Monorail - an alternative solution for the urban transport in Romania

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Abstract. A well-developed system of public transportation can provide an answer to the problems that appear as a result of traffic overcrowding and congestion in large urban settlements. Taking into consideration the continuously worsening traffic conditions in more and more cities in Romania, it was relevant to search for answers in countries that have started addressing this urgent issue. It appears that the best answer to this situation is building a monorail network; this is the ideal solution since the overhead driveway makes it independent from all the other means of transport. In this article, monorail systems used around the world are also presented, as well as their advantages and disadvantages. Offering an overview of the possibility of integrating such a network in Bucharest, the authors suggest some possible routes, pinpointing the reasons taken into consideration before choosing them. Thus, building a monorail can be seen as a reliable, economic and ecological way to address the issue of overcrowding and congestion by offering shorter travelling times between various points of interest and by increasing traffic fluency in Bucharest.

1. Introduction
In the latter years, the whole world has witnessed a significant increase in the number of privately and corporate owned cars. According to the most recent surveys and statistics [1], throughout Europe there has been a 13.7 million increase in the number of new, privately purchased cars, overlapped by those owned by companies and state institutions. The data is valid for the year 2015 alone, and an even greater figure was expected for 2016. The consequences of this dramatic increase are, amongst others: severe congestion of major urban centres, the traffic jams in all populated areas – worse in metropolitan areas than around the outskirts, a lack of parking places and, with serious impacts on human health and lifestyle, increased pollution in and around larger cities.

These problems are common not only to the already developed states, but also to the developing countries in Eastern Europe. Finding solutions to these problems is imperative and most governments are trying to improve the situation; however, these answers must not hinder the urban transportation networks or population mobility. It is recommended that the solutions should only enhance common transport.

Bucharest, Romania’s capital and the largest city, also suffers from pollution, traffic congestion and a parking place crisis. Occupying about 27,500 ha, it is home to more than 9.5% of all Romanians living within the borders, or 16.8% of Romania’s urban population. According to research carried out by GPS and navigation software manufacturer TomTom, using data collected throughout 2016, Bucharest is the fifth most congested city in the world, occupying the first place in Europe [2]. The survey also suggests that people driving in Bucharest spend, on average, 57 extra minutes per day
stuck in traffic jams, a situation that tends only to get worse. The time required to travel the same
distance has increased by 7% since 2015. This amounts to almost 218 hours’ worth of delay per year
[2]. Apart the huge number of cars (approximately 1.3 million of them, at a population of 2.1 million
people), the causes of this worrying situation include: an underdeveloped, aging infrastructure never
designed for such intense traffic, the lack of a highway ring road to divert transiting vehicles from the
streets in the city centre, the lack of parking places, an ever increasing number of construction sites,
etc. The risk of being involved in an accident is higher, as a result of congestion, while pedestrians and
drivers alike experience discomfort. Furthermore, the factors mentioned above make Bucharest less
attractive to investors and tourists, a source of income for the local budget worth considering.

A solution to solve this problem is to develop and enhance the urban transport network, making it
punctual, safe to use and comfortable, discouraging the use of cars for every day trips. Even though
Bucharest is home to an extensive metro network, the rapid transit system is easily overcrowded
during rush hours, causing significant delays; furthermore, it is developing way too slowly, and some
heavily populated areas will not be reached until 2019. It is also costly and technically difficult to
expand it. The light rail, tramway, bus and trolleybus networks are suffering because of traffic
congestions and cannot provide punctuality. The attempts of creating special lanes on some routes
were unsuccessful, causing more jams and sometimes even blocking sideways and parking places.

A new approach in developing the urban transport network is therefore needed. A new system is
needed; it should be entirely over ground, to reduce building costs and the necessity of advanced
technical solutions, but it must be independent from the road network. The idea of having a suspended
network comes up as being a solution to congestion, offering much faster public transport, regardless
of the traffic jams and problems on the streets below. This way, unconventional vehicles such as
monorails or Maglev trains can be used. Their increased capacity reduced operating and construction
costs and lack of interference with road vehicles are some features found in suspended networks that
make them a solution for the future. Technical details, vehicle models and their transport capacity
have been studied by various authors [3-6], showcasing the benefits of such a system.

The purpose of this paper is to offer an alternative answer for the urban transport networks in
Romania and abroad choosing Bucharest as the main example and starting point for studies and tests,
showing how and why it should be implemented. The purpose is to offer quality service for the
population in an environmentally-friendly way; an analysis of potential vehicle types is also included.

2. Unconventional vehicles used for urban transportation

2.1. A short history
Ever since the invention of conventional railway vehicles, in the early 19th Century, the engineers
working on those early designs tried to make use of their whole potential. The most important feature
for them was the self-steering capability of these yet innovative vehicles. New ways of exploring the
advantages of this feature were sought after.

Conventional rail vehicles use a specially designed railway, made from rails, tied to sleepers which
are in turn placed on a platform supported by the railway infrastructure. The so-called unconventional
vehicles use a completely different running surface; depending on their type, they can be grouped in
two main categories: monorails, which move with the help of wheels pressed against the running
surface consisting on a single rail (or beam), and magnetic levitation vehicles. The latter do not have
wheels and levitate with the help of extremely powerful electromagnets, eliminating contact between
the vehicle and the running surface. These are expensive, demand highly skilled personnel to operate
and are relatively new; these are the reasons why we will only discuss monorails.

Single rail vehicles have been developed since the 1800s, and are derived from conventional trains.
The first documented experiment took place in 1820 in a village nearby Moscow where the Russian
engineer Ivan Elmov designed a so-called „road on pillars” made with a single wooden rail mounted
on pillars [7]. Animal traction was used to move the vehicles. However, due to a lack of funding, the
design failed to be patented; nevertheless, this is considered to be the first monorail in human history.
The oldest officially recorded attempt dates back to November 22\textsuperscript{nd}, 1821 [7], when patent number 4618 was recorded in Great Britain. It referred to a vehicle designed to operate on a single steel rail; Henry Robinson Palmer, its inventor, describes this innovative system as consisting of a single steel railway, which leaned against pillars at a certain height, with the vehicles’ centre of gravity well under the rolling surface.

Monorails did not see commercial use until 1824 and 1825, when, in Great Britain, the first two networks were opened, for freight and passenger service. Soon after, the importance and many possibilities offered by monorails were understood. The first modern system, however, would only be inaugurated on the first of March, 1901, in Wuppertal, a city in Germany [8]. Since it is still in operation, it is the oldest system of its kind still in use. Designed by the German engineer and entrepreneur Eugen Langen, who used the term monorail for the first time, it is mostly suspended above the Wupper River, with a short 3 kilometre span crossing the city streets. The vehicles lean against a steel rail, and double rimmed wheels ensure safe and reliable movement. Powered by electric motors, it is environmentally-friendly and also low-maintenance. It has proven its efficiency during the years it has been in operation.

Monorails experienced a period of decline in the early 1950s, as cars became more popular and affordable. During those years, research continued and new vehicles were developed, different in construction and technology than all of their predecessors. The new models use a concrete beam as the running surface, being suspended from steel tracks built inside this concrete beam or standing on its surface, using the sides for self-steering. Using rubber tires, the noise and vibrations were reduced while increasing adherence.

2.2. Monorail types
The Wuppertal Monorail features a classic build, being suspended on a single steel rail identical to those used by conventional trains. The steel, double rimmed wheels are held together by a bogie, and the vehicle itself is attached to it by a sturdy steel beam with leaf spring suspensions. Switching rails is particularly difficult with this model, and the vehicles have to use turning loops placed at the terminus points. This constructive solution is not suitable for the needs of a modern metropolis, because it has certain drawbacks: it is noisy, it shades the ground, requires turning loops etc. However, by understanding this system we are able to analyse actual solutions.

Switching was solved by using moving flanges or articulated concrete beams to change tracks. These methods are similar to those used by conventional trains. Once this problem was solved, two types became prominent; these are fundamentally different, the only similarity being their use of rubber tires.

ALWEG was a German company [10], known worldwide for the pioneering work undertaken to develop the monorail. It is the developer of the straddle-type monorail, which uses a concrete beam as
running surface (figure 3). Even though this method leaves the vehicles exposed to the elements, they can climb steep gradients of up to 6% and have a smooth and silent operation.

The other popular type was developed in France in the early 1960s. It became known as SAFEGE (figure 4), but it is fundamentally different from the ALWEG design. The running surface consists of a box-section concrete beam, with an opening in the lower part. Inside it, the bogies equipped with rubber wheels are inserted, and the vehicle frame hangs below them, attached to the bogies with steel beams. This makes the SAFEGE model completely weatherproof, making it ideal for cities where heavy snowfalls, rainfall or low temperatures are common. Even though they are less popular than ALWEG models, SAFEGE [8] type vehicles are found in Germany and Japan, where they are successfully operated, with Mitsubishi being their main producer.

![Figure 3. ALWEG Monorail, adapted from [11].](image1)

![Figure 4. SAFAGE Monorail, adapted from [12].](image2)

The ALWEG type monorails are more popular on a worldwide scale, being operated by many city administrations in Asia, Europe and in the Americas. Hitachi and Bombardier are the main companies building this kind of networks and vehicles. ALWEG was purchased by Hitachi, establishing the Hitachi-Alweg division [10] in 1960. Bombardier recently made it to the headlines with their Innovia 300 [13] monorail design, which won a prize for performance in 2015, from the Chicago Athenaeum. The 7 unit variant is capable of carrying 1000 passengers, is ready for Automatic Train Control and Protection systems and can be fitted with all modern security and comfort features required by modern standards.

Hitachi has produced some of the best-selling models in the world, and can modify a particular design to meet specific customer demands, either by increasing or decreasing capacity or by installing certain features, not included in the main design. Both companies also offer assistance in operating, repairing and even upgrading networks and vehicles designed and built by them.

An ALWEG-type train is used as an express connection between Tokyo city center and the Haneda Airport; it runs every 4 minutes, giving passengers an easily predictable timetable and mobility.

Hitachi is currently developing a new network in the city of Daegu, South Korea, which has a population of over 2.5 million citizens and is currently suffering from the same problems Bucharest is, suffocated by the intense traffic and perpetual jams. To solve the problem, the local authorities turned towards the Japanese manufacturer, asking for a less expensive yet efficient solution. Nowadays, the network measures 24 kilometres in length, running from the north-western part of the city to the southeast; it has 30 stations and the main purpose was to connect the city centre with the suburbs. The straddle-type monorail was the perfect solution, according to the local government, and the research carried out during the early stages of the construction revealed that it had reduced impact on existing traffic, fitting in the landscape perfectly. 28 vehicles operate on the network; these are fitted with all features required by modern standards, such as fire extinguishers, safe evacuation systems along the guideways, liquid-crystal screens that change from transparent to blind as it runs through residential areas, guaranteeing privacy to those living near the line [14].
Bombardier Innovia 300 [15]. Mitsubishi Monorail [16].

Bombardier is the manufacturer of the INNOVIA series that comprises automatic people movers, monorails, and low-medium capacity rapid transit systems. With safety as a main concern, the driverless vehicles are equipped with state of the art CITYFLO 650 automatic train control technology, earning the company many awards for their designs. The INNOVIA Monorail 300 (figure 5) vehicles are straddle type monorails, fitted with rubber tires and capable of negotiating 6% gradients; their maximum speed can be as high as 80 km/h, and the maximum transport capacity is of about 40,000 people per hour. Features include spacious interiors with flexible seating arrangements, inter-car walkthrough, special spaces for passengers with restricted mobility or confined to a wheelchair, intelligent power management for increased efficiency and more. In time, the automatic operation has, proven its efficiency, reliability and advantages, such as lower headways and smoother braking and acceleration [17].

3. Identifying the potential routes

To start talking about a monorail network in Bucharest, we must begin by analysing and identifying possible routes, which have to meet the following demands:
- the existence of a wide boulevard or road underneath is imperative so no expropriations and demolitions are required, and the traffic can be safely diverted while building the pillars, running surface and other elements required to operate a monorail;
- it has to connect important, densely populated areas, such as the outskirts and the city centre;
- it must be connected to other means of transport, ensuring an intermodal transport system;
- it should be used for touristic purposes as well since it allows people to observe the city and its objectives from an elevated point.

On a worldwide scale, there is a demand of offering accessibility and connections between rapid transit systems, light rail networks and surface urban transport, increasing flexibility and covering a widespread area. These will constitute the main reasons behind the decisions regarding station positions.

One possible route takes into account the importance of connecting the city centre with an ever developing outskirt known as Prelungirea Ghencea. Our choice is based on the criteria mentioned above and on the fact that it lies on the borders of Municipalities 5 and 6, and the still to-be-opened Metro line 5, in Drumul Taberei, can be connected to this monorail network with ease. The route will connect the central part of Bucharest with the north-eastern and south-western parts, bypassing two major commercial centres, a couple of high schools and countless schools, kindergartens and other important objectives, such as The Parliament’s Palace, the Romanian Patriarchy and the largest cathedral in Eastern Europe, currently under construction.
The terminus points can be placed as follows: one nearby Domnești railway crossing, near the DNBC road; this station can take part of the passengers coming from the villages and towns surrounding Bucharest.

![Figure 7. The route exemplified on the Bucharest map.](image1)

![Figure 8. NO2 pollution in Bucharest map [18].](image2)

The other end can be placed in Alba Iulia Square or nearby Muncii Square. Between them, the monorail will be suspended above Prelungirea Ghencea Street, Ghencea Boulevard, 13th of September Boulevard until it reaches Libertății Boulevard. It can be continued towards Unirii Boulevard, until it reaches the city centre and Unirii Square, heavily populated areas and tourist attractions. It will connect the city centre with the Alba Iulia square and, continuing alongside Decebal Boulevard, the Muncii Square metro station can be reached as well, to provide flexible, intermodal transport.

Approximately 13 kilometres in length, this route (figure 7) can be entirely travelled in 40 minutes, with a personal car, possible if the traffic is reduced and there are no construction sites on the road. With the existing urban means of transport, it can take as much as 90 minutes, and many changes are required. Building this monorail network will encourage the population to use eco-friendly transportation instead of personal cars, reducing congestion, pollution and delays caused by traffic jams. Furthermore, green lanes can be built under the monorail system, as it does not create too much shade on the ground.

By considering this monorail network with the given examples, we noticed that the existing roads and buildings do not cause any technical problems in terms of building the pillars and the running surface on which the vehicles will operate. By being built above the main arteries, the risks of getting stuck or suffering an accident are eliminated, without restricting terrestrial traffic underneath the monorail network. Least but not last, this route bypasses important touristic places attractions, and it can provide a vantage points for tourists with little time to spare. It is implied that the population will stop using personal cars when it is not necessary, greatly reducing the actual high pollution (figure 8) since monorails are powered by electricity.

For example, the Wuppertal Monorail, which has been in operation for 117 years, has a comparable network length of 13.3 kilometres, travelling at an average speed of 27.5 km/h. In normal conditions, the trip takes about 30 minutes, from one terminus station to the other. There are 20 stations, with the average distance between stops being of 698 meters. Per weekday, the system is used by approximately 65,000 people, amounting to 23 million passengers per year and the average journey length is of 4.7 kilometres [19].

Other routes that should be taken into consideration aim at reducing over congestion in the suburbs, where a great number of people live, far from the rapid transit system and with too few bus and tramway routes. Poorly served by the urban transport network, almost all residents of these areas rely on their personal cars to commute to and from work, and to travel towards shopping centres. Moreover, some of the major malls are situated at the city limits, yet again inaccessible for the rapid
transit system and, with busses suffering from the same traffic congestions, people rely on taxis and cars to get there. The Henri Coandă International Airport, situated in the town of Otopeni, is connected to the city only by busses, without any rail, metro or tramway connections. It goes without saying that this further adds to the problem, and this is why another possible route should try to connect the International Airport with the small but heavily populated town of Tunari, the business and economic centre of Bucharest, Pipera and Aviației, eventually meeting the metro network either at Aurel Vlaicu or at Aviatorilor stations. This connection will be of great use not only to the residents of those areas, but also to anyone visiting the city with important business matters, and to tourists who will get faster and more conveniently to the city centre.

4. Conclusions
Taking into account the construction of the rolling track, suspended from the ground, the monorail becomes a safe and efficient mean of transport. The lack of intersection of the route and the vehicle with terrestrial means of public transport, the low-beam curves it can run and practically the independence from the ground (ramps / slopes) make the monorail vehicle become a potential replacement of classic vehicles used in urban transport - buses, trolleybuses and trams.

From the two main categories of rolling suspended vehicles, the SAVAGE type monorail is more suitable for its introduction in Romania for the following reasons:
- the driveway is closed, the bogie running inside it, leading to an independence of the weather conditions (rain, ice, snow, etc.);
- the possibility of modelling the track along the main arteries already existing in the big cities; its competitor needs straight lines;
- compared to the Alweg monorail, the SAFAGE monorail stations are built at much lower heights, so the costs are low.
- not at least, in comparison to trams or trolleybuses in this type of vehicle, the power supply is placed inside the track beam, which is more secure and pleasant in appearance.

The urban transport of the monorail type presents a number of disadvantages, including:
- necessity of clear procedures and means of evacuating the passengers in the event of a major accident or major problem;
- compared to urban surface transport the cost of the stations is very high;
- the cost of extending an existing network is high, and sometimes it is more convenient to change it altogether by replacing the road and vehicles.

Finally, referring to more than 115 years of operation of the Wuppertal monorail, we believe that introducing Romania’s capital and largest city, Bucharest, in the exquisite club of monorail users will have certain advantages, some of them being:
- it proves that Bucharest is open towards environmentally-friendly, clean and fast alternative means of transport, willing to develop itself in harmony;
- the city becomes more friendly towards foreigners interested in tourism and also for investors who will regard the metropolis as being economically developed and with great potential for future growth;
- the possibility of reducing pollution by decreasing the amount of cars on the roads in the city center and connecting arteries, by offering a flexible, intermodal network;
- suspending the network above the boulevards and roads will, in certain places, allow the authorities to increase capacity, while reducing the accident risk and associated dangers
- the positioning of Bucharest among the main metropolitan centres of the developed countries, its prestige increasing through an important and easy to notice achievement.

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