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Climate Impact-Minimizing Road Infrastructure Layout for Growing Cities

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***Abstract*—**City road transport contributes significantly to climate change, and the ongoing world urbanization is only increasing the problem. The paper describes a city planning concept minimizing the number of vehicles on the roads while increasing overall mobility. This becomes possible by utilizing a recently invented two-level road junction with a unique property of serving both as an intersection of uninterrupted traffic and an easily accessible transport hub capable of accumulating private vehicles, and therefore becoming an especially effective park-and-ride solution, and a logistics or business center. Optimized layouts of city road infrastructure, living and work areas, and major roads are presented. The layouts are suitable both for the development of new cities as well as for the expansion of existing ones. Costs of the infrastructure and a positive impact on climate are evaluated in comparison to current city growth patterns.

***Keywords*—**Congestion, city infrastructure, park-and-ride, road junctions.

I. Introduction

THE yearly cost of road traffic congestion in the European Union is estimated at 2% of its GDP [1]. Also, transport is responsible for 22% of global CO_2 emissions and road transport is responsible for three quarters of that amount [2]. Continuing population growth and spontaneous urbanization [3] will only exacerbate the problem. Therefore, minimization of road traffic congestion remains an important problem.

The main culprit of traffic congestions is a private car. As the modal split distribution shows for European passengers, 83% of their journeys are travelled by car, whereas buses and rail constitute the remaining 17% [4]. On average, only 1.5 passengers travel in one car including the driver [5], and consequently, CO_2 emissions attributed to one passenger of a private car (58 g/km per passenger) are about four times larger compared to bus passengers (15 g/km per passenger) [6]. Similarly, the average external costs of a bus (34€ per passenger per 1000 km) are almost twice lower than that of a private car (65€), whereas rail (15€) is twice more efficient than a bus [1]. The extensive usage of private cars is therefore responsible both for the traffic congestion and a considerable contribution to greenhouse gas emissions. A systematic approach to development plans of new cities and improvement of transportations systems is a key to solving this problem.

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II. Causes of Traffic Congestion

Recent strategic development plans of various cities put a lot of emphasis on new routes for public transport systems – subways, trams, and buses, whereas bikes and pedestrian traffic are encouraged. Simultaneously, advanced intelligent transportation systems are supposed to facilitate the use of these modes of transport. However, there is a lack of an infrastructural solution which could help integrate all these systems into one, and this article is trying to fill this gap.

One of the reasons passengers prefer private cars to public transport is the impossibility of public transport to provide door-to-door service in a chaotically spread-out city with most places of business concentrated in its center. Moreover, many cities provide parking spaces in city centers and other incentives directly or indirectly encouraging the use of private cars. Fig. 1 illustrates a common traffic situation in such a city – thickness of major roads corresponds to a size of traffic flows, which naturally increases towards the city center as there is usually no convenient or sufficient infrastructure to park cars and switch to public transport (park and ride). The increase of traffic raises the chances for road accidents, which in turn further increases congestion.

Fig. 1 A typical layout of a city with traffic increase in its center

Optimization of locations of passenger attraction centers with respect to road infrastructure could be a solution, but in general it is considered to be non-realistic, as businesses are given the freedom to decide for themselves their most optimal place in a city. Autonomous vehicles could be another solution, as they could decrease the distance between driving cars and therefore increase the capacity of all roads. However, this might lead to an even deeper dependence on personal cars. Their larger usage would negatively impact the environment and congestion in city centers would also remain a challenge.

A comprehensive solution is needed to solve the congestion problem.

III. Proposed City Transportation System

In order to optimize the multi-modal transportation system of a city, to reach zero-emissions of the city transport, and to optimize logistics systems and energy usage, the following interrelated measures are proposed:

- A fast circular ring-road around the city with no blocking intersections,
- Reconstructed junctions on intersections of major radial roads with the ring-road,
- The new junctions should be suitable for Park&Ride integration with the public city transport and also include logistics centers and other passenger attraction facilities,
- An intelligent traffic control system to manage traffic flows on major radial roads,
- Establishing the city center as a zone for electric cars only.

The measures would require only minimal road infrastructure changes on the outskirts of the city, whereas it can remain the same in the inner part of the city. Further city development will eventually require another ring-road (Fig. 2). New city segments delimited by major roads could be developed in a self-sustainable way with all major services (health, education, recreation, etc.) available locally in order to decrease travel necessity to other city segments. A key element of the model is the junction on the intersections of the ring-roads. The junction should be able to pass non-stop flows of traffic, and at the same time, it should accommodate public transport hubs and also be well suited for parking lots to facilitate modal changes for passengers. However, none of the conventional junctions satisfy these requirements.

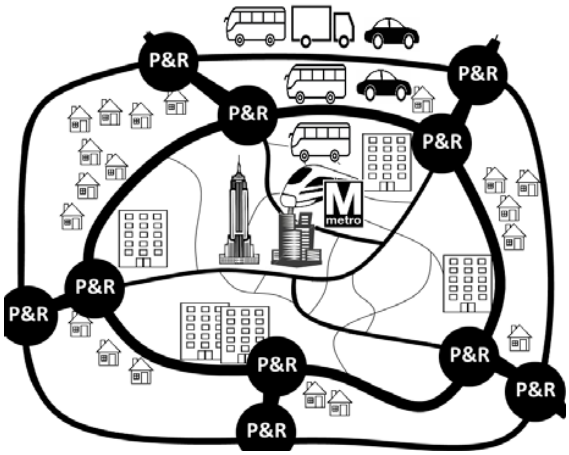

Fig. 2 Proposed structural layout of a city

Conventional 4-way junctions of continuous flow are designed in such a way that their territory is split into four areas and any nearby facilities are isolated in one of the four areas making them difficult to reach or to leave. Therefore, they are only dividing cities into separate segments and offer no integration with other modes of transport.

IV. The Pinavia Junction

Adding one more dimension to a conventional roundabout creates a unique two-level junction called Pinavia [7] (Fig. 3). The junction is suitable for intersections of high-traffic roads where left turns are necessary. Functionally, it is equivalent to a four-level stacked interchange as no traffic flows cross or interfere. Each roadway can be separated by a wall in order to further increase driving safety. The radii of the curves can be chosen to accommodate driving speeds equal to those of the crossing roads. A different number of lanes can be designed for each roadway independently to satisfy concrete capacity requirements.

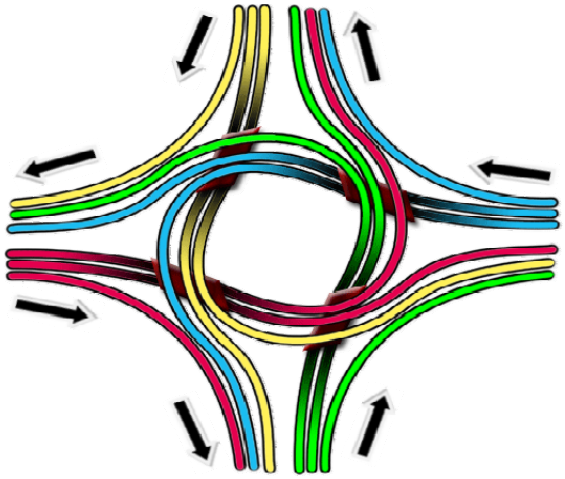

Fig. 3 Junction of a new generation Pinavia

Traffic flows through the Pinavia junction in a natural way: the rightmost roadway turns right, the middle one goes straight via two tunnels or overpasses (they can arranged differently depending on the terrain), and the left one makes a left turn via three tunnels or overpasses. It is worth noting that the tunnels (or overpasses) are needed for just half the road, therefore their cost is considerably lowered.

The drawback of the junction is its size, as there should be sufficient distance between the neighboring tunnels, otherwise the road from one to another will be too steep. Its radius also considerably increases for larger designed driving speeds. However, this drawback becomes its largest advantage because it is possible to access and utilize the large plot of land in its center by adding an extra driveway for entering and leaving without intersecting any other traffic flow (Fig. 4).

The usable land area in the middle of the Pinavia junction is approximately 18 ha in size when the driving speed is 70 km/h. In its very center, a small roundabout is suggested as the traffic flows are sufficiently small and slow there. This layout also solves the U-turn problem of the junction. The remaining area can be allocated to multi-level parking lots, and also any needed facilities for multi-modal transport. The parking lots

can be designed with right-turn entrances and exits as well, making them easily accessible. Three-level parking could accommodate up to 20,000 cars. Bus or tram stops can be arranged in the center, and a subway station underground. Due to easy access of the territory from all four outside roads the area could be not just a simple Park&Ride facility, but also a business and logistics center with multi-story offices and new work places away from the city center (Fig. 5).

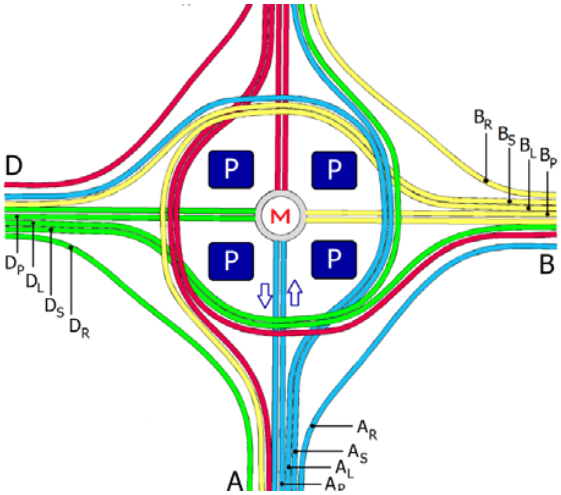

Fig. 4 Pinavia junction with an entrance to its center

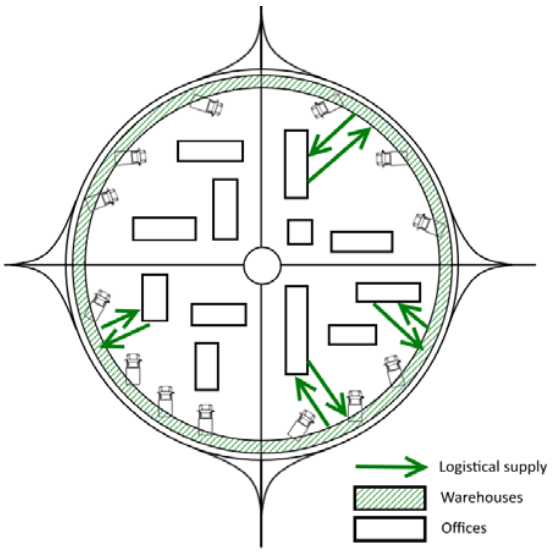

Fig. 5 Urbanization example of the Pinavia junction

Large flows of passengers using the junction to change their mode of transport create profitable conditions for all businesses in the area, and therefore direct business investments or private-public partnerships can be used to finance the construction of the junction itself. Even though the territory inside the junction is surrounded by roads, its size and proper placement of warehouses or vegetation eliminates noise and pollution concerns for the centermost areas.

V. Living Areas of a City

Having Pinavia-type junctions on all major intersections around a city makes it possible to optimize traffic in living areas of the city as well (Fig. 6). The Pinavias serve as Park&Ride facilities, and therefore passengers could use their cars, bicycles or local buses to reach one of them and then continue to other Pinavias or the city center using rapid mass transit. The local roads in the living areas could also benefit from one-way traffic roads.

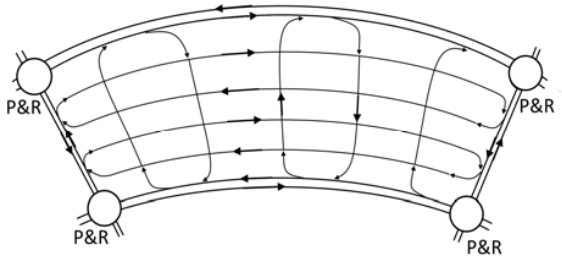

Fig. 6 Traffic flow diagram of a living area of a city

VI. Traffic Organization in a City

Implementation of the Pinavia junction would create naturally decreasing traffic flows towards the city center (Fig. 7).

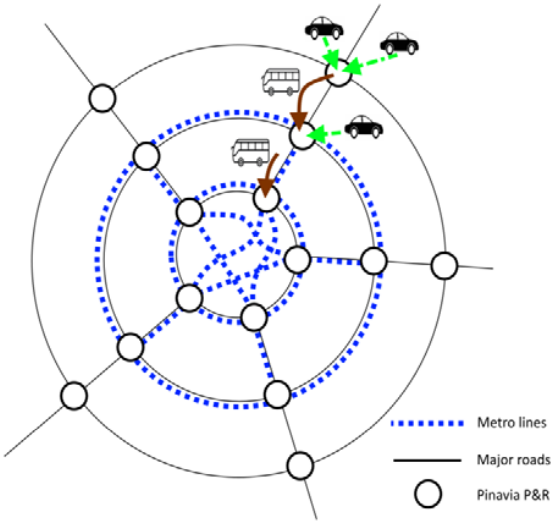

Fig. 7 Traffic organization in a city using Pinavia junctions

Most administrative work places could be relocated from the city center to one of the Pinavias leaving the historical city center as much car-free as possible, encouraging pedestrian and non-motorized traffic. The city center could be enclosed by the first ring-road and all major radial roads could come only through Pinavias on their intersections to facilitate control of incoming traffic. All conditions in the centermost part of the city should favor public transportation: all roads should have lanes allocated to public transport; traffic lights should favor public transport; high taxes for cars entering the

area; high parking fees.

People living in suburbs would use their cars or local buses to reach the nearest Pinavia. Some part of them would either stay there to work, or would take rapid public transport to reach any other Pinavia or the city center. Car sharing services may be used to reach their final destination if needed. Some passengers would choose to continue in their own cars, and if their number is too large, the city would have the same problem of congestions as before. However, this situation can be prevented.

To estimate the effect of Pinavia junctions on the external ring-roads of a city, we assume all major roads to have three lanes in each direction. During peak hour, all lanes will be used by traffic going from the suburbs (north) towards the city center (south), as in Fig. 8.

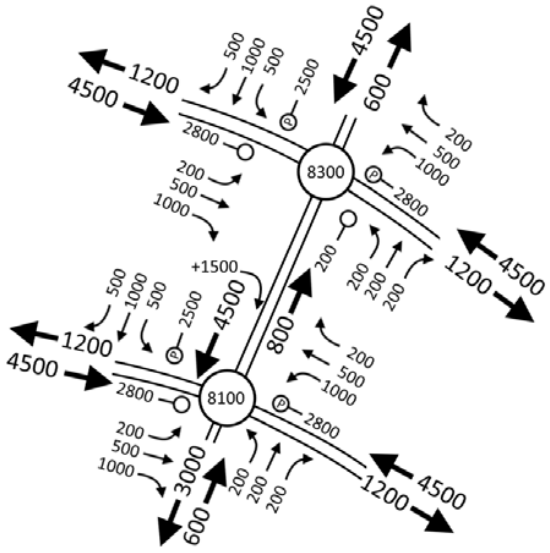

Fig. 8 Traffic matrix example for two Pinavia junctions

The maximum capacity of each lane is assumed to be 1,500 cars per hour. The first (top) Pinavia is receiving a maximal influx of cars from the north (suburbs), west (ring-road) and east (ring-road), while only a small number of cars is coming from the city (in this example: 800). The parking lots in the Pinavia can accommodate about 8,300 cars during the hour, and so 3,000 cars continue towards the second Pinavia. On the way they are joined by additional 1,500 cars coming from the local nearby area, and so, the second Pinavia receives the same flow as the first one. It can also accommodate additional 8,100 cars, and so only 3,000 continue to the city. The other passengers would use public transportation. A subway would be most suitable for the amount of passengers. The example is intended to show the traffic minimization effect of the Pinavia junctions, because without them, the flow towards the city would be close to 20,000, instead of the previous 3,000. As the roads are incapable of accommodating such flows, traffic congestion is guaranteed. The numbers in this example are arbitrary. However, for the given number of lanes and maximal incoming flows, the traffic would self-organize into a very similar scenario, because the drivers would choose to park their cars in the Park&Ride facilities instead of remaining in the congested traffic. Intelligent road signs on approaches to the Pinavias could facilitate the choice. An intelligent transport system could also warn drivers of possible problems further down the road and suggest for them to choose one or another Pinavia to park their cars, even if there is no imminent congestion.

VII. Logistics

Cargo transport also has a significant impact on city traffic. Most warehouses are located nearby major roads, so they are easy to reach from one direction, but extra distance has to be covered to reach them from the other one. In the proposed Pinavia-based city layout, with warehouses inside the Pinavia it becomes easy to reach them from any direction. It also creates a convenient possibility to develop some specialized rail lines to deliver cargo on to the city center.

VIII. Economic Considerations

The proposed city layout is intended to minimize and even eliminate traffic congestions. Economic impact of a particular Pinavia junction will vary depending on a city. However, even neglecting pollution and fuel costs, and time savings of passengers, and assuming each day some 10,000 drivers would choose to use the Park&Ride system instead of travelling extra 10 km to a city center, then one Pinavia would save more than 48 million car kilometers. Assuming an average depreciation cost of one car to be 0.57€/km, the savings would reach 27 million €, and this number exceeds the construction costs of the junction (estimated at around 25 million € for a 70km/h Pinavia). However, it is important to emphasize, that a single Pinavia road junction cannot solve the city traffic congestion problem without implementation of a fully integrated city transportation system.

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