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A NEW LONG-TERM SUSTAINABLE PUBLIC TRANSPORTATION SYSTEM FOR THE CITY OF SKOPJE

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Abstract

Skopje, the capital of Macedonia recently has been enlisted as one of the most air polluted cities in the World. A large portion of this huge pollution came from traffic, unorganized and unbalanced public transportation system currently based on diesel buses. In this paper, the authors propose a new, long-term sustainable public transportation system suitable for the city of Skopje based on the electric driven monorails, being focused on sustainability and clean energy. The proposed concept, its benefit along with the challenges, is briefly addressed. This research contributes to the literature as a pioneer study in Macedonia's academic work, along with its practical significance. Namely, it posts some valuable findings and suggests many recommendations that may serve as initiating ideas in the line of introduction of fast, reliable, massive, modern and ecologically friendly city transportation system.

Keywords: Public transport system, Monorail, Air pollution, Skopje

INTRODUCTION

Skopje, the capital of Macedonia with its total population of 506,926 inhabitants (2002 census) is one of the largest and most populated cities in the region. According to present estimations, the city of Skopje today has more than 650,000 inhabitants, and with daily inflow of almost 20,000 people, mostly for business purposes, it becomes one of the busiest and economically most valuable cities in the South-East Europe.

This results in life quality reduction, along with aggravated potentials for public transportation and commuting within the city. The thorny problem that the city of Skopje encounters is the traffic organization including reduction of traffic congestions, air pollution, and parking problem. With the gradual increase of its population, it becomes very difficult to commute from one to another part of the city in easy, fast and convenient manner. The streets became too narrow to accommodate the increased number of vehicles and the duration of so-called pick traffic hours sharply increased spreading almost over the whole working day. On the other side, these traffic problems along with the increased number of cars, buses and other transportation vehicles have a profound negative influence on the local environment. Additionally, due to its unfavorable geographical positioning being placed inside a large valley, the city of Skopje is highly susceptible to fog and keeping low-height clouds, thus dramatically increasing the air pollution, particularly during winter.

In the winter of 2018, the city of Skopje was ranked for several times at the unfavourable first place on the list of the most polluted cities in the World. It was noted over 374 $\mu g/m^3$ of PM_{10} and PM_2 particles, being almost ten times more than the critical values, and toping other

largely populated and polluted cities like Kolkata (India) 361 μg/m^3, Dhaka (Bangladesh) 329 μg/m^3, or Lahore (Pakistan) 232 μg/m^3. Although not being the major, traffic is definitely one of the largest air pollution factors along with industrial plants and household heating facilities. The citizens of Skopje strongly demanded responsible institutions to undertake measures and activities significantly to reduce the air pollution, in the first line by decreasing the values under the critical. One of the potential solutions definitely is introduction of a new modern, ecologically friendly and long-term sustainable city transportation system that may replace the current system based on diesel-fuelled busses, being identified is one of the largest sources of air pollution in the city.

This paper elaborates a project idea of introducing a new sustainable city transportation model based on light and electricity driven monorail system [1-3]. In order to mean the aim, the paper is structured in several sections. The first section briefly explains the status of the current city transportation system putting an accent on its most prevailing problems. The second section, presents some stylized facts on the monorail transportation system, by discussing some major (dis)advantages along with supporting facts why such system might be suitable for the city of Skopje. The final section introduces a potential monorail structure which may be easily developed and expanded in accordance to the city's future needs.

PUBLIC TRANSPORTATION SYSTEM IN SKOPJE

The current public transportation system for the city of Skopje is run by the Skopje Public Transportation Company (**JSP** – **J**avno **S**oobrakajno **P**retprijatie). Some operational data for 2016 for this system are presented in Table 1, according to company's Annual Report [4].

Table 1 *Operational data for Skopje Public Transportation Company (JSP) for 2016 [4]*

Number of bus lines *(Urban/Suburban)*	**82** *(38/44)*
Transportation length [km] *(Urban/Suburban)*	**1,252** *(428/824)*
Yearly distance travelled [km]	**18,935,970**
Urban area / Suburban area	*11,379,926 / 7,556,044*
Total number of passengers per year	**45,925,737**
Average number of passenger per month	*3,827,144*
Average passengers per hour	*7,070*
Total number of busses	**428**
Average age of the busses [years]	**10.09**
Average consumption of diesel fuel per year [l]	**7,764,418**
monthly / daily	*647.035 / 21.214*
Average achieved commercial speed [km/h]	**19.47**
Average price per ticket	**0.55 $**

Based upon Table 1, it is noticeable the significant number of bus lines, transportation lengths and passengers. The age of the buses and diesel fuel spent daily, monthly and yearly is also very high, being a serious indication for substantial negative environmental implications. The average achieved transportation speed (< 20 km/h) is extremely low, generally due to narrow streets and congested traffic. This provokes significant unfavourable impacts on the interest for using the current transportation system (average 7,070 passengers per hour), despite the low price which usually does not cover full operating costs. Consequently, this leads to necessity of introducing changes in the transportation system for the city of Skopje, which will be focus on sustainability and clean energy.

Up-to-date, various models for new city transportation system have already been discussed, such as the gasification of the buses and/or procurement of new electric buses, up to introducing trolleybuses or even trams. However, so far, no model has been introduced or even deeper investigated. Some are just make-up solutions (gasification), others are not suitable due to existing overcrowded city structure and its geographical characteristics (trams), or their implementation needs totally new and expensive infrastructure that leads to additional traffic congestions (trolleybus and tram). Introduction of a subway was quickly rejected due to extremely high investment cost and lack of feasible number of passengers (needs > 20,000 passengers/hour) to justify such high investment costs [1] (Figure 1a).

Consequently, this leads to only two possible solutions: 1) Replacement of the current diesel buses with new electric or hybrid ones, or 2) Introduction of modern system for massive city transportation, like monorail or **LRT** (**L**ight **R**ail **T**ransit) system. The biggest obstacle for model based on simple substitution of the existing diesel-fuelled buses with electric ones is that the transportation infrastructure would remain still crowded and the transportation capacity could remain unchanged. Increasing the number of buses to achieve higher number of passengers, simply leads to increase of current traffic jams. Thus, in order to achieve long-term sustainable, fast, reliable, massive and environmentally acceptable public transportation system, although initially more expensive, one may prefer introduction of monorail or LRT transportation system over simple bus swaps. Even more, the number of passengers that may be carried at the same time, along with the flexibility of interconnection, is much larger when using monorails or LRT compared to buses. Since LRT transportation system requires heavy construction work and installation of double rail tracks, thus leading to additional narrowing of the available traffic space, this paper argues the introduction of monorail. Thus, this research proposes monorail transportation system as the most suitable, modern and long-term sustainable massive public transportation system for the city of Skopje.

WHAT IS MONORAIL PUBLIC TRANSPORTATION SYSTEM

Monorail (**MR**) is a modern, economical and environmentally friendly, fast and widely-used way for urban transport, particularly applicable for large city environments. Many countries worldwide apply this way of urban transport due to many advantages that it has. Today, such systems are widely used in almost all major world cities in the United States, Japan, Germany, Australia, France, Sweden, South Korea, Taiwan, Canada, China, etc.

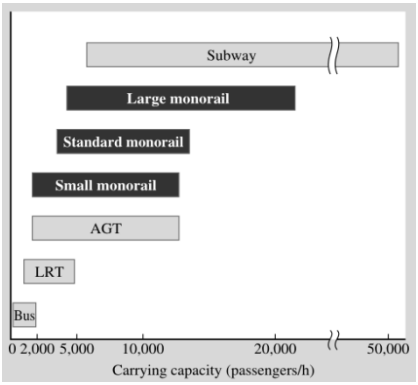
From a technological viewpoint, the MR may be considered as long electricity driven bus that moves along a single rail above the ground. MR tracks are usually not more than half the width of the vehicle, which means for safety reasons, a monorail vehicle has to be internally stabilized to prevent its lateral overturning. Thus, due to its narrow rails, these systems provoke less negative economic and environmental impacts compared to light or heavy rail systems. Commercially, there are three major MR types:

1. **Monorails that envelope/straddle a track.** A typical and most applied MRs worldwide concept named Alweg Monorail or Straddle Monorail, because it envelopes and straddles a narrow deep track. It is supported by two bogies and is guided by rows of stabilizing rubber wheel along each side of the track (Figure 1b and 2a).
2. **Monorails that run on top of a track or a slab at the surface.** A typical example of new MR technology comes under trade name Urbanaut®, which has a unique central guide rail on top of the track that prevents uplift and derailment of the vehicle (Figure 1c and 2b).

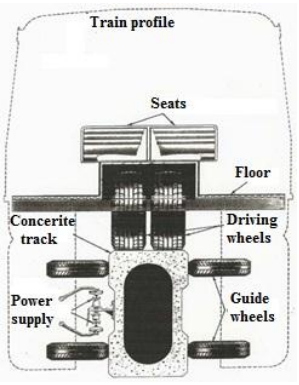
3. **Suspended monorails** under a track which is above the vehicle and the propulsion motors and bogies are on the top of the vehicles (Figure 2c).

Construction of elevated MR transportation structure may provide several major advantages, such as:

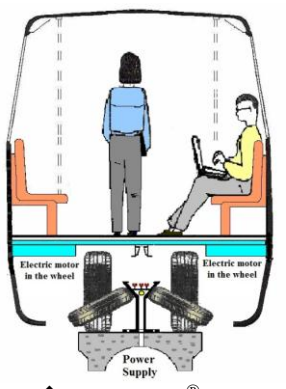
1. Elevated above the ground, MR occupies less space, provides better traffic safety, and it is faster and more secure;
2. Construction of MR driving system has a close resemblance to bus construction, meaning it is quite cheap, easy operational and straightforward for maintenance, and since it uses concrete or metal tracks, provides fast, fairly cheap and simple driving;
3. Due to electrical driving system, MR is almost noiseless, environmentally highly acceptable and recommended for very densely populated central city cores, thus avoiding collisions or traffic accidents;
4. MR is ***"green"*** thus saving lot of pollutant's emissions, which makes it advisable for densely populated areas;
5. MR may be easily accommodated within the current transportation system enabling transportation of people and goods directly in the city centre, using the so-called hide-in stations. The stations may be embedded in or side by existing buildings, shopping malls or any other facilities. All new stopping stations may get added-value by gaining inter-disciplinarily purposes like shopping, meeting and/or marketing places, etc., enabling passengers to get on/off the MR literally above the main street; and
6. Keep green areas under the tracks and among pillars enables environmentally friendly footprint of the facility. In this line, cars, people and any other traffic under the tracks may be unobstructed, meaning that the MR is actually increasing the space usage.



◆ *Transportation system capacity*



◆ *Straddle type*



◆ *Urbanaut® type*

Figure 1 *Transportation system capacity and vertical cross-section, and driving system*

a) *Straddle type*

b) *Urbanaut® type*

c) *Suspended type*

Figure 2 *Most common types of MR structures today worldwide*

WHY MONORAIL IN SKOPJE

Anybody who recently visited Skopje has the feeling that something must be done to improve the city transportation since the current is slow, inefficient and does not respond well to the city's needs. However, anybody could also ask, why MR should be selected as a model for future improvement of the city's public transportation network? We enlisted several major reasons that favour MR over other city transportation models:

1. Skopje is a 'flat' city being longitudinally aligned along the river Vardar. According to the latest census in 2002, the biggest municipalities are Gazi Baba and Aerodrom with over 72,000 inhabitants, Chair, Kisela Voda and Karposh with over 60,000 inhabitants and Centar and Gjorce Petrov with almost 50,000 inhabitants. In addition, it should be noted that these municipalities are located opposite to the Skopje city centre giving the opportunity for easy coverage with MR. Namely, with only two suitably designed MR lines with total length of about 16 km, one could accommodate almost 70% of all city public transportation needs;
2. Skopje has very unfavourable environment history, which means investing in environmentally acceptable long-term public transport is extremely useful. This should be promoted and supported by the Government, city authorities and various European environmental funds;
3. Skopje's geographical position divides it into central city area, industrial zones, and large "bedrooms" such as the municipalities of Aerodrom and Karposh, along with the international airport nearby;
4. Raising public transport above the ground level may release the current space for vehicles, new parking places, green areas and parks, bicycle track, etc., which may optimally improve the remaining transportation needs throughout the city;
5. Macedonia is heavily dependent on import of petroleum and natural gas, which instead of being used for transportation, it may be used more efficiently for electricity generation, thus enabling electrically driven MR transportation systems; and
6. Macedonia has good developed construction business, meaning that all operative may be successfully managed by domestic, local companies. In this line, all work in terms of foundations, track construction, stopping station erection works, etc. may be constructed with domestic input. Furthermore, the vehicles, power supply, as well as the control stations may also be produced by local companies supervised by international company fully experienced in development of MR transportation system, willing to transfer know-how and other knowledge. Like this, the local companies may obtain the necessary expertise which may lead to strengthening the economy by undertaking similar activities in neighbouring countries.

Proposed potential monorail lines

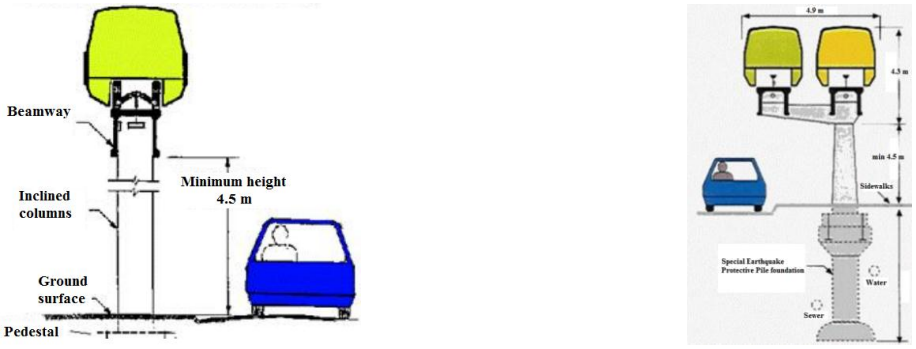
As previously mentioned, considering the city location, the number and location of potential passengers, the location of various important urban units, the proposed MR system may be initially constructed with two perpendicularly positioned lines:

1. **The Red Line** - from the municipality of Gjorce Petrov to Novo Lisice, with future potential line extensions to the municipality of Saraj and the recreation center Matka on one side, and Skopje International Airport on the other side, and
2. **The Blue Line** - from the suburbs of October 11, through Kisela Voda and the Koco Racin Boulevard towards the municipality of Chair and Butel, ending in the vicinity of the Skopje central Cemetery.

The economy of the project

The biggest challenge for such large-scale project as the MR is secure the financing. It is a common misconception that constructing something above the ground usually is very expensive, thus the MR system is far too expensive for countries in development like Macedonia. However, many countries that face similar problems such as traffic jams, over-crowded traffic and poor public transportation system, have made firm decision resulting in construction of public transportation system based on monorail technology. This is the evidence of China, Malaysia, Korea, and even Russia.

The construction costs for any MR structure depends on several factors. As the most important are: total length of the system, terrain topography, location and current utilities, passengers' requirements, speed, number of stopping stations, etc. The practice shows that almost 85% of the investment costs stand just for three items: civil works, monorails and/or special vehicles, and monitoring and control system [5,6]. Some insights of the construction costs for the Urbanaut® type monorail are presented in Table 2, while the vertical cross-section for the Urbanaut® monorail type I (single) and type II (dual) elevated systems are visually presented in Figure 3 [6].



a) *Type 1 (single line)* b) *Type 2 (dual line)*

Figure 3 *Vertical cross-section of the Urbanaut® MR system type I and type II with foundations [6]*

Table 2 *Typical cost for construction of Urbanaut® type monorail [million $/km][6]*

Type of activity	Type I (single line)	Type II (dual line)
A. Elevated Guideways, Including Foundations	**3.20** (42%)	**5.85** (41.8%)
B. Passenger Loading / Unloading Facilities (2 Stations)	**0.75** (10%)	**1.20** (8.5%)
C. Maintenance Yards & Operational Control Facility	**0.50** (7%)	**1.00** (7.2%)
D. Electrical Power, Signals, and Moving Block Control	**0.45** (6%)	**1.00** (7.2%)
E. Rolling Stock (3 Single Vehicles or 3 Car Train)	**1.80** (25%)	**3.25** (26.8%)
F. Fees & Contingencies of A, B, C, & D	**0.75** (10%)	**1.20** (8.5%)
Total cost (Intermediate Size) *[million $/km]*	**7.45** (100%)	**13.5** (100%)

Based on findings in Table 2, some initial projection of financing is made. Accordingly, construction of two MR lines, as proposed for the city of Skopje, with a total length of approximately 16 km may cost between 120 (single line) and 220 (dual line) million euro. These lines will be the backbone of the whole future MR public transportation system. The suggestion is to be constructed as dual lines allowing passengers' commuting in both directions, as well as enabling further extension of the system with other single MR lines to other areas. In the first phase, all stations of the MR system should be well connected with other city's suburb areas that already have active bus lines. This will support utility and

increase number of passengers for the MR system at least for additional 50%, thus achieving usage rate of more than 10,000 passengers/hour. This undoubtedly will improve the feasibility of the whole project. Therefore, the expected number of passengers may expand to approximately 65 million per year, allowing the average price of at least 1$ per single use. However, more detailed feasibility analysis are required, leading to financial justification, whereas, everything that may result in investments return rate under 12 years, is strongly acceptable.

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