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Modular Autonomous Vehicles' Application in Public Transport Networks: Conceptual Analysis on Airport Connection

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Abstract: Increased efficiency and optimized operation of transport networks represent two of the main topics of interest when discussing modern road vehicle solutions. Taking steps towards more sustainable options, manufacturers of road vehicles are looking into advanced technologies that allow vehicles to run more efficiently and take advantage of all the available data on the road. When looking at public transportation applications, trends point in the direction of using varied types of vehicles that can carry people around. The intermodality of these types of vehicles represents the most optimized way of traveling, combining the fast and secure characteristics of airplanes and trains with the flexibility of last-mile options, such as taxis, buses, or trams. This paper discusses the aspects of implementing a modular autonomous vehicle (MAV) solution for the last-mile part of travel routes, connecting key points of a city, such as an airport or a train station, to other key locations in the city, such as the city center, important facilities, or marginal neighborhoods.

Keywords: modular autonomous vehicles; public transport; energy efficiency; airport connection

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1. Introduction

1.1. Background

The rapid pace of technological evolution in recent decades made its mark in various industries, allowing for difficult solutions to become mainstream and easier to implement, leading to discoveries and improvements in all types of domains. As a downside of this worldwide spread of accessible solutions, pollution stands out as one of the most destructive consequences to the environment [1]. All industries that find themselves in a position of harming the environment by polluting, exploiting limited resources, or crowding certain locations are acting to optimize the way they operate and, in the case of pollution, reduce their carbon footprint in the atmosphere.

One of the main players interested in reducing carbon emissions is the transportation industry, the effects of which have been studied for decades. The World Health Organization classifies emissions coming from diesel-powered vehicles as carcinogenic, following studies from 2010 [2] and 2012 [3]. As similar consequences are found for all fossil fuel-powered vehicles, the industry has started to study the alternatives when it comes to powertrain solutions, with battery electric vehicles, fuel cell vehicles, and hydrogen vehicles coming into the picture [4,5]. As optimization is key when talking about reducing the negative effects on the planet, developments of automated systems that allow assisted and autonomous driving offer solutions for reducing operating costs of commercial and passenger vehicles, minimizing energy consumption of all sorts, and offering a safer and more reliable way of transportation.

The benefits of similar automated systems are to be found in domains that use them for a longer period of time, such as aeronautics and railroad industries. Here, human intervention has been reduced or removed completely from controlling airplanes, trains, and subways, resulting in safer exploitation of the equipment, increasing the lifecycle, and reducing operational costs. In the past decade, intelligent vehicles (IVs) have benefited from the development of artificial intelligence (AI) to make use of the available technologies and data in order to bring new applications to the public domain, such as border transport and urban taxis [6].

In the direction of evolving these automated systems, the Society of Automotive Engineers (SAE) defines six specific levels of driving automation that a vehicle can achieve, based on features and functions that it can offer. The first three levels (SAE Level 0–SAE Level 2) imply that the driver is still responsible for all driving duties and the vehicle does not present self-driving capabilities. In these levels, driver support features are present, such as automatic emergency braking (SAE Level 0), adaptive cruise control (SAE Level 1), and adaptive cruise control together with lane centering (SAE Level 2). The next three levels (SAE Level 3–SAE Level 5) describe self-driving vehicles. Driver interventions are expected only for SAE Level 3, as vehicles in this class are intended to serve as traffic jam chauffeurs, while at higher speeds, the automated systems are not fully operational. SAE Level 4 and SAE Level 5 applications represent vehicles that can drive autonomously, e.g., local driverless taxis. The difference between the two levels is that the latter can drive the vehicle under all conditions, whereas the other one can operate safely under limited conditions [7].

Self-driving systems and advanced driver-assistance systems (ADAS) use complete sets of sensors, communication drivers, and information processing algorithms to ensure autonomous transportation from one location to another, ranging from V2I communication drivers, GPS, inertial motion units (IMUs), cameras, LiDAR, and ultrasonic sensors, as T. K. Chan and C. S. Chin highlight in their review [8]. In China, detailed research studies and development programs facilitate clear target points and roadmaps for the industry regarding intelligent and connected vehicles (ICVs), as Q. Xu et al. interpret in their 2022 work [9].

1.2. State of the Art of Autonomous Vehicles

In applications of passenger transportation, such as public transport networks, autonomous vehicles (AVs) of various kinds are starting to make their appearance [10–12], ranging from small shuttles with reduced carrying capacity, such as the units implemented in the Horizon Europe ULTIMO project [13], to full-sized buses, like the specimen presented by CAVForth in Scotland this year [14]. As the need for autonomous vehicles with the sole purpose of transporting passengers exists in various locations, with or without the optimal conditions to operate such vehicles, the more popular solutions that are adopted and implemented for public use are represented by the shuttle buses. Being smaller in dimension and with a limited carrying capacity of up to fifteen persons, applications are often found to be in restrained areas and controlled environments with less traffic, such as campuses, industrial areas, and airports. In 2020, upon a comprehensive review of autonomous shuttle buses as a solution for public transport, C. Iclodean presented the active fleets of autonomous shuttle buses all over the world, summing up to 55 applications [15].

Progressing from the concept of autonomous vehicles, several applications in public transport networks can greatly benefit from the implementation of modular autonomous vehicles (MAVs), similar to other domains that already use such concepts: farming, freight transportation, and warehouses. By combining the power and capacity of multiple autonomous vehicles in shuttle configurations, it is possible to form a train of vehicles that execute the same transportation task and run on the same route until each of the modules breaks apart the connection to the leader and starts performing its own transportation task on a different route. In such a way, a fleet of a limited number of vehicles can cover a larger pool of requests for different routes. Each vehicle can be treated as a module in a connected fleet, which, if managed in a proper manner, can optimize the operation tasks with the purpose of reducing waiting times for the passengers, taking care of all driving-related tasks in order to obtain a safer trip, and using the available energy in the most optimized way possible.

Modular autonomous vehicles represent a current sustainable transport solution that has the potential to revolutionize local public transport networks, especially airport connections. The main advantages of MAVs compared to the classic transport system are energy efficiency, the comfort and safety of the passengers, the reliability of the vehicles, the flexibility of the reconfiguration of the routes and the operating schedule, respectively, and the possibilities of integrating any public people transport network.

Another important aspect resulting from the integration of MAVs into a public passenger transport system is the research and development side for the concept of autonomous driving, especially due to feedback from a large target group of people, which opens up the possibility of operating on mixed routes (airport—closed circuit, urban routes—roads open to public traffic, respectively) and their integration into various IT platforms for ticketing and GPS tracking that serve public people transport needs.

Correlated with European and international legislation regarding the implementation of autonomous vehicles on roads open to public traffic, before testing the operation of an autonomous vehicle in real conditions, it is necessary to carry out simulations on a virtual model of this vehicle, covering real application scenarios in a virtual environment similar to the real environment, highlighting any possible deviations from real scenarios ("The manufacturer of the autonomous vehicle must evaluate the functional safety of the autonomous driving system using a number of test scenarios that include false negative and false positive ones. Simulation method may be used, subject to their validation by the approval authorities/technical services in accordance with the procedure for virtual testing in Directive 2007/46/EC or Regulation 858/2018").

Hence, there is a need to develop virtual models of autonomous MAVs configured based on the real characteristics of the main shuttle bus models spread across Europe: Navya, EasyMile, Auve Tech, 2GetThere, e.Go, etc.

Using advanced scheduling and optimization methods, a carefully developed management system can take into account all types of aspects, from available energy for each module and route requests to traffic jams and other hazardous events. By using intelligent algorithms and accessing data over a large period of time (e.g., one year in order to cover all possibilities of transport requests, crowded seasons, and hazards), an advanced system can predict the necessary capacities and ensure all modules are ready from all perspectives to act accordingly and complete the tasks without or with limited human intervention. Such systems may also track the usage and wear of each module and schedule any mandatory or needed service work and inspections.

1.3. Objective and Contributions

The goals of the research project hOListic Green Airport (OLGA) are increasing the energy efficiency in airport-related activities, on both landside and airside, along with reducing pollutant emissions for persons traveling to and from the airport. Focusing on these goals, our team proposes a mobility-as-a-service (MaaS) solution, which provides efficient and easy-to-use travel from the aircraft to key locations inside the city or residential areas. This uses the existing infrastructure of passenger transport on the landside and airside of the International Airport of Cluj-Napoca to bring persons to their accommodation or points of interest (e.g., venues, central squares, office buildings, or technology and industrial parks).

The correlation between aircraft arrivals at the airport and public transport departures from the airport into the urban area is calculated based on the total number of incoming passengers into the terminal, arrival times, which are changing dynamically, and public transport requests. As the majority of the total number of passengers choose to use public transportation, fleet resources are allocated in accordance with travel demand. Our proposal of using modular vehicles comes in support of this dynamic resource allocation strategy, allowing an optimized assignment of transport tasks and keeping the overall energy consumption of the fleet to a minimum.

A comparison to the existing transportation solution (i.e., battery electric buses) is performed in order to identify the advantages of the MAV solution in an already existing scenario. The first physical implementation target of our proposed system is to run modular autonomous vehicles during the nighttime, ensuring safe travel, optimal waiting times for passengers, and reduced operational costs of the equipment.

To analyze the benefits of implementing an MAV fleet in an existing public transport network, a specific case is taken into consideration: the public transport routes from the city of Cluj-Napoca, Romania, linking key locations of the city to the "Avram Iancu" Cluj International Airport. These locations represent extremities of the urban area, such as the southern end of the city and the western end, which is located in the opposite direction to the airport, located in the eastern part of Cluj-Napoca, as well as a high-interest area: the bus terminal. These specific routes are picked due to their demand and capability to serve as a vital component of the intermodality concept, having the role of last-mile personal transport. In this idea, a person coming into the city via airplane or train (considering the train stop near the airport terminal) can use public transport to reach their destination, whether that be a bus terminal that connects the metropolitan area or other small cities nearby or an accommodation in one of the main neighborhoods of the city. This proposed solution may be put into use in a nonstop operating schedule or only at night when the conventional public transport routes are limited to just a small number. The second option also benefits the limitations of autonomous systems of SAE Level 4, which thrive in a less crowded environment with controlled routes.

2. Current Solution

The requests for transport tasks and covering of the routes are directly linked to the population, people flow through the airport, key places in the city, events (e.g., concerts, summits, cultural or sports events, manifestations, meetings), and more. As an overview of the situation, Table 1 presents some of the relevant factors defining the needs taken into consideration when developing a public transport network.

Table 1. Public transport network overview [16].

Parameter	Value
Population	286.598
Number of travelers using public transport (annually)	76.918
Number of available routes	55
Number of bus stops	305
Number of available buses	246

Looking at the current solution that is implemented in the public transport network, the linkage between the bus terminal, which is located north of the city center, is served by a combination of two bus routes during the day, which continue further to other parts of the city, as presented in Figure 1. The routes linking the airport to the bus terminal are marked in purple and pink on the city map.

However, during the nighttime, these routes are limited and connections from the airport to the bus terminal are made with full-sized buses, which often travel more than half-empty through their entire route. In this application, energy consumption is compromised in order to honor regular routes.

Figure 1 presents the current planned route linking the airport to the most western part of the city, passing through the city center and multiple neighborhoods. This is composed by combining the connection from the airport to the city center (marked in purple), together with the illustrated bus line marked in red.

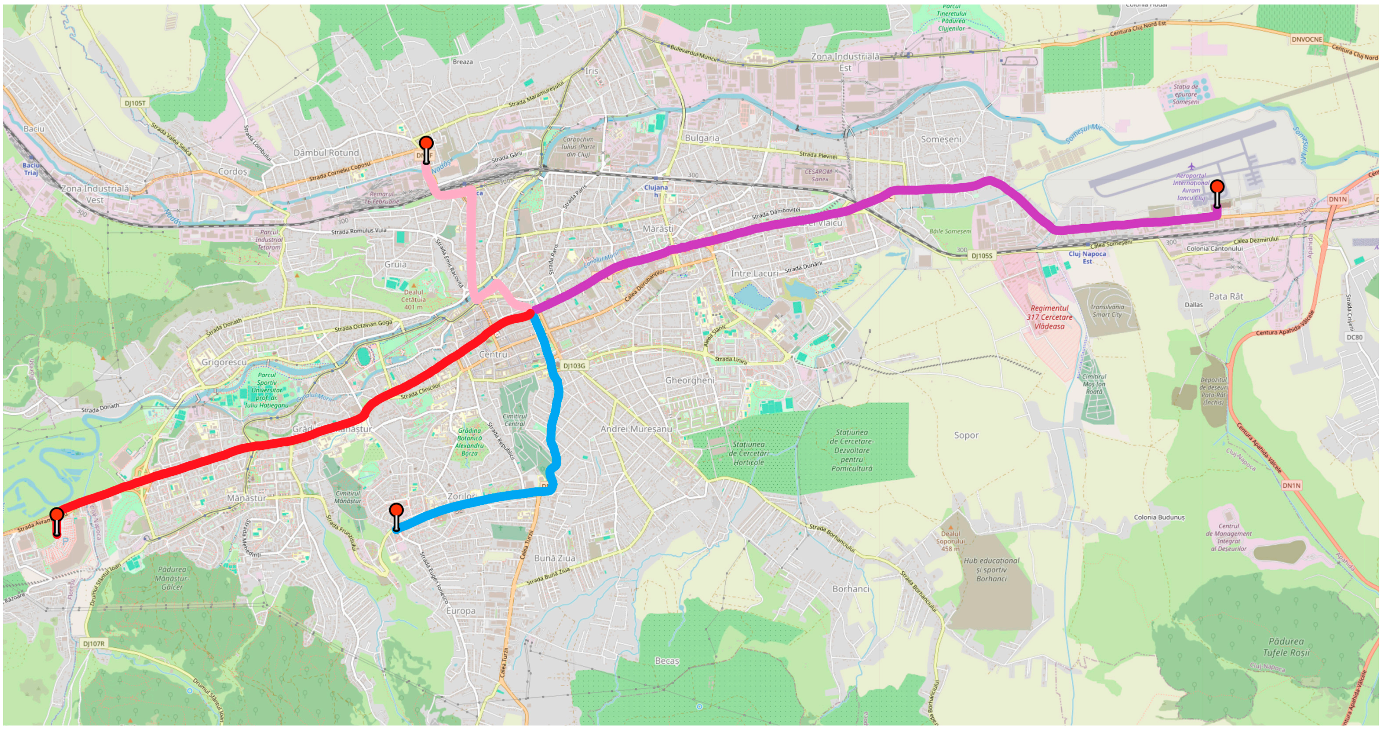

Figure 1. Public transport routes from the airport to Cluj-Napoca city center (purple), bus terminal (pink), southern area (blue), and western area (red) of the city.

While still going halfway through the city center, the routes connecting the airport to the southern neighborhoods steer away from the most crowded areas and experience smaller requests than those that head west, where a nearby locality with 52.735 inhabitants lies. Although the route through the southern area of the city leads to important objectives in the metropolitan area, such as industrial parks (Turda, Câmpia Turzii), the public transport routes do not reach those locations, as they are further than 30 km from the city. This route is presented in Figure 1, marked in blue.

Studying the available data leads to the conclusion that not all routes are optimized in a meaningful way, often having the same outcome: buses travel more than half empty to the end of the line in order to satisfy a reduced request from travelers. With the scope of reducing the time buses are riding at less than 50% capacity, a feasible solution that allows modification of the configuration of the vehicles is to be studied. The main application that can satisfy these criteria is the implementation of modular vehicles along all specified routes.

3. Materials and Methods—MAV Solution

The present chapter is split into two subsections—firstly, the simulation scenario is defined, containing the digitization of driving routes, and secondly, the simulation subjects are modeled (i.e., electric buses and autonomous modules).

3.1. Definition and Digitization of Travel Routes

In order to present the modular autonomous vehicles' implementation in a more accessible approach, the routes of the existing public transport network presented in the previous chapter are broken down into relevant segments, which correspond to parts of the course on which the modules (i.e., individual autonomous shuttles) are riding together, connected to one another, and parts that are covered by one or more vehicles, disconnected from the main train of vehicles.

For this scenario, three separate classes are considered:

- ABT—modules that ride from the airport to the bus terminal, in the northern vicinity of the city center;

- ASC—modules that ride from the airport to the southern area of the city, passing through some of the main neighborhoods;
- AWC—modules that ride from the airport to the western area of the city, passing through different main neighborhoods than the ones ASC is passing through.

By picking only these three routes, the majority of main neighborhoods, which are the oldest, most developed, and most populated ones, are covered in one way or another. This does not mean that the presented connections satisfy all the transport requests in these locations, as there is a large area to cover, making it virtually impossible to accomplish using only three routes.

As the airport is situated in this case on the outside of the city, near the Eastern border of the urban area, the marked route in Figure 2 shows the starting point for all routes, which is the International Airport bus terminal (marked as "Airport").

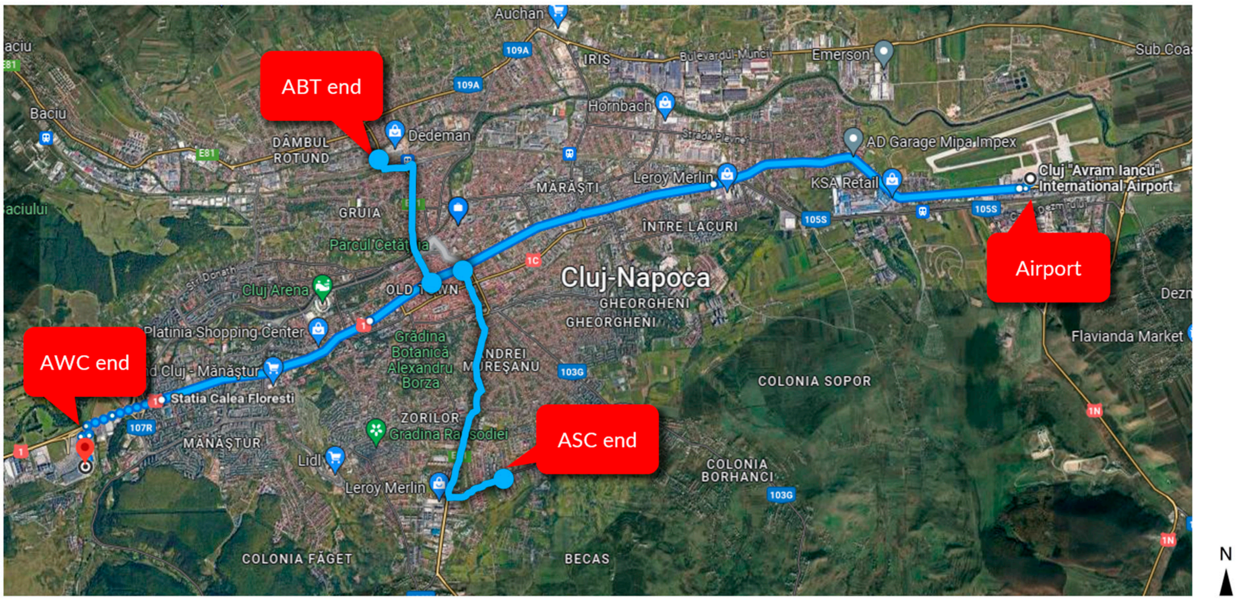

Figure 2. Planned routes for MAV solution simulation.

The ends of each line or route are highlighted in the same figure as follows:

- ABT end—end of the line for the route from the airport to the bus terminal;
- ASC end—end of the line for the route from the airport to the southern area of Cluj;
- AWC end—end of the line for the route from the airport to the western area of Cluj.

The above-mentioned modules are considered to be designed in such a fashion that they are allowed to physically connect to each other and form a train of vehicles, with the modules that detach last from the formation leading the pack. Note that each designated module, like AWC, ASC, or ABT, is presented as a singular unit here for simplification. Depending on the circumstances, the module might be formed by multiple units, leading to an increased capacity for each individual route. Figure 3 illustrates the vehicle train order, as the modules ride together until one of them needs to detach and follow their own designated route.

Along the route, there are so-called "detaching points", where modules disconnect from the pack and start operating on their own. These locations might differ over time depending on various hazards, events, traffic jams, or restrictions and are not necessarily the same as "attaching points", which are to be considered the locations on the map where these modules come back together and form a pack traveling to the International Airport bus terminal. It is not mandatory that the same modules must pair on the return routes, as the segments that they cover are not the same length or do not have the same duration of travel. In addition, on the return route, there might be fewer restrictions or lower passenger capacity, leading to suboptimal operation of the fleet if the total capacity of the module train is similar to the cases of conventional buses—less than 50%.

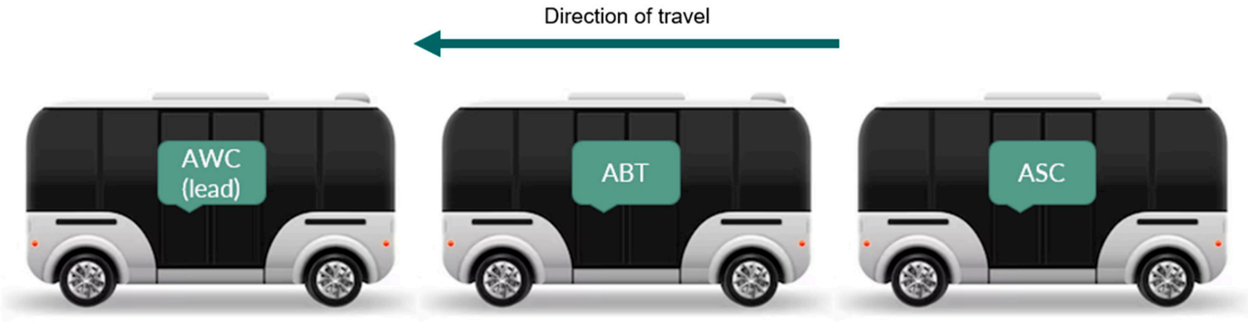

Figure 3. Illustration of a road train of vehicles.

Detaching points are noted on the map shown in Figure 4 as “ABT out” and “ASC out”. There is no “AWC out” point in this case, as the AWC module is leading the formation and continues its journey to the end of the line—AWC end.

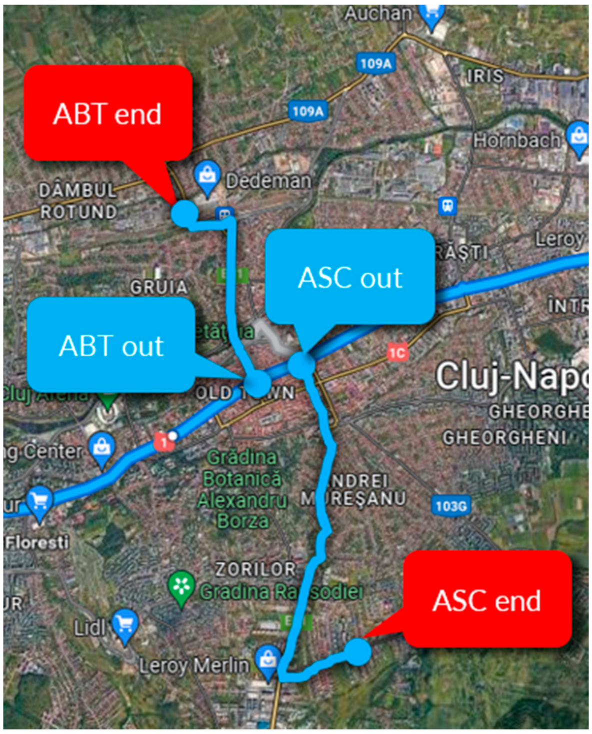

Figure 4. Detaching points for each module.

The order of attaching and detaching of the train module, for exemplification purposes, considers the AWC component as a leading module. Table 2 shows the progress of each module while covering their respective routes and fully executing each task.

Table 2. MAV train configuration along the routes.

Start End	A [1] ASC Out	ASC Out ABT Out	ASC Out ASC End	ABT Out AWC End	ABT Out ABT End
AWC	L [2]	L		L	
ABT					L
ASC			L		

[1] airport; [2] MAV train leader; train configurations are highlighted in grey color.

To expand on the concept definition and obtain data for studying the differences between the conventional way of transportation and the MAV solution, IPG CarMaker is used to model and simulate the public transportation tasks that need to be executed in order to cover the specified routes.

IPG CarMaker 12.0.1 is a simulation software developed by IPG Automotive GmbH, which is used in the industry as a support application for developing and testing automobiles and light-duty vehicles. Throughout the catalog, some solutions offered by IPG fit with this paper's direction of analysis—autonomous vehicles. Being an open platform, it can be integrated into other software, leading to complex data acquisition and processing, as well as advanced modeling of vehicles, traffic characteristics, and driving courses.

Based on available market solutions such as EasyMile EZ10 or Navya Arma autonomous shuttle buses, a module is defined in CarMaker as an AV with a maximum capacity of 900 kg (approximately twelve people). Road trains containing more modular vehicles are then defined by putting modules together. Defining parameters of the modules are added up to obtain the specification list of the train, holding two or four modules together.

By acquiring relevant information (distance, trajectories, elevation, etc.) from Google Earth and Google Maps in GPX (GPS Exchange Format) and KML (Keyhole Markup Language) files of the routes linking the city with the airport, accurate representations of the courses can be loaded into the CarMaker software. The defined routes are accurate representations of the existing public transport routes in the city, as described in the second chapter, having the starting point as the International Airport bus terminal, leading to the city center. From the city center, one route is continuing its course to the western area of Cluj-Napoca, whereas the other one is linking the city center to the city bus terminal. Along the routes, the vehicles drive entirely on public roads with unrestricted access and the same speed limit: 50 km/h for all vehicles, except heavy-duty vehicles, which have a speed limit of 30 km/h. At intersections, their speed limit is 30 km/h. All bus stops are placed on the right-hand side of the road, on the first lane, with some having pull-in space. A small portion of 1.9 km contains a dedicated lane for which the bus stops are placed inside the lane with no pull-in space. The dedicated lane is accessible for public transport vehicles, taxis, and cyclists.

On the above-mentioned courses, specific maneuvers are defined in the application (e.g., driving on the first lane, not cutting corners), as well as driving behavior regarding speed regulation and accelerations (e.g., rapid acceleration until reaching the velocity thresholds, tolerances around the target traveling speed). Using these details, transport solutions can be configured precisely to fit the needs of individual routes.

3.2. Definition and Modeling of Vehicles

This subsection shows the modeling of the two presented solutions: conventional electric buses and modular autonomous vehicles. From the modeling perspective, the electric bus is defined to be approximately the same weight and capacity as a road train containing four separate modules. Table 3 shows the specifications of the bus model parameters, based on the Solaris Urbino 9 LE electric bus [17,18].

Table 3. Electric bus model parameters.

Parameter	Value
Body Mass	11.098 [kg]
Maximum Mechanical Power	160 [kW]
Maximum Torque	1.400 [Nm]
Battery Capacity	124 [kWh]
Idle Voltage	600 [V]
Passenger Capacity	50
Load (front/center/rear)	1.200/1.200/1.200 [kg]

By considering a passenger capacity of twelve for one autonomous module, in order to match the electric bus capacity, four modules are coupled together at the beginning of the simulation until the first detaching point along the route. MAV solution modeling implies the parametrization of one module in IPG CarMaker and then expands the specifications to match an entire road train of four vehicles. In Table 4, modeling parameters for one autonomous module are listed based on specifications of autonomous shuttle buses, such as Navya Arma and EasyMile EZ10.

Table 4. Autonomous module model parameters.

Parameter	Value
Body Mass	2.130 [kg]
Maximum Mechanical Power	16 [kW]
Maximum Torque	41.25 [Nm]
Battery Capacity	10 [kWh]
Idle Voltage	48 [V]
Passenger Capacity	12
Load (front/center/rear)	300/300/300 [kg]

From the above specifications, it results that, for a total passenger capacity similar to that of a Solaris Urbino 9 LE electric, a combination of four autonomous modules with a total weight load of 3.600 kg is modeled based on the parameters in Table 5.

Table 5. Road train of four autonomous modules' model parameters.

Parameter	Value
Total Body Mass	8.520 [kg]
Total Maximum Mechanical Power	64 [kW]
Total Maximum Torque	165 [Nm]
Total Battery Capacity	10 [kWh]
Idle Voltage	48 [V]
Passenger Capacity	48
Total Load (leader, follower #1, #2, #3)	900/900/900/900 [kg]

For each of the two solutions, simulations are made on each defined segment of the road, with an equally distributed passenger load of 900 kg per module (front, center, and rear of each module) at the start of the simulation scenarios. By following the algorithm of pairing and unpairing the modules defined in Table 2, passenger loads, total body mass, and powertrain-specific parameters are altered on each disconnection of modules, simulating people boarding and exiting the vehicle and modules detaching from the main road train and forming smaller couples of autonomous modules to execute their specific transport task. Traffic characteristics are not considered, only road-specific variables, such as elevation changes and curves. The maximum traveling velocity is set to 30 km/h, while the driving behavior of the electric bus driver and self-driving systems is set to neutral—keeping a safe distance, using less aggressive acceleration and braking profiles, steering lightly, not cutting corners, and keeping in the designated traveling lane (first lane) all the time. The goal of the simulated trip is to be as safe, cautious, and comfortable as possible.

4. Results

The considered routes cover a distance of 14.2 km from the International Airport to the most western area of Cluj-Napoca and another of 10.5 km from the International Airport to the bus terminal. By applying the same concept on different routes, which may present even longer dedicated bus lanes and common road sectors, the impact of MAVs on energy efficiency increases. When traffic conditions are also taken into account, traveling in dedicated lanes improves the overall energy consumption and efficiency of the vehicles, reducing standing times and additional braking–accelerating actions while navigating through traffic. In the studied case, all dedicated lanes are also prioritized through the city center, allowing an easy flow of public transportation in and out of the most central area of the city. The traffic lights are synchronized in such a way that the vehicles in dedicated lanes are not held in traffic and go through intersections when there are no other vehicles driving through them. This significantly reduces the waiting times of passengers at bus stops and improves the overall consumption of resources of the vehicles.

To better understand the overall configuration of the analyzed public transport routes, common road sectors, dedicated bus lanes, and the total length of the routes are described in Figure 5.

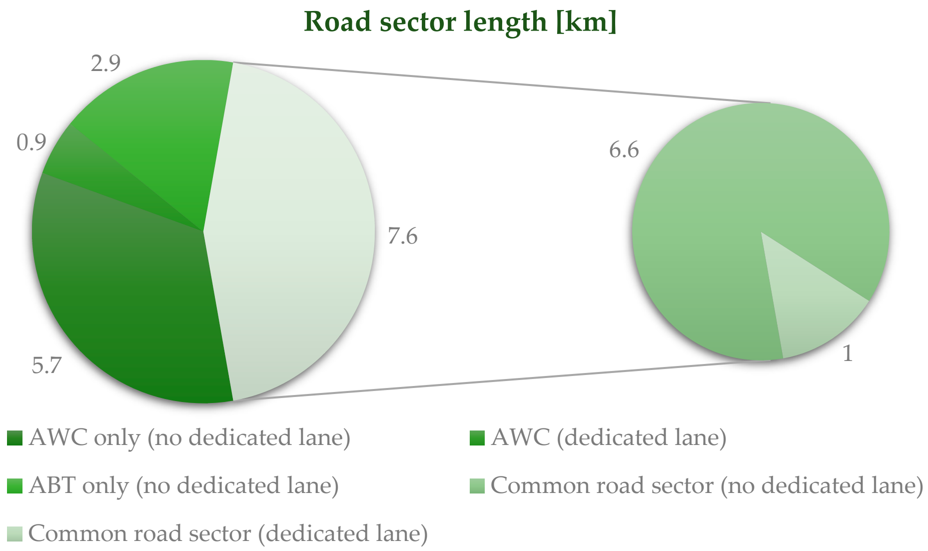

Figure 5. Road sector distribution.

Using the conventional solution simulation results as the benchmark, the outcome of the modular autonomous vehicle simulations shows significant improvement in overall battery management efficiency. As multiple electric buses are needed in order to cover multiple routes within the urban area, the cumulative energy consumption of those buses exceeds the total consumption of all the modules used in the MAV setup. Even though the electric buses are not riding at full passenger loading capacity, the energy consumption differences between a half-empty bus and a fully loaded bus do not match the energy consumption of a road vehicle train. Starting from 85% state of charge (SoC) for both test cases, Figure 6 shows a comparison between the final state of charge of the vehicles after transportation task execution for the buses (conventional solution) and MAVs (proposed solution).

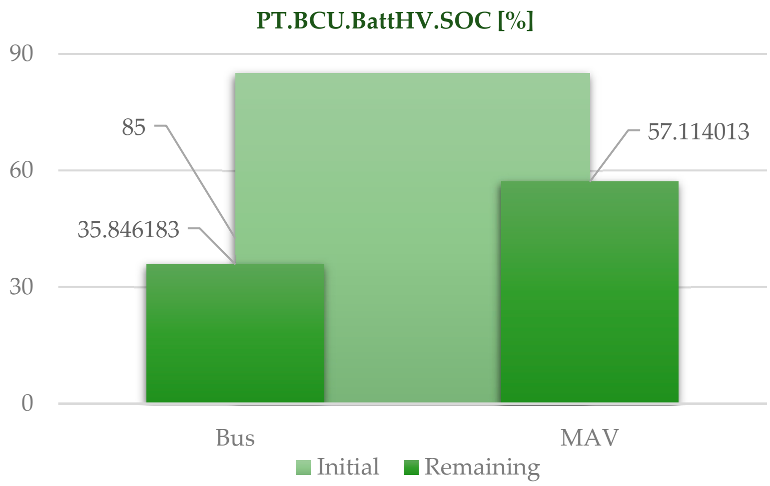

Figure 6. State of charge comparison.

The results point to a significant improvement in the remaining state of charge, measuring 59% more energy stored in the MAV battery pack while carrying the same number of passengers in the same road conditions. Evaluating the absolute energy consumption, the two electric buses that are needed to cover the two routes are 40.67% less efficient than the modular system configuration, as shown in Figure 7.

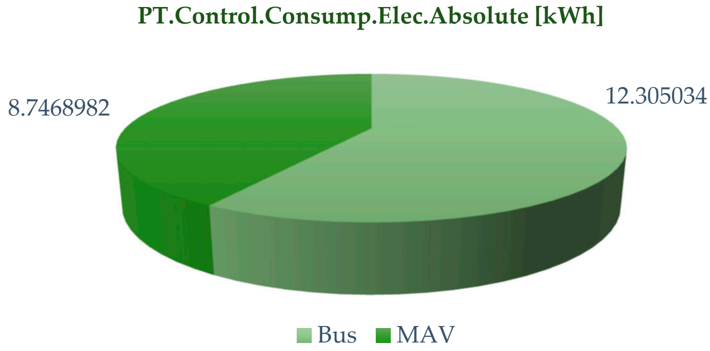

Figure 7. Absolute energy consumption comparison.

By considering the passenger loads of the two compared solutions, fifty people for the electric bus and forty-eight people for the modular setup, the total absolute energy consumption is translated per passenger, as illustrated in Figure 8.

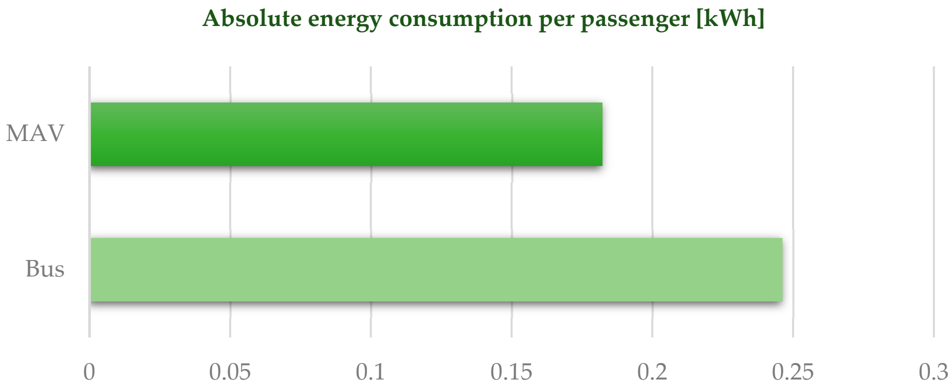

Figure 8. Absolute energy consumption per passenger comparison.

These evaluation criteria on electrical energy consumption confirm even further the advantages of energy efficiency of a modular autonomous vehicle configuration for two or more distinct routes through the city with common sectors along the course.

5. Discussion

As a first step in tackling the issue of public transport network optimization and the implementation of green solutions that lead to more sustainable transportation in the future, the electrification of bus fleets is the way to go. Even though the costs of starting and maintaining such applications are high, local pollution is demonstrated to be reduced in the case of the same city, Cluj-Napoca, by 668.45 tons of CO_2 and 5.618 tons of NO_x each year [19].

Moving forward within this trend and following the latest and most advanced solutions on the market, the autonomous shuttles, especially in a modified form of modular autonomous vehicles, show a feasible solution for an existing network in an old city with narrow streets and existing infrastructure that presents limited possibilities of expanding and highly expensive options to repurpose urban areas and streets.

As autonomous vehicle trends are expanding, even more manufacturers, researchers, and officials turn their attention to this domain. A legal framework, although sometimes not existing or existing in a very limited form, is starting to show recognition, understand the necessity of such applications, and move forward with creating laws, regulations, and specifications that allow others to research and develop with the scope of obtaining safer, more cost-efficient, and optimized road networks [20].

Investigation from A. Ansariyar and M. Tahmasebi concluded that connected and autonomous vehicles reduce delay times in urban traffic by dynamically changing the traveling routes, directly impacting the congestion rates and urban traffic quality. As the market penetration rate (MPR) of connected vehicles (CVs) rises, the delay times are improved significantly, especially when passing the 50 percent mark [21].

Considering the concept of MAVs implemented in an existing transport network, for the case study of the city of Cluj-Napoca, Romania, there are clear advantages that suggest an implementation of such sort will lead to an optimal system that allows a reduction in the wear of equipment, operational costs, and energy consumption and an improvement in the overall efficiency of the public transport network while maintaining or reducing waiting times for the passengers and providing a safer environment for inhabitants of the city.

By evaluating aspects of energy consumption and the overall efficiency of the fleet in scenarios with multiple transport routes, the key benefit point of modular vehicles is represented by the ability to share and restructure equipment resources based on travel demand. Although driving on the same path with a similar weight load, the energy consumption on a conceptual level is similar to a battery electric bus. When referring to multiple routes, the main advantage of MAVs is that they directly influence the overall energy consumption of the fleet, as illustrated in the above simulation results. The use of language models for route optimization may highly impact MAV solutions and ICVs as a whole, starting from studies in urban route optimization, as Y. Liu et al. reported in 2023 [22].

The disadvantages of this kind of application are the same worldwide: there are clear concerns about the safety and reliability of the systems when interacting with populated areas, and there is no clear legal framework to be put in place at the moment, as these solutions are starting to operate in limited areas. As time advances and solutions become safer, more dependable, and more adaptive, there is a certainty that an increasing number of cities, industrial areas, and university and sports campuses will benefit from the advantages of MAVs' integration into existing solutions.

In a broader context, solutions such as the one presented in this paper may greatly benefit from the implementation of artificial neural networks (ANNs) in various applications. As W. Zhu et al. found when they studied the dynamic prediction of traffic incidents, deep learning algorithms prove to add value to ICV applications, providing accurate and quick information on incident duration for operators of transport equipment and vehicles, as well as for travelers [23]. Machine learning applications prove to be beneficial for traffic flow predictions, traffic management, and data generation, leading to a better-trained decision-making algorithm, ultimately increasing the comfort, safety, and user-friendliness of automated and intelligent transport systems, as X. Qu et al. envisioned in 2023 [24].

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