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Analysis of the functional efficiency of small town arterial thoroughfare (Case Study of Našice Town)

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Abstract

The main factors that affect the choice of the intersection type when constructing a new or reconstructing an existing intersection are desired traffic flow rate and achievable traffic safety. At the same time, a significant challenge is to find optimal solutions for (re)construction and traffic organization at intersections in settlements, especially in agglomeration centers, due to their specific and, in most cases substantial, spatial and traffic constraints. This paper presents the examination of the functional efficiency of the introduction of roundabouts in the road network of Našice Town. As the location for the analysis, a section of county road 4168 is selected, which includes two consecutive 4-legged signalized intersections. For the purpose of the investigation presented in this paper, these signalized intersections are to be substituted with two single lane roundabouts. Conceptual design of these roundabouts includes prescribed performance checks: swept path analysis, speed and visibility checks. Finally, the rating of the analyzed road corridor functional efficiency and dynamics of intersections reconstruction is given based on the defined levels of service for the current state and the intersection reconstruction proposals.

Keywords: intersection ; reconstruction ; roundabout ; level of service

1. Introduction

The increase in the use of roundabouts in urban environments, particularly single-lane roundabouts, can be explained by their well-known advantages over traditional, directly channeled intersections. These advantages

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primarily include greater traffic safety due to fewer number of conflict points and milder consequences of traffic accidents due to lower vehicle speed, as well as lower maintenance costs (Hydén and Várhelyi (2000), Pratelli and Souleyrette (2009)). Numerous studies showed that the application of modern roundabouts can help reduce the excessive emissions and fuel consumption and noise pollution associated with idling time, acceleration and deceleration of vehicles that usually occur on traditional signalized intersections, which is particularly important for urban environments (Mandavilli et al. (2003), Coelho et al. (2006), Chamberlin et al. (2011), Estévez-Mauriz and Forssén (2017)).

Regardless of the advantages of single-lane roundabouts, when designing a new or reconstructing an existing intersection, it is necessary to assess the appropriateness of implementing this type of intersection in the transport network. According to the Croatian guidelines HC (2014), following criteria must be analyzed: functional criteria, spatial planning criteria, traffic flow criterion, project technical criteria, traffic safety criteria, permeability criteria, environmental criterion and economic criterion. In this process, a significant challenge is to find optimal technical solutions for intersection design and construction and traffic organization in urban environments, especially in central city areas, due to their specific and, frequently critical, spatial and traffic constraints.

This paper presents the examination of the functional efficiency of the substitution of two consecutive 4-legged signalized intersections of the road network of Našice Town with roundabouts. As the location for the analysis, a section of County Road 4168 passing through central area of Našice Town was selected. When examining the justification of their application, following intersection functions were analyzed: the primary traffic function of the intersection, the position and role of the intersection in the wider road network, and its position in relation to the settlements (Kozić (2016)). For each of the analyzed types of intersections the quality of the traffic flows (level of service - LOS) was defined using measured volume and distribution of traffic (Devald (2018)).

In order to improve the existing traffic conditions, a proposal for reconstruction is given whereby instead of the existing intersections, two mini roundabouts would be introduced. Even thou the first urban mini roundabout in Croatia was built in nation’s capital Zagreb in 2002 (Šurdonja (2012)), there are no national standards or guidelines that would deal in detail with these specific types of intersections. Current Croatian guidelines for roundabout design on State roads HC (2014) only define basic strategies for their planning and design. Because of that, a large dissipation in the success of introducing mini roundabouts in the urban environment at the national level can be noted.

Due to spatial constraints and unequal distribution of traffic load on the approaches of aforementioned intersections, mini roundabouts with unconventional geometrics and elements are analyzed: “two-geometry roundabout” (with circular central island and the elliptic external margin, by Gazzarri et al. (2014)) with bypass. For the purpose of the correct geometric design of the considered intersections, performance checks that include swept path analysis, speed and visibility checks were conducted. The rating of the analyzed road corridor functional efficiency and time dynamics for intersections reconstruction is given based on the defined LOS for the current traffic volumes and intersections, and the intersection reconstruction proposals.

2. Case Study

Našice is a town located in eastern Slavonia, Croatia, 51 km southwest of regional hub Osijek and approximately 230 km east of Zagreb, with less than 8000 inhabitants occupying 200 square meters of town area (Croatian Bureau of Statistics (2012)). However, it is not a typical sleepy small town, but an economic and cultural center of the wider area, known for its cultural and historical heritage, and well-developed business, sport, and excursionist tourism.

The main arterial thoroughfare is County Road 4168 - a transversal street that is passing through the narrower city center, connecting the eastern and western parts of the settlement. In the center of the city, access points of the collector streets on this County Road are established by two at-grade four-legged signalized intersections. At both intersections, two approaches are part of the County Road, and two are part of the local (collector) streets. All streets outside the intersection area are two-way two-lane streets, with a speed limit of 50 km/h. In the immediate vicinity of this part of the city’s road network there are numerous centers of activity (City Hall, farmers market, police station, post office, etc.) that, along with the city transit, attract additional local traffic of motor vehicles, as well as pedestrians and cyclists (Fig. 1.).

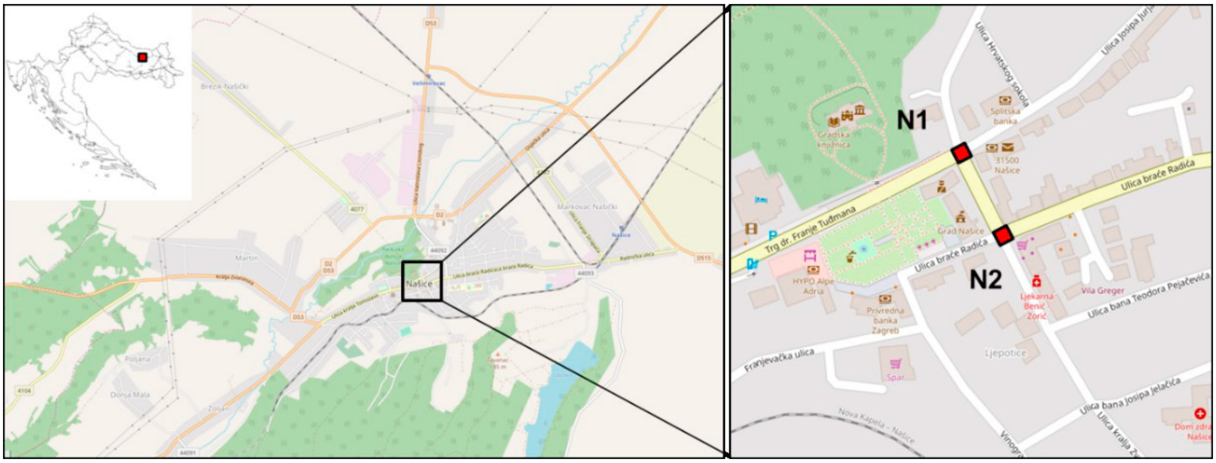

Fig. 1. Našice Town road network map with highlighted analyzed section (between intersections N1-N2) of County Road corridor.

2.1. Level of service analysis

In order to quantify and evaluate the LOS of existing intersections, analyzed network section geometric conditions were defined based on spatial planning and design documentation, while traffic and signalization conditions were established by on field observations. The analyzed intersections N1 and N2 are placed at a very short distance (80 m), all approaches have exclusive left-turn lanes and all the signal phases are pretimed (Fig. 2.a).

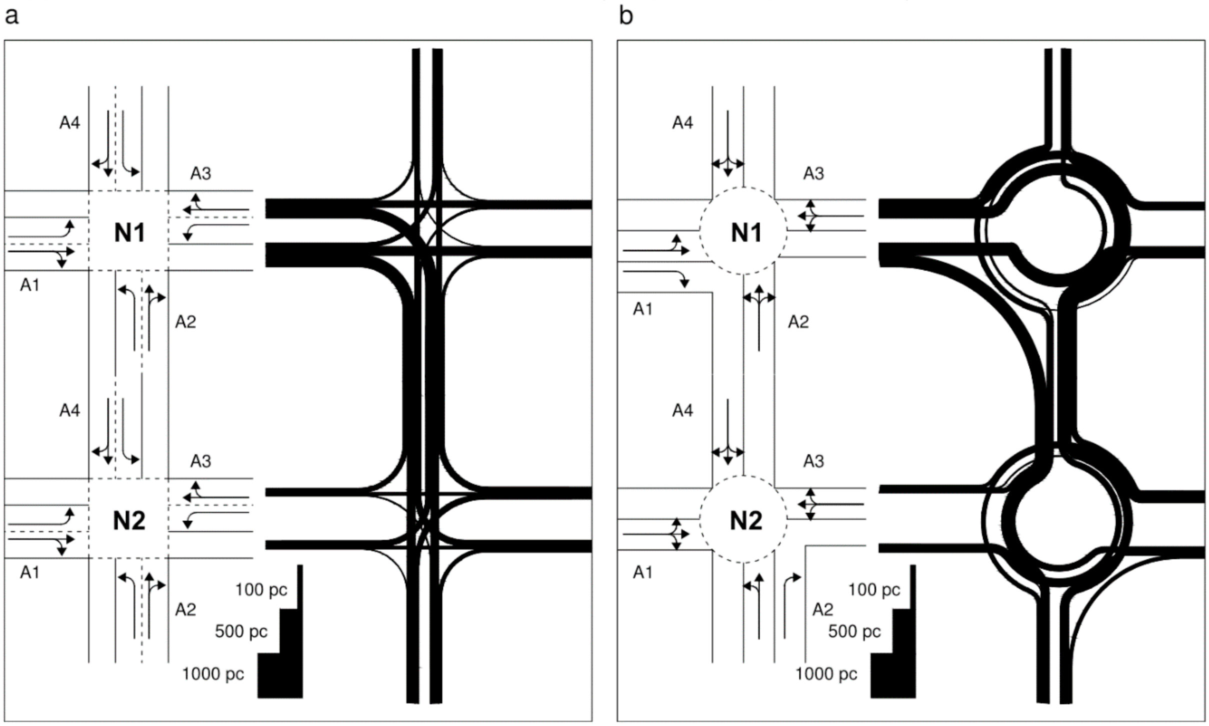

Fig. 2. Traffic volumes and distribution at (a) current intersections; (b) planned intersections.

Measurements of traffic volumes and signal phases were conducted during April 2018 in the peak hours of morning and afternoon. The average control delay per vehicle for the existing situation was estimated for each traffic stream and aggregated for each intersection approach, according to the methodology given in TRB (2000). This methodology was used in the absence of national regulations regarding LOS estimation on signalized urban intersections. The LOS evaluation results are given in table 1.

Analysis has shown that LOS B is achievable on most of the approach lanes for the existing traffic infrastructure and organization. However, the values of calculated average control delays per vehicle for this (satisfactory) LOS were at the upper limit of its range. The calculation of the aggregated LOS for each approach confirmed that the LOS C prevails on the approaches of both intersections. The lowest LOS F, with more than 5 minutes of average control delay per vehicle, was calculated on shared through and right turn lane on the approach A1 of intersection N1, in the direction of intersection N2, i.e. in the County Road corridor. It should be noted that this is the only movement for which an excess of demand over capacity was calculated. The longest average control delay per vehicle at intersection N2 was noted on the approach leg A4. It was concluded that this path, largely conducted realized on the County Road corridor, is critical for the networks sections LOS.

Table 1. LOS estimation results.

Intersection	Approach	Existing conditions				Projected conditions	
		Lane	Average control delay d (s/pc)	Aggregated average control delay d_A (s/pc)	LOS	Average control delay d_A (s/pc)	LOS
N1	A1	Through & Right	307	260	F	5	A
		Left	17				
	A2	Through & Right	20	22	C	9	A
		Left	24				
	A3	Through & Right	23	22	C	7	A
		Left	19				
	A4	Through & Right	37	35	D	6	A
		Left	18				
N2	A1	Through & Right	16	18	B	6	A
		Left	20				
	A2	Through & Right	17	20	C	6	A
		Left	22				
	A3	Through & Right	18	17	B	6	A
		Left	15				
	A4	Through & Right	28	26	C	6	A
		Left	20				

Poor progression of vehicles through intersections and therefore larger values of control delay could be a result of poorly pre-timed signal cycles on intersection N1. Possible improvements could be achieved if the green time for the identified critical path was longer, but this is not a viable option because it could aggravate the LOS on the other lanes. Also, as the County Road section consisting of approaches A2 of N1 and A4 on N2 is only 80 meters long, it probably could not accept any increase in the number of vehicles due to phase change (longer red time) on these approaches. The other possibility was the introduction of roundabouts.

According to HC (2014), it is necessary to consider the following recommendations based on the overall traffic volumes and movements when planning roundabouts. The application of a roundabout is recommended primarily at intersections whose approaches serve approximately equal traffic volumes. Roundabouts are justified in cases of large or unstable future traffic volumes, at intersections where the signalization is not justified, and the intersection's capacity is exceeded, but also if there is a small number of left turns on opposing approaches and a large number of right turns, as in the case of analyzed intersections. Analysis of LOS on planned roundabouts was conducted with following restricting design conditions. All existing movements of traffic streams through the intersections must be retained; critical right turns should be physically separated from circulating flows by the introduction of bypass; maximization of possible sidewalk areas in the area is a necessity.

While pondering the proper methodology for LOS estimation on urban roundabouts approaches a variety of sources were counseled, since the application of such intersections is of a relatively recent date and there are still no unified algorithms for LOS estimation at the national level. After re-arranging, the traffic flows to accommodate the aforementioned presumptions and to account for the bypasses (Fig. 2.b), adjusted approach and circulating flow rates were defined according to TRB (2000). Capacity calculation of single-track roundabout approaches was performed according to Report 572 (TRB (2007)), and the average control delay per vehicle was estimated for each roundabout approach according to national regulations HC (2014). The evaluation showed that with the introduction of roundabouts LOS A for each approach could be achieved, even for critical direction (Table 1.).

2.2. Planning and design criteria

As for position and role of the planned intersections in the wider road network, it can be argued that replacing signalized intersections with roundabouts can be an optimum solution for improving the current traffic situation while retaining all the existing movements through the intersections. Namely, in many situations, roundabouts have the same capacity as the signalized intersections, but smaller delays and increased traffic safety in the unsaturated time periods (HC (2014)). Regarding the position of the intersections in the Našice traffic corridor, primary traffic function of the analyzed intersections is both transit and origin-destination, even though they are positioned in urbanized area.

Appropriate type and size of the roundabout depend on the traffic characteristics of the existing intersection as well as the spatial constraints of the location. When checking a traffic flow criterion, the intersection of a certain type can be planned if the daily approaching traffic is smaller than the limit value for that intersection type. Evaluation of daily traffic occurring at intersections N1 and N2 performed based on measured peak-hour flow rate, showed that the average annual daily traffic (AADT) is lower than 15000 personal vehicles per day at both intersections. According to HC (2014), this is a suitable AADT value for the application of both mini and small urban roundabout. Recommended AADT value for mini urban roundabouts, with an outer diameter in the range from 14 to 25 meters, is between 10000 to 15000 personal vehicles per day. These values range from 15000 to 18000 personal vehicles per day for small urban roundabouts, with an outer diameter in the range from 22 to 35 meters.

While checking a spatial criterion, which answers the question of whether there is enough free space to construct the roundabouts of certain dimensions, it was concluded that there is not enough space to accommodate small roundabouts at the considered locations (Šurdonja et al. (2012), HC (2014)). Because of that, and the fact that the peak-hour flow rate was used in the calculation of AADT that certainly gave a somewhat overestimated AADT value, mini roundabouts were chosen to improve the traffic functionality of analyzed intersections. Another advantage of mini roundabouts over small urban roundabouts, when reconstruction of intersections is in question, is the fact that their islands can be assembled from prefabricated elements, which can be done fast, with low cost, without large construction works and long-term traffic interruptions. Due to unequal distribution of traffic load on the approaches, on each mini roundabout one bypass was planned.

When checking a design criterion, following parameters are analyzed: position, number and the alignment of the approaches, number of required traffic lanes, and the design vehicle (as it crucially influences the choice of intersection geometry features). There are four approaches on both analyzed intersections. Longitudinal slope of these approaches is smaller than 4 %, and their approach axes intersect at angles ranging from 76 to 103 degrees. The longest vehicle that is expected in the analyzed road network is municipal waste disposal vehicle 9.0 meters long and 2.5 m wide, with the axle clearance of 4.6 meters – because of that, it was chosen as a design vehicle. Aforementioned parameters confirmed the possibility of the mini roundabout application on analyzed locations according to HC (2014).

2.3. Roundabout design

The standard roundabout design is an iterative process, consisting of preliminary geometry design, performance checks (swept path, fastest path, and visibility analyses), and final geometry design. However, this procedure was not applied in the design process of analyzed roundabouts - they were designed based on the results of the design vehicle swept path analysis, according to Ahac (2014), due to the significant spatial constraints on selected locations (Fig. 3.). The design was conducted in the following steps. First, the swept path analysis for the design vehicle was performed by means of the specialized software (Autodesk Vehicle Tracking 2015) for the right-turn movements on both intersections, as it was concluded that this movement was the critical one for the investigation. Then, based on the resulting vehicle trajectories and lateral protective widths of 0.25 m, the shape of the right curbs and the diameters of the central island were defined. Diameters were set to 7.0 meters at intersection N1, and 6.7 meters at intersection N2, which is in accordance with Croatian guidelines HC (2014).

Geometric centers of the roundabouts (i.e. centers of central islands) should be placed in the intersection point of the approach axes. Because axes of the approaches on analyzed intersections do not intersect at the same point, centers of central islands were placed inside the quadrant defined by approach axes intersection points. This was done in order to assure the following safety requirements: that drivers approaching the intersection are able to perceive the central island as the main canalization feature of the roundabout (Pratelli and Souleyrette (2009)) and that the placement of central islands provides required deflection of the passenger cars, and consequently required reduction in vehicle speed, HC (2014). Finally, external margins of roundabouts (i.e. outer diameters) were defined. Due to spatial constraints, "two-geometry roundabout" with circular central island and the elliptic external margin was designed on intersection N1. This elliptic external margin was designed with a semi-major axis that was 8.8 meters long and semi-minor axis that was 7.8 meters long. External diameter on intersection N2 was set to 16.6 meters.

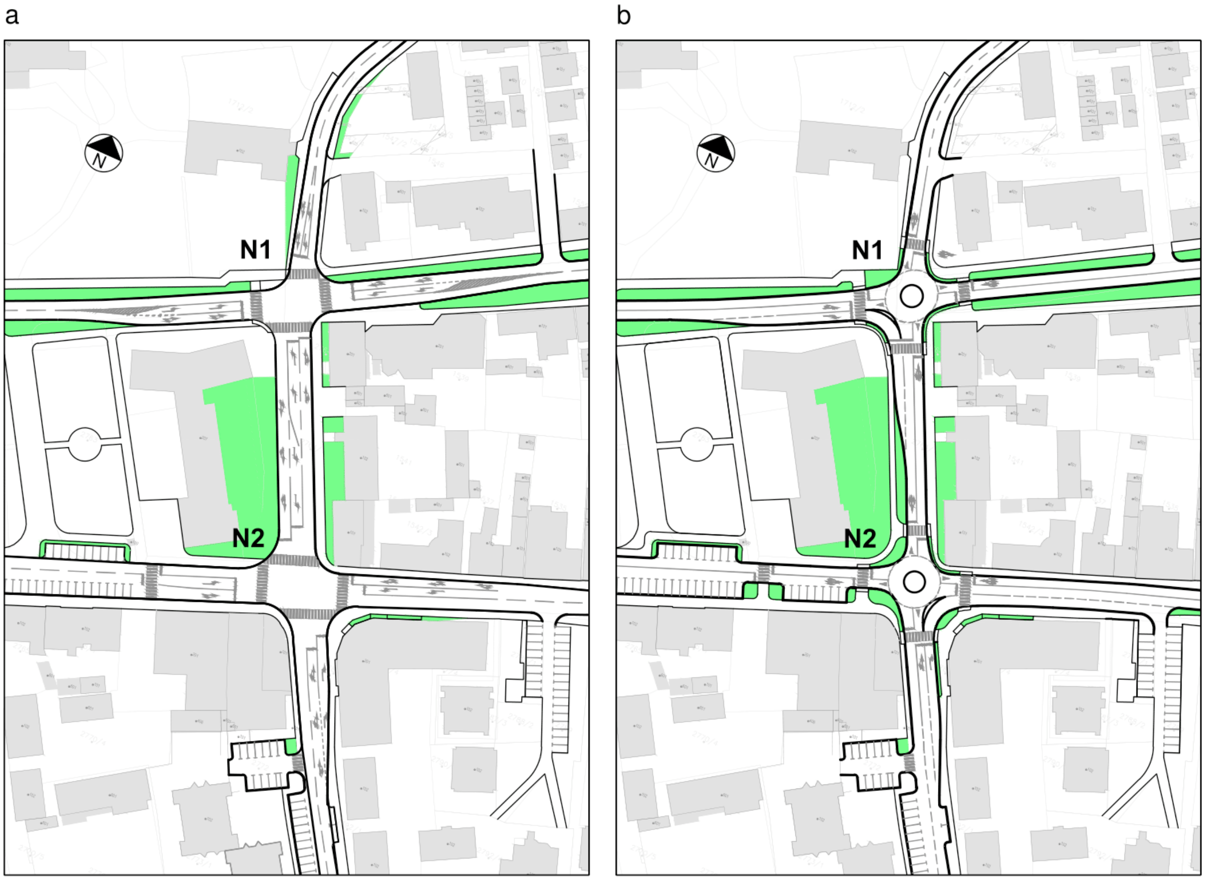

Fig. 3. Design of (a) current intersections; (b) planned intersections.

Fastest path analysis and vehicle speed estimation were conducted in accordance with the American guidelines (TRB (2010)) for each roundabout. These guidelines were selected because the procedure for this performance check for urban mini roundabouts is not described in the Croatian guidelines. Results of the analyses were in accordance with the instructions given in HC (2014): the vehicle speed around the central islands was lower than 25 km/h for all movements, and entry speed was in a range from 25 km/h to 33 km/h on all approaches. Exit speed was in a range from 35 km/h to 50 km/h, which is also favorable, according to Šurdonja et al. (2012).

Visibility checks on the designed intersections were conducted according to French guidelines CERTU (1999) because the procedure for this performance check for urban mini roundabouts is not described in the Croatian guidelines. Visibility checks confirmed the possibility of the mini roundabout application on analyzed locations: sight lines to the left on each approach were unobstructed on both intersections.

2.4. Reconstruction dynamics variants

In order to emphasize the improvement of LOS due to the introduction of roundabouts in the Našice Town road network, and to evaluate the possibilities of phased reconstruction work organization, the average control delays per vehicle at the approaches of existing signalized intersections and planned roundabouts are shown graphically on shared time-space graph (Fig. 4.). The graph was created for the identified critical driving direction, with the assumption of an average achievable running speed of 25 km/h. Estimated travel times were compared for three different variants of reconstruction work timing. Variant 1 predicts that both intersections (N1 and N2) are reconstructed at the same time, variant 2 predicts reconstruction of intersection N1, and variant 3 predicts reconstruction of intersection N2.

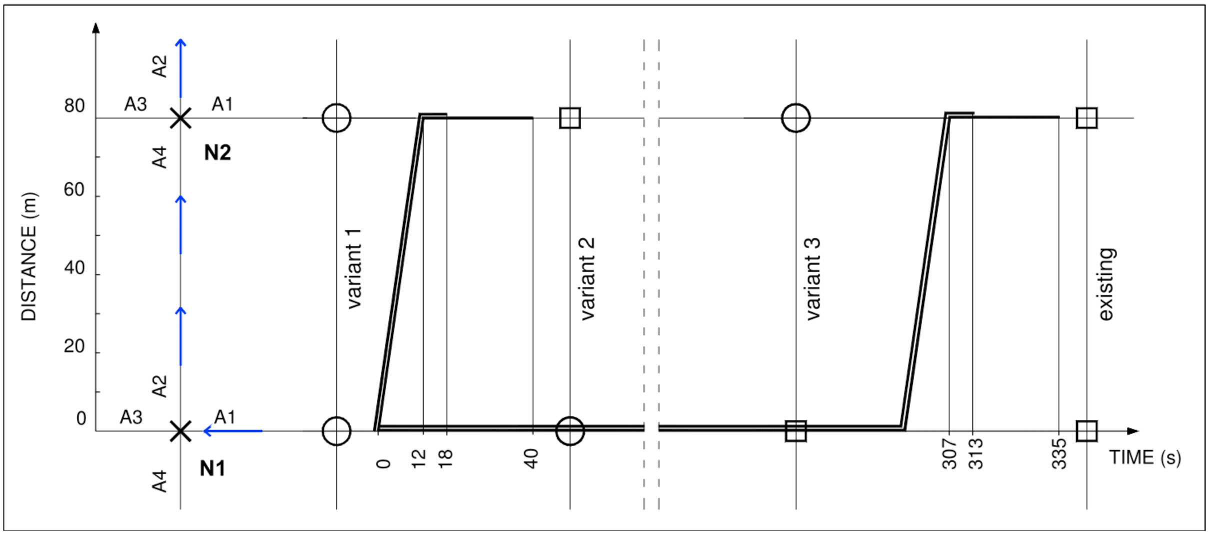

Fig. 4. Variants of time-space graph for critical path.

As it can be seen from the Fig. 4, traveling time after reconstruction would be significantly reduced (for 5 minutes) if intersections are reconstructed simultaneously. Due to the small distance between the intersections, simultaneous reconstruction would facilitate construction works and it would not significantly affect the urban and transit traffic through Našice Town. In the event that the proposed interventions cannot be carried out at the same time (for financial or organizational reasons), intersection N1 (variant 2) should be the first to reconstruct, as this could also reduce the average delay during the period between intersections reconstruction for nearly 5 minutes.

3. Conclusions

It is generally considered that replacing signalized intersections with roundabouts increases the traffic flow rate and reduces the average control delay. However, in settlements, especially in agglomeration centers, complex traffic conditions can annul the benefits of such interventions. In this Case Study, the rating of the analyzed urban road corridor functional efficiency and dynamics of intersections reconstruction has shown that introduction of mini urban roundabouts could reduce the average control delay per vehicle for the most critical path for as much as 5 minutes. At the same time, a significant challenge was to find optimal solutions for (re)construction and traffic organization of observed intersections, due to their specific and substantial spatial and traffic constraints.

The complex process of the introduction of a roundabout in an urban environment is even more challenging when there is a lack of uniform planning and design strategies. In this Case Study, the possibility of application of planning and design criteria given in national standards for State roads HC (2014) on urban mini roundabouts was analyzed. It was concluded that due to the significant spatial constraints on analyzed locations, these criteria needed to be supplemented with unstandardized roundabout design and performance check procedures. These procedures included the design of roundabout geometric elements based on the results of the design vehicle swept path analysis conducted according to Ahac (2014), the definition of fastest paths according to TRB (2010), and visibility checks conducted according to CETRU (1999). The results showed that that the combination used resulted in an optimal intersection design in the sense of respecting the previously mentioned spatial limitations. In addition, by reducing the road corridor width, existing lanes could be converted into green belts, parking areas or sidewalk, which would make this central city area more accessible. However, these benefits are achievable only if both intersections are reconstructed simultaneously or the priority is given to the reconstruction of the intersection with bypass for the highest volume of right turn movements.

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