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OPPORTUNITIES FOR REDUCING EMISSIONS AND CONGESTION IN CITIES THROUGH THE USE OF ECO-FRIENDLY MINIBUSES IN PUBLIC TRANSPORTATION*

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Abstract. *The application of modern technologies in combination with logistics centers in the public passenger transportation system can contribute to reducing fuel consumption, preserving the environment, and increasing driving comfort. This work examines the door-to-door passenger transport model as one of the ways for smart traffic management, but also as a means of improving driving comfort, primarily for people with special needs or those requiring constant medical care, etc. Modern technologies include the use of artificial intelligence and machine learning and vehicles powered by alternative fuels in city transport. In the paper, the regional significance of the proposed eMiniBuS project is examined as a first step toward sustainable mobility in the region. The study shows that implementing a door-to-door transportation system with eco-friendly minibuses could reduce the number of passenger vehicles by up to 50% over six years in medium-sized cities, leading to lower* CO_2 *emissions and improved accessibility. The use of natural gas, hydrogen, and electric vehicles, combined with intelligent management systems, significantly enhances energy efficiency and supports sustainability goals.*

Key words: *Emission, Door-to-Door Transportation Model, Smart Cities, Vehicles*

1. INTRODUCTION

The passenger transportation in smart cities is becoming an increasingly important topic as technology evolves and urbanization continues to grow. Inside smart cities, innovations and new technologies are increasingly being used to improve the quality of life for citizens.

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A key part of that process is the passenger transportation (particularly for smaller groups of citizens with special needs). Here are some key aspects [1, 2]:

- Smart Transportation Systems: In smart cities, transportation systems utilize sensors, data analytics, and various applications to optimize traffic flow. This includes smart traffic lights that adjust to real-time conditions and apps that help commuters find the fastest route.
- Electric and Autonomous Vehicles: Many smart cities are adopting electric buses and self-driving vehicles to reduce carbon dioxide (CO_2) emissions and enhance transport efficiency.
- Ride-Sharing Services: Car-, minibus-, bike-, and scooter-sharing services are becoming increasingly popular, allowing citizens to travel without owning a private vehicle. This helps reduce traffic congestion and pollution.
- Integration of Different Modes of Transportation: Smart cities enable the integration of various transportation modes (public transportation, biking, walking, door-to-door model) so that passengers can easily switch from one to another.
- Data and Analytics: By using data collected from various sources, cities can better plan infrastructure, improve transportation services, and adapt to the needs of citizens.
- All these innovations contribute to the creation of more efficient, sustainable, and user-friendly transportation in urban areas, leading to improved quality of life and a reduced environmental impact.

Efficient management of municipal vehicles, particularly garbage trucks and street-cleaning fleets, is essential for the smooth operation of urban environments [3]:

- Telematics: The use of GPS and sensors to monitor vehicle efficiency, fuel consumption, and preventive maintenance.
- Route Optimization: Software solutions that enable the most efficient routes for waste collection or other municipal services, reducing time and costs.
- Automation: The use of autonomous vehicles in specific municipal services can significantly reduce human error and improve overall operational efficiency.
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Smart cities use technology to improve the quality of life for their citizens, reduce congestion, and increase the efficiency of public services. Through innovation and the integration of smart solutions, cities can become more sustainable and more responsive to the needs of their residents [4, 5].

In this way, it contributes to the preservation of the environment by reducing the emission of harmful gases and noise from vehicles. Door-to-door transportation on demand using eco-friendly minibuses can significantly increase the comfort of passengers and persons with special needs [6, 7].

2. METHODOLOGICAL APPROACH

This paper is based on a qualitative and analytical approach, relying on the review and synthesis of relevant scientific literature, statistical data from the European Union vehicle fleet, and case examples from practice. The analysis includes a review of technological trends, environmental impact assessments, and transportation system structures. A model-based evaluation of the door-to-door transport concept was conducted for a mid-sized city with 100,000 registered vehicles, assessing the potential for emission reduction and increased transport efficiency over a multi-year period. The aim is to identify effective strategies and technologies that can contribute to cleaner and more inclusive urban mobility in smart city environments.

2.1. Modern transportation systems in smart cities

Road transport emits one-fifth of the CO_2 emissions in the EU, which accounts for more than two-thirds of the total greenhouse gas emissions in the transportation sector [8].

Urban transport emits the largest share of emissions within the road transport sector. Moreover, by predominantly relying on fossil fuels in urban transport, we are responsible for air pollution in urban environments [9].

On the other hand, the mode of passenger transportation (private and public, individual and mass) can significantly contribute to reducing the negative environmental impact. Priority is given to the use of alternative fuels alongside a parallel reduction in the use of fossil fuels. The primary alternative fuels for propulsion and mobility systems include electricity, hydrogen, and various types of biofuels. Synthetic fuels continue to represent a viable technological option. While some of these technologies demonstrate high efficiency, their implementation costs remain a significant challenge [10].

Another way to reduce emissions in the transport sector is the use of flexible passenger transportation (such as door-to-door or on-demand systems), which enables a reduction in the number of cars and buses in urban areas, aiming to avoid traffic congestion and its negative environmental impact, as shown in Fig. 1. Public urban transport-and public transportation in general-plays a vital role in reducing dependence on fossil fuels. To achieve this, the adoption of alternative propulsion technologies is essential, along with the development of new public transportation subsystems and the enhancement of infrastructure and service quality [8, 11].

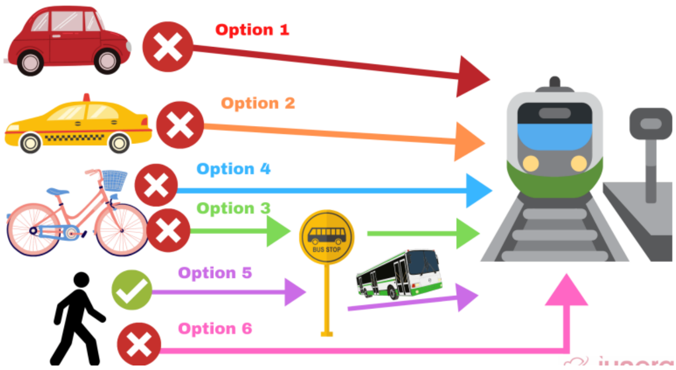

Fig. 1 Options for passenger transportation over longer distances

The introduction of on-demand public transportation—such as door-to-door services—is proposed primarily because of the comfort it offers passengers, which can be comparable to that of private cars. This is especially beneficial for elderly individuals, people with disabilities, and those requiring regular medical treatments. Implementing such systems in urban areas helps reduce the overuse of private vehicles, thereby decreasing traffic congestion and harmful emissions [12].

The nature of mobility has changed over time, as has the way people travel; today, people travel long distances. Motor vehicles have gradually replaced non-motorized vehicles, giving preference to means of transport such as cars [13].

The use of motor vehicles (cars, motorcycles, buses, etc.) has simultaneously required increasing amounts of energy, which mostly comes from burning fossil fuels. For this reason, fossil fuels remain the dominant energy resource in the transport sector today.

At the same time, due to the increasing energy demands in the transportation sector, there is a growing trend toward the application of alternative propulsion systems such as hydrogen-powered vehicles and electric vehicles (with electricity from renewable sources), which reduces the reliance on fossil fuels derived from oil [6].

On the other hand, legal regulations set limits on the allowable emissions of toxic and harmful combustion products from motor vehicles and mandate the use of environmentally "cleaner" fuels.

When it comes to the use of transportation means, people who live and work in rural areas, suburban settlements, and mountainous regions, as well as those working in isolated plants and inaccessible areas far from road networks, are forced to use their own cars, which contributes to congestion, the use of fossil fuels, and air pollution in urban environments.

In general, the reasons why the human population intensively uses cars for urban transport are numerous: inconvenient public transport, residential areas not covered by public transit, inaccessibility (for people with children, the elderly, individuals with disabilities, etc.), inflexibility (breaking routine), the bad habit created by cheap fuel, and the increasing affordability of used (second-hand) vehicles, etc.

Urban traffic and traffic flow have the greatest impact on exhaust emissions and air pollution, especially in narrow streets, city center zones, etc. The characteristics and types of roads also affect the cost of travel, safety, and passenger comfort. Furthermore, significant contributions to reducing exhaust emissions in urban traffic can be achieved through the application of various technologies and methods. Some of these can be very efficient and affordable and do not require additional costs, such as [6, 11, 14]:

- Utilizing alternative fuels-such as biofuels, ethanol, natural gas, and hydrogen or electricity together with other forms of clean propulsion energy and implementing flexible transportation systems that minimize the number of vehicles in urban zones can significantly reduce traffic congestion, fuel consumption, and harmful emissions.
- Optimizing the combustion process in internal combustion (IC) engines, by employing modern equipment and minimizing internal friction and mechanical losses, can significantly reduce fuel consumption and harmful emissions.
- Enhancing vehicle reliability during operation and over their service life necessitates an optimal preventive maintenance strategy. Such a strategy relies on models that integrate planning processes, informed decision-making, spare parts logistics, and the deployment of skilled maintenance personnel.
- Efficient vehicle recycling logistics at the end of their service life are critical. Particular emphasis should be placed on dismantling procedures and the proper extraction of rare materials from electric vehicles, including neodymium and other valuable elements.

If the number of passenger cars in urban traffic were significantly reduced, substantial benefits could be achieved in terms of lowering fuel consumption and protecting the environment, thereby contributing to improved environmental quality and social well-being. The following strategies can support these trends and have already been demonstrated in practice:

- A sharp rise in fuel prices, coupled with constrained supply, has had a notable impact on the market.
- Regulatory penalties are enforced for exceeding legally permitted exhaust emission levels.

Consequently, alternative ecological fuels and modern propulsion systems for buses and other passenger vehicles are playing an increasingly critical role in public transportation.

It is essential to implement transportation systems that provide high-quality services and passenger comfort comparable to private cars while remaining accessible to all users. These optimal transportation systems, which can complement conventional modes of transport, can be deployed in the following ways [15, 16]:

- Modern city buses and minibuses represent effective transport solutions, facilitating the integration of alternative fuels and advanced technologies into public passenger transportation.
- Implementing door-to-door transportation models can bring services closer to users, supported by integrated information and communication systems. Such systems provide real-time passenger information and enable the intelligent and efficient management of the public transport network, as illustrated in Fig. 2.

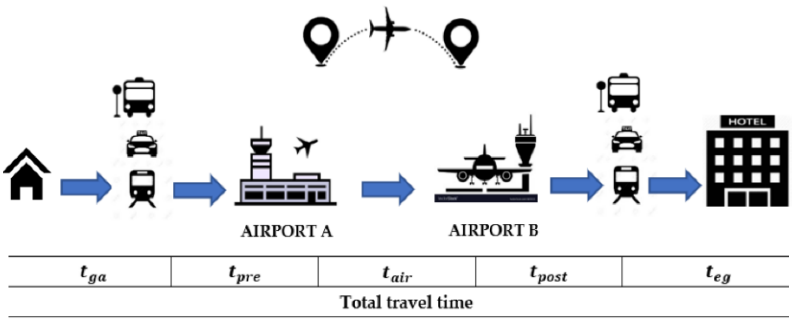

Fig. 2 Door-to-door passenger travel time

A transport system for fast, everyday public passenger transportation over short distances, so-called a "shuttle", represents one way to reduce the number of passenger cars on the streets. This type of transportation has proven to be effective and inexpensive for users, easy to implement, and contributes both directly and indirectly to reducing fuel consumption and emissions.

2.2. Statistical data on the vehicle fleet in the EU

For the year 2023, the EU's vehicle fleet and powertrain types can be characterized by the following data [17, 18]:

- Diesel trucks dominate the EU fleet at 96.4%, gasoline trucks constitute 0.6%, and zero-emission trucks represent only 0.1% of all trucks.
- The EU bus fleet is predominantly diesel (89.2%), with electric and hybrid buses representing 2.5% and 2.2%, respectively. The highest proportions of electric buses are observed in the Netherlands (17.7%), Luxembourg (14.7%), and Ireland (13.5%).

- The EU has an average of 563 passenger cars, 83 commercial vehicles and buses per 1,000 inhabitants.
- In the EU, Italy has the highest car density (694 per 1,000 inhabitants), and Cyprus has the highest density of commercial vehicles and buses (138 per 1,000 inhabitants). Latvia, on the other hand, has the lowest densities for both cars (381) and commercial vehicles and buses (50 per 1,000 inhabitants).
- Nearly 40% of Danish households did not own a car, while 31% of French households had two. The average annual distance traveled in the surveyed countries was 12,346 km.

Statistical data on the number of vehicles in the EU, broken down by vehicle type and powertrain, are presented in Table 1.

Table 1 EU Vehicle Numbers by Type and Powertrain

Category of Motor Vehicles	M1	M2+M3	N1	N2+N3
Gasoline, %	50	0.4	5.9	0.6
Diesel, %	39.5	89.2	90.5	96.4
Electric vehicles, batteries, %	1.8	2.5	1.1	0.1
Plug-in hybrid vehicles, %	2.1	0.5	0.2	0.0
Hybrid powertrain, %	3.2	2.2	0.2	0.1
Natural gas, %	**0.6**	**4.2**	**0.5**	**0.8**
Liquefied petroleum gas (LPG), %	2.6	0.0	0.8	0.1
Total	Passenger cars M1 (**248,824,542**) Buses M2+M3 (**679,802**) Vans N1 (**30,080,656**) Heavy-duty vehicles N2+N3 (**5,998,915**)			

An analysis conducted in May 2025 showed a 25% increase in battery electric vehicles and a 16% increase in hybrid electric vehicles, while plug-in hybrid electric vehicles experienced a 46.9% rise.

By the end of May 2025, registrations of gasoline-powered cars had fallen by 20.2%, with the largest markets experiencing significant declines. France recorded the steepest drop at 34.3%, followed by Germany (-26.1%), Italy (-15.4%), and Spain (-13.3%).

With 1,305,525 newly registered cars, the market share of gasoline-powered vehicles fell to 28.6%, down from 35.6%. The number of diesel-powered cars also declined by 26.6%, resulting in a 9.5% market share in May 2025. Year-on-year analysis indicates a decrease of 18.6% for gasoline and 27.6% for diesel vehicles compared to May 2024.

Modern technologies aim to improve fuel efficiency and reduce harmful exhaust emissions, particularly CO_2, whose levels are regulated by law, with any exceedance subject to penalties.

2.3. Alternative powertrain systems using natural gas

Natural gas as an engine fuel is gaining a growing share of global energy consumption, as evidenced by the presence of over 28 million natural gas vehicles (NGVs) worldwide [19].

Natural gas vehicles are powered by IC engines, and the fuel is stored under pressure either as compressed natural gas (CNG) or liquefied natural gas (LNG). The main advantages of using natural gas as a motor vehicle fuel in road traffic are as follows [20, 21]:

- Due to its low carbon (C) content compared with gasoline or diesel, the combustion of natural gas generates lower amounts of CO_2, nitrogen oxides (NOx), and sulfur, while emissions of particulate matter and smoke are also reduced.
- Natural gas can be utilized in gasoline engines without significant technical modifications, whereas diesel engines require specific conversions.
- The production cost of natural gas is significantly lower than that of gasoline and diesel, and the operating costs of NGV fuel are also reduced, among other advantages.
- The use of biomethane further reduces the amount of harmful substances in combustion products.
- Natural gas exhibits high resistance to knocking, with an octane number of approximately 105.

As an example of a natural gas bus, the MAZ-BIK 203CNG-S, produced in Kragujevac (Fig. 3), can be cited. The use of such buses instead of conventional diesel-powered vehicles can significantly reduce noise and harmful exhaust emissions. From this perspective, the deployment of these buses has been initiated in major cities [6].

Fig. 3 City low-floor CNG bus MAZ-BIK 203CNG-S on GSP Belgrade line 74

This propulsion system can also be implemented in minibuses within the public passenger transport system, following a door-to-door service model.

3. IMPLEMENTING THE DOOR-TO-DOOR TRANSPORTATION MODEL IN SMART CITIES

The door-to-door transportation model for environmentally friendly and cleaner urban transport relies on modern information systems and may comprise several key components [22, 23]:

- Integration of different modes of transport involves combining public transportation, bicycles, walking, and electric vehicles to provide flexibility and easy access to multiple options.
- Travel planning applications involve the development of mobile apps that enable users to plan their journeys across different modes of transport, offering the option to select more environmentally friendly alternatives.
- Bicycle and pedestrian paths involve the construction and enhancement of infrastructure for cyclists and pedestrians, encouraging citizens to adopt these modes of transportation.

- Electric vehicles and car-sharing initiatives involve promoting electric cars and vehicle-sharing services to reduce harmful gas emissions.
- Incentives for public transportation use involve introducing subsidies or affordable fares for public transportation users, encouraging more people to choose it over private cars.
- Education and awareness initiatives involve organizing campaigns to highlight the benefits of environmentally sustainable transport and its positive impact on the environment.
- Green corridors involve the development of dedicated pathways throughout the city for public transportation, bicycles, and pedestrians, thereby reducing congestion and pollution.

The successful implementation of this model requires close collaboration among local authorities, transport companies, and citizens to achieve sustainable urban transport solutions.

The essence of this transportation model comprises main bus lines supported by auxiliary lines, with minibuses transporting passengers to the primary routes. The proposed system is flexible in terms of bus categories, the number of secondary lines, and passenger capacity. Additionally, the system can be adapted for the use of electric or autonomous vehicles, as illustrated in Fig. 4 [24, 25].

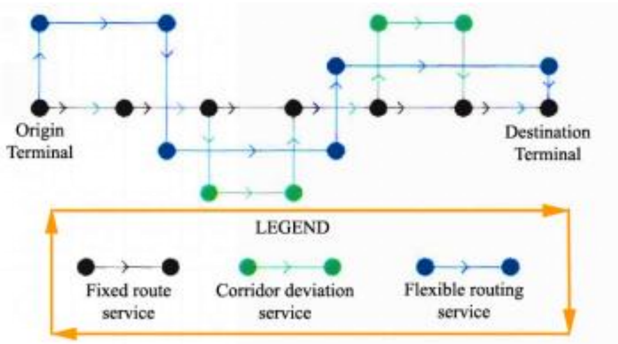

Fig. 4 Flexible routing in a door-to-door transportation system

The primary objective of implementing this transportation system is to alleviate congestion on urban streets, which is expected to directly result in lower fuel consumption and, consequently, a reduction in harmful gas emissions and noise pollution. In a medium-sized city with 100,000 vehicles, a 50% decrease in passenger vehicle usage is projected by the sixth year of the door-to-door transportation system's implementation.

4. PROPOSAL FOR A NEW ELECTRIC MINIBUS VONCEPT (EMINIBUS)

In order to initiate scientific collaboration with industry, foster student team organization, and acquire new knowledge in the field of the automotive industry and vehicle manufacturing, the development of a new electric minibus concept (eMiniBuS) has been proposed.

The proposed phases for the development of this pilot project are as follows:

- Market Research.
- EMiniBuS Design and Development.

- Development of the vehicle prototype.
- Testing of the Vehicle Prototype.
- Vehicle Traffic Logistic Support – Development of Supporting Applications.
- Preparation of Vehicle Technical Documentation and Certification.
- Professional discussions and analyses, based on which a decision regarding the serial production of vehicles and the application of logistics tools should be made.

Based on a preliminary market analysis, as well as the situation in cities regarding the provision of the most comfortable transportation for passengers of various profiles, it has been concluded that a low-floor electric minibus of smaller capacity (6-12 passengers) for on-demand or as-needed transport in urban and suburban areas can be successfully used for the following purposes:

- Transportation services for elderly passengers with reduced mobility and people with special needs.
- Transportation to medical institutions, public service offices, schools, and other locations.
- Transportation services for small groups, including hikers, senior citizens, and sports teams.
- Integrating transport services to connect suburban residents with urban public transit lines.
- Transportation services for pregnant women, new mothers, and mothers with young children.
- A strategy to motivate citizens to use public transportation, helping to reduce street congestion, lower the number of vehicles, and decrease emissions.

Key characteristics and requirements or design solutions of the new minibus concept are shown in Table 2.

Table 2 Key features of the proposed eMiniBus concept

Characteristic	Design solution
Powertrain	Fully electric, equipped with 80-120 kWh batteries, offering a range of at least 200-250 km per charge
Seating capacity	Seating for 8–12 passengers, excluding the driver
Accessibility	Semi-low-floor bus construction with a wheelchair-accessible ramp, suitable doors, a panoramic roof, and other features
Speed	Max. 70 km/h (limits for urban zones)
Battery charging	Fast DC charging up to 80% in 40 minutes
Optional equipment	Cameras, Wi-Fi, A/C system, LCD displays, USB ports
Smart system	Features include GPS vehicle tracking, an app for ride planning and requests, and dynamic route planning/modification
Vehicle dimensions, mm	6.5 × 2.2 m for 8-12 passengers; in a subsequent phase, develop a vehicle measuring 8 × 2.5 m with seating for 31 passengers

Fig. 5 presents the design of the proposed minibus.

In the case of using the eMiniBuS to integrate suburban settlements with the main public transport lines in urban areas, the system would operate as follows: Passengers use a purpose-designed mobile application to request an on-demand ride → using appropriate devices and software, an optimal route connecting multiple passengers is then planned → the minibus picks up passengers based on the “door-to-door” system and transports them to their requested destinations.

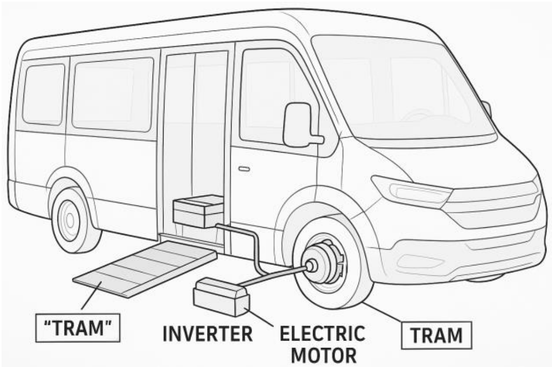

Fig. 5 Concept design of the eMiniBuS with wheelchair-accessible ramp

The proposed passenger transportation system uses suitable algorithms for flexible route planning (similar to Uber Shuttle, Via, Bolt Drive, etc.), thereby reducing the number of trips made by minibuses without passengers and increasing overall efficiency.

4.1. Expected advantages of implementing the eMiniBuS project

Based on preliminary research and analysis of the market for such vehicles, passenger needs, urban environments, and logistics centers in smart cities, the following benefits of this vehicle concept have been identified:

- Environmentally friendly passenger transportation-achieving zero CO_2 and other harmful gas emissions, along with noise reduction. The electricity for battery charging is assumed to come from solar panels or other alternative clean energy sources.
- Inclusive transportation, designed to accommodate passengers with special needs.
- Cost-effective operation, reduced fuel and maintenance expenses throughout the eMiniBuS's service life.
- Smart transportation system, ability to optimize routes and adjust in real time.
- Integration within existing urban public transport systems, rather than competing with them.

5. Conclusions

In smart cities, the implementation of modern technologies is essential, along with the deployment of transportation systems managed using artificial intelligence and machine learning techniques.

The implementation of the door-to-door transportation model using eco-friendly buses is expected to reduce the number of cars on urban streets, thereby lowering fuel consumption, exhaust gas emissions, and noise pollution.

The deployment of minibuses with alternative propulsion systems, powered by natural gas and electricity, also enhances driving ergonomics and facilitates mobility for individuals with special needs.

The electric drive system allows for substantial reductions in fuel and maintenance costs. With zero exhaust emissions, unlike conventional IC engine vehicles, the eMiniBuS is well-suited for urban areas and city centers subject to emission restrictions (Low Emission Zones – LEZ). Beyond its ecological advantages, the proposed vehicle and transportation system enhances public transport accessibility and mobility while alleviating traffic congestion.

The project envisages that the electricity required for vehicle operation will be obtained from renewable sources, and that the process generating this electricity will have no negative environmental impact.

From the perspective of social categories, the implementation of the electric minibus project and the door-to-door transport model is expected to make transportation more accessible for people with special needs. On the other hand, it should encourage greater use of public transport, which would consequently reduce the number of cars on the streets, leading to lower noise levels and reduced emissions of harmful gases.

From a scientific standpoint, within the proposed electric minibus project, the goal is to systematize and integrate innovations and student ideas related to the propulsion system, design, and equipment of the minibus, particularly the equipment used by people with special needs.

The eMiniBuS project also represents an innovative step toward sustainable mobility in the region. By developing and testing this minibus concept and passenger transportation system, the Faculty of Engineering at the University of Kragujevac can establish itself as a regional leader in electric vehicles and smart (remotely operated) transportation systems.

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