea fonică. În plus, sunt mai compatibile cu rețelele de transport preexistente și pot circula în locuri fără serviciu de troleibuz. De *asemenea, autobuzele electrice cu baterii sunt mult mai silențioase decât autobuzele hibride sau diesel, așa că sunt excelente pentru rutele care trec pe lângă parcuri sau alte locuri în care zgomotul este o problemă. Aceste mașini sunt mai rentabile pentru sistemele de transport public pe termen lung datorită costurilor reduse de întreținere în comparație cu cele alimentate cu combustibili fosili. Folosind date colectate pe parcursul a trei săptămâni, acest studiu examinează relația dintre consumul de energie și traficul de pasageri de-a lungul unui traseu major din municipiul Craiova.*

Alexandru OPRICA, PhD Student, University of Craiova, Faculty of Mechanics, ATII, 107 Calea Bucuresti street, Craiova, Romania, alex.oprica91@gmail.com, Office Phone: +40 251 543 739

Ilie DUMITRU, PhD Professor, University of Craiova, Faculty of Mechanics, ATII, 107 Calea Bucuresti street, Craiova, Romania, ilie.dumitru@edu.ucv.ro, Office Phone: +40 251 543 739

Laurențiu RACILĂ, PhD Assoc. Professor, University of Craiova, Faculty of Mechanics, MApCC, 107 Calea Bucuresti street, Craiova, Romania, laurentiu.racila@edu.ucv.ro, Office Phone: +40 251 543 739

Augustin CONSTANTINESCU, Lecturer, University of Craiova, Faculty of Mechanics, ATII, 107 Calea Bucuresti street, Craiova, Romania, augustin.constantinescu@edu.ucv.ro, Office Phone: +40 251 543 739