Maglev System Benchmarking by Planning Metropolitan Mass Public Rapid Transit with a View on The City of Zagreb

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Nenad Dujmović
University of Zagreb/Croatia, Faculty of Mechanical Engineering and Naval Architecture, Ivana Lučića 5, Rolling stock Factory TZV-Gredelj, Zagreb/Croatia; International Airport Pleso (ZAG) Zagreb/Croatia 10000 Zagreb, HR, nenad.dujmovic@fsb.hr

ABSTRACT: The objective of this paper is to discuss the application of magnetically levitated transport system as an optimal solution for an effective mode of public passenger transportation in urban and suburban areas. A strategic approach in terms of finding an optimal solution to mass public transit implies establishing of criteria and its relevant indicators in order to elaborate the process of urban transport benchmarking. An analysis of the performances of a short-stator maglev vehicle is done by computer simulation. The simulation is performed for changing driving regimes and station distances. The results are graphically presented. The possibility of application of MAGLEV as mass public rapid people movers and actual traffic situation of the City of Zagreb, the capital of Croatia, is considered.

1 INTRODUCTION

The large urban und suburban areas are daily faced with serious traffic difficulties, manifested in congestions and chaotic traffic jams of mass public passenger transport. The inappropriate and inadequate low-flow traffic infrastructure mostly relying on road transport, inefficient intermodal cooperation of existing traffic systems as well as their simultaneous use at the same level of movement are major reasons for this situation.

The consequences of such traffic condition are negative in several ways reflecting in significant difficulties in economic, ecological and social sense: general reduction of the quality of life in urban and suburban areas, decrease of the level of safety of all participants in traffic especially pedestrians, negative influence on the environment through emission of harmful substances, noise and vibration resulting in endangering human health as well as large losses of energy and time

Relating to the large urban areas, solutions to these problems can be found exclusively in the application of such mass public passenger transport systems, which are transport efficient, environmentally friendly, economically justified and socially acceptable.

All of such traffic systems are without doubt in close connection with modern track-guided vehicles. Therefore the public mass transit in large urban areas significantly relies on their application owing to the high level of safety, reliability, large capacity in the transport of passengers considering the speed of movement and vehicle tact frequency, precise keeping to the timetable through automatically control of electric drive, acceptable consumption of energy as well as ecological suitability.

Conventional track-guided vehicles move along and follow a precisely defined rail way or track using mechanical wheel/rail components like rolling stock (railways, tram-train, light railway, metro or one-track vehicles).In parallel, innovative track-guided vehicles use the new technical components for carrying and guiding of vehicles along the track without mechanical contact driven by linear electro-motor.

Those new technical solutions of carrying and guiding of the vehicles along the track without mechanical contact are just applied by the development of magnetically levitating transport vehicles (maglev), and opened wide possibilities for their use in urban areas and their surroundings.

2 JUSTIFICATION OF MAGLEV VEHICLE CHOICE IN THE TRAFFIC OF LARGE URBAN AREAS

2.1 Strategic approach

The basic strategy for solving public mass urban and suburban traffic congestion is the use of track-guided vehicles, which have to meet the following main strategic goals:

Transport efficiency
Ecological suitability
Economic justifiability
Social acceptability

In order to carry out the evaluation, it is necessary to establish the criteria and their indicators relevant for the choice of optimum track-guided vehicle transport system, in connection with the specific urban and suburban traffic situations. According to these criteria, traffic systems are evaluated considering their integration into the existing infrastructure and regional plans, traffic efficiency, environmental impact, consumption of energy, investment costs as well as the maintenance of the system as whole.

2.2 Establishing the criteria and relevant indicators

Establishment and description of criteria by means of relevant indicators for determining the level of satisfaction of the set goals by certain evaluation measures is a standard rational procedure in decision-making process in professional institutions, investment agencies, as well as political structures, especially in large and significant transport infrastructure projects.

That is the reason why the establishment and description of the criteria by means of relevant indicators in relation with certain strategic goals and their evaluation in this kind of projects is a basic preliminary work and a background for purposeful decision-making in order to avoid unreal estimation of situation and wrong decisions.

2.2.1 Transport efficiency

The efficiency of the traffic system as a strategic goal is evaluated on the basis of the following criteria:

System capacity
Vehicle kinematics
Track guidance

Each individual criterion is described and valued separately on the basis of relevant indicators, which on quantitative and qualitative level contain the characteristics of the traffic system in question.

In that sense, the capacity of the system is described and evaluated according to the performance of passenger space in vehicles, possibility of its adjustment to traffic situations, as well as the frequency of vehicles in relation to the signaling and safety conditions.

Vehicle kinematics is described by means of vehicle traction characteristics, nominal speed of movement, the possibility of vehicle acceleration and deceleration taking into account the boundary values of ride safety and comfort.

Track guidance as a criterion for traffic efficiency is covered by the indicators referring to the distance between stations, direct connections of significant points and intermodal interfaces with other means of transport.

2.2.2 Ecological suitability

Ecological suitability of the traffic system as a strategic goal is evaluated on the basis of the following criteria:

Protection of the environment and human health
Preservation of sensitive and ecologically valuable zones

The indicators describing the criterion of environment and human health protection are the level of noise and vibration, land use and spaces, as well as the appearance of various dangerous emissions, such as gas and solid particles or electromagnetic waves.

Preservation of sensitive and ecologically valuable zones is connected with track guidance, which can be realized by above-ground and under-ground lines to avoid and preserve the city center, pedestrian zones, green and recreational areas. At the same time, track guidance enables the creation of new ecologically suitable areas.

2.2.3 Economic justifiability

Economic justifiability as a strategic goal is evaluated on the basis of the following criteria:

Investment costs of design and construction
Costs of the system operations
External costs of traffic system

Investment in the design and construction of a traffic system is described by quantitative indicators referring to the costs of preliminary engineering, design and construction of infrastructure according to the type of the track, vehicles, electric energy transmission, signaling devices, stationary objects and passenger station, as well as the connection nodes with other means of transport.

The costs of traffic system operations consist of the system work, the energy consumption and the maintenance of the entire system.

External costs are the criterion which describes the costs caused by the consequences of the work of the traffic system, and the indicators are the expenses as consequences of traffic accidents, ecological pollution of the environment, land use and traffic congestion.

2.2.4 Social acceptability

Social acceptability as a strategic goal is evaluated on the basis of the following criteria:

Costs of traffic system usage

Attractiveness of traffic system

Availability to passenger infrastructure

The indicators in connection with the costs of traffic system usage are ticket prices, as well as the establishment of selective tariffs for certain customers and certain traveling distances.

Attraction is described by means of indicators connected with the speed of movement and reduction of traveling time, comfort of passenger space and the manner of connecting with other means of transport.

Availability to passenger infrastructure is defined by means of spatial distribution of stations, pedestrian approach to stations and logistics of passenger flow, as well as direct connection of significant points without changing the means of transport and/or optimal connection of optimal means of transport.

Table 1. Criteria and indicators in connection with the strategic goals

Strategic goal	*Criterion*	*Indicator*
Traffic efficiency	• System capacity	• passenger space design in the vehicle • vehicle flow and frequency
	• Vehicle kinematics	• traction characteristics • speed, acceleration, deceleration
	• Track guidance	• coverage of significant points • intermodal connections
Ecological suitability	• Environment and human health	• noise, vibration, land use • harmful emissions
	• Ecological zones	• track guidance • new ecologically appropriate areas
Economic justifiability	• Design and construction	• preliminary works and design • infrastructure, vehicles
	• Operations	• system work • consumption of energy • system maintenance
	• External costs	• traffic accidents • ecological pollution • land use • traffic congestion
Social acceptability	• System usage	• ticket prices • selective tariffs
	• Attractiveness	• traveling speed and time • comfort of passenger space • intermodal connections
	• Availability to infrastructure	• connection of significant points • change of the means of transport • distribution of stations • pedestrian approach and flow through stations

2.3 Qualitative evaluation of maglev vehicle use

The applicability and justification of magnetically levitated vehicles (maglev) for using in public mass urban and suburban traffic ensue from their advantages in relation to all other track-guided practically wheel/rail vehicles, which are connected with the following strategic goals and based on the optimal fulfillment of the following criteria:

- a high level of protection of the environment and human health considering the noise, vibrations, emissions and land use. At the same time preserving sensitive and ecologically valuable zones and the existing urban architecture by guiding the tracks on significantly sharper gradient and smaller curve radii than the existing track-guided vehicles;
- attractiveness of the system to the customers considering the travel speed, appropriate level of comfort, capacity and tact traffic, availability and intermodal connection as well as reasonable pricing of use.
- high level of safety, availability and reliability of the system;
- balanced investment for traffic system design and construction, as well as favorable specific prices for the construction of infrastructure;
- reasonable costs of traffic system operation regarding its maintenance and consumption of energy with predictable considerably lower external costs.

3 TECHNICAL SOLUTIONS FOR MAGLEV TRAFFIC SYSTEM

Magnetically levitated track-guided vehicles (maglev) are brought and maintained in the state of levitation by levitating devices. Thus, the vehicles are guided along the tracks without mechanical contact, whereas they are driven by linear electromotor. The applied systems for carrying and guiding the vehicle along a certain track are the following:

- electrodynamic suspension – EDS
- electromagnetic suspension – EMS
- permanent magnets.

Maglev vehicles are driven by three-phase linear long or short stator electromotor. The long-stator variant brings primary electric energy used for operation by stator coils set along the track. The advantage of the long-stator system lies in the fact that the vehicles are less complex and not so heavy, but on the other hand, the costs of construction are higher and requires a sophisticated vehicle drive regulation system.

The short-stator linear motor contains stator packages in the vehicle and the electric energy for the operation is brought by stator coils from the electrical line in the track through pantograph situated on the vehicle. Considering infrastructure costs, this is a much more acceptable variant than the long-stator variant, but the construction of the vehicle is much more complex. Nowadays, the non-contact inductive energy transfer is being intensively studied.

The use of three-phase asynchronous linear electromotor (LIM), whose is controlled similar to traction control of locomotives with three-phase asynchronous motor, is acceptable for maglev vehicles intended for the use in urban areas for mass public passenger transport which practically means movement on relatively short inter-station distances characteristic for urban and suburban traffic.

4 CONSIDERATION OF MAGLEV PERFORMANCES FOR URBAN APPLICATIONS

All means of transport, including maglev vehicles, are required to have as high traveling speed as possible and the larger acceleration and deceleration as possible to achieve the shortest possible traveling time and tact schedule. Border values of these important parameters are primarily connected with passenger comfort, linear motor power characteristics, energy network capacity and traction substations for supplying the system with electric energy during acceleration or generator braking.

For a vehicle with the characteristics as shown on the figure 1, traveling times have been calculated as a function of distance between stations and maximum speed limit (Figure 2). Vehicle characteristics rely on the existing test performances (Linear induction motor, short stator) for urban usage in Japan and South Korea. A multi-section vehicle of 90 tons and capacity for 360 passengers was envisaged.

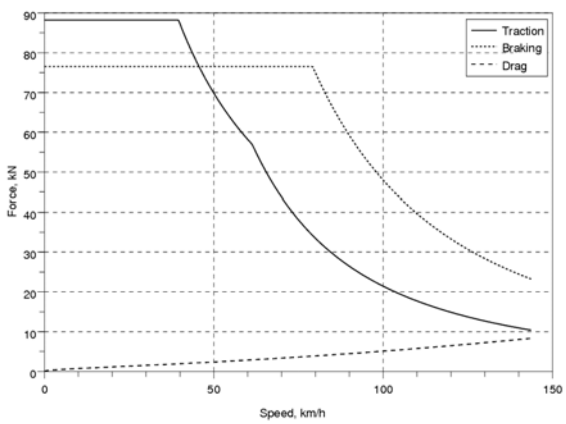

Figure 1. Traction and braking effort and drag as a function of speed.

The goal was to calculate vehicle kinematics for urban-suburban traffic considering the presupposed inter-station distances from 500 to 4000 m, as well as the characteristics of presupposed linear electromotor considering the vehicle mass. Thus, traveling times and peak periods of energy system can be considered, as well as the transition to the movement at a constant speed limited between 70 and 120 km/h.

Figure 2 illustrates the need for a large traction force in urban applications. It can be seen that on short inter-station distances the benefit of higher design speeds in traveling time can be very low or even none. In such a case shorter traveling time can be obtained only by employing a more powerful motor.

In connection with the increase of motor power, it should be borne in mind that due to passenger comfort the maximal acceleration should not exceed about $1 m/s^2$ (Figure 3).

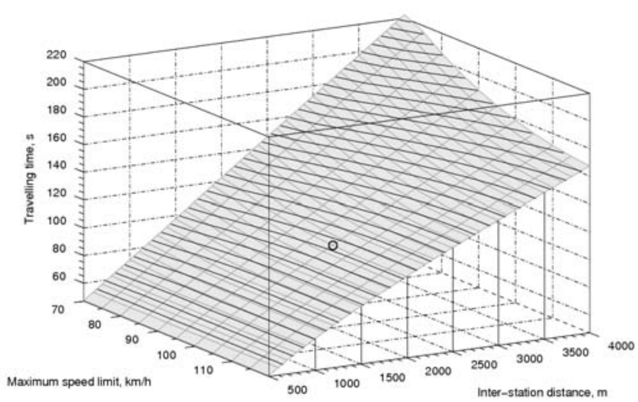

Figure 2. The surface is parameterized by an orthogonal mesh of inter-station distances vs. maximum speed limit. The curved contours correspond to traveling times. The circle marks the case detailed in Figure 3.

Therefore, the consideration of speeds exceeding 100 km/h with the assumed motor and distances has no justification. So this speed for the examined vehicle and linear motor in urban-suburban traffic conditions can be considered as appropriate (Figure 3).

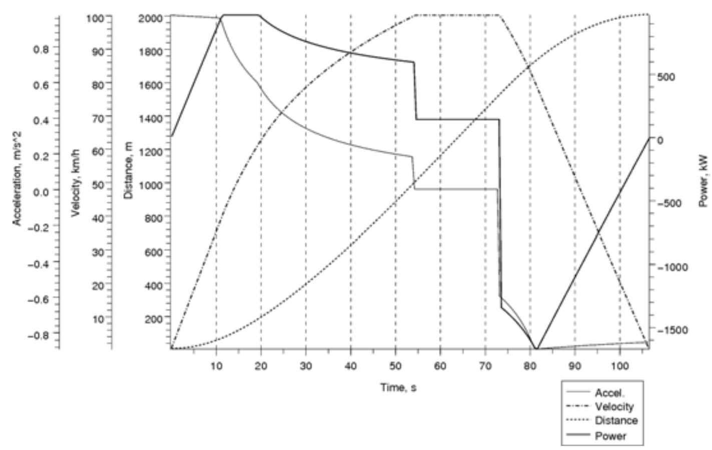

Figure 3: Results of calculation with 2000 m inter-station distance and maximum speed limitation of 100 km/h.

5 THE APPLICATION OF MAGLEV VEHICLES INTO THE CITY OF ZAGREB AND ITS SURROUNDING AREA

The City of Zagreb, the Croatian capital, is included among those European cities with about one million inhabitants and with a particular need for efficient mass public transit between the city and its surrounding areas. Therefore, Zagreb should be considered not only from the point of public transport focused on the core of the city but also taking into consideration its suburban and regional areas. In this terms, in parallel with the search for the most appropriate solution for the optimal passenger flow within the city area, it is important to find a solution for the traffic connection of the city and its suburban and regional surroundings, where large sources of passengers have formed. They are gravitating on business, social or cultural basis towards the narrow city area and therefore they need to have an optimal traffic connection with it

The situation today is characterized by a pronounced unbalances between mass public transport demand and the existing transport infrastructure of the city of Zagreb and its gravitating surroundings, resulted in congestions and bottlenecks with clear indications of real traffic total collapse.

Currently the mass public passenger transport of Zagreb and its surrounding areas relies on road vehicles. Furthermore, the existing tram network, situated on the same level as road communication lines, is inappropriate for actually sprawl of the city because of too low average speed. At the same time, the existing railway network has been inappropriately included into urban and suburban transport owing to limited transport possibilities relating to the current state of construction and technical equipment of infrastructure and vehicles. Therefore, it is justified to seek a solution for public, mass transit in the city of Zagreb and its surroundings in the framework of modern innovative maglev vehicle transport system.

The strategic approach to the investigation of the optimal solution for the public, mass, passenger traffic in the city of Zagreb using magnetically levitating transport vehicles has to take into consideration the vision of the development of the city and its urban peculiarities, the need in linking urban administrative authorities, business centers and industrial zones with shopping and residential areas as well as cultural, educational and sport institutions and facilities and optimal intermodal interfacing with all other traffic systems. The solutions should be realized gradually by defining priorities within one future network for magnetically levitating vehicles.

Considering the city of Zagreb, specific traffic conditions which enter into the evaluation process, arise from its geographic position, economic and social situation, current public transport demand within the city center and its regional surroundings, as well as prognosis for further passenger flows development. In parallel, the obligatory points of transport connection in the narrow city area and its gravitating surroundings have to be defined as well as ecologically sensitive zones, junctions and the interconnections with other kind of transport.

The current transport situation in the city of Zagreb unequivocally indicates the fact that in the first phase of the project, it would be relevant and purposeful to consider the connection of the city of Zagreb urban center (intercity and regional railway and road transport node) with the southern part of the city area in the direction of the international airport Pleso (ZAG). It is about a 20 km route with five or six stations (Figure 4).

If the considered short-stator magnetically levitating transport vehicles, with a capacity of 360 passengers should be used in automatic two-minute tact traffic, it would be possible to realize the transport of 10,000 passengers within one hour which would suit the peak hour load in Zagreb at that distance.

Having in mind that the design and construction of a modern network for maglev vehicles, with above-ground and under-ground tracks, requires a huge long-term investments, it should be necessary to evaluate the specific situation of traffic in the city of Zagreb and its gravitating surroundings in order to define the real level of ambition in such a large planning of transport infrastructure undertaking.

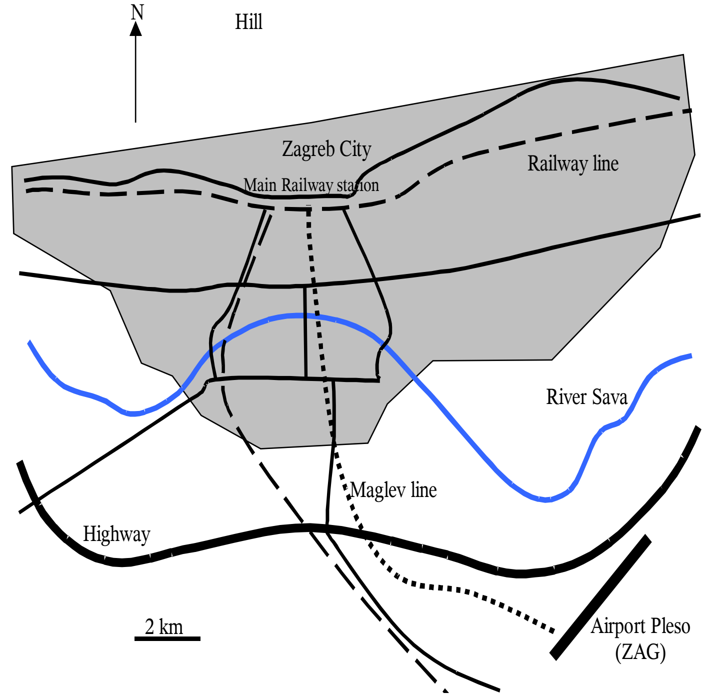

Figure 4: Zagreb city map.

6 CONCLUSIONS

Considering the current traffic situation of large urban areas and their surroundings, transport systems with magnetically levitating track-guided vehicles perfectly meet the strategic goals, criteria and indicators in the search for the best solution for mass public passenger transport. In that sense, the significant advantages of these vehicles are well-adjustment into the existing infrastructure and city area with their specific manner of track guidance (above-ground and under-ground), high transport efficiency, acceptable environmental impact, appropriate consumption of energy as well as the amount of investment and maintenance of the system as whole.

Taking into account the short inter-station distances within urban areas, it seems that the using of short-stator linear motor vehicles with the speed of up to 100 km/h could be the most appropriate.

Having regards to the transport needs and the peculiarities of the city of Zagreb, in particular strong demand for the passenger mass public transit between the city area and its surroundings, preliminary engineering is already initiated by the University of Zagreb and the national Ministry of Science in order to define the 20 km pilot route for the magnetically levitating vehicle (MAG-ZAG) between the center of the city of Zagreb and the international airport Pleso (ZAG). It is expected to start with intensive works on the project in the next year.

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