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AUTONOMY OF URBAN LIGHT RAIL TRANSPORT SYSTEMS AND ITS INFLUENCE ON USERS, EXPENDITURES, AND OPERATIONAL COSTS

Summary. The aim of this paper is to study and highlight various effects of automizing urban light rail transport systems by examining the impact of such structures on common users, as well as the expenditures and operational costs involved. By providing an overview of different transportation networks through the three categories of expenditure—transportation, maintenance, and administration—an idea of the general operational cost can be established. Additionally, by indicating the aforementioned cost, the effect of the grade of automation on costs can be determined and explained. However, this paper does not include an attempt to estimate these costs; it only states what may affect such costs. Furthermore, the factor of safety is considered by underlining the changes expected to occur with the implementation of such networks. The implementation of autonomous rail systems would result in lower operational costs, which is discussed in this paper based on another study. At the same time, the factor of safety was also observed as simultaneously increasing, as were the overall experiences of users, both in terms of aesthetics and function. The only setback found by the research is that some users would be reluctant to use a network without an operator.

1. INTRODUCTION

In recent years, a lot of discussion about self-driving vehicles has occurred. If such a system is effectively implemented – which includes autonomous vehicles that provide equal service as taxis and commercial heavy goods vehicle drivers but with enhanced safety rules—it will represent a significant step forward in transportation. However, the technology employed to run these vehicles will necessitate the employment of complex and structured algorithms, including a precise understanding of traffic circumstances, safety laws, human psychology during the process of driving, path shapes, and a multitude of other aspects that will make this plan more challenging [15]. Driverless rail vehicles seem to be far easier to design and execute (especially in the case of navigation) than driverless trucks or automobiles. A rail vehicle can travel in only two directions: forward and backward. As a result, unlike a road vehicle driver, a vehicle operator does not have to bother with other trains moving on the same track of its route, nor do they need to make evasive actions (as long as it is not subject to upper sway or wearing track wheel interaction).

When driverless rail vehicles are discussed, two contexts should be compared, namely autonomy and automation. A system that executes predefined procedures and regulations that are supported by information conveyed from the environment is an automated system. This kind of system can be run

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with or without an operator. Meanwhile, an autonomous system does not require human-defined instructions and, as such, can make autonomous decisions to respond to all events with a certain reaction. Therefore, it must be equipped with functions of comprehension, environment analysis, and decision-making without an operator's intervention. These definitions were developed in [24]; a wider range of definitions can be found in [16].

The Business Research Company [26] published a report connected to global autonomous rail vehicles. Last year, the market value for such vehicles was \$7.73 billion, whereas, by a quarter of the century, it is expected to be over \$10.8 billion. This might be a measure of importance in the case of such vehicles.

Autonomous rail technology requires technologies including platform track control systems [17], platform screens, intrusion avoidance, and adequate remote sensing systems [31]. These devices help reduce the risk of deaths on tracks while significantly increasing rail system dependability. If a passenger applies the emergency brakes, the control center, supported by passenger area monitoring, can evaluate a vehicle's condition. This situation is related both to smoke alarms within a train and alerting a control room against a collision. This allows a machine to readily comprehend the situation, develop required pauses, and reroute a network.

In an age of overpopulation, transportation is continually operating at maximum capacity. Consequently, driverless rail vehicles are regarded as a remedy to free the industry from human mistakes, allowing it to achieve new levels of efficiency. On the other hand, certain psychological challenges arise, namely the transfer of public safety aspects to machines and the prospect of significantly downsizing employment. All these concerns are valid, but the benefits of self-driving global networking far outweigh the drawbacks [15].

Automation in railway networks refers to the process through which rail vehicles' operational management responsibility is transferred from an operator to the vehicle's control system. There are several degrees of automation, or grades of automation (GoA), which specify the responsibility of a human and a system in the core railway operations duties. The five GoA of the International Union of Public Transportation are GoA 0, GoA 1, GoA 2, GoA 3, and GoA 4.

A manual operation that does not contain automated rail vehicle protection is referred to as GoA 0. This refers to on-sight train driving, in which a rail vehicle's operator has complete control over a vehicle's movements. Examples include tramway and shunting movements in a tramway depot for mainline purposes. Both GoA 1 and GoA 2 (e.g., Milan Metro lines 1 and 3 in Italy, applied in 2010 [5]) require a rail vehicle operator, with some tasks performed by technical systems. The automated train protection (ATP) system is fitted in GoA 1 and applies the brakes automatically if a rail vehicle passes a closed signal or runs at an excessive speed. In the most current main line, the railway signaling systems use a variable (continuous or point-based control) degree of an ATP system to prevent any restricted movement of a rail vehicle regardless of a rail vehicle's operator orders. ATP incorporates the concept of a self-contained safety system. The systems as KVB (the abbreviation stands for *contrôle de vitesse par balise* in French or speed control by balise in English), and ETCS (European Train Control System), and others are components and integrators of ATP system. In addition to the current ATP, GoA 2 adds an automatic train operation (ATO) to manage a rail vehicle's movement during regular operations. It is worth noting that a rail vehicle operator is needed to board a vehicle in each of these instances. In contrast to the previously mentioned GoA, GoA 3 and GoA 4 are dedicated to autonomous and unattended vehicle operations (ATO, popularly known as unattended train operations – UTO), respectively. The system in each of these instances continually includes ATP and ATO functions, guaranteeing safe movement and driving. In the case of any disruption, GoA 3 has an attendant on board to handle doors, align passengers with help if necessary, and run the vehicle (e.g., Barcelona Metro line 9, 10, and 11 in Spain). A rail vehicle of GoA 4 is fully automated, as all the following requirements may be met without the presence of a human on board (e.g., Dubai Metro in the United Arab Emirates, created in 2009 [23]). The procedure of safe door closing can be triggered automatically or delegated to a rail vehicle's attendant in the case of impaired modes. As a result, the standard specifies and categorizes the job of a rail vehicle operator and technological systems to guarantee several classes of functions necessary for safe operation. Depending on the technical and economic viability of the application (tramway, metro, high-speed, conventional rail), different applications utilize varying levels of automation [21]. More than 123 autonomous rail vehicle systems (GoA 4) operate in urban areas all over the world; these are mostly tram systems and selected metro lines.

The aim of this paper is to consider the autonomy of urban light rail transportation systems and their impact on users, expenditures, and operational costs. First, the literature analysis gives an overall idea about the autonomous light rail and its different GoA, along with examples from around the globe. Then, the methodology section explains the methods which are used in order to find the results of this paper. Finally, the results show the safety of the autonomous light rail transportation system, the efficiency of such transportation systems, and the difference in cost depending on the GoA of the rail system.

2. LITERATURE ANALYSIS

With the continual growth of the global population, new challenges have emerged regarding managing this growth in many aspects. A major aspect is transport management. Engineers and other responsible officials all over the world are constantly working on the development of public transport services to accommodate rising populations. There is also an emphasis on accommodating environmental needs alongside essential human needs [24]. Efficiency in public transport solutions is necessary to mediate these needs. In the era of logistics 4.0, which is the most recent advancement in logistics (which integrates the Internet of Things and Big Data, among other aspects), autonomy in transport and logistics has solved efficiency problems, as well as concerns related to safety, expenditures, and operational costs.

Rail vehicles are considered a reliable means of transport and are heavily used globally. Both in developed and developing countries, the general population relies heavily on this mode of transport, as many consider it a safe and efficient way to get from the point of origin to the destination in the shortest time. Railway transport constitutes one of the safest and the most procedurally controlled branches of transport; nevertheless, its safety is undoubtedly a result of massive investments. It can be also stated that the balance of safety, performance, and cost constitutes a major global challenge in the railway industry.

The safety of rail transport depends on various factors, including the physical state of the railway system, the rolling stock, the organization of traffic and rail transport, and the professional skills and the satisfactory performance of employees [33]. With the integration of autonomy, one can expect a fruitful reward in each of these aspects. For example, when it comes to the organization of traffic and rail transport, with the use of management assistantship solutions that ensure a flexible supply chain with great transparency and accuracy, the organization of the railway system can be dictated by professional machines and algorithms that rely on trial-and-error simulations, as well as the phenomenal aspect of machine learning. Furthermore, it is always an advantage to exclude human error, as machines do not get tired or bored, and their use involves no risk of incompetence. On the other hand, it should be borne in mind that many people could feel unsafe if no human officials control the movement of a rail vehicle. Multiple incidents were noted in the history of rail transport in case of a rail vehicle was GoA 0, such as the Llanbadarn (Wales) incident on 19 June 2011, when the train driver dashed into the level crossing at Llanbadarn and came to a stop with the train's front end approximately 31 meters beyond the crossing while the barriers at the crossing were being lifted [20]. According to the Rail Accident Investigation Branch in June 2012, there were no road vehicles or pedestrians on the crossing.

The safety and comfort of passengers are linked and influence passengers' opinions of their confidence in autonomous transport. The authors of [7] analyzed Sydney (Australia) metro passengers' opinions on their safety and comfort during rides. As the authors summarized, it was still the case that passengers must become of an increased awareness that the absence of a rail vehicle operator in a cabine does not mean an increased risk of an incident or accident of a driverless rail vehicle. On the other hand, the rejection of autonomous railway vehicles is likely a consequence of saving the vehicles' operator-less costs. Previously, in [6], a significant number of representatives mentioned that an artificial driver room should be present on autonomous rail vehicles.

The safety protection in the case of rail vehicles includes three essential control capacities: vehicle separation, overspeed protection, and course interlocking. In a manual framework, these capacities are performed by a rail vehicle's administrator, who maintains a visual perception of the track ahead and runs the vehicle in conformance with specific rules and techniques. When these capacities are mechanized, there are mechanical gadgets and electrical circuits on a vehicle itself that guarantee the adequate behavior of a vehicle in case an undesired event occurs. Examples of such events can be related to maintaining an adequate distance (a separation) that a vehicle not exceed the speed necessary for an emergency stop (halting) or turning (overspeed protection) and that clashing moves along the lines or during the movement through switches are stopped (course interlocking) [30, p. 28–31].

The networks of autonomous rail vehicles would account for multiple advantages in terms of running costs while increasing the efficiency of the network. The ATO can easily lead to better punctuality, thus increasing train frequency, decreasing the average fleet capacity, and providing consistent monitoring of rail vehicles [17]. Such a system presents an opportunity to free vehicle operators from their navigating roles and let them focus on accommodating the passengers and improving the quality of service, which would enhance customers' experiences and ensure their return. This, of course, would lead to profit maximization for the railway company or government. The first line to be operated with ATO and a cabin operator was London Underground's Victoria line (London, UK). Meanwhile, the first autonomous mass-transit rail network was developed in Kobe, Japan [17].

Automatic train control (ATC) costs, both the initial capital expense of constructing and building ATC systems and the cost of operating an ATC transit system, pose various significant concerns. In the field of capital cost, the cost of acquiring an ATC system needs to be analyzed in absolute terms and in comparison to the expenditure of the whole transit system. The incremental capital spending related to enhancing the level of automation from a basic ATP system to one that also involves ATO and automatic train supervision (ATS) should also be investigated. The general problem with respect to operating costs is the comparative costs of transportation networks that use varying degrees of automation. Relevant issues related to manpower and labor cost savings that can be obtained from automation are part of this issue. Another question is the feature related to energy savings, which can be obtained owing to the more efficient train operation demanded to result from ATO and ATS [30, p. 109]. When discussing energy saving, it is worth mentioning solutions connected to regenerative braking, by which case the kinetic energy of braking is stored for autonomous rail vehicles operation without prolonged traction catenary—for example, when NiMh (nickel-metal hydride) batteries or Li-ion batteries are applied in mentioned rail vehicles [11, 28]. Furthermore, the application of such batteries may increase the safety, security, and comfort of passengers during potential power failures within urban transport systems [28]. Such systems ensure catenary-free transportation (e.g., Citadis tramways in Nice, France [28] or trams in Nanjing, China) [11].

The cost of ATC equipment for a rail rapid transit framework makes up about 3–6% of the overall cost of capital, according to [30, p. 112]. The author estimated that the investment connected to the ATC cab signal with transmission by the track circuit or cables laid in the track is equal to c.a. 300k EUR per unit. Wayside equipment makes up 90% or more of the ATC cost. A variety of factors affect the capital costs of an ATC scheme. These include, but are not limited to, the level of automation, system size, condition of installation, and uniqueness of design.

For many years, the question of whether maintenance savings over the life of the equipment and devices will be recovered by the larger investment needed to acquire an ATC system has received much attention. This is an important issue, not only because of the public funds invested in capital grants and operational subsidies but also because automation supporters contend that, in the long term, ATC is more than paying for itself [30, p. 110].

Efficiency analysis is a crucial step for studying any change in any area of application, especially the transition from the human workforce to an autonomous framework. The resources available as inputs in a production process that lead to a series of outputs (throughputs) are investigated. These throughputs are considered inputs for other functions. The transition phase, in this sense, is represented through the essential economic decisions for the stakeholders regarding how to use finite capital to optimize a utility. This should go beyond producer-limited considerations (in this case, railway companies). According to [9], there are three major theoretical approaches to evaluating the ability to turn inputs into outputs: partial efficiency metrics, average production functions, and methods focused on Frontier (parametric and non-parametric methods).

The efficiency of a railway is assessed by extracting key performance indicators (KPIs), such as productivity, effectiveness, and rentability, based on verified published data. KPIs are indicators that are used to track progress on issues that have been recognized as crucial to the achievement of a transportation organization's goals and objectives. An indication of what sources and forms of publicly accessible data exist was provided in [27] (supplemented by data that the authors of this publication have collected). Any railways in the EU, along with Swiss, Norwegian, Chinese, American, Canadian, Japanese, and Indian railways, were included in their sample. They suggested a method that can be used in a short time frame with limited data to generate some railway productivity information. The metrics suggested applying basic size and scale indices and that fundamental performance and productivity ratios (e.g., traffic density, wagon/coach productivity) can be built from these criteria. One could build a simple but balanced railway performance scorecard that would consist of six types of metrics by incorporating a few more data points. These six types are system scope, utilization of assets and human resources, operational and financial performance, and customer-centric service quality [10].

3. METHODOLOGY

Conclusions about the difference in the operational costs of railways before and after automation were drawn by dividing the expenditures into three categories: transportation, maintenance, and administration. Each category has its own cost in each transportation system. An overview of the operational cost for five different transportation networks was used in this paper to define and explain the variation of the operating costs depending on the GoA in each transportation network. It also showed how the GoA and autonomy plays an essential role in the operational cost of the automated and autonomous railway and why such differences in operating costs occur.

Additionally, a study of safety factors was conducted by analyzing different factors that are embedded within railway systems. We presented the relativity of logistics 4.0 to railway frameworks to achieve better safety and efficiency. This paper does not aim to identify the actual costs of autonomy in rail transport since they vary significantly for different urban transport systems, different regions, and so on. Nevertheless, some structures supporting such assessments are mentioned in this paper. Moreover, readers may be interested in certain methods of operating cost calculation given in [34], which were developed for the Chinese market.

4. DISCUSSION

The global autonomous train market is anticipated to expand at a compound annual growth rate of 11.2% from \$6.95 billion in 2020 to \$7.73 billion in 2021, whereas, according to [26], it is expected to increase to over \$10.8 billion in 2025. Enterprises are resuming regular operations and starting to adapt to the new regularity of life balance as they had to adapt to COVID-19, which led to restrictive containment measures such as social distancing, remote work and education, and the closure of commercial activities.

The growing need for a safe, efficient, inexpensive, quick, and dependable method of transportation stimulates the worldwide autonomous rail vehicle industry. Rail transport is the safest mode of land transportation, as well as the most appealing to customers. It is also one of the quickest modes of transportation, running at speeds of even more than 300 km/h on high-speed lines, meaning a distance of 1000 kilometers may be covered in five to seven hours. It also provides substantial temporal flexibility, allowing rail vehicles' schedules and runs' frequencies to be better suited to demand during peak and off-peak periods.

This situation offers an improved service to potential passengers and increases the number of passengers. The competition among railway operators and suppliers is foreordained as maintaining affordable ticket prices, not only in well-developed countries but also (and especially) in those with low income per capita [27]. The ameliorated safety and less expensive fees than other transport systems resulted from not only rail transport itself but also (foremostly) from the autonomous rail vehicle market.

The market for autonomous rail vehicles is likely to be hampered by high deployment and operational costs, as well as growing security concerns. Maintenance expenses, operating costs, and substantial capital investments are likely to relate to the capital costs of signaling and control equipment. On the other hand, the information and data flow associated with a rail vehicle's safety-critical system are exposed to a possible hacking target. Interconnectedness with other systems makes ATO an increasing threat, leaving it susceptible to cyber-attacks. Keeping this critical data safe is crucial for the entire railway system since it sends high-resolution, real-time determination information between systems such as ATP, ATO, ATS, the waysides, the rail vehicles, and the control center [12].

Light detection and ranging (LiDAR) and artificial intelligence are increasingly being employed to increase the safety and performance of autonomous trains. LiDAR technology detects rail vehicle speed, records track abnormalities and assesses rail track conditions. It captures speed indications from both tracks separately using two sets of optics. On each side, the track speed, curvature, and lateral and vertical geometry changes are measured [25]. On the one hand, the cost of running rail vehicles is significantly cheaper in systems using ATO, as this system reduces the share of employees' expenditures associated with transportation system service. On the other hand, repair expenses may become much greater. One of the ostensible advantages of automatic railway control (especially ATO and ATP) is that it can reduce the transit system's operational expenses [4, 32]. This reduction is primarily caused by lowering the number of employees required. Based on references such as [22] for active rail vehicle operators [14], the average salary, and [2] employer outlay, the authors of [1] computed that autonomous rail vehicles correspond to a 4.7% decrease in cost per kilometer due to the reclassification of rail vehicles drivers to other positions. The authors also mentioned that, in the case of rail vehicles, the cost per passenger-kilometer with vs. without autonomous vehicle technology was 0.44 vs. 0.47 CHF per passenger-kilometer (in regional, not urban, transport) [1],

Table 1 provides an overview of operating costs for five transportation networks (although these data are historical, the purpose of presenting them is to outline some general characteristics regarding operating costs). Because the volume and quality of operation of these networks vary greatly, the data are organized by showing expenses in US dollars per vehicle-mile of sales and as percentages of each system's gross operating costs. The total operating costs and expenditures are listed with division among three categories: transportation, maintenance, and administration. The operation of passenger services was included under the category of transportation. This category also includes payroll, and the fringe benefits for rail employees, central control staff, station attendants, and managers are the primary components; nevertheless, energy bills and all other transit-related expenses were also calculated within this category. The category of maintenance includes all administrative costs associated with the upkeep of equipment, tracks, signals, and buildings, as well as materials and service costs. Other operational costs connected to staff, support, and logistical facilities, as well as all general expenditures not explicitly related to transportation or maintenance activities, were included in the administration category.

The five systems are listed in Table 1 in order of increasing automation from left to right, although the primary distinction is between the New York City Transit Authority (NYCTA), Chicago Transit Authority (CTA), and Massachusetts Bay Transportation Authority (MBTA) with conductors on rail vehicles and those without, as well as the Port Authority Transit Corporation (PATCO) and Bay Area Rapid Transit (BART). It should be noted that the cost disparities between these methods are not only due to rail vehicle control automation [30].

In 1970s, the PATCO was characterized by the lowest total cost of operation, which was an ATO system with a single vehicle operator; however, the BART, which is similarly automated in the ATO region, was almost 8.52 times more expensive than the PATCO and thus the most expensive among all the five presented systems. Nonetheless, the maintenance expenses were still significantly greater than in manually operated railway networks. This is unquestionably the outcome of larger maintenance problems that have impacted the BART system rather than a specific result of ATO, as can be observed based on Table 1. As transportation expenses decreased, the proportion of repairs rose, and the two together account for around 75–90% of the total operating costs. When maintenance costs were evaluated as a mix of transportation expenses, the relative cost of maintenance was more likely to increase because of automation.

Table 1

Rail Rapid Transit Operating Costs

		NYCTA	CTA	MBTA	PATCO	BART
Operating Cost ($/revenue car mile)	Transportation	1.05	0.95	2.15	0.72	0.89
	Maintenance	0.62	0.44	1.45	0.59	11.33
	Administration	0.26	0.15	1.22	0.16	0.30
	Total	1.93	1.54	4.82	1.47	12.52
Percent of Operating Cost	Transportation	55	62	45	49	36
	Maintenance	32	29	30	40	52
	Administration	13	9	25	11	12
Ratio of Maintenance Cost to Transportation Cost		0.59	0.44	0.68	0.82	1.48
Salaries Wages & Benefits as Percentage of Operating Cost		82	82	80	64	74

Source: [30, p. 113]

As the category of transportation, including labor costs, is mentioned, the operating cost with autonomous systems can be lower, especially in the case of manually driven rail vehicles, for which a typical crew consists of two, three, or even more employees (not including, for example, station attendants). The examples of systems presented above with ATO system arrangements, despite the decades of their design, benefit by lowering labor expenses and, consequently, overall operational costs (driverless train operation systems can save operational costs by 10% due to staff reductions [32] and by even 30% more in comparison to conventional metro lines of; this value is given for Paris after [18].

We now focus on more recent projects. An analysis was made in metropolitan Italy on the cost-benefit of a fully automated metro line. The city of Naples planned the development of the public network in the city. Some of the development's goals were related to aesthetics, to give metro stations an identity and a story, to achieve sustainability, and to improve the general quality of life of the city's inhabitants. These aims were possible to achieve by replacing the traditional metro line with an autonomous one [3]. According to an analysis, the proposed outcome of the autonomous switch reflected greatly on the transport network and on the user's experience. Firstly, the new line would have higher standards of efficiency and safety. With autonomous lines, the frequency of rail vehicles in the loop can be increased by decreasing the headway, which is highly expected in urban transport systems. In terms of user experience, this would mean more vehicles would be available at any given time and less frequent overcrowding inside vehicles. This sort of transportation enhanced safety by removing human errors from the operations. In the case of previously mentioned urban transportation systems, it was underlined that operational costs decreased; however, no data were mentioned to prove it. Regarding the Naples metro system, the authors stated that the operating cost of the new autonomous line per kilometer was reduced by 40% in comparison to the older lines. The economic cost of the project included operative and maintenance costs, which were equal to 363.519.000 EUR. While the investment costs are expected to be higher, the projected increase of 12% was not much higher than that of non-autonomous lines. Moreover, the new rail vehicles were more eco-sustainable than previous ones, meaning they have a smaller carbon footprint (climate gas savings). These vehicles also contributed to fuel cost savings and reduced road congestion, accidents, pollution, and noise. Such environmental factors help enhance the overall environment of the city as well as concerned customers' satisfaction with the public transportation network, as summarized in [3]. Finally, the aesthetic value of the transport hubs, which is an often underestimated aspect, affects users' choices and enriches the attractiveness of the analyzed mode of transportation [3]. This means that the user can wait for up to six minutes or more or walk for up to nine minutes to commute through an aesthetically pleasing station [3].

With substantial advances in technology from a switch to autonomous means, the expectation of better safety standards is imminent. Throughout history, there have been many cases of rail accidents. These incidents have been caused by multiple factors, such as an inadequately designed system, human error, the inability to detect a change, or obstacles on the railway track. With the use of technology that has been made available from the most recent logistics transition, it has become possible to tackle these problems systematically.

Operating urban light railway systems, especially autonomous ones, requires their location to be known. There are many technical parameters connected to logistics 4.0, one of which is real-time locating. With manual rail vehicles or other such vehicles with a low grade of autonomy, the connection between a vehicle and a particular headquarter or other vehicles may be determined in an estimated range, though not in a consistent way. Real-time locating sensors can be applied to vehicles, giving officials fixed references on their exact location in a continuous real-time pattern instead of intermittent intervals. Of course, this real-time aspect can play a significant role in avoiding accidents and catastrophes. The abovementioned LiDAR can be applied for the same purposes as well [31]. Moreover, as authors of [8] mentioned, LiDAR can be used to collect high-quality maps during rail vehicle rides, which, as a result, may contribute to collision avoidance systems, as well as semi-automated or fully autonomous rail vehicles.

Another technical parameter that could be integrated into autonomous railway frameworks is smart remote sensing. The authors of [13] conducted a study on a surveillance strategy concept that utilizes the smart sensing mechanism. The rail collision avoidance system was designed to allow a vehicle to autonomously detect the possibility of a collision based on the environmental inputs present and automatically communicate these messages to a rail vehicle operator [13]. Every autonomous rail vehicle should be equipped with sensors that provide parameters such as position, speed, and time to ensure the efficiency of the rail collision avoidance system. These parameters are made available to all other rail vehicles and units. The idea is that when the data are transmitted, other vehicles can assess them in the context of potential collision threats long before a critical situation could be determined by a visual observation of the track. Taking into consideration the braking distances of rail vehicles, which can extend even to several kilometers, an early warning message to an operator or a particular signal to an autonomous vehicle would ensure a sufficient braking distance and prevent a crisis from occurring [13].

Finally, the matter of dispensing with the conventional track must be addressed. The answer is to utilize an autonomous "tram" that runs on rubber tires, not directly on a steel rail (for example, as presented in [17]). Such a vehicle is powered by batteries that are recharged at each stop and at the points of origin and destination. Therefore, no catenary is necessary. Such vehicles could represent the future of light "rail" urban transportation, and we will continue observing this system.

5. CONCLUSION

The research and presented solutions represent only a selection from hundreds of applications of local transport systems. They give some idea of the benefits of autonomous rail transport. Future research should carry out a deep literature review. Moreover, it is worth considering this opportunity in regions where a reversal of rail transport has been implemented and in regions facing transport deprivation. It also is worth studying operational costs, which are the most common reason for cutting a conventional railway line in the context of autonomous rail systems. That is, it should be explored whether lowering the operational costs of autonomous rail systems would make it worth reopening a line.

This paper concludes with the following list of selected benefits of autonomous rail transport:

- Decrease in costs and improvements in safety and sustainability,
- Eradication or reduction of the inattention or distraction in the case of a rail vehicle operator and a simultaneous reduction of staff availability (increasing challenge of crew shortages),

- Reduction of roadside workers for maintenance (a separate aspect worth analyzing is the autonomous maintenance in rail transport, such as robotic and autonomous systems and the reduction of staff availability,
- Higher comfort and safety (consistent, smooth rides with fewer jerks and lower acceleration changes),
- Better for the environment, as autonomous rail systems function at much higher efficiency rates than manual ones, which certainly leads to substantial cuts in the energy delivered by the network,
- Improved service quality for users, as the drivers could now assist passengers,
- Increased service frequency and fewer delays.

Certainly, autonomous rail transport applications should be preceded by dealing with obstacles, not only due to a lack of passenger confidence in the vehicle without an operator but also prevention in the condition monitoring of the whole system and, foremostly, cyber-attacks. This is another research topic that must be taken into consideration.

In future research, the authors plan to assess the values of selected factors mentioned in this paper in European countries.

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