# INTERCHANGE OF A NEW GENERATION PINAVIA

**StanislovasButeliauskas**
The General Jonas Žemaitis Military Academy of Lithuania
Šilo 5A, LT-10322, Vilnius, Lithuania
Phone: +370 212 103 553
Email: stanislovas.buteliauskas@pinavia.com

**AušriusJuozapavičius**, corresponding author
The General Jonas Žemaitis Military Academy of Lithuania
Šilo 5A, LT-10322, Vilnius, Lithuania
Phone: +370 212 103 555
Email: ausriusj@gmail.com

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**ABSTRACT**

A new two-level interchange of a unique design called PINAVIA is presented. The new interchange is functionally similar to a conventional four-level stacked interchange: transport flows do not intersect, the driving speed in all directions can be equal to the speeds of the intersecting roads, and the design allows arbitrary capacity in any direction. The PINAVIA design makes it possible to utilize the center area of the junction making it unique in its class. As a consequence, it is a natural component of a Park&Ride system, where private cars can be parked and public transport hubs created. Easy access without intersections to the center area makes it possible to create additional infrastructure with new working places. A new city transportation strategy can be implemented using several PINAVIA interchanges around a city, which could substantially reduce traffic in the city center. Alternative interchange designs are also possible based on the same principles of PINAVIA: designs for three or five roads, elliptical versions, and mirrored versions. Low costs, high safety and environmentally friendly aspects of this design make this invention suitable for improvement of city transportation systems.

*Keywords*: Two-level interchange, alternative interchange, Park and Ride

## INTRODUCTION

Road intersection is a facility with the main purpose to safely and efficiently distribute traffic flows. At-grade intersections tend to generate a pulsing traffic after them and are responsible for most cases of transport congestion, while graded interchanges are costly in terms of construction costs and required right of way (ROW). The transport congestion problem is recognized worldwide, and in the US alone it costs more than $121 billion a year (*1*). Assuming one 4-level stacked interchange costs around $300 million (*2*), it would be possible to build 400 such interchanges for this amount of money, more than there currently exist. However, it would be impossible to replace all 14,000 interchanges (an estimate based on the Federal Highway Administration data), and the number of at-grade intersections is several magnitudes larger. Consequently, the search for cheap and functional interchanges continues. A good example is the now popular improvements of the conventional diamond interchanges implementing the diverging diamond interchange concept, and then its newest conceptual improvement - the Double Crossover Merging Interchange (*3*).

Even the most sophisticated graded intersections can be congested, because their capacity (number of lanes) is usually higher than the capacity of the highway, and the merging of lanes after the intersection can create a bottleneck. This example illustrates the fact that interchanges alone cannot solve the congestion problem. However, even if the whole road network could be improved simultaneously as a whole, it has very rigid geometrical constraints in cities, and it cannot grow indefinitely, while the transportation demand has wider limits.

Frost and Sullivan's report (*4*) predicts a rapid increase in the urban transportation demand driven by online retail growth and the general urbanization of the world population. New measures will be needed by city planners to control vehicle access, and the report suggests the Hub and Spoke logistics model as the future model in urban environments. According to the model, freight distribution centers will be located on the outside of an outer ring road of a city 25 miles (40 km) away from the city center, nearby intercity highways (the spokes), and heavy commercial vehicles will unload their freight in those big warehouses. Medium and light commercial vehicles will deliver goods to central distribution centers on the inside of the ring road. Evidently, new graded intersections will be needed for the easy access to the warehouses on the spokes.

Despite the forecasted increase of the number of commercial vehicles, traffic in cities would be dominated by private cars in the foreseeable future. Consequently, in order to alleviate the transport congestion problem, most policies are oriented towards minimization of number of private cars. One of the popular tools for shifting the modal split towards the public transport is Park & Ride (P&R) facility. Contrary to expectations, P&R may lead to an overall increase in car transport (*5*), but it is decreased in a city center - the most congested area, so P&R remains a useful tool. However, for a P&R to be successful, it needs to be convenient for users, implying in particular its close location to rapid public transport routes (*6*). This is not always possible due to high land costs for the parking lots (*7*). Additionally, each larger P&R creates an additional intersection, if it is located near a highway.

This article presents an interchange named PINAVIA (*8*) with an unusual feature - despite the conventional function to distribute traffic flows, it can also give a free-flow access to a large plot of land, making it an attractive candidate for logistics centers or for P&R systems. Its various conceptual layouts are described first, followed by the discussion of its possible applications in a public-transport-oriented city transportation system. The multifunctional capabilities of the PINAVIA interchange, its possibilities to decrease traffic flows in addition to just redistributing them makes it more than just an interchange.

# LAYOUTS OF THE PINAVIA INTERCHANGE

## 4-Leg Circular PINAVIA Interchange

All PINAVIA interchanges are graded, two-level interchanges. The simplest 4-leg PINAVIA layout is presented in FIGURE 1. Each road for passing through the intersection has three roadways: the right one is for turning right ($A_R$, $B_R$, $C_R$, $D_R$); the middle one is for passing straight ($A_S$, $B_S$, $C_S$, $D_S$), and the left one is for turning left ($A_L$, $B_L$, $C_L$, $D_L$).

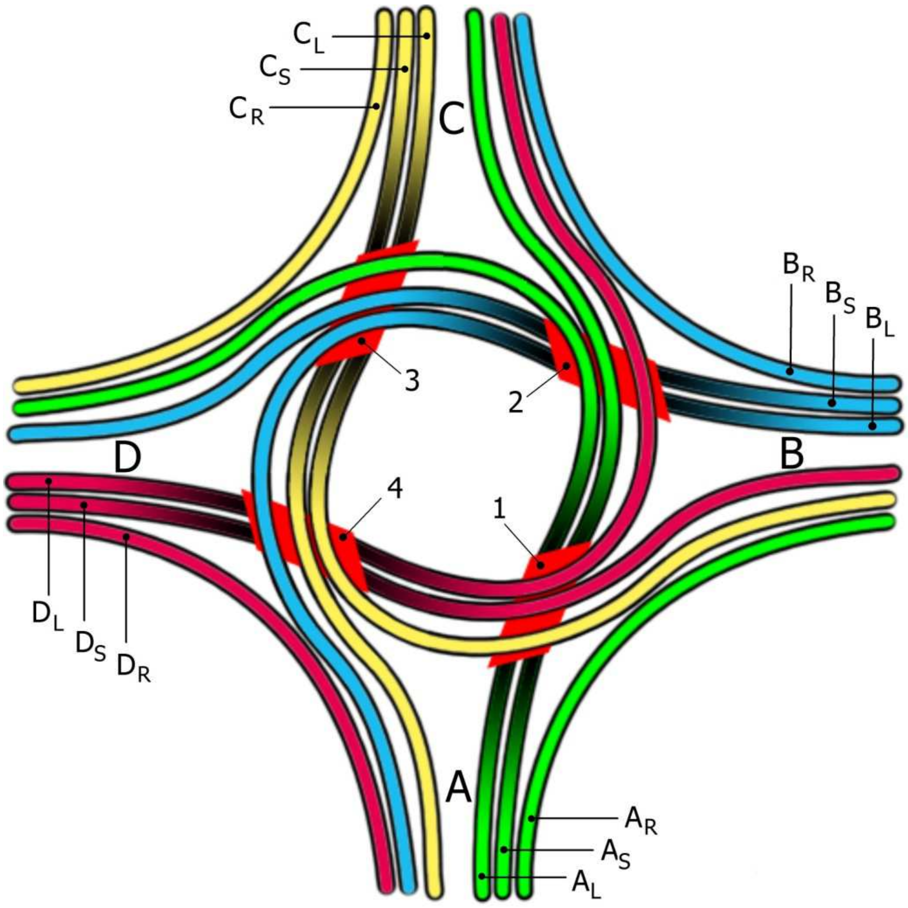


**FIGURE 1 Basic 4-leg PINAVIA interchange.**

Each roadway for turning right is separated from the entry road before the junction and merges the road on the right in a curve of a large radius.

The other roadways $A_L$ and $A_S$ of the entry road A pass over or under the crossing road using a tunnel or an overpass 1. The roadways continue in a left-turning curve until they pass over or under roadways of road B. Then the roadway $A_S$ turns right towards road C, while $A_L$ continues in the left-turning curve until it passes over or under roadways of road C. Finally, $A_S$ turns right and joins road D.

Any of the four road crossings can be built either as a tunnel or an overpass. There is no weaving needed while driving through the junction, and so the roadways can be separated by a fence or a concrete wall. The radii of all curves inside the junction are never smaller than the smallest radii of the intersecting roads, allowing to cross the junction without altering the driving speed. AASHTO discourages the use of left-hand exits in an interchange, but the equal driving speed on all roadways of PINAVIA mitigates the crash possibilities, and it becomes a matter of proper signing in order to negate possible driver confusion before entering the interchange. Alternatively, a mirror reflection of the basic PINAVIA layout could be used to eliminate the left-hand exits (FIGURE 2).

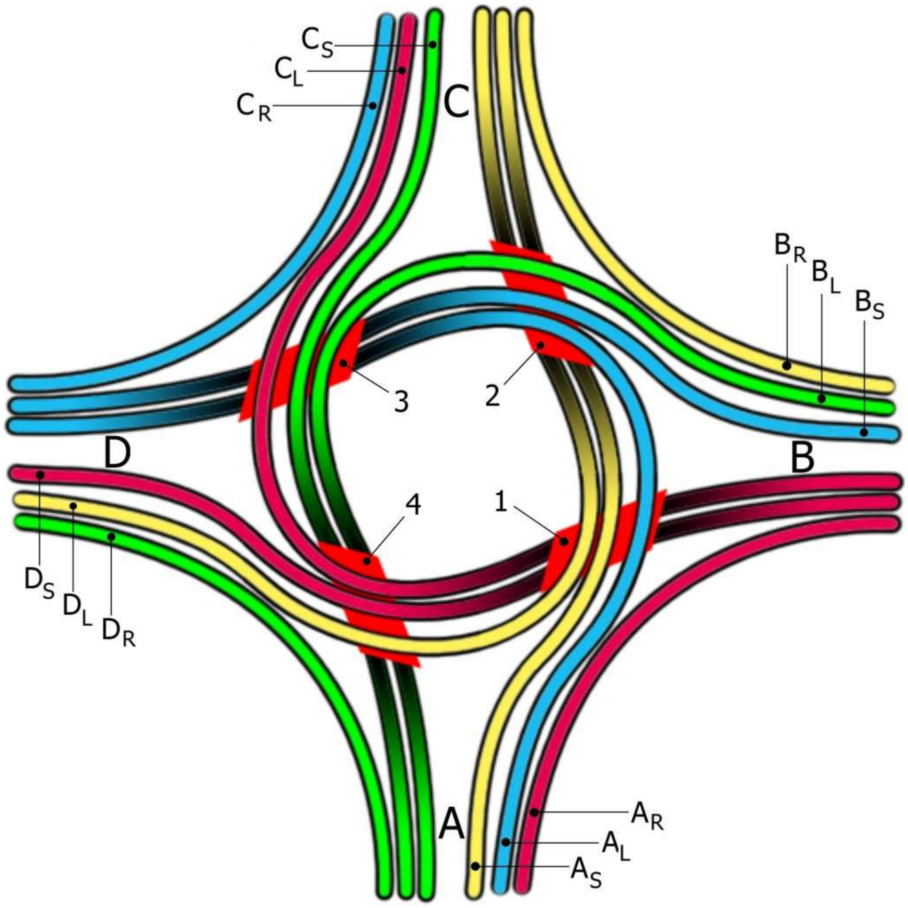


**FIGURE 2 Mirror version of the 4-leg PINAVIA interchange.**

In the mirror case the roadway for driving straight $A_S$ is located on the left, with the left-turning roadway $A_L$ next to it on the right. The right-turning roadway $A_R$ can be separated from the right side of the road earlier, as in the original basic layout. The left-turning roadway $A_L$ passes three tunnels or overpasses and joins the left road D from the left, so a left-hand entrance is introduced. Again, all three roadways have very similar curvatures and the same driving speed.

However, the mirror layout has a more serious drawback - it eliminates the possibility to access the large central area inside the interchange, which is one of major advantages of the PINAVIA junction. Simply adding another roadway on the left makes it possible to access (and leave) the center area of the original PINAVIA without interfering with other traffic flows (FIGURE 3). The large easily accessible area can be utilized for parking lots, public transport hubs (such as metro), logistics warehouses or any other development. The roadway $A_P$ for accessing the parking area may be separated from the main road after passing the first overpass (or tunnel) in order to minimize the size of the structure needed (it is however drawn in a straight line in FIGURE 3 for simplicity). The exit roadway goes along the same path as the entry roadway, and merges the main road from the left. Traffic in the very center of the interchange is low speed and regulated with a simple roundabout, although other designs are possible. It is worth to note that this layout has a U-turn possibility from any road.

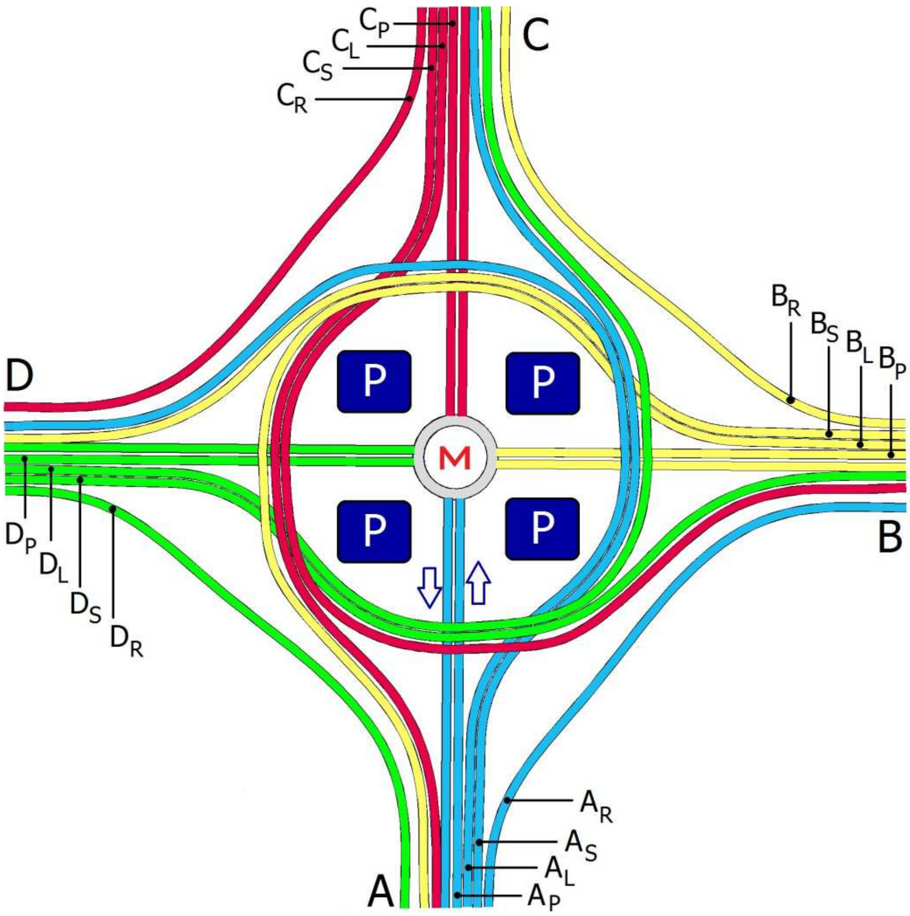


**FIGURE 3 PINAVIA interchange with an access to its center.**

The PINAVIA interchange is unique, because no other free-flow interchange layout allows to utilize its occupied plot of land for another purpose apart from distributing traffic flows. Rapid public transport routes connecting the parking lots inside the PINAVIA with a city center could create an effective P&R system, limiting the number of cars passing towards the city. Additionally, new easily accessible working places can be established inside the junction, decentralizing the city. A stadium could also profit from being placed inside such a layout, because its exists are unobstructed into all four directions.

The size of the PINAVIA interchange is influenced by two main parameters: the minimum radius of the horizontal curves (directly related to a chosen design speed, which is equal for all directions) and the maximum allowed grade of roads when climbing from a tunnel onto a next overpass. The second parameter is irrelevant for design speeds above 60 km/h (40 mph), because large radii of horizontal curves pushes the overpasses far apart. In general, the total required ROW for the PINAVIA is very large. On second hand, the ratio of the size of the utilizable land inside the interchange to its total area increases with the size of the interchange. E.g. it needs 20 ha (ca. 50 acres) for 50 km/h (35 mph) design speeds and gives access to a 2 ha (5 acres) plot of land in its center, so 10% of ROW can be recovered. However, the 70 km/h (45 mph) PINAVIA occupies 53 ha (130 acres) and the center area increases to 23 ha (57 acres), so even 44% of the ROW can be utilized for an additional high-profit development.

**Alternative PINAVIA designs**

In a situation when two highways of different design speeds intersect, an elliptical form of the PINAVIA interchange might be applied (FIGURE 4).

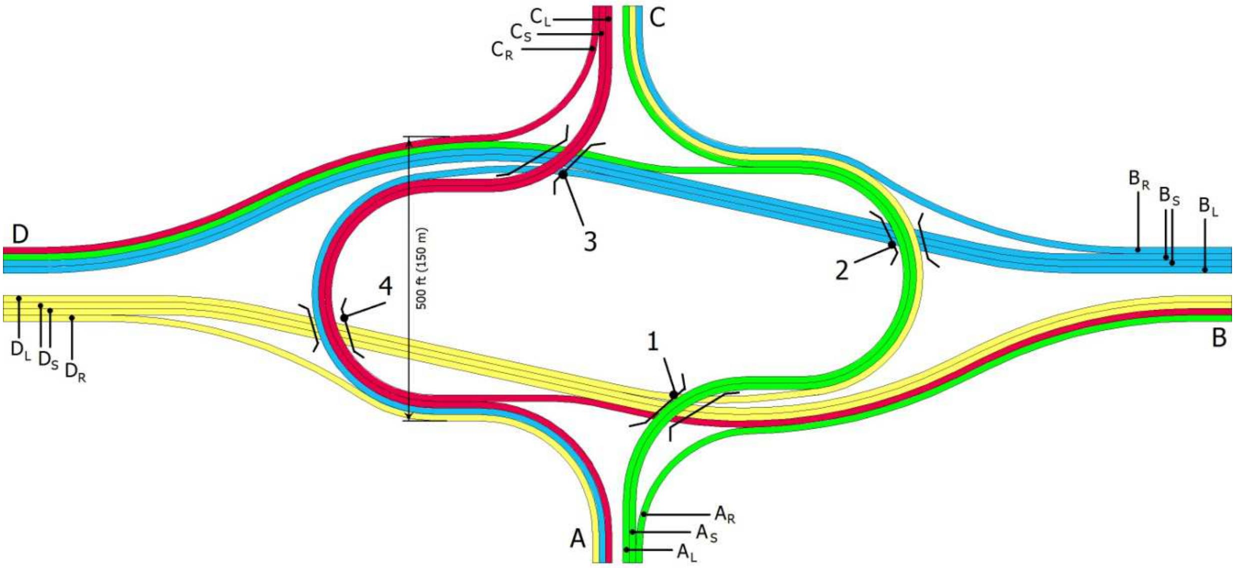


**FIGURE 4 Elliptical PINAVIA interchange layout.**

The elliptical layout requires substantially less ROW: the interchange of 50 km/h (35 mph) and 70 km/h (45 mph) roads occupies only 7 ha (17 acres), but the size of the usable land inside decreases as well.

The same principle of plaiting the roadways can be applied to 3-leg and 5-leg intersections (*8*). The 3-leg version is obtained by simply eliminating one of the four roads in the basic 4-leg PINAVIA. However, its circular form requires a lot of ROW, and a conventional directional junction with 3 overpasses is superior. The 5-leg version is more complicated than its 4-leg analog. Even though it uses only 5 structures, it occupies a large area, and it might be more cost effective to split the 5-leg intersection into 3-leg plus 4-leg system in most cases.

A general drawback of all PINAVIA layouts is the large widening of road median in order to create the empty central area. It is therefore more costly to upgrade almost every existing interchange where the through-lanes tend to go in a straight line. Also, curving of the through-lanes decreases the driving speed. In order to leave the through-lanes of crossing roads in their previous positions the PINAVIA would need additional structures. One of possible layouts is presented in FIGURE 5. Median of only one road (B-D) is expanded to accommodate the looping of left-turning roadways $A_L$ and $C_L$ of the other road. All exits and entries are on the right side in this layout. However, 6 structures are needed in this case, and the ROW is very sensitive to the size of radii of the left-turning roadways. Also, the largest advantage of the PINAVIA interchange - its added functionality due to a centrally accessible area is lost in this layout. In that respect, many other designs could be superior to this PINAVIA layout, in particular - the newly invented Double Crossover Merging Interchange, DCMI (*3*).

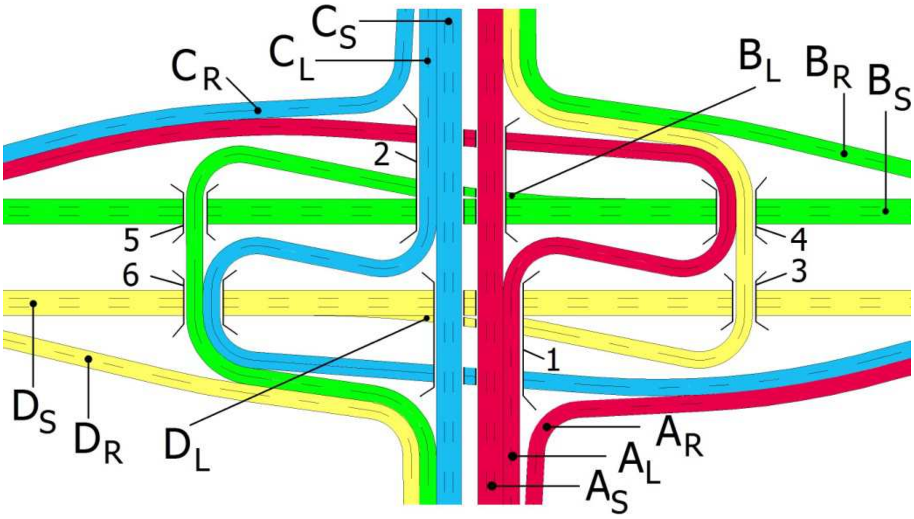


**FIGURE 5 Centrally-crossed PINAVIA interchange.**

## COMPARISON OF INTERCHANGES

The main characteristics of the PINAVIA interchanges and several other representative intersections are given in TABLE 1.

**TABLE 1 Comparison of Selected Interchanges**

| **Intersection type (ramp speed)** | **Conflict points** | **Free flow** | **Construction costs (M$)** | **Suitable for P&R** | **Extra value** | **ROW (ha/acres)** |
|---|---|---|---|---|---|---|
| At-grade | >4 | No | Minimal | No | No | Low |
| Roundabout | >4 | Not for left turns | Small | No | No | Low |
| Cloverleaf | 4 | Not for left turns | Average | No | No | Large |
| Diamond | 8 | Not for left turns | Small | No | No | Average |
| DCMI<br>35 mph (50 km/h) | 0 | Yes | Average | No | No | Large<br>20/50 |
| 4-level stacked<br>45 mph (70 km/h) | 0 | Yes | Very large<br>120 | No | No | Large<br>28/69 |
| PINAVIA Circular<br>45 mph (70 km/h) | 0 | Yes | Large<br>54 | Yes | Center area 18 ha (44 acres) | Large<br>36/89 |
| PINAVIA Elliptical<br>35 mph & 45 mph<br>50 km/h & 70 km/h | 0 | Yes | Average<br>18 | Yes | Center area 2 ha (5 acres) | Average<br>7/17 |
| PINAVIA Centrally Crossed, | 0 | Yes | Large | No | No | Average<br>9/22 |

The construction costs are only indicative and presented mainly for comparison, they would differ depending on a place and time. They were obtained by measuring the needed asphalt area and the area of structures, and calculated following the method in Harris' thesis (*2*). The ROW of the DCMI interchange is a rough approximation.

Of all free-flow interchanges considered, the 4-level stacked interchange is the most expensive, while DCMI would be a clear winner if a reconstruction of an existing diamond interchange is considered. However, if a new interchange is being considered, then the Elliptical PINAVIA might become a feasible alternative. Moreover, if land costs are very high, and the environment permits a construction of the Circular PINAVIA with an access to its center (FIGURE 3), then it will have a clear cost advantage.

## CITY TRANSPORTATION SYSTEM IMPROVEMENT STRATEGY

Limited through-speed and large ROW of PINAVIA interchange leaves a rather narrow window for its applicability - only the suburban areas could be considered. However, that is where a P&R system could be most effective, and growing cities could profit by implementing the following transportation system strategy when building or reconstructing their ring-road (FIGURE 6).

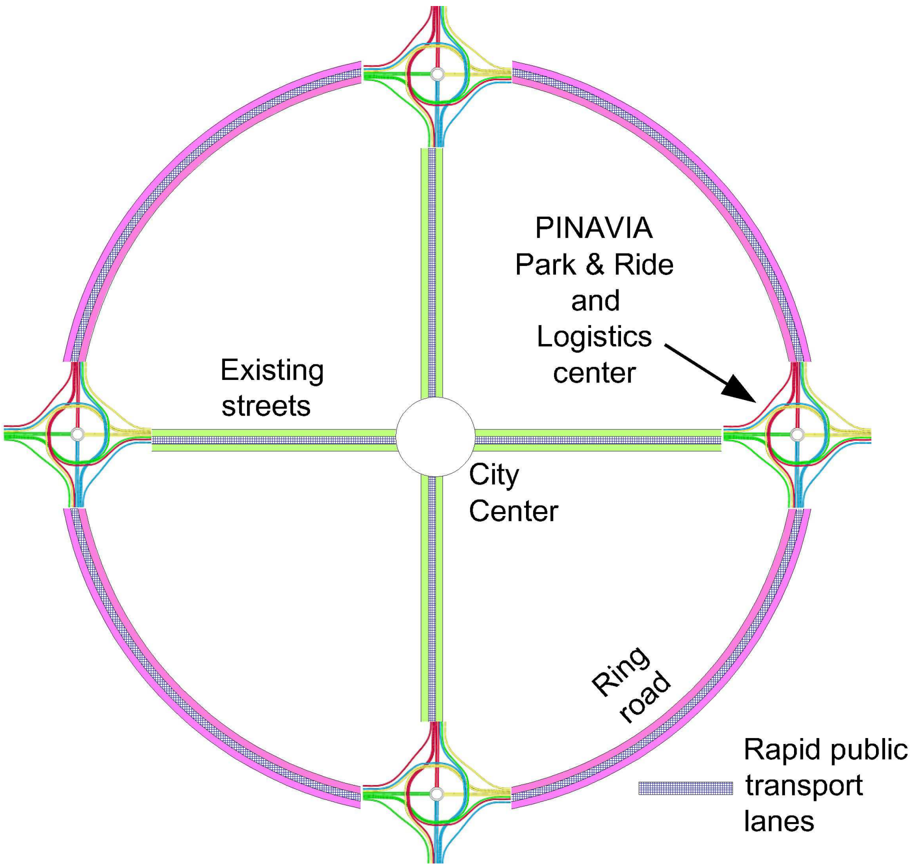


**FIGURE 6 A concept of city transportation strategy involving PINAVIA.**

The road infrastructure inside the city remains unchanged, although some policies in favor of public transport might be implemented, such as congestion fee, larger parking fees, or an increased quantity of dedicated public transport lanes. The main element is the PINAVIA interchanges built on all major intersections of the ring-road. Every interchange should have parking lots and hubs of rapid public transport inside it. The public transport routes should be connecting the hubs and the city center. The interchanges may also host logistics centers, supermarkets, business centers etc. A 3-level parking garage inside the 70 km/h (45 mph) PINAVIA interchange could house up to 20 thousand cars. If just a third of the parked cars are coming from outside the ring road then 6-7 such interchanges around the city could eliminate more than 50 thousand vehicles from the city center daily. Additionally, new decentralized and easily accessible working places inside the PINAVIA interchanges could reduce the traffic load in the city center even more.

Evaluation of the overall economic effect of the proposed system should consider these positive contributions: 1. fuel, time, pollution, and car exploitation savings for P&R users; 2. same type contributions from other traffic participants in the less congested city; 3. time savings for workers in the new easily accessible working places inside the PINAVIA; 4. income from the additional road pricing policies; 5. income from the highly valuable plots of land inside the PINAVIA rented or sold to businesses. It is of course possible to have the ordinary P&R and interchange system, but the ordinary P&R would require additional plots of land, which are not so easily accessible and much more inconvenient to use than the proposed PINAVIA P&R.

## CONCLUSIONS

Transport congestion depends on the capacity of a road network, traffic intensity, and means of traffic organization and control. As a consequence, local solutions such as improvement of conventional road interchanges cannot solve the problem alone. In addition to road infrastructure improvements, policies directed towards larger usability of public transportation are being implemented, with Park & Ride systems as one of popular tools in this direction. The congestion problem is not easily resolvable because improvements to the road infrastructure, in particular - to large interchanges, are very costly, and the P&R system does not always work if it fails to fulfill the convenience expectations of its users. In this article a multifunctional interchange of a new generation PINAVIA is presented. In addition to its primary functions of high capacity free-flow distribution of traffic flows, it gives a possibility to easily access and utilize a large plot of land in its center. The recovered right-of-way can be used to create an effective P&R system, a logistics center, or some other kind of business center. In order to achieve maximum effect of the interchange, it should be used as one element in a whole city transportation system, placing several PINAVIA on a city ring-road, and connecting them with routes of fast public transport. 6-7 PINAVIA interchanges for design speeds of 70 km/h (45 mph) could eliminate up to 50 thousand private cars from the central area of the city, reducing the congestion.

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