Intersections at different levels - an alternative solution to the development of the road network

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Abstract. Modern road network should provide conditions for safe and comfortable movement, both for drivers and for pedestrians. Transport industry development specialists face such transport problem as the low capacity of the road network. Low capacity causes congestion in the road network, disruptions in the organization of normal traffic flow, traffic jams, an increase in the number of traffic accidents. One way to solve this transportation problem is to use alternative solutions when designing. These solutions include constructing the intersections at different levels. The aim of the study is to compile data on alternative diamond-shaped intersections at different levels with a change in the side of movement. The main results of the study are that at the moment there are three schemes of a diamond-shaped intersection with a change in the side of the movement. These types of intersections have a smaller number of conflict points, compared with the intersection of the diamond type. The experience in the operation of road sections with diamond intersections showed a decrease in accident rates. Cyclists and pedestrians can use the junctions as well. The results of the study give an idea of the level of design of alternative types of intersections abroad. Considered interchanges can be used not only when at crossings of high-category roads, but also in cities, in the conditions of the existing development.

1. Introduction
Every year there is a tendency of increasing number of cars, which makes it necessary to carry out measures for the reconstruction of the existing road network and the construction of new roads. The existing road network does not correspond to socio-economic needs, which is primarily due to the high growth rate of motorization. Imbalances in the development of the road network strongly affect the uneven loading of roads, which in turn stimulates the growth of traffic accidents, especially in the areas with low traffic capacity and high traffic intensity. One of the most emergency sections of the road network is the intersection of highways. Accident statistics show that, on average, 60% of all traffic accidents occur exactly at the one level intersections of roads.

With a high intensity of traffic, intersections of one level do not satisfy the requirements of movement, since they have insufficient capacity. In this case, there are congestions and traffic jams, a
high density of movement, and the need for maneuvering creates unforeseen and dangerous situations. This leads to an increase in the number of traffic accidents.

In order to improve the conditions of traffic flow and reduce the number of conflict points at intersections, transport interchanges are built with different levels. There are various intersection patterns at different levels. The advantage of these intersections is the absence of interception points of traffic flows, there are only merging and branching points.

2. Influence of planning and schemes of intersections at different levels on the accident rate

Intersections at different levels can have different configurations and traffic patterns. The effect on traffic safety of various geometric elements of intersections at different levels was studied in detail by American (Lundy, 1967; Cirillo, 1968, 1970; Yates, 1973) and Norwegian (Wold, 1995) researchers. These studies examined the safety of different types of intersections at different levels, the influence of the values of the turning radius at the ramps, the significance of the secondary road pass location (above or below the main road), and the length of the acceleration and deceleration lanes. The results of these studies are presented in Table 1.

| Intersection types at different levels                                      | Impact on the types of accidents | Best result | Limits of results variation |
|----------------------------------------------------------------------------|----------------------------------|-------------|----------------------------|
| Diamond intersection at different levels instead of pipe type intersection  | All types of accidents in the intersection zone | -25         | (-50; -23)                 |
| Diamond intersection at different levels instead of straight ramps        | All types of accidents in the intersection zone | -25         | (-59; +40)                 |
| Diamond-shaped intersection at different levels instead of the clover leaf | All types of accidents in the intersection zone | -6          | (-17; +6)                  |
| Diamond intersection at different levels instead of at 2 levels with 2 straight ramps | All types of accidents in the intersection zone | -9          | (-25; +10)                 |
| Increase of the turning radius at the ramps                               | All types of accidents in the intersection zone | -23         | (-28; -17)                 |
| The minor road passes over the main road instead of the main road above the minor | All types of accidents in the intersection zone | -4          | (-17; +10)                 |
| Lengthening the acceleration lane for 30 meters                           | All types of accidents on the acceleration lane | -11         | (-17; -5)                  |
| Lengthening the deceleration lane for 30 meters                           | All types of accidents on the deceleration lane | -7          | (-13; +0)                  |

The results of the study showed that diamond-shaped intersections at two levels are the safest intersection types. First, the diamond-shaped intersection is simple in layout and provides good visibility for drivers, which greatly reduces the likelihood that the driver can choose the wrong direction to enter or exit. Second, the ramps of the diamond-shaped intersection at different levels have a direct form.
Curvy ramps have a higher degree of risk than direct ones. Third, in most cases at the diamond-shaped intersections a minor road passes over the main road.

3. Modifications of diamond-type intersections
The era of designing and developing of traffic interchanges began in 1916, when the American Arthur Hale received a patent for a clover leaf interchange [2]. Since then, the number and modification of intersections in different levels has significantly grown. Many intersections and junctions of highways were developed with two levels, which were based on the “clover leaf”. One type of such intersections is a “diamond” type interchange, which is based on an incomplete “clover leaf” [3, 4]. In this type of intersection, there are no left-turning exits that are present in the “clover leaf”.

In 2003, Gilbert Chlewicki proposed a modification of the diamond-shaped intersection [5]. This is a diamond-shaped interchange with a change in the sides of the movement. In the proposed solution, traffic flow on the minor road moves from the right side to the left side and vice versa. The change of traffic flows happens before and after the overpasses.

There are several variations of this interchange. The first option - a minor road runs along the overpass over the main road. The change in the sides of the movement takes place before and after the overpass, i.e. above the main road (Figure 1).

The second option - a minor road passes under the overpass, the main road passes over it. A change in the direction of movement takes place before and after the overpass, i.e. under the main road (Figure 2) [5].

The third option is a modification of the second, when the diamond and the nodes of the movement change are shifted away from the intersection point of the axes of the main and minor roads [6].

![Figure 1. Changing the sides of the movement before and after the overpass.](image1)

![Figure 2. Changing the sides of the movement under the overpass.](image2)

4. Investigation of the features of diamond-shaped intersections with changing traffic movement sides

4.1 Elements of diamond intersections with changing traffic movement sides
Diamond-shaped intersections with changing sides of the movement have five unique working areas [5]:
1. Approach zone - refers to the street segment between the upper intersection and the first intersection of the roundabout.
2. Intersection zone - refers to the intersection itself and the entrances and exits from this intersection.
3. Exit zone - refers to the area between the diverging area of the freeway and the cross street.
4. Entry zone - refers to the area between the second intersection and the junction of the freeway.
5. Leaving area - refers to the area between the second intersection and the next adjacent signal at the intersection.
The working zones of diamond-shaped interchanges with a change in the sides of the movement are presented in Figure 3.

Figure 3. Working areas of diamond-shaped intersections with changing sides.

One of the advantages of the diamond-shaped intersection is the solution of the left-turn exits. The proposed option is much more convenient compared to left-turning exits at the intersections of the clover leaf type, where in order to make a left turn, the driver has to turn right at the exit. The left-turning exits of the "clover leaf" are made in the form of a ring of small radius in the layout. In the considered variants, after passing the traffic light at the first node of the change of direction, the driver moves to the left side of the road and sees a turn to the left, i.e. there is no loss of driver orientation. The left exit is smoother, it is not necessary to do a full circle, like at the intersection of the “clover leaf” type. We can say that this is the same left turn exit as in the “clover leaf”, but pulled along the main road.

This solution of the diamond-shaped intersection has a positive effect on the emotional state of the driver and on his perception of the road situation [6, 7]. Since the change of direction occurs before the crossing of the overpass, the driver has time to think about the maneuver while the car was standing in front of the traffic light. There is no loss of orientation, in opposite to the “clover leaf”, where driver has to turn right for the left-side exit. Thus, the emotional state of the driver remains stable and does not interfere with the movement at the diamond intersection.

It should also be noted that the diamond-shaped intersection with a change in the direction can be used in urban conditions, because it is quite narrow. All exits are extended along the main road. This allows us to enter the intersection in a dense urban area without affecting existing buildings.

4.2 Safety of diamond intersections with changing sides.

The number of conflict points present at the intersection determines the degree of danger of the intersection. Conflicting points arise at the intersection of traffic, pedestrian and bicycle flows. Conflicts between vehicles can be described as merging, branching or crossing of the flows, where conflicts pose the greatest risk for accidents. Although traffic control devices can reduce the number of crashes by eliminating conflict points or controlling them with traffic signs, traffic lights or road markings, traffic control and intersection geometry cannot completely eliminate the mistakes made by road users.

The design of the diamond-shaped intersection with a change in the sides of the movement showed that it improves the movement of turning vehicles on the road, which contributes to a significant reduction in the number of conflict points between vehicles compared to conventional intersections of the rhombus type. A diamond-shaped intersection with a change in the sides of the movement reduces the severity of conflicts, since conflicts between left-side movements and opposing through movements are eliminated.
The decrease in the number of conflict points at the diamond-shape intersection with a change in the sides of the movement as compared with the intersection of the rhombus type is associated with a change in the direction of traffic flows and the placement of traffic lights in front of these nodes [8, 9].

The interchange developed by Chlewicki has 14 conflict points: 2 intersection points, with traffic lights in front of them, 6 merging points and 6 branching points of traffic flows (Figure 4). The presence of traffic light regulation forces drivers to be more attentive, to move at a slower speed when moving from one side of the road to another. We should note that the diamond-shaped interchange does not have a long section of flow maneuver, like a “clover leaf” or “rum” type, where there is an intersection of cars that entering the left exit and leaving it [10, 11, 12, 13, 14, 15]. Diamond shape avoids this due to changes in the movement sides and the presence of traffic lights that limit the speed of traffic flow. It is worth noting that the diamond-shape intersection has 26 conflict points: 10 intersection points, 8 merge points and 8 branch points of the traffic flows.

![Figure 4](image)

**Figure 4.** The number of conflict points at the diamond-shaped intersection with a change in the sides of the movement.

At the development of geometrical parameters of a diamond-shaped intersection with changing sides of the movement, we should take into account that this type of intersection will be effective for road crossings of I and II technical categories or for crossings of streets of urban significance with continuous traffic and traffic light regulation. On the roads of I and II categories we can project 4 or more lanes. The presence of two lanes in the same direction is the minimum at which this interchange will function. One lane is for traffic in the forward direction. Another lane is for driving to the left, but it will have a merging of the flows that make a left turn and left u-turn. Therefore, in order to avoid an increase in the number of conflict points, we should design two lanes for moving in the forward direction, one lane for making a left turn, and one more lane for a left u-turn (Figure 1). Thus, the overpass should be designed with four lanes in each direction.

At the development of diamond-shaped intersection in urban areas, it is imperative to consider the presence of sidewalks for pedestrians. If the side change diamond is below the main road, then pedestrian crossings and sidewalks should be built along the minor road (Figure 2). Sidewalks can be located on the overpass if the main road passes underneath. The literature provides an example of the organization of pedestrian traffic [14]. In particular, when the diamond is located above the main road, the sidewalk can be located between the traffic change flows, i.e. along the overpass axis. At the traffic lights the walkways are divided into right and left sides of the junction and pedestrians should cross the road using “zebra” (Figure 1).
4.3 The formation of a speed mode on a diamond-shaped intersection with a change in the sides of the movement

At the roundabout, traffic flows merge in the right-hand lane of the main direction (with the exception of junctions with straight left turns) and to assess the throughput of the confluence zone, it is necessary to determine the distribution of the intensity of the direct direction along the lanes of the carriageway. This distribution depends on the intensity and composition of the movement (Figure 5). On city highways with higher traffic, the distribution of traffic along the lanes of the carriageway is more stable.

Figure 5. The distribution of traffic intensity on the lanes of roads.

The intensity of the main direction has the same effect on the boundary time interval in the confluence zone as at any conflict point: at average densities of the main flow, an increase in traffic intensity in the right lane causes a decrease in the boundary time interval in the confluence zone of the traffic intersection, and at low and high density the time interval in the confluence zone of the traffic intersection remains almost constant (Figure 6).

The boundary interval can be reduced by reducing the difference in the speeds of the main and inflowing flows. The most unfavorable case, corresponding to the smallest throughput of the confluence zone, is a preliminary stop of the car before leaving the exit. This situation can be eliminated by the installation of transition-speed lanes. However, the difficulty of exiting can be completely eliminated in the absence of traffic on the transition-speed lane. Otherwise, the exit conditions from the congress will be determined precisely by this traffic intensity.

Free flow speeds are limited by the diamond-shaped geometry with changing sides of the movement. Studies of diamond-shaped interchanges with changing directions of movement throughout the United States showed that the free flow between cars is lower than the established speed limit. Free flow rates for left turn and right turn movements are also limited by intersection geometry.
Figure 6. The effect of traffic intensity on the right lane of the main road on the boundary time interval in the confluence zone of the traffic intersection (85% coverage flow).

Studies of the free flow velocity at 6 diamond-shaped interchanges with changing sides of the movement are given in Table 2 [5].

Table 2. Parameters of the speed of the car on the diamond interchanges with a change in the sides.

| №  | Intersection                  | Speed limit (km/h) | Vehicle speed (km/h) | Speed of left turn off the highway (km/h) | Speed between vehicles (km/h) |
|----|-------------------------------|--------------------|----------------------|------------------------------------------|------------------------------|
| 1  | MO 13, Springfield, MO        | 64,36              | 38,62                | 24,14                                    | 40,23                        |
| 2  | National st., Springfield, MO | 64,36              | 40,23                | 33,80                                    | 46,67                        |
| 3  | Bessemer st., Alkoa, TN       | 56,31              | 41,84                | 24,94                                    | 51,50                        |
| 4  | Dorsett Rd, Maryland, MO     | 48,27              | 41,84                | 37,82                                    | 49,89                        |
| 5  | Front st., Kansas-city, MO   | 56,31              | 38,79                | 32,19                                    | 43,13                        |
| 6  | Winton Rd, Rochester, NY     | 72,4               | 46,51                | 29,93                                    | 50,05                        |

Table 2 shows that vehicle speeds range from 38.62 to 41.83 km/h regardless of speed limits. Similarly, speeds above or below the bridge between cars range from 40.22 to 49.88 km/h. Therefore, the geometric design of the interchange controls the vehicle’s free-flow speeds more than the set speed limit. This can reduce bandwidth, but also offers benefits to calm traffic.

The distance between traffic lights at the junction has a direct effect on bandwidth. A shorter distance between the two signals will tend to provide higher throughput, because the signals can be better coordinated and less time is required to move between cars. A greater distance increases the likelihood of starvation of demand on a downward cross signal for through traffic. Figure 7 presents a theoretical example of the percentage of unused time passing vehicles due to the travel time between cars [5].
Figure 7. An example of a percentage starvation of demand for a diamond-shaped intersection with a change in the sides of the movement (assumed speed = 50 km/h).

The graph is based on an estimated vehicle speed of 50 km/h and shows three different cycle lengths (80, 120 and 160 seconds). As the distance increases, the travel time between the cars takes up a larger part of the cycle, assuming that both signals turn green at the same time. In practice, part of this unused time can be captured by setting the signal offsets according to the distance of travel, but the opportunity for unused time still increases with a large distance.

5. Conclusion

The increase in the number of vehicles leads to a gradual exhaustion of the resources of the road network. In this regard, the resulting traffic congestion becomes a serious problem, due to which the capacity of the road network decreases and the number of traffic accidents increases. To solve the problem of increasing the capacity of the road network, we can highlight the basic approach: introducing constructive changes to the road network - building traffic intersections at different levels.

Studies have shown that the safest intersection types are diamond-shaped intersections at two levels. The main advantage of this design is the absence of left-handed turning flows, which would cross the opposite direction. This is achieved by a temporary change in the side of movement within the junction. From the point of view of road safety, a diamond-shaped intersection with a change in sides of the movement is also safer than the classic diamond-shaped intersection. This is influenced by two factors. The first is just two conflicting points of intersection of flows. The second is a reduction in the speed of movement on the minor road due to the geometrical characteristics. The cons of this type of intersection are rather large occupied area (relative to other types of diamond-shaped junctions). This is due to the characteristics of the geometric elements of the minor road. There is also possible some kind of confusion among drivers in the place where the movement changes the side - keeping to the right, they can enter the oncoming traffic. Therefore, these places should be very well signposted and guide drivers.

The diamond-shaped intersection with a change in the side of the movement is a relatively new interchange, which has not yet been applied in Russia. The installation of these intersections at different levels will entail additional costs for informing and training drivers, cyclists and pedestrians on the rules of travel and passage along this type of interchange.

Such non-traditional types of intersections are based on variant design. That allows us to offer its own set of solutions for the organization of traffic, pedestrians and cyclists, for specific conditions. The use of a diamond-shaped intersection with changing sides of the movement allows to increase traffic...
safety, reduce delays, and is available for cyclists and pedestrians, compared to traditional types of intersections. The presented solutions are not always familiar to domestic designers and may cause difficulties in the design of this type of interchanges.

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