TRAFFIC ANALYSIS AND OPERATIONAL IMRPOVEMENTS FOR VÍTĚZNÉ NÁMĚSTÍ IN PRAGUE

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by

LAUREN ELAINE BROWN, Bc.

THESIS

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Faculty of Transportation Sciences
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MASTER'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

Student's name and surname (including degrees):

Lauren E. Brown, B.S.CE

Study programme (field/specialization) of the student:

master's degree – SC – Smart Cities

Theme title (in Czech): **Analýza dopravní situace a návrh jejího zlepšení na Vítězném náměstí v Praze**

Theme title (in English): **Traffic Analysis and Operational Improvements for Vítězné Náměstí in Prague**

Guidelines for elaboration

During the elaboration of the master's thesis follow the outline below:

- Review existing multi-modal architecture at aforementioned roundabout
- Perform a literature review of how historical influences effect transportation planning on area-of-interest
- Model current design and alternative designs (i.e., MUTCD and Internation Competition Winner's Design)
- Measure previously defined indicies (e.g., travel time, queue length) to compare and analyze designs against each other

Graphical work range: N/A

Accompanying report length: At least 55 pages.

Bibliography:

N. Hui, S. Saxe, M. Roorda, P. Hess, and E. Miller. Measuring the completeness of complete streets. 2017. https://doi.org/10.1080/01441647.2017.1299815.

V. Perk, L. Hymowitz, M. Catala, M. Mantius, K. Corcor an. Capturing the benefits of complete streets. 2015. Tech Report; BDV26-977-04.

Master's thesis supervisor: **doc. Ing. Tomáš Horák, Ph.D.**

prof. Dr. Ing. Miroslav Svítek, dr. h. c.

Dr. Ruey Long Cheu, Dr. Jeffrey Weidner

Date of master's thesis assignment: **June 30, 2022**

(date of the first assignment of this work, that has be minimum of 10 months before the deadline of the theses submission based on the standard duration of the study)

Date of master's thesis submission: **May 15, 2023**

a) date of first anticipated submission of the thesis based on the standard study duration and the recommended study time schedule

b) in case of postponing the submission of the thesis, next submission date results from the recommended time schedule

L. S.

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doc. Ing. Tomáš Horák, Ph.D.
head of the Department
of Logistics and Management of Transport

....

prof. Ing. Ondřej Přibyl, Ph.D.
dean of the faculty

I confirm assumption of master's thesis assignment.

....

Lauren Brown
Student’s name and signature

Prague .... June 30, 2022

Declaration

This thesis/report is an output of the International Dual Master Degrees Program in Smart Cities Science and Engineering, a collaboration between Czech Technical University, Czech Republic, and The University of Texas at El Paso, United States of America.

I declare that this Master's thesis is my own work and that I list all references in compliance with ethical guidelines on elaboration of Master's thesis.

I have no relevant reason against using this work in the sense of § 60 of Act No. 121/2000, on the copyright law.

Prague, Czech Republic

May 8, 2022

……………………………………
Lauren E. Brown

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Firstly, I would like to give a very special thanks to my advisors Dr. Cheu, Dr. Weidner, and Dr. Horak for all their guidance and support during my graduate studies. I would like to thank Dr. Cheu specifically for all his guidance and mentorship over all the years I have been his student and his research assistant; he has been considerate and consistent and has helped shape me into the person I am today. I would like to thank Dr. Weidner for offering me guidance and mentorship and for so many great book recommendations. I would like to thank Dr. Horak specifically for all of his help with adjusting to a new environment, new culture, and a new education system; adjusting to life and studies in Prague would have been much more difficult without his support.

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Thirdly, I would like to thank my friends and family for their love and support for me during this momentous occasion in my life. I would like to specifically thank my parents for rooting for me in all my decisions over the years and helping financially support me in the pursuit of my dream. I would like to specifically thank my partner, Aaron Ortiz, for his love and support, even when I doubted myself. Finally, I would like to thank my fellow peers and dearest friends Luisa Castrejon and Larissa Hernandez for taking on this great adventure in Europe to learn more academically, professionally, and most of all, ourselves.

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Chapter 1: Introduction

The Vítězné Náměstí roundabout is a key intersection in Prague 6, Czechia, home to the Building of the General Staff of the Czech Army and a university district. This intersection is a direct connection to the Václav Havel Airport. Multiple modes of transportation converge at this roundabout, including several tram lines, a subway connection, personal vehicles, bicyclists, and pedestrians. Throughout the day, queue buildup along all entry edges occurs, especially during peak hours in the morning and the late afternoon. Recently, an international competition took place that produced a new design for the roundabout; however, there are no known modeling efforts that compared the new design to see if it improves the traffic operations at Vítězné Náměstí. The purpose of this thesis is to observe, document, and simulate the current geometry design and traffic control plan of the roundabout.

1.1 Background

Roundabouts are becoming more common in transportation networks internationally due to their benefits, including the improvement of safety, reduction of traffic delays, and improvement in traffic flow. Since 2000, the number of roundabout withing the Czech Republic has increased (1,200+ as of 2016) (Ambros et al., 2016). One of the Czech Republic's older roundabouts is the Vítězné Náměstí roundabout, which is the subject of this study. Originally built in 1925, this roundabout underwent some changes (the complete history of the roundabout will be discussed in Chapter 2) that made it the roundabout that exists today (see Figure *1-1*).

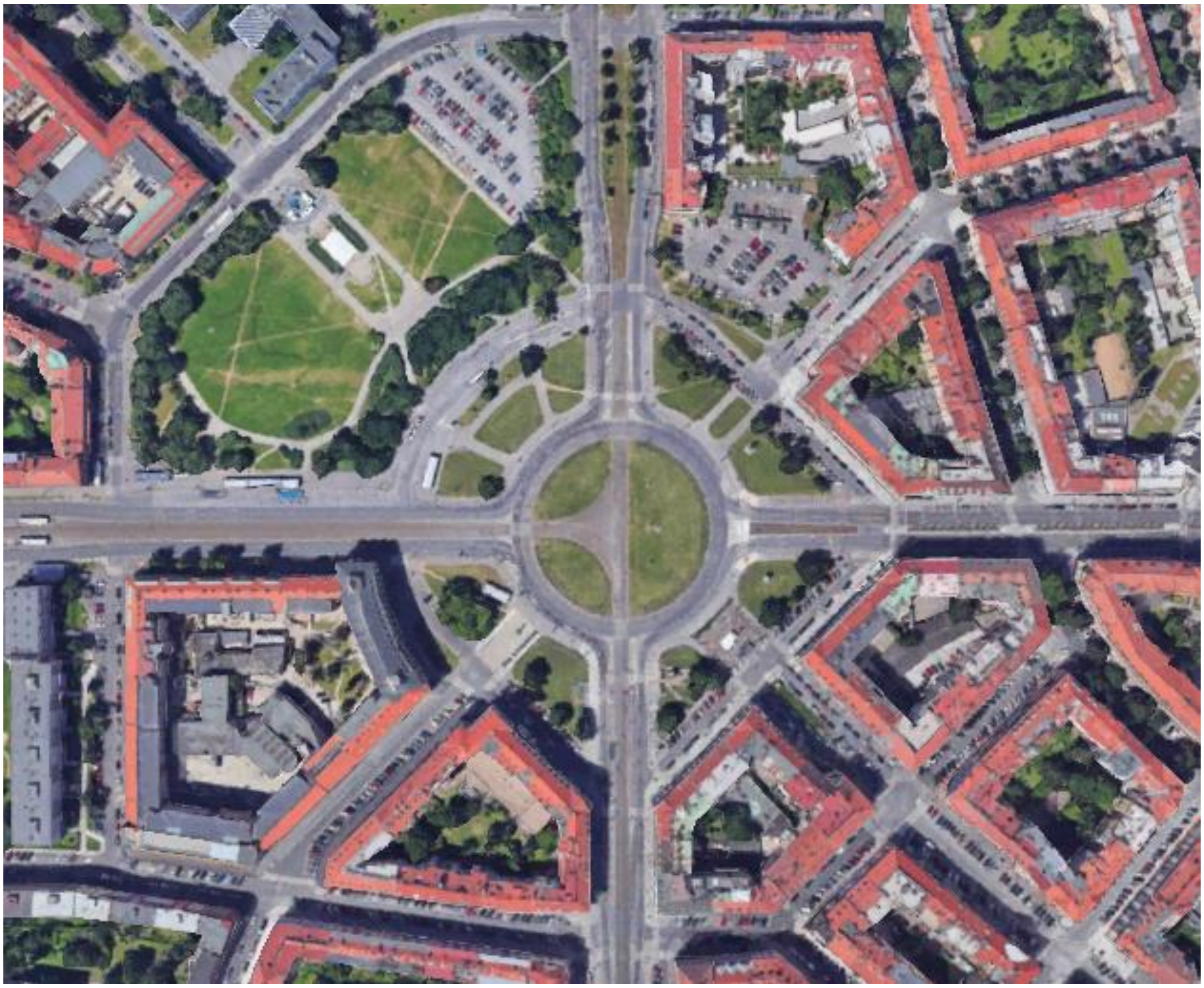


Figure 1-1 Google Earth View of Vítězné Náměstí

Many tram lines, bus routes, and the metro A line pick up and drop off passengers at this intersection; additionally, many bicyclists and pedestrians frequent this intersection due to its proximity these public transit modes, as well as to a university district (containing the main campus of the Czech Technical University, the Catholic Theological Faculty of Charles University, the University of Chemistry and Technology, and the Czech National Library of Technology), places of business, etc. On a typical, non-public holiday working day, the Vítězné Náměstí roundabout experiences peak conditions on one or more of the entrances/exits to the roundabout between midmorning until almost noon; traffic also picks up in afternoon as travelers return to their places of residence from their place of study, work, and so on. The Vítězné Náměstí roundabout, due to the congestion created by traffic volume that exceeds its existing capacity, does not experience the benefits a roundabout should give (i.e., improvement of safety (Lara (2023) investigates this in her Master's thesis), reduction of traffic delay, and improvement of traffic flow). Such issues have motivated an international competition to redesign the roundabout, of which a winner was recently selected.

1.3 Thesis Objectives

This thesis has several objectives:

The first objective is to propose a redesign of the roundabout located in Vítězné Náměstí considering the nearby Blanka Tunnel Complex entrances and exits and the following approaches: Jugoslávských partizánů (southbound approach), Československé armády (westbound about), Svatovítská (northbound approach), and Evropská (eastbound approach).

The second objective is to perform a simulation modeling the (a) existing traffic conditions, (b) the winning design by Pavel Hnilička Architects from The International Urban Planning Competition for Vítězné Náměstí (Victory Square) in 2018, and (c) the author's proposed redesign.

The third objective is to collaborate with Luisa Castrejon and Larissa Lara to incorporate the work of this thesis with their respective theses' focus, green infrastructure and safety.

The fourth and final objective is to analyze the outputs of the simulation modeling and to make some recommendations.

1.3 Thesis Outline

Chapter 1 introduces the issues at the Vítězné Náměstí roundabout and provides descriptions of the thesis objectives and thesis outline.

Chapter 2 reviews the of the history of Vítězné Náměstí and the surrounding area of Dejvice in Prague 6. This chapter will delve into the origin of the intersection, the evolution of the intersection, and the recent developments in the international competition for the intersections redesign.

Chapter 3 describes the current roundabout design, highlighting its dimensions, public transit routes, and observed problems.

Chapter 4 describes the simulation software used to model the intersection, the data sources used to calibrate the model, and the various scenarios modeled.

Chapter 5 focuses on the outputs of the simulations.

Chapter 6 analyzes the outputs of the simulations.

Chapter 7 concludes the research presented in the thesis, a summary of the results, and suggests possible future research ideas related to the topic.

Chapter 2: Review of Land-Use and Transportation Development at Vítězné Náměstí

Vítězné Náměstí is in Prague 6, the largest district in all of Prague. Prague 6 is in the north-west of Prague and borders the oldest districts in Prague, Prague 1 and Prague 2 (see Figure *1-1*), which together hosts important historical sites and government buildings such as Prague Castle and the Parliament of the Czech Republic. Vítězné Náměstí can be considered the heart of Prague 6 and the gateway to the rest of the city. Evropská, the western approach to the square, connects directly to the Václav Havel International Airport and hosts Prague's Smart City Testbed, where smart cities technologies and services are tested. The northern approach, Jugoslávských partizánů, runs along a university hub and leads to the Czech University of Life Sciences in Suchdol; the southern approach, Svatovítská, has an entrance and exit to the Blanka Tunnel Complex, leads to Prague Castle, and connects to the older, historical portions of Prague. Along the edges of the square are a variety of restaurants and shops, the Ministry of Defense of the Czech Republic, the Dejvická bus stop, the Dejvická metro station, and the Vítězné Náměstí tram stop; five tram lines, eleven bus lines, and one metro line all stop at this intersection throughout the day. Many changes have occurred throughout history to bring the square to what it is today; the following subsections will highlight the important changes that resulted in the Vítězné Náměstí seen today.

Figure 2-1: Map of Prague

2.1 Antonín Engel's Plan and Development of the Tram Line

As housing developments boomed in Bubeneč and Czechoslovakia formed as independent nation, a need for a place to host the new country's central institutions arose; this led to an urban planning competition that architect Antonín Engel won (Prague Institute of Planning and Development, 2013). His plan, shown in Figure 2-2, featured a horseshoe-shaped square with apartment, public, national, and institutional buildings along its edges. Of these plans, only the Ministry of Defense of the Czech Republic and apartment buildings were actually built due to issues ranging from a lack of funds and changes in functional and aesthetical requirements and standards (Prague Institute of Planning and Development, 2013). All other buildings adjacent to the square were designed and developed through various design competitions over the next century.

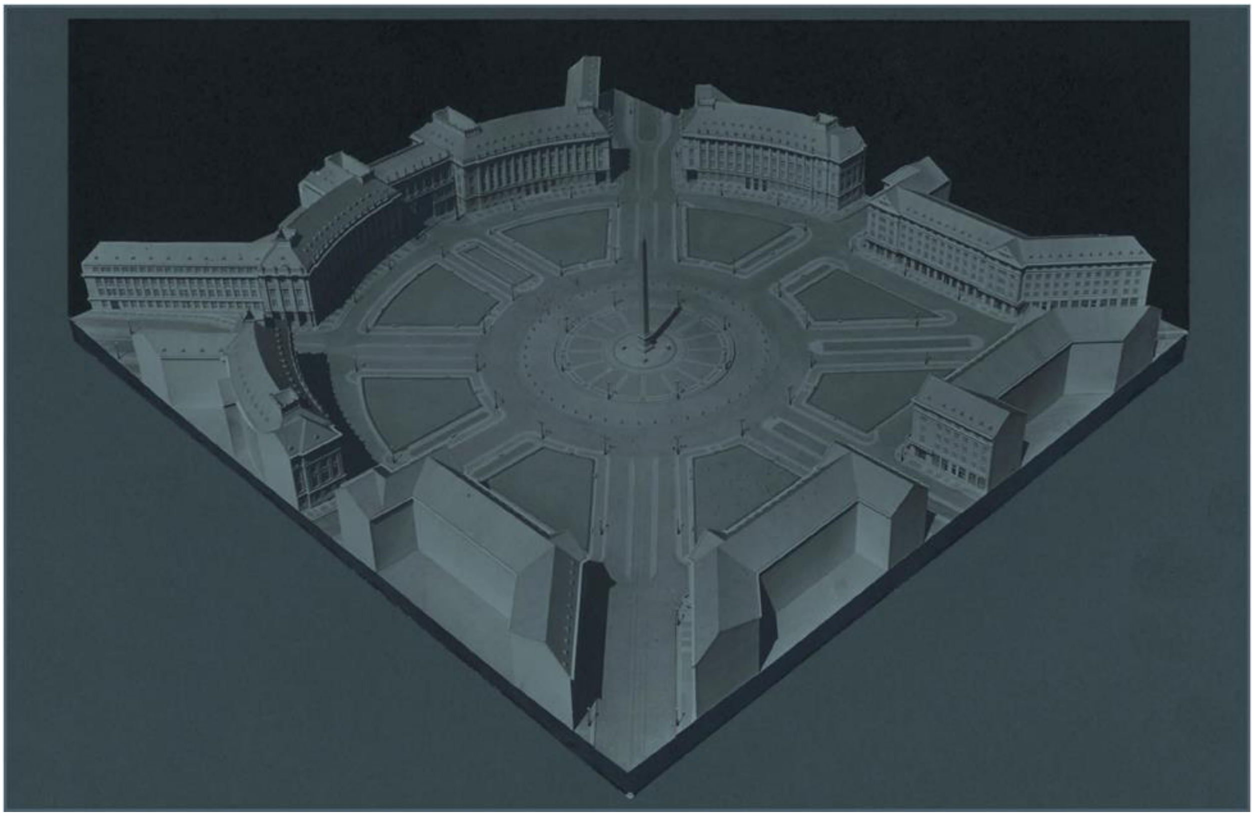


Figure 2-2: 3-D Model of Engel's Victory Square (Prague Institute of Planning and Development, 2013)

Housing developments motivated urban planning of the area as well as transportation planning. Due to the increase of housing, a new tram line was created to connect Prašný Most with the newly built Masaryk student dormitory in Dejvice (Pražské tramvaje). Construction for the line began in October of 1925 and was finished in May of 1926. Line 20 was tested in the summer, and by the end of the year an extension of the tram network began to Podbaba, north of the square, and was completed in December of 1928 (Pražské tramvaje). Figure 2-3, taken in 1933, shows Vítězné Náměstí, the completed tram lines, and the institutional and apartment buildings from Engel's plan. It is important to note that the tram flows with the roundabout; as density and traffic increased in the 1930s, municipal planners redesigned the area and switched the tram from the half-circle to the triangle circle that has been used from 1942 to today (Prague Institute of Planning and Development, 2013).

Figure 2-3: 1933 Aerial View of Vítězné Náměstí (the Archive of the Club for Old Prague)

2.2 Opening of the Metro A Line

The first ideas of underground transport began in the 19th century; however, it was not until the 1960s that the concept of the underground tramway system came into being (it evolved into the “true” metro design shortly after) (Prague Metro). The Metro A line was the second line to open in Prague’s metro system. Following the completion and the beginning of operations of the Metro C line in May of 1974, construction began for the Metro A line. The Metro A line, composed of seven stations, opened for operations in August of 1978. Dejvická, the station near to Vítězné Náměstí, was the terminus of the Metro A line until it was expanded by four stations to Nemocnice Motol in April of 2015 (Prague.TV, 2015). Figure 2-4 illustrates the entrances and exits to the Dejvická metro station along Evropská (the westbound approach to the roundabout).

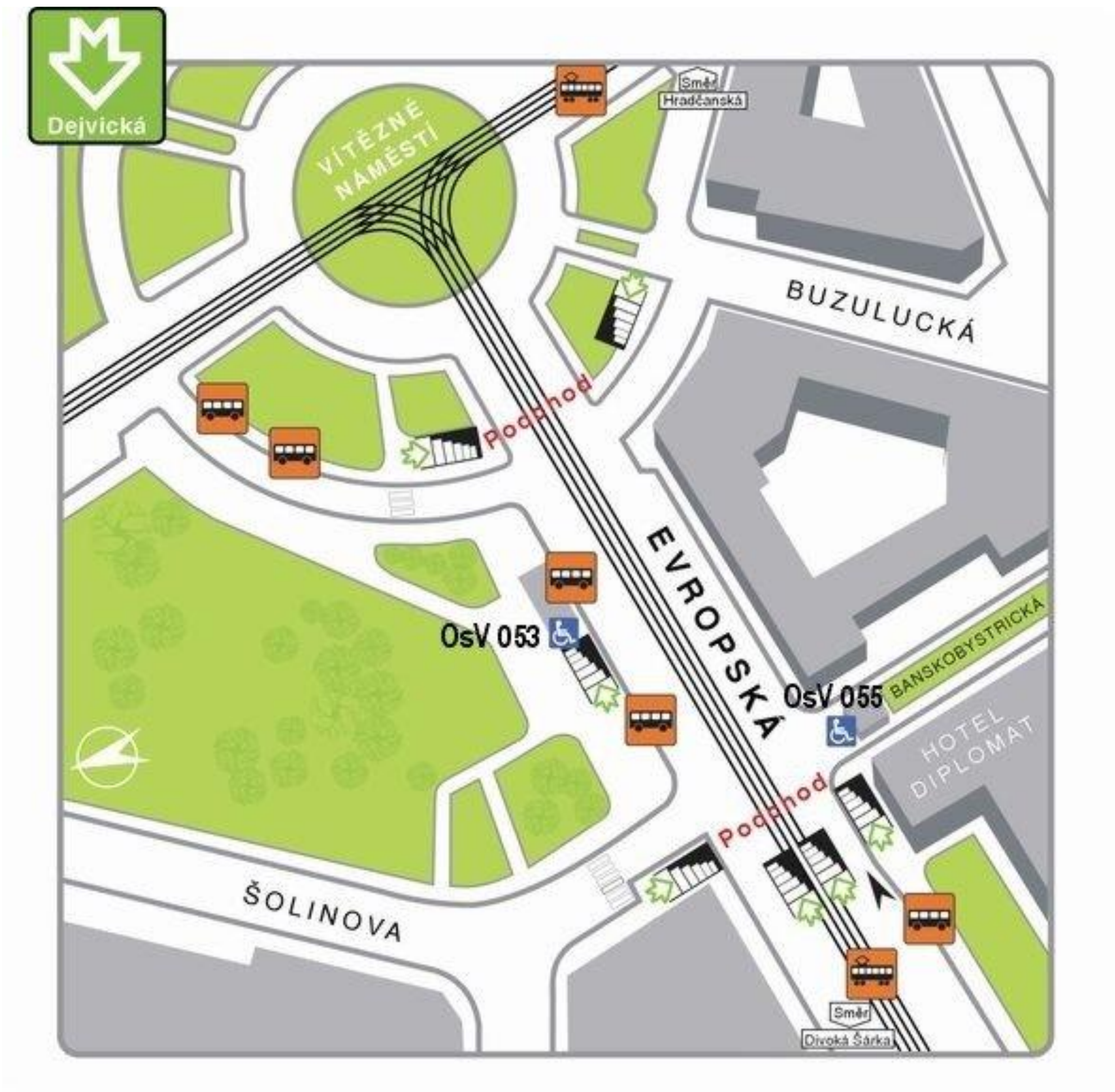


Figure 2-4: Map of the Dejvická Metro Station (Pražská Integrovaná Doprava)

2.3 Opening of the Blanka Tunnel Complex

In addition to the construction of the metro lines, the 1970s also saw the beginning of construction for Prague's City Ring Road. With growing motorization of the city, additional infrastructure was designed to handle the city's traffic load. The Blanka Tunnel Complex (see Figure 2-5), the 5.5 kilometers long portion of the City Ring Road, would not begin construction until 2006 (Heidelberg Materials, 2023). The Blanka Tunnel Complex began operations in September of 2015 and is composed of three tunnels: the Brusnický tunnel, the Dejvický tunnel, and the Bubeneč tunnel [6]. The Dejvický tunnel, between Prašný Most and Letna, is the portion of the complex that directly impacts Vítězné Náměstí. The Blanka Tunnel Complex has four lanes in total, two per direction.

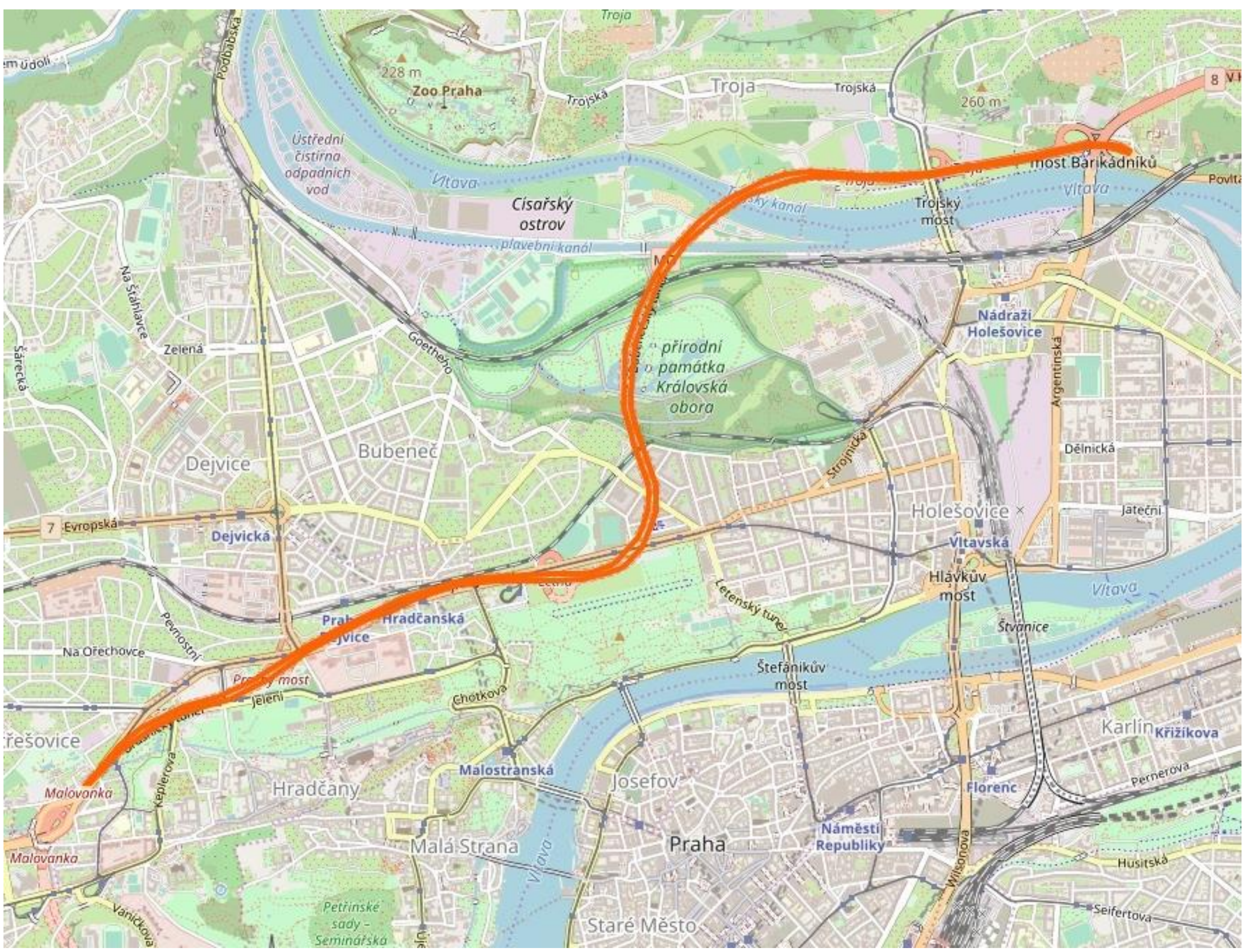


Figure 2-5: Map of Blanka Tunnel Complex

2.4 The International Urban Planning Competition for Vítězné Náměstí

The International Urban Planning Competition for Vítězné Náměstí was hosted by the Prague Institute of Planning and Development in 2018; the open, two-stage competition lasted for six months and announced its winner, Pavel Hnilička Architekti, close to the end of the year (Prague Institute of Planning and Development, 2023). The winning design (see Figure 2-6) features similar attributes to Engel's plan for the area, as well as the arrangement for the tram lines prior to 1942. Figure 2-7 is a detailed drawing of the proposed geometry for the redesign of Vítězné Náměstí. This design is a turbo roundabout, which encourages drivers to select the correct lane before they enter the roundabout and to maintain their selected lane until they exit the roundabout.

Figure 2-6: Concept Drawing by Pavel Hnilička Architekti

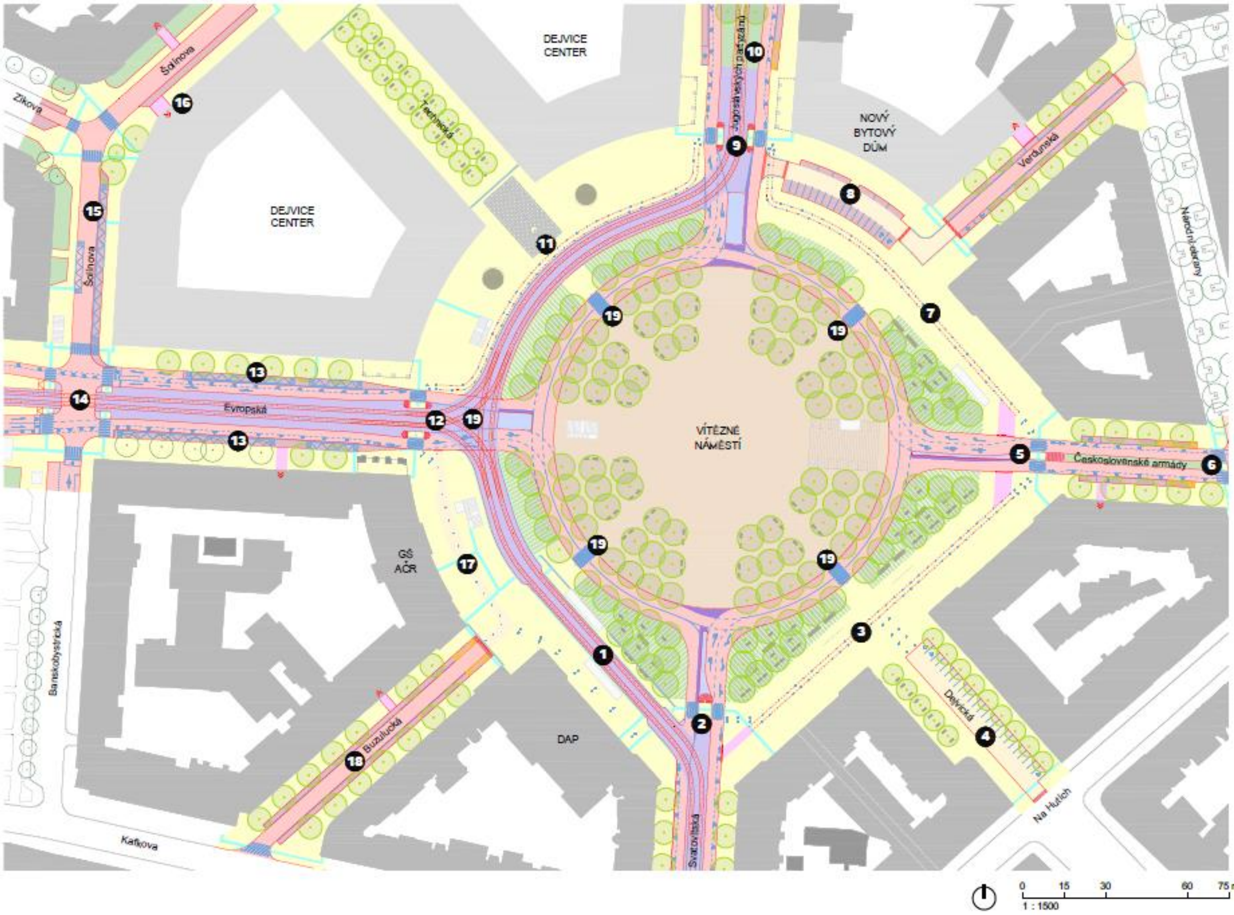


Figure 2-7: Proposed Geometry by Pavel Hnilička Architekti

Chapter 3: Description of Current Roundabout Design

The goal of this chapter is to describe the current design of the Vítězné Náměstí roundabout. This chapter covers the dimensions of the roundabout, the public transit lines currently servicing the area, and the observed problems affecting the area.

3.1 Dimensions

The Vítězné Náměstí is a three-lane roundabout that has four entrances and exits. The northern and southern approaches, Jugoslávských partizánů and Svatovítská, are single lane with a width of approximately four meters. These entrances have a dedicated lane to the closest immediate exit from the roundabout. The eastern and western approaches, Československé Armády and Evropská, are two lane with each lane being approximately three-and-a-half meters. To exit the roundabout at the closest exit from these approaches, drivers must enter the roundabout in the middle lane then merge to the outermost lane. The northern and southern exits are single-lane, with a respective lane width of five and four meters; the eastern and western exits are two-laned with each lane measuring at approximately three-and-a-half meters. Additional dimensions are marked in Figure 3-1.

The roundabout can be dissected into four "quadrants." The northwestern quadrant hosts the Dejvická bus terminal and pathways to the CTU campus. The northeastern quadrant features a park that visitors to the area can use, street parking, shops, and a construction site for a new apartment complex. The southeastern quadrant has additional shops and restaurants. The southwestern quadrant hosts the Building of the General Staff of the Czech Army. Both western quadrants have an exit from the Dejvická Metro A station stop.

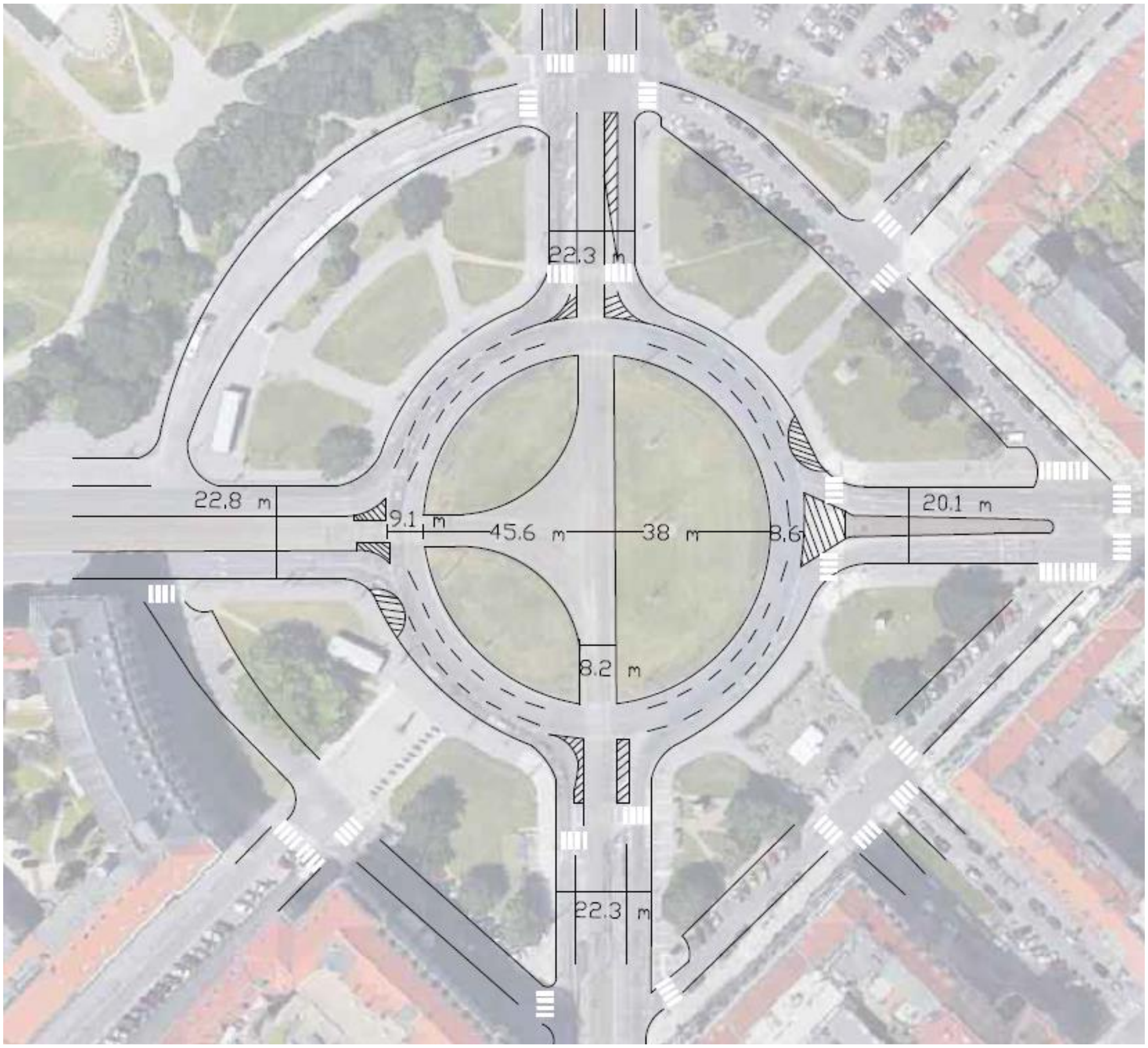


Figure 3-1: Dimensions of Current Geometry

3.2 Public Transit Routes

As previously stated, three forms of public transit access the Vítězné Náměstí roundabout: trams, buses, and the metro system. The figures in this subsection display public transit that is only available during normal operating hours (i.e., excluding night buses and night trams). Both figures are sections of maps publicly provided by Pražská Integrovaná Doprava (Prague Integrated Transport, abbreviated as PID). PID is the integrated transport system of Prague and manages a variety of modes of transit like trams, buses, metros, ferries, and a cable car. Figure 3-2 shows four tram lines that stop at Vítězné Náměstí: the lines 8, 18, 20, and 26. Figure 3-3 shows the eleven bus lines that stop at the Vítězné Náměstí or Dejvická bus stops. The dots and triangles in Figure 3-3 represent a two-way stop and one-way stop, respectively. Both Figure 3-2 and Figure 3-3 feature the Metro A line, which is show via the thick, green line. Public transit gets priority at this intersection.

Figure 3-2: Tram Lines Servicing Vítězné Náměstí by PID

Figure 3-3: Bus Lines Servicing Vítězné Náměstí by PID

3.3 Observed Problems

The primary issue of the Vítězné Náměstí roundabout is morning and afternoon congestion. Figure 3-4, Figure 3-5, Figure 3-6, and Figure 3-7 were taken as part of a site investigation by the author on a non-public holiday Tuesday on October, 25th, 2022 between 3:30 pm and 4:30 pm; although they were taken in the afternoon, they are similar to the congestion seen during a separate morning peak site investigation. These figures illustrate how congested the roundabout can be on all four approaches, and Figure 3-6 shows how congestion occurs within the roundabout. Congestion within the roundabout can block public transit from continuing its route (seen with the bus exiting the bus terminal in Figure 3-5), and the delay provokes some drivers to drive erratically (e.g., making unsafe lane changes, speeding through the tram tracks, etc.). Additionally, the congestion sometimes blocks the tram tracks.

Figure 3-4: Congestion on the Československé Armády (Westbound) Approach

Figure 3-5: Congestion on the Jugoslávských Partizánů (Southbound) Approach

Figure 3-6: Congestion in the Roundabout from the Evropská (Eastbound) Approach

Figure 3-7: Congestion on Svatovítská (Northbound) at the Vítězné Náměstí Tram Stop

Chapter 4: Simulation Modeling

One of the objections of this thesis is to perform a simulation modeling the three different geometries at Vítězné Náměstí: the current geometry (see Figure 3-1), the winning design by Pavel Hnilička Architects from (see Figure 2-6), and a redesign proposed by the author following suggestions from the 2009 version of the Manual for Uniform Traffic Control Devices (MUTCD) created by the Federal Highway Administration (FHWA). The three geometries will be analyzed at peak hour conditions on a non-public holiday weekday.

This chapter describes the software selected to create the models. Additionally, this chapter describes the types of data required to populate the model and the sources of these data. These three models, the current design, the International Competition Winner's design, and the MUTCD design, are distinguished later in the following sections of this chapter. The output of these three simulations and the evaluation of the simulation results are discussed in Chapter 5 and Chapter 6, respectively, followed by the conclusion in Chapter 7.

4.1 Simulation Software

The simulation software selected to model the three scenarios is PTV Vissim by the German developer Planung Transport Verkehr (PTV) Group. Vissim is a microscopic, multi-modal traffic flow simulation program that easily integrates all modes of transport into its simulations. The software has complete, thorough documentation, in addition to YouTube tutorials, webinars, etc. provided by the PTV Group. The software is flexible in how it models traffic behavior and allows for the collection of data such as queue length, travel times, and more. Data from the results of simulations can be downloaded in raw formats or analysis can be provided within the software given user inputs prior to the simulation start.

Talk about VISSIM. Its links, connectors, car-following model, lane changing models, routes and routing decisions, conflict areas, priority rules. <4 pages. Including a few references of VISSIM being used in roundabout modeling.

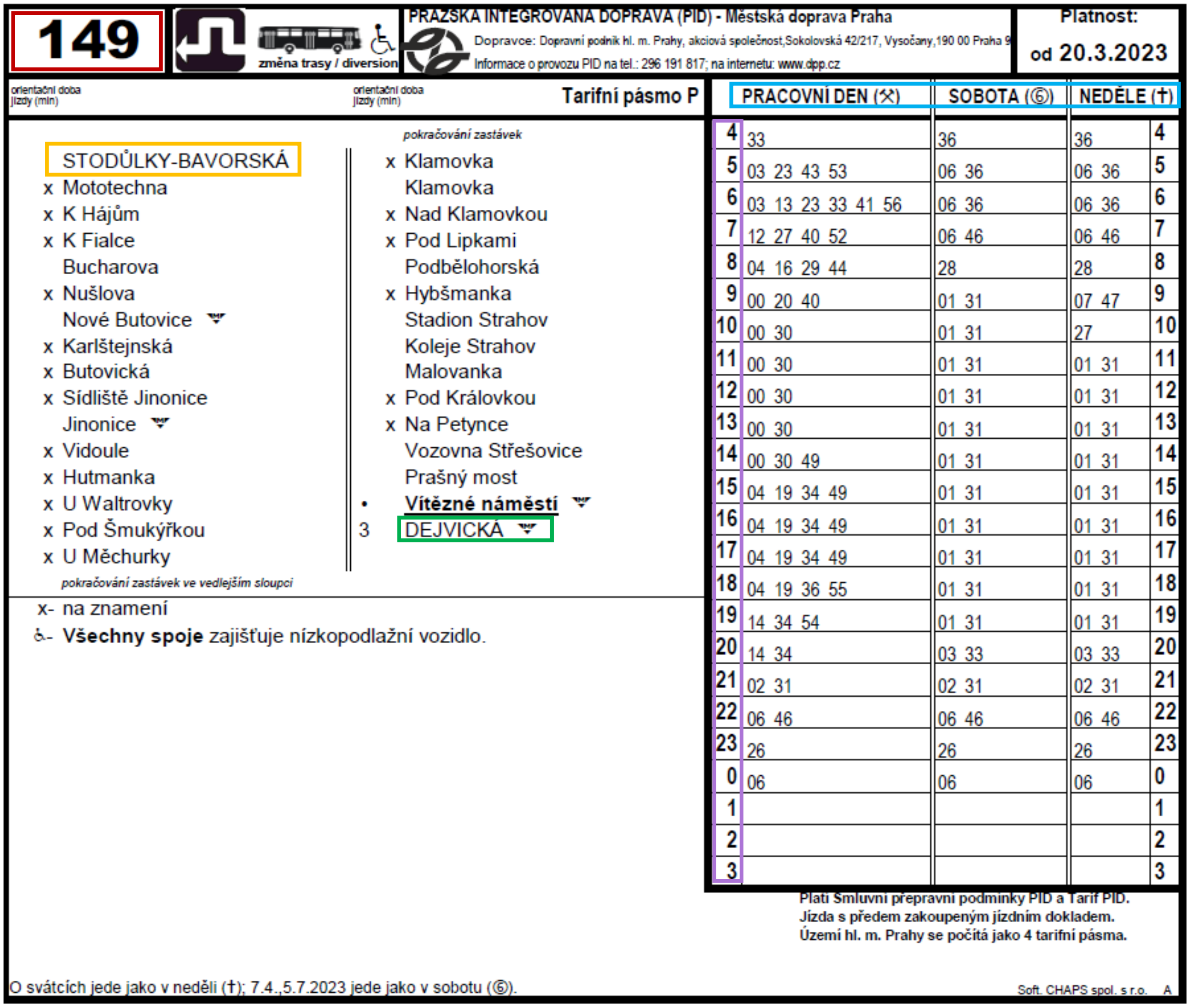
4.2 Data Sources

Two main sources of data were necessary to develop the simulation models: vehicle data and public transit data. The first set of data came from a traffic survey conducted by the Faculty of Transportation at CTU for Technická Správa Komunikací (Technical Administration of Communications, abbreviated as TSK). The survey was conducted on Thursday, May 25th, 2017, and measured traffic via cameras from seven am until seven pm. This survey includes the intensity of traffic flow, traffic flow composition, and the direction of travel. The peak hour traffic conditions were identified to be from ten am until eleven am. The direction and volume of flow for this period are summarized in Table 4-1. The first column lists the abbreviated street name for each of the four approaches while the second column lists the abbreviated street name for the exits. The third column is the vehicle volume for the hour for a given route, e.g., the traffic volume from Československé Armády (C.A.) to Jugoslávských Partizánů (J.P.) is 32 vehicles. The final column is the total volume per approach. The total volume for the entire intersection is listed at the bottom right corner of the table.

Table 4-1: Peak Hour Traffic Volumes

Entrance	Exit	Vehicles/Movement (veh/hour)	Total Vehicle Input/Entrance (veh/hour)
C.A. (East)	J.P	32	824
	E.	534	
	S.	258	
J.P (North)	E.	69	448
	S.	353	
	C.A	26	
E. (West)	S.	132	591
	C.A	319	
	J.P	120	
	E.	20	
S. (South)	C.A	59	549
	J.P	329	
	E.	161	
	Total # of Vehicles		2412

The second set of data is provided publicly by PID. Figure 4-1 is an example timetable available at bus stops, tram stops, and online. This timetable hosts information about a given line, including the stops along the line and the frequency of arrival at the given stop, and will be described here by referring to different colored boxes in the figure. The number boxed in red in the upper corner is the transit line number. Numbers between 1 and 26 are tram lines. Numbers between 100 and 299 are urban buses, while numbers between 301 and 850 are suburban buses. The name boxed in yellow is the originating stop of the line, while the name boxed in green is the final stop on the line. The name bolded and underlined indicates the stop that the timetable is providing for; Figure 4-1 is the timetable for Vítězné Náměstí. The three columns boxed in blue are the days of the week: column one is for weekdays, column two is Saturday, and column three is Sunday. The numbers boxed in purple are the hours of the day with the numbers in each row specifying the minutes of the hour that the public transit line arrives at the stop.



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změna trasy / diversion

PRAŽSKÁ INTEGROVANÁ DOPRAVA (PID) - Městská doprava Praha

Dopravce: Dopravní podnik hl. m. Prahy, akciová společnost,Sokolovská 42/217, Vysočany,190 00 Praha 9

Informace o provozu PID na tel.: 296 191 817; na internetu: www.dpp.cz

Platnost: od 20.3.2023

orientační doba jízdy (min) | orientační doba jízdy (min) | Tarifní pásmo P

STODŮLKY-BAVORSKÁ
x Mototechna
x K Hájům
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Bucharova
x Nušlova
Nové Butovice
x Karlštejnská
x Butovická
x Sídliště Jinonice
Jinonice
x Vidoule
x Hutmanka
x U Waltrovky
x Pod Šmukýřkou
x U Měchurky

pokračování zastávek ve vedlejším sloupci

pokračování zastávek

x Klamovka
Klamovka
x Nad Klamovkou
x Pod Lipkami
Podbělohorská
x Hybšmanka
Stadion Strahov
Koleje Strahov
Malovanka
x Pod Královkou
x Na Petynce
Vozovna Střešovice
Prašný most
• **Vítězné náměstí**
3 DEJVICKÁ

x- na znamení

♿- **Všechny spoje** zajišťuje nízkopodlažní vozidlo.

	PRACOVNÍ DEN (⚒)	SOBOTA (⑥)	NEDĚLE (†)	
4	33	36	36	4
5	03 23 43 53	06 36	06 36	5
6	03 13 23 33 41 56	06 36	06 36	6
7	12 27 40 52	06 46	06 46	7
8	04 16 29 44	28	28	8
9	00 20 40	01 31	07 47	9
10	00 30	01 31	27	10
11	00 30	01 31	01 31	11
12	00 30	01 31	01 31	12
13	00 30	01 31	01 31	13
14	00 30 49	01 31	01 31	14
15	04 19 34 49	01 31	01 31	15
16	04 19 34 49	01 31	01 31	16
17	04 19 34 49	01 31	01 31	17
18	04 19 36 55	01 31	01 31	18
19	14 34 54	01 31	01 31	19
20	14 34	03 33	03 33	20
21	02 31	02 31	02 31	21
22	06 46	06 46	06 46	22
23	26	26	26	23
0	06	06	06	0
1				1
2				2
3				3

Platí Smluvní přepravní podmínky PID a Tarif PID.
Jízda s předem zakoupeným jízdním dokladem.
Území hl. m. Prahy se počítá jako 4 tarifní pásma.

O svátcích jede jako v neděli (†); 7.4.,5.7.2023 jede jako v sobotu (⑥).

Soft. CHAPS spol. s r.o. A

Figure 4-1: Example Public Transit Timetable by PID

For all three models, twenty timetables (eight for tram lines and twelve for bus lines) were gathered to model the bus and tram lines and their frequency. Tram line and bus line timetables were saved if they visited at least Vítězné Náměstí or Dejvická. Details about the timetables input into the three models will be described in the following section.

4.3 Simulation Models

The details of the three simulation models are discussed within this section; the geometry and attributes of each model (e.g., routing decision information, conflict area locations, etc.) varies. However, each of the three models share the same number of public transit lines, speed pertransit line, and the distribution of public transit being loaded into the model. Table 4-2 lists each of the public transit lines by their number, followed by their destination stop, as well as the speed distribution per public transit lines. Of the bus lines outlined in Figure 3-3 from the previous section, the 116 and the 340 lines are excluded from the model due their timetables currently being unavailable. Additionally, lines 107, 108, 147, 160, 340, 350, and 355 terminating at Dejvická are excluded from the model as information about their arrival time cannot be accurately acquired.

Table 4-2: Public Transit Lines Values for Scenarios 1, 2, and 3

Public Transit Line	Speed Dist. (km/h)
8: Starý Hloubětín	30
18: Vozovna Pankrác	30
20: Malostranská	30
26: Nádraží Hostivař	30
8: Nádraží Podbaba	30
18: Nádraží Podbaba	30
20: Červený Vrch	30
26: Vozovna Vokovice	30
107: Suchdol	40
108: Hodčina	40
143: Dejvická	40
143: Stadion Strahov	40
147: Výhledy	40
149: Stodůlky Bavorská	40
149: Dejvická	40
160: Výhledy	40
180: Dejvická	40
180: Zličín	40
350: Kladno, Oaza	40
355: Únětice	40

Scenario 1 and Scenario 3 share the same geometry of the bus terminal, as Scenario 3 is meant to be a design that maintains as much of the current existing infrastructure in Scenario 1. Figure 4-2 highlights the stops within the bus terminal; the geometry and the rearrangement of stops for Scenario 2 will be discussed within its subsection.

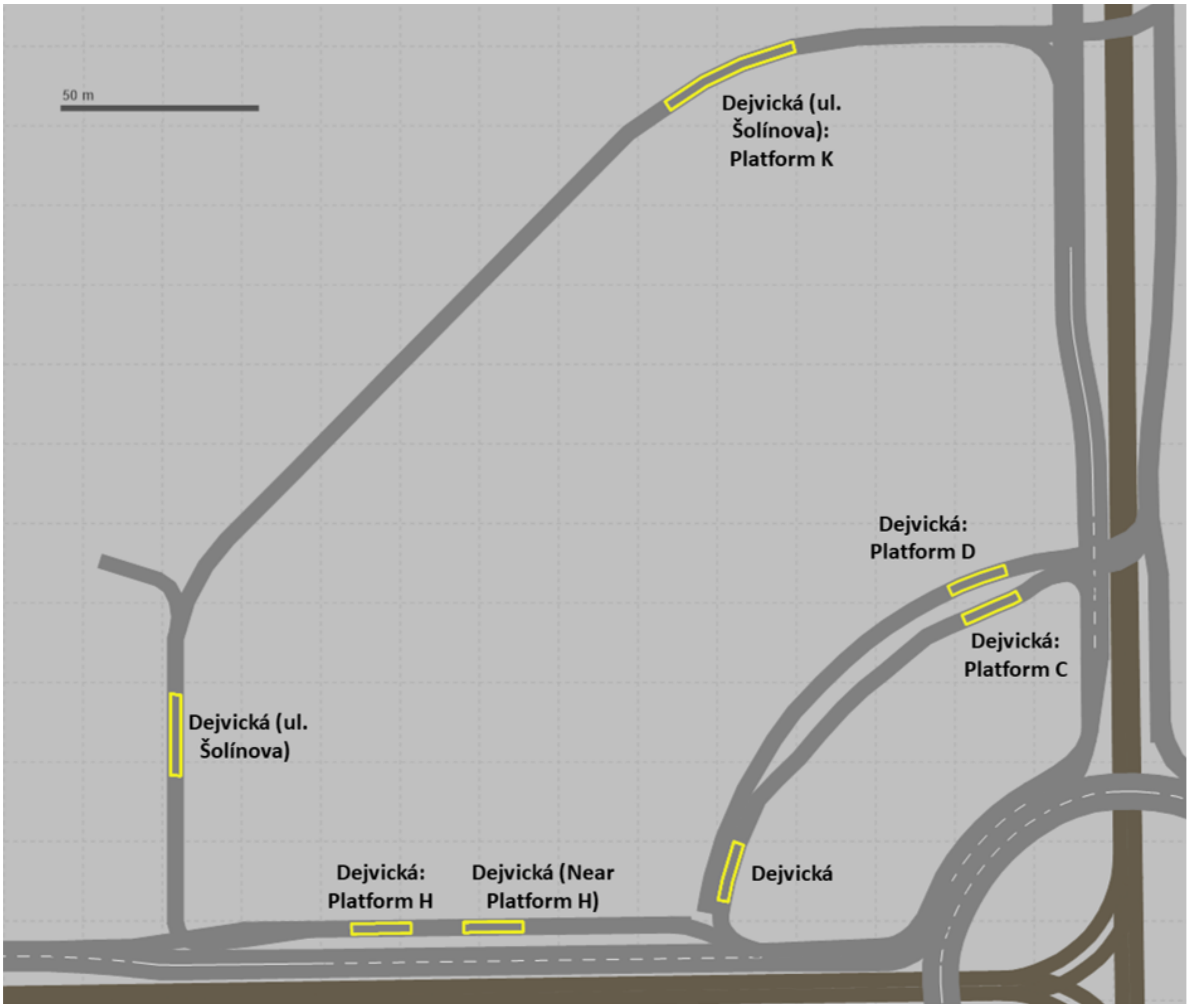

Figure 4-2: Locations of Bus Stations in Scenario 1 and 3

Each scenario is run for a total time of 6300 seconds and is divided into three periods: a warmup period (0 to 900 seconds), the analysis period (900 to 4500 seconds), and the cooldown period (4500 seconds to 6300 seconds). The input volumes during each of these three periods vary from one period to another and are described for each of the three scenarios.

Scenario 1: Current Design

The geometry of Scenario 1 has been previously described in Chapter 3 and Figure 4-3 shows it within Vissim. Figure 4-4 displays the links (blue lines) and connectors (pink lines).

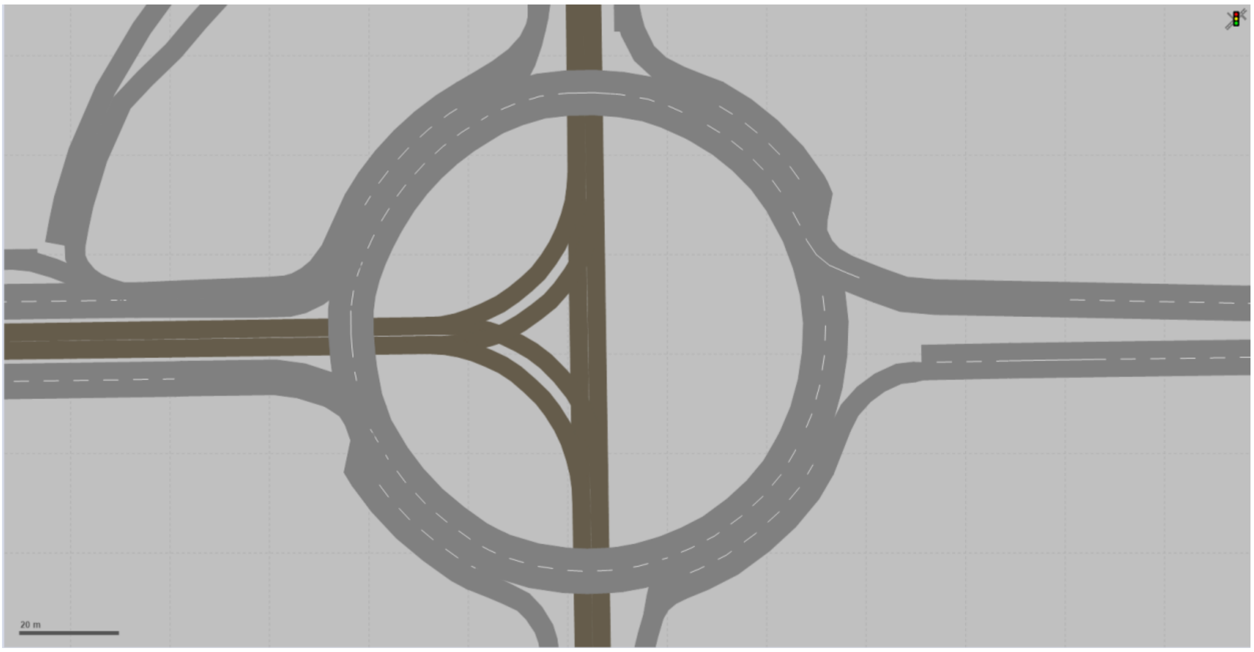

Figure 4-3: Lane Alignments for Scenario 1

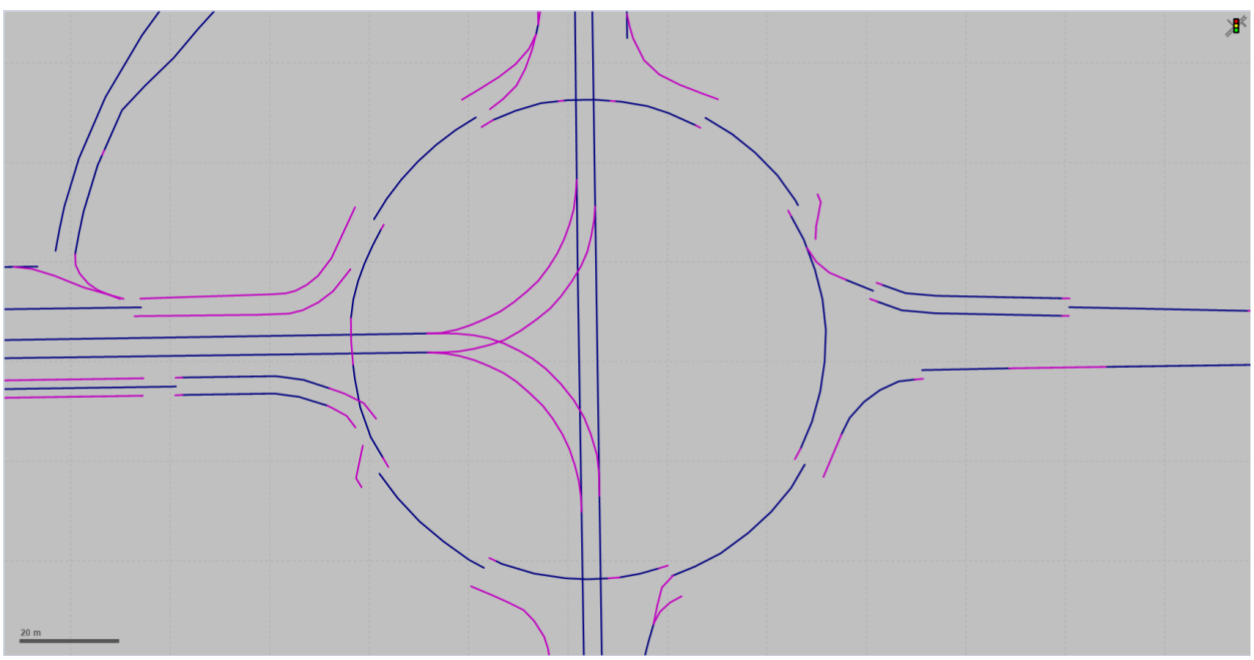

Figure 4-4: Links and Connectors for Scenario 1

The gray lanes in Figure 4-3 are the paved roadways while the brown lanes are the lanes only accessible by public transit. Figure 4-5 demonstrates the conflict areas and priority rules locations that guide the behavior of the roundabout. Vehicles approaching the red sections must yield to the vehicles in or approaching the green sections. Trams entering or exiting the roundabout get priority over vehicles progressing through the roundabout.

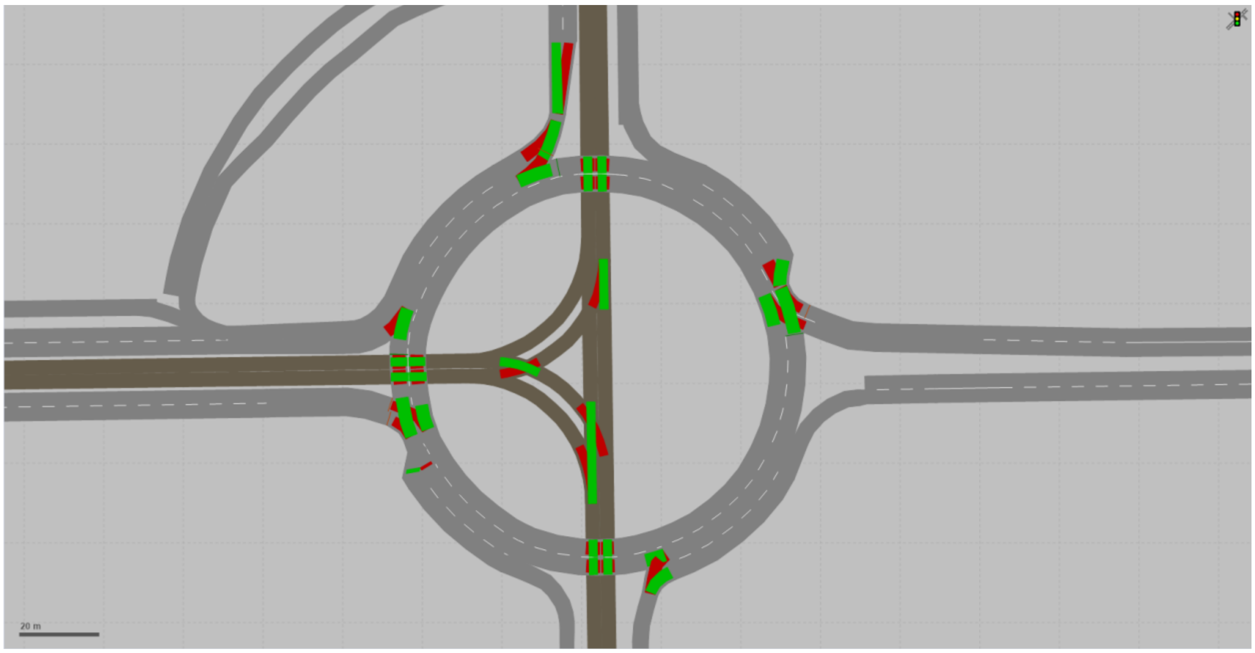

Figure 4-5: Conflict Areas and Priority Rules for Scenario 1

Table 4-3 shows the traffic input values throughout the simulation for Scenario 1 on each of the four approaches. The northern approach (J.P) and the southern approach (S.) do not have traffic inputs separated by lane as each entrance into the roundabout is one lane; the eastern approach (C.A.) and western approach (E.) have traffic inputs separated by right lane and left lane as both approaches are two lanes each. The values vary based on the time period of the simulation; Volume (0-900) is the input volume during the warmup period, Volume (900-4500) is the input volume for the analysis period, and Volume (4500-6300) is the cooldown period.

Table 4-3: Traffic Input Values for Scenario 1

Entrance	Lane	Volume (0-900)	Volume (900-4500)	Volume (4500-6300)
C.A.	Right	103	412	0
	Left	103	412	0
J.P.	-	112	448	0
E.	Right	73	296	0
	Left	73	295	0
S.	-	137	549	0

Traffic input values were separated by lane to better model the routing decisions of the vehicles, as vehicles that want to turn right use the right lane, those that want to turn left use the left lane, and those that want to go straight will use both lanes. Table 4-4 shows where the routing decisions begin and end and the relative flow per routing decision. The values in these tables reflect the actual number of vehicles per turn (e.g., 32 vehicles start in the right lane of C.A. and exit at J.P). The final column combines routing values for exits with the same general approach (e.g., 534 vehicles go from C.A. and exit at E.)

Table 4-4: Static Routing Values for Scenario 1

Route Start	Route End	Rel. Flow	Total Rel. Flow
C.A. (Right)	J.P.	32	32
	E.	380	534
C.A. (Left)	E.	154	
	S.	258	258
J.P.	E.	69	69
	S.	353	353
	C.A.	26	26
E. (Right)	C.A.	164	164
	S.	132	287
E. (Left)	S.	155	
	E.	20	20
	J.P.	120	120
S.	C.A.	59	59
	J.P.	329	329
	E.	161	161

Scenario 2: International Competition Winner's Design

The geometry of Scenario 2 is based on the Pavel Hnilička Architekti redesign of Vítězné Náměstí (refer to Figure 2-7). The design in Vissim, shown in Figure 4-6, slightly varies from the conceptual drawing in that the northern approach (J.P.), the eastern approach (C.A.), and the western approach and exit (E.) were kept as two lanes instead of one lane. Figure 4-7 displays this geometry as links (blue lines) and connectors (pink lines).

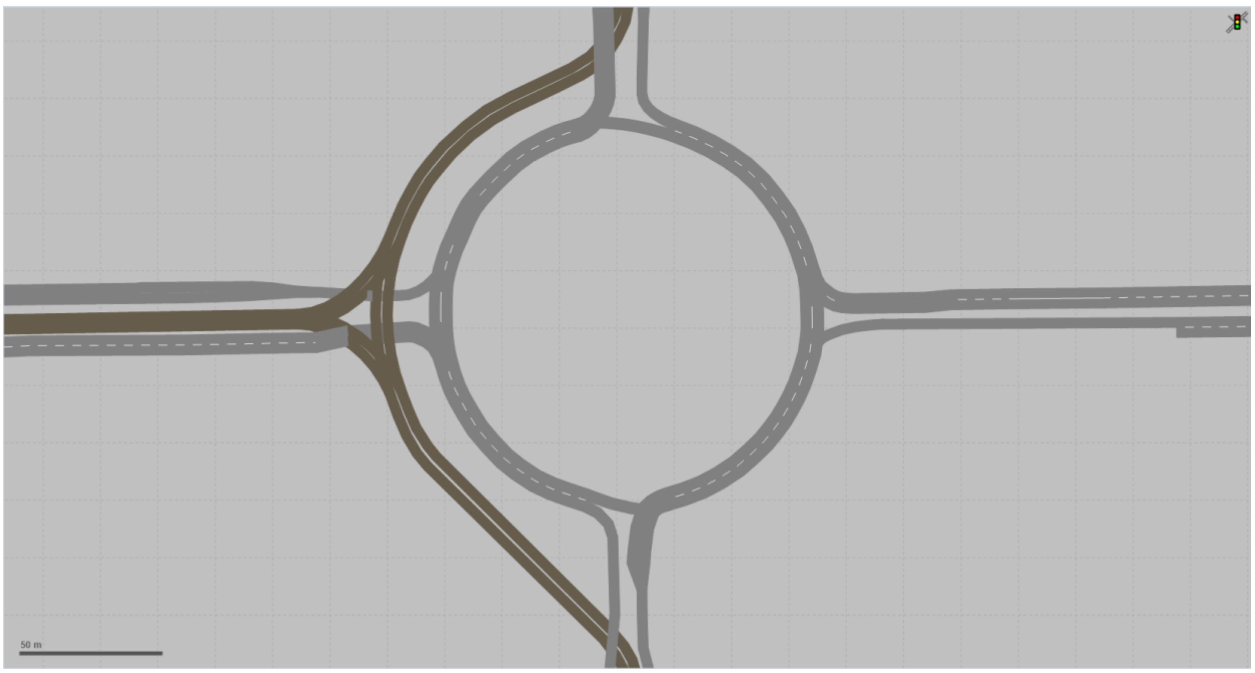

Figure 4-6: Lane Alignments for Scenario 2

Figure 4-8 demonstrates the conflict areas and priority rules locations that guide the behavior of the drivers while entering and exiting the roundabout. Vehicles approaching the red sections must yield to the vehicles in or approaching the green sections. Trams entering or exiting the roundabout get priority over vehicles progressing through the roundabout. This geometry has more conflict area points between vehicles and the trams due how trams continue their given route on the western side of the roundabout.

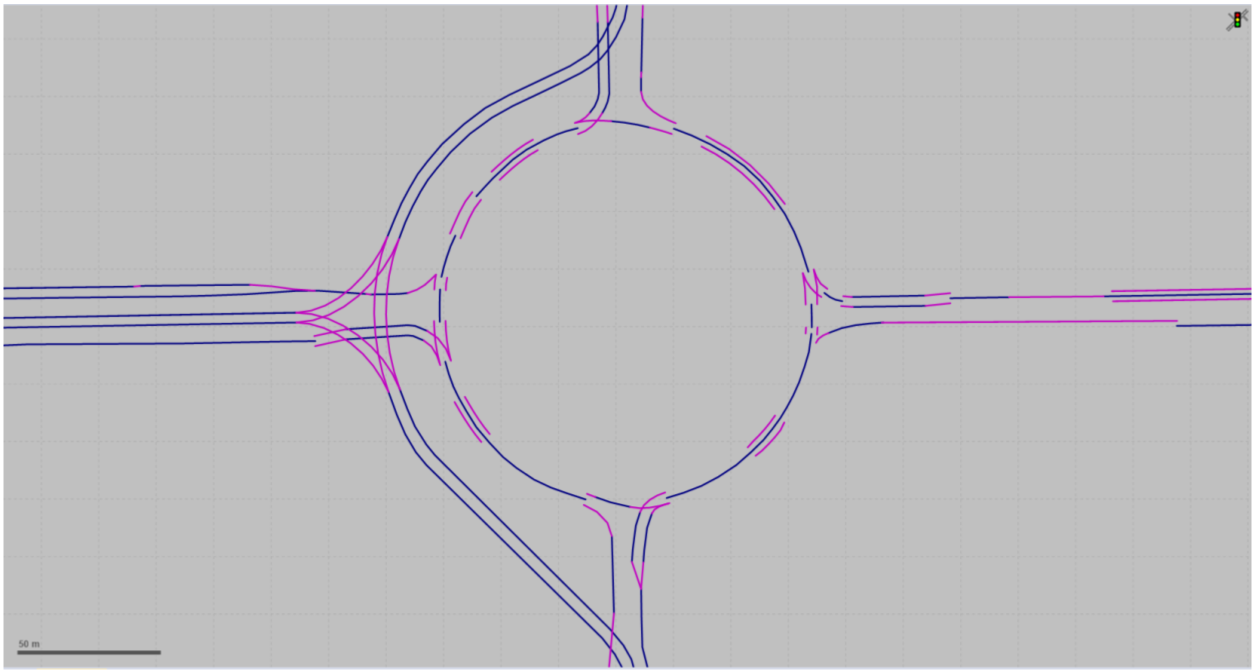

Figure 4-7: Links and Connectors for Scenario 2

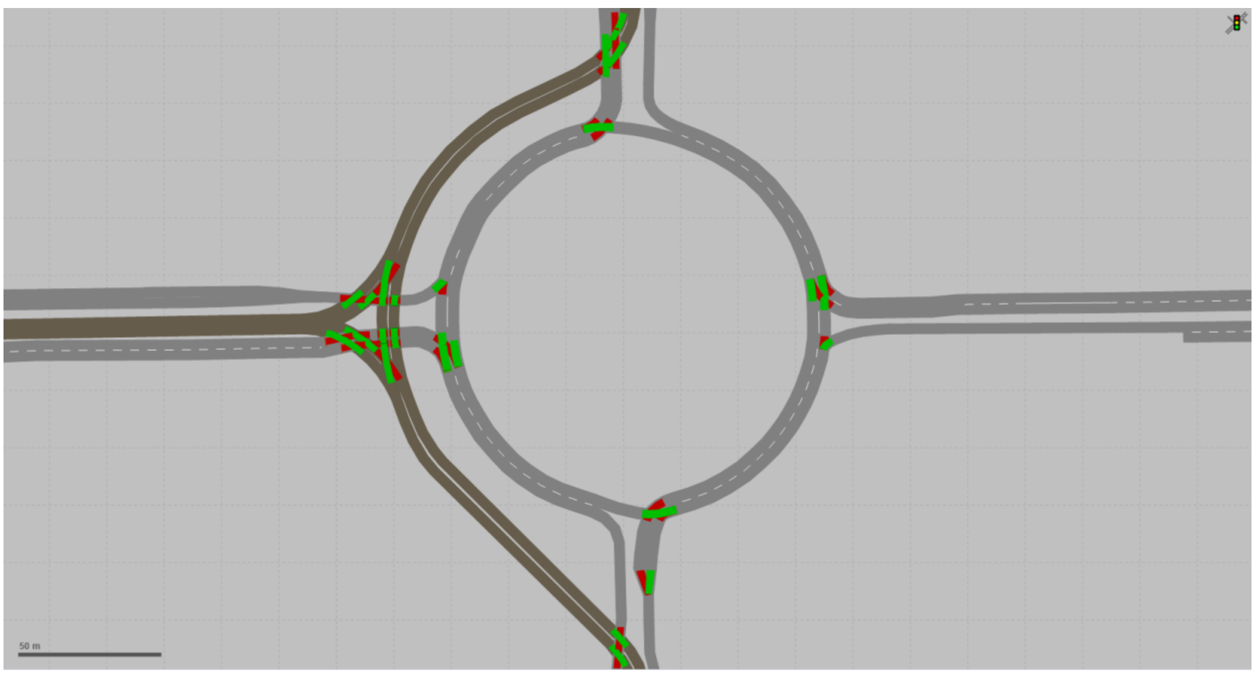

Figure 4-8: Conflict Areas and Priority Rules for Scenario 2

Table 4-5 shows the traffic input values throughout the simulation for Scenario 2 on each of the four approaches. The southern approach (S.) does not have traffic input separated by lane as each entrance into the roundabout is one lane; all other approaches have traffic inputs separated by right lane and left lane as they are all are two lanes each. Like Scenario 1, the values vary based on the time period of the simulation.

Table 4-5: Traffic Input Values for Scenario 2

Entrance	Lane	Volume (0-900)	Volume (900-4500)	Volume(4500-6300)
C.A	Right	103	412	0
	Left	103	412	0
J.P.	Right	105	422	0
	Left	6	26	0
E.	Right	73	296	0
	Left	73	295	0
S.	-	137	549	0

Table 4-6 shows where the routing decisions begin and end and the relative flow per routing decision. The values in these tables reflect the total number of vehicles per route.

Table 4-6: Static Routing Values for Scenario 2

Route Start	Route End	Total Rel. Flow
C.A. (Right)	J.P.	32
C.A. (Left)	E.	534
	S.	258
J.P. (Right)	E.	69
	S.	353
J.P. (Left)	C.A	26
E. (Right)	S.	132
E. (Left)	C.A.	319
	J.P.	120
	E.	20
S.	C.A.	59
	J.P.	329
	E.	161

As previously mentioned, the configuration of bus stops varies for Scenario 2 from the configuration in Scenario 1 and Scenario 3. The bus terminal featured in Scenario 1 and Scenario 2 were removed in this design to make room for the new arrangement of the tram lines. Figure 4-9 highlights the new bus stop arrangement; the names correspond with the stops that previously existed and were moved.

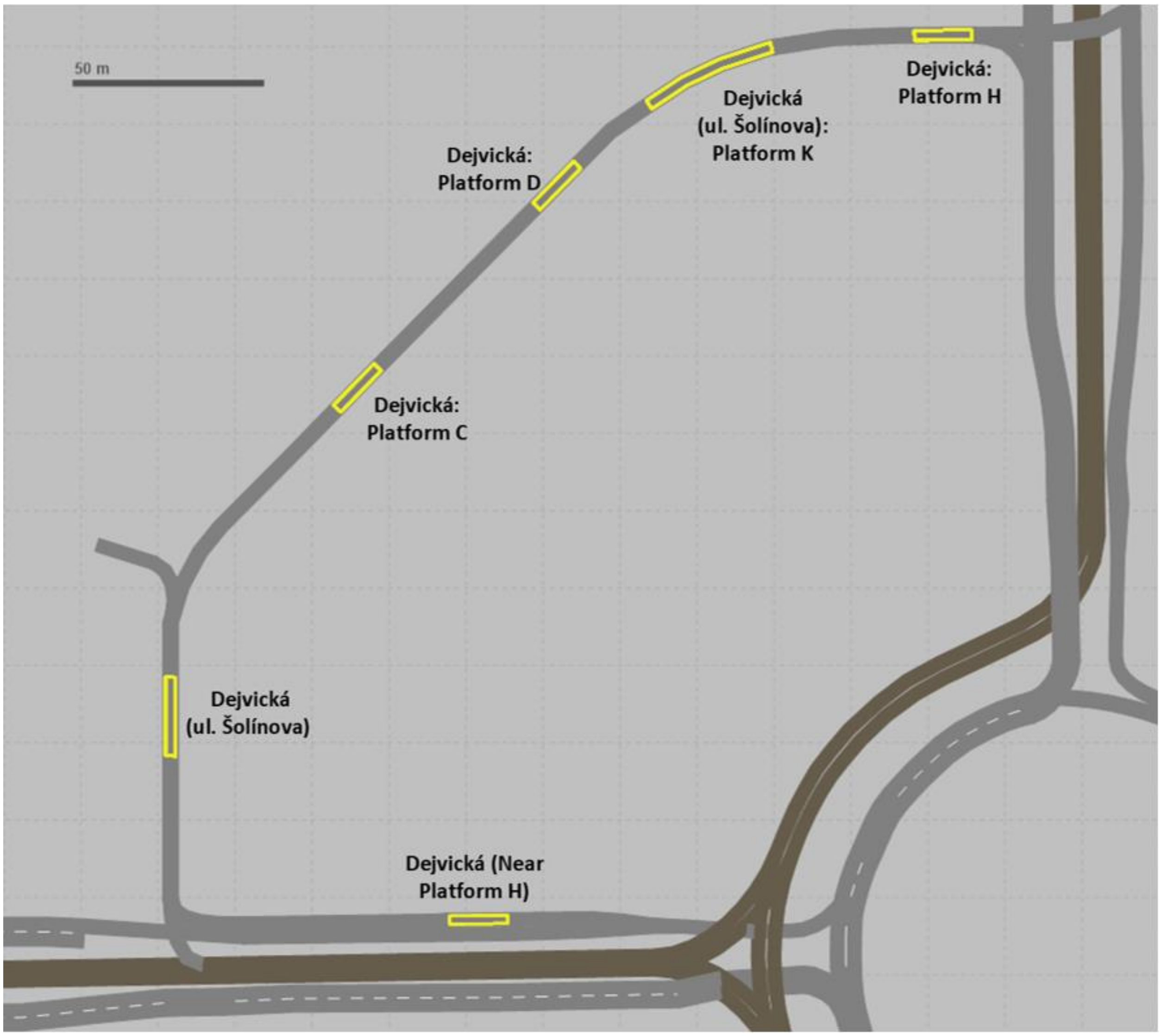

Figure 4-9: Locations of Bus Stations in Scenario 2

Scenario 3: MUTCD Design

Scenario 3 is modeled like the example shown in Figure 4-10. This design was selected as it would best fit the current location and geometrical arrangement of Vítězné Náměstí, especially regarding the public transit infrastructure.

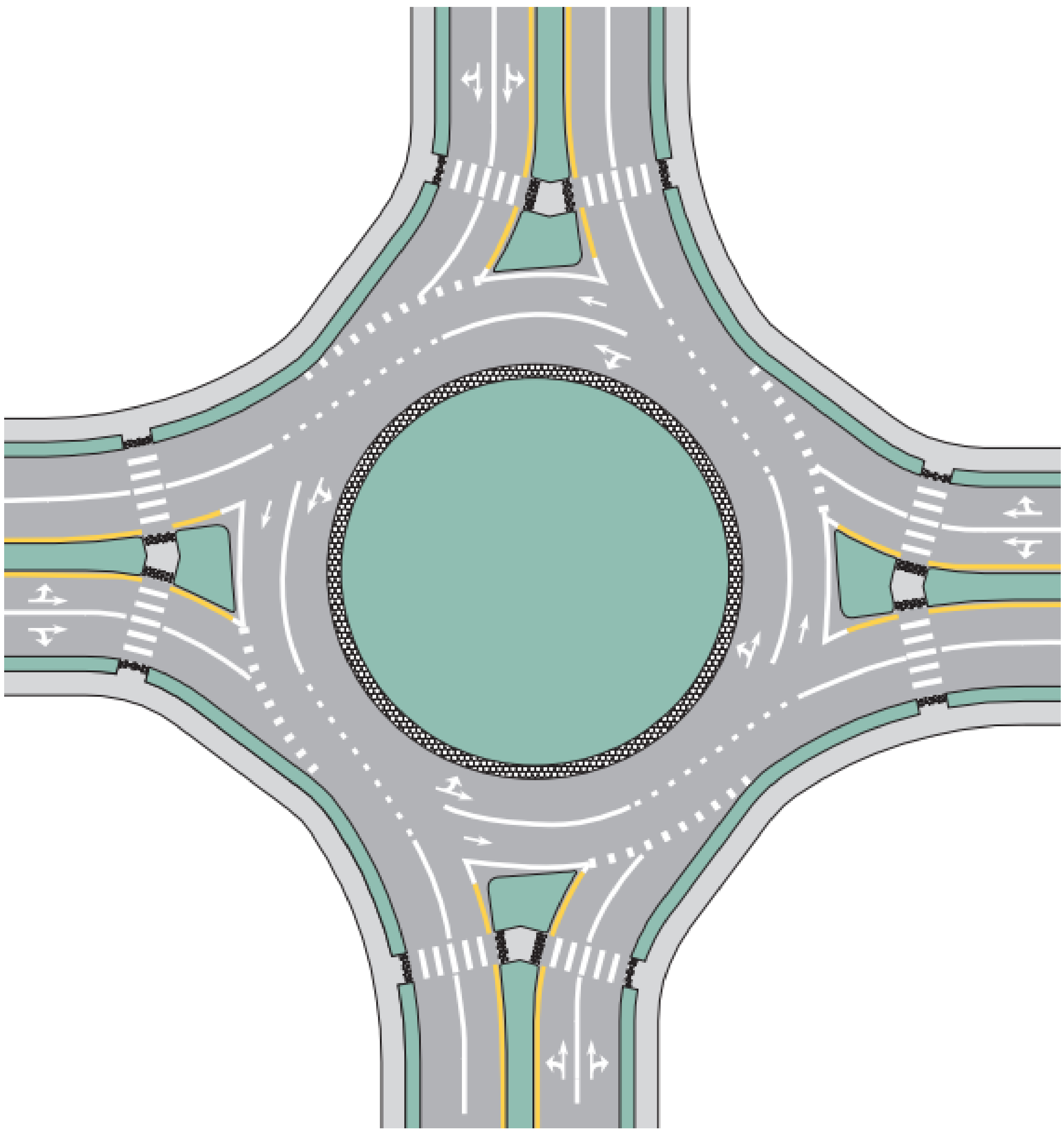

Figure 4-10: Example of Markings for a Two-Lane Roundabout with Two-Lane Exits Figure (FHWA, 2009)

The design in Vissim, shown in Figure 4-11, slightly varies from the example markings from the MUTCD manual as the diameter of the roundabout is much larger at Vítězné Náměstí. Additionally, both the southern approach and exit (S.) are single lanes due. This decision was to minimize additional changes to the area as much as possible (i.e., preserving the existing infrastructure). Figure 4-12 displays this geometry as links (blue lines) and connectors (pink lines).

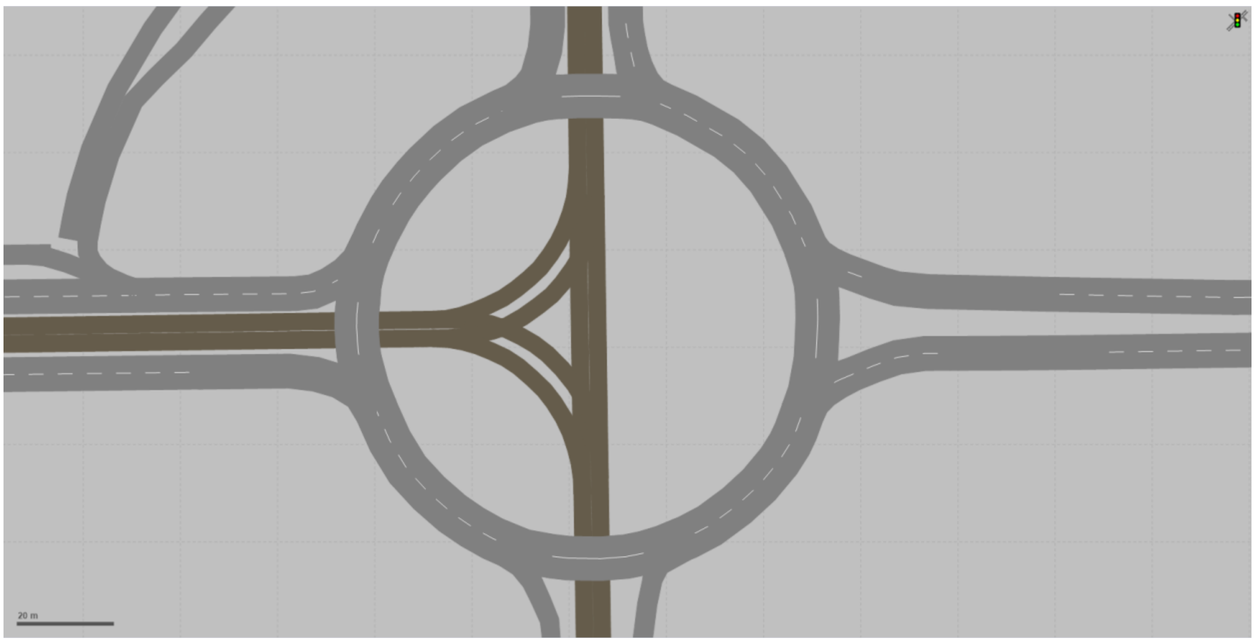

Figure 4-11: Lane Alignments for Scenario 3

Figure 4-13 demonstrates the conflict areas and priority rules locations that guide the behavior of the roundabout. Vehicles approaching the red sections must yield to the vehicles in or approaching the green sections. Trams entering or exiting the roundabout get priority over vehicles progressing through the roundabout. The conflict areas are similar to that of Scenario 1, but additional priority rules were added at the northern, eastern, and western approaches to better simulate vehicle interactions between vehicles exiting from the inner lane and vehicles continuing through the roundabout in the outer lane.

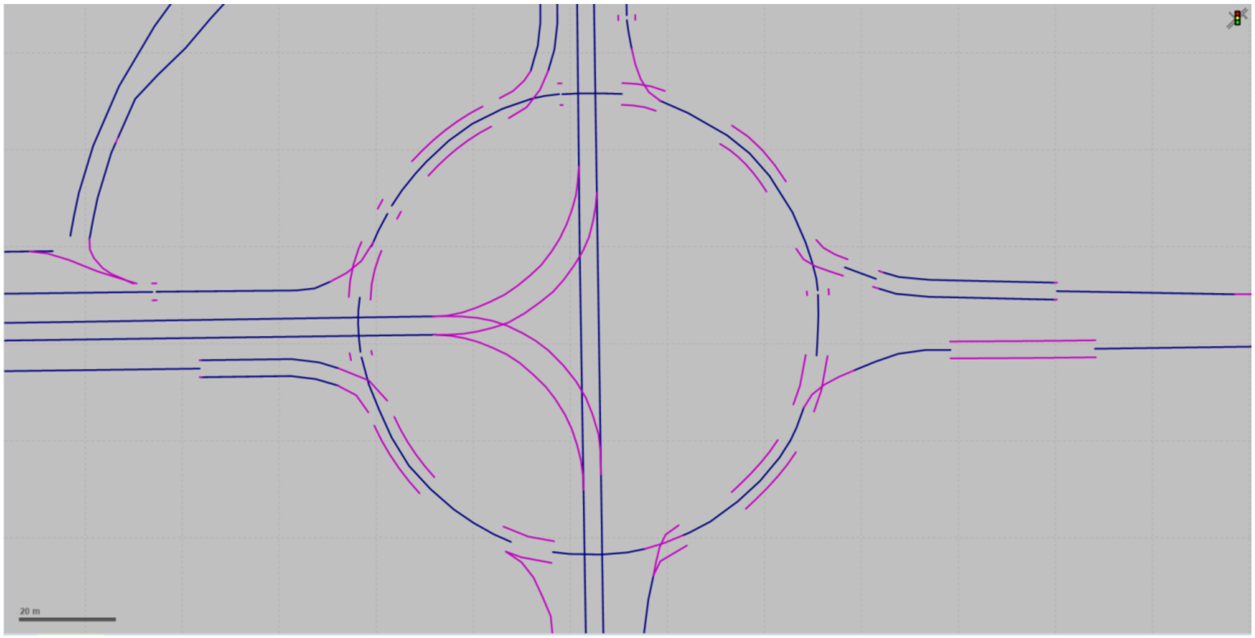

Figure 4-12: Links and Connectors for Scenario 3

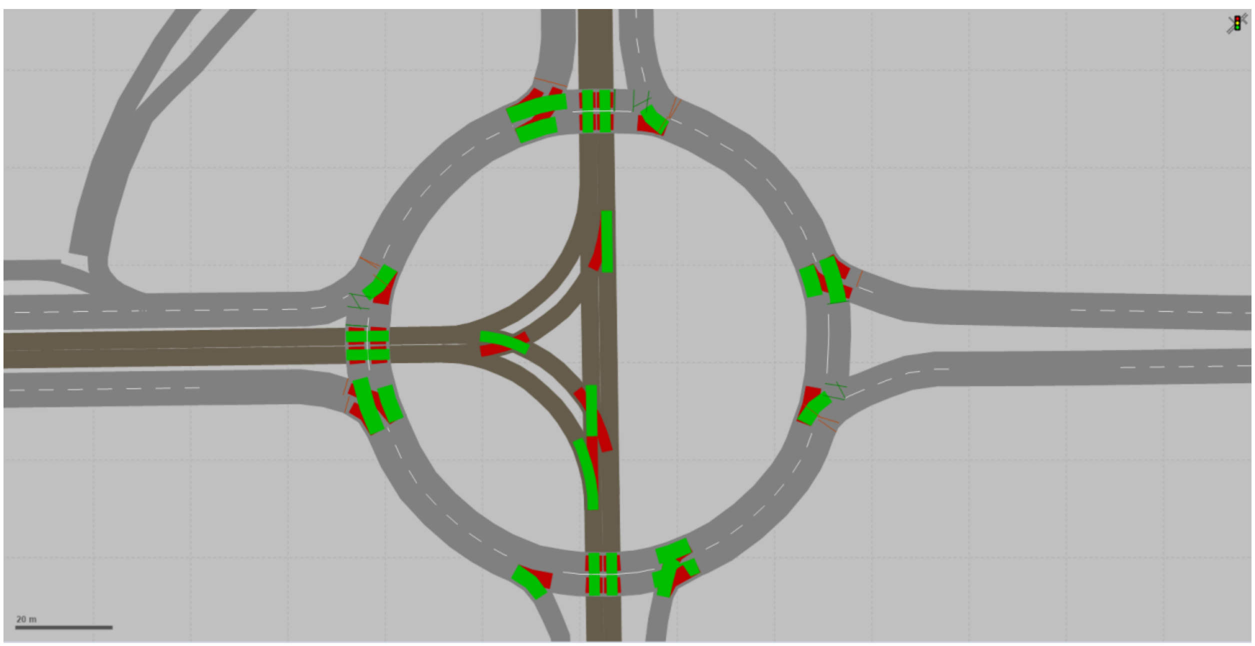

Figure 4-13: Conflict Areas and Priority Rules for Scenario 3

Table 4-7 shows the traffic input values throughout the simulation for Scenario 3 on each of the four approaches. The southern approach (S.) does not have traffic input separated by lane as each entrance into the roundabout is one lane; all other approaches have traffic inputs separated by right lane and left lane as they are all are two lanes each. Like Scenario 1 and Scenario 2, the values vary based on the time period of the simulation.

Table 4-7: Traffic Input Values for Scenario 3

Entrance	Lane	Volume (0-900)	Volume (900-4500)	Volume (4500-6300)
C.A.	Right	103	412	0
	Left	103	412	0
J.P.	Right	105	422	0
	Left	6	26	0
E.	Right	73	296	0
	Left	73	295	0
S.	-	137	549	0

Table 4-8 shows where the routing decisions begin and end and the relative flow per routing decision. The values in these tables reflect the actual number of vehicles per turn (e.g., 32 vehicles start in the right lane of C.A. and exit at J.P). The final column combines routing values for exits with the same general approach (e.g., 534 vehicles go from C.A. and exit at E.)

Table 4-8: Static Routing Values for Scenario 3

Route Start	Route End	Rel. Flow	Total Rel. Flow
C.A. (Right)	J.P.	32	32
	E. (Right)	380	534
C.A. (Left)	E. (Left)	154	
	S.	258	258
J.P. (Right)	E.	69	69
	S.	353	353
J.P. (Left)	C.A.	26	26
E. (Right)	S.	132	132
	C.A. (Right)	164	319
E. (Left)	C.A. (Left)	155	
	J.P.	120	120
	E.	20	20
S.	C.A.	59	59
	J.P. (Right)	216	329
	J.P. (Left)	113	
	E.	161	161

4.4 Summary of Model Features

Table 4-9 summarizes the number of approach lanes, entry lanes, circulatory lanes, conflict areas, and priority rules that have been described within this chapter.

Table 4-9: Model Features by Location

Model feature	Location	Scenario 1	Scenario 2	Scenario 3
No. of approach lanes	Northbound	2	2	2
	Westbound	2	2	2
	Southbound	2	2	2
	Eastbound	2	2	2
No. of entry lanes	Northbound	1	2	1
	Westbound	2	2	2
	Southbound	1	2	2
	Eastbound	2	2	2
No. of circulatory lanes	Northwest quadrant	2	2	2
	Southwest quadrant	2	2	2
	Southeast quadrant	2	2	2
	Northwest quadrant	2	2	2
No. of conflict areas	Northbound entrance	3	3	4
	Westbound entrance	3	4	2
	Southbound entrance	3	2	2
	Eastbound entrance	2	4	2
	Northbound exit	0	0	1
	Westbound exit	1	1	1
	Southbound exit	0	0	1
	Eastbound exit	0	1	1
No. of priority rules	Northbound entrance	0	0	0
	Westbound entrance	1	0	1
	Southbound entrance	1	0	2
	Eastbound entrance	2	0	2
	Northbound exit	0	0	3
	Westbound exit	0	0	3
	Southbound exit	0	0	0
	Eastbound exit	0	0	3

Chapter 5: Simulation Outputs

For each scenario, ten simulations were run using the seeds shown in Table 5-1. Vissim has a variety of options for analysis computation within the application, as well as for the output of raw data.

Table 5-1: Simulation Seed Numbers

Run No.	Rand. Seed No.
1	41
2	44
3	47
4	50
5	53
6	56
7	59
8	62
9	65
10	68

Figure 5-1 shows the evaluation configuration for each of the three scenarios. Any box that is checked (e.g., queue counters, vehicle inputs, vehicle travel times) will be measured during a selected period. A period is selected by imputing values in the "from-time" and "to-time" columns. As previously stated, the analysis period for all three scenarios is from 900 seconds to 4500 seconds. All selected evaluation parameters can be measured by mode type, which is done by highlighting all relevant vehicle classes.

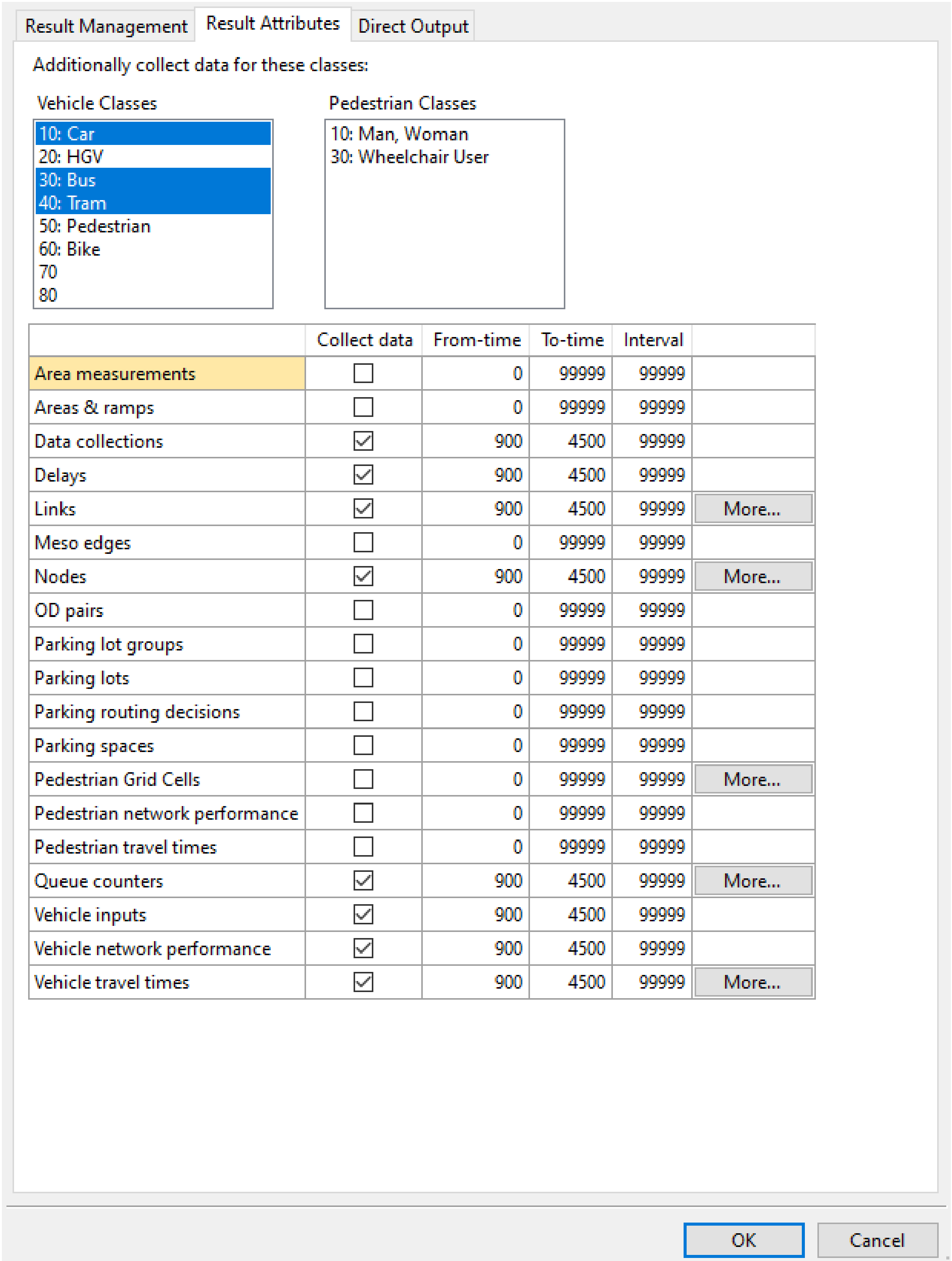

Figure 5-1: Evaluation Configuration Dialogue Box in Vissim

Regarding the raw data simulation outputs, the following items can be saved in a variety of different file formats that can be converted to an Excel spreadsheet easily:

- Area measurements (raw data)
- Convergence Data collection (raw data)
- Discharge record
- Green time distribution
- Lane changes
- Managed lanes
- Nodes (raw data)
- Pedestrian record
- Pedestrian travel times (OD data)
- Pedestrian travel times (raw data)
- Public transport waiting times
- Signal changes
- Signal control detector record
- SSAM Vehicle input data
- Vehicle record
- Vehicle travel times (raw data)

For this thesis, the necessary data (i.e., information about queues and the travel times of vehicles) were saved by copying the data within Vissim and saving it in a .xlsx format. The outputs regarding queue lengths and travel times of vehicles for all three scenarios are found in the following subsections. Queue counter locations and vehicle travel time locations are consistent throughout the three scenario models.

Regarding the location of the vehicle travel time counters, they are downstream from the roundabout at approximately 270 meters on the northern approach, 280 meters on the western and eastern approaches, and 240 meters on the southern approach. As seen previously in Table 4-1, there exist thirteen combinations of approaches and exits: three starting at the northern approach, four starting from at the western approach, three starting from the southern approach, and three starting from the eastern approach. Depending on the geometry of the scenario, the implementation of routing decisions would vary (as seen by the differences between Table 4-4, Table 4-6, and Table 4-8 in the separation of routing decisions by lane in the event of a two-lane approaches from a given direction.)

5.1 Scenario 1 Outputs

Figure 5-2 highlights the queue counter locations via a pink line across a lane or lanes. Table 5-2 shows the length of the queue buildup at each queue counter over ten simulations, the average queue over all ten simulations, the maximum queue length, the minimum queue length, and the standard deviation among measurements.

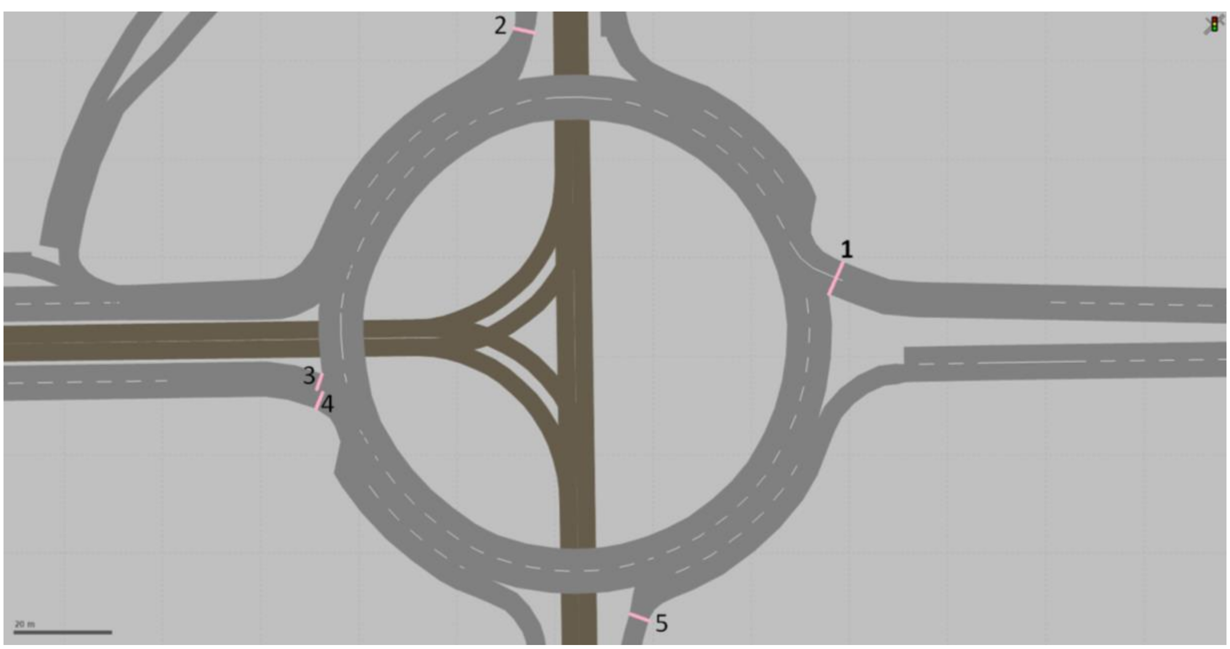

Figure 5-2: Queue Counter Locations for Scenario 1

Table 5-3 shows the average travel time for each travel counter over ten simulations, the average over all ten simulations, the maximum travel time, the minimum travel time, and the standard deviation among measurements.

Table 5-2: Scenario 1 Queue Length Output Values

Queue Length (m)	**Queue Counter**				
Sim. Run	1	2	3	4	5
1	367.5	212.0	30.0	10.1	11.0
2	379.0	191.3	24.7	14.8	6.7
3	326.9	256.0	20.7	13.3	13.9
4	345.2	150.0	65.9	58.6	6.2
5	332.4	121.7	15.8	10.0	20.4
6	294.8	184.6	39.0	33.3	7.8
7	290.1	134.2	11.8	6.4	6.7
8	374.9	61.9	23.6	13.9	7.4
9	294.2	84.3	27.9	23.0	14.8
10	369.5	138.6	9.5	3.4	7.0
AVG	337.4	153.4	26.9	18.7	10.2
MAX	379.0	256.0	65.9	58.6	20.4
MIN	290.1	61.9	9.5	3.4	6.2
STDDEV	35.3	58.8	16.3	16.4	4.8

Table 5-3: Scenario 1 Travel Time Output Values

Travel Time (s)	**Travel Time Counter**													
Sim. Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	131	215	408	223	233	240	82	89	47	56	63	40	50	59
2	122	188	407	182	205	212	75	79	48	58	60	35	47	55
3	205	234	388	230	235	276	66	74	50	61	70	38	53	62
4	217	238	369	165	175	190	140	129	49	58	67	34	46	57
5	207	237	383	167	164	178	62	67	52	61	70	46	57	68
6	84	149	302	225	204	244	104	100	50	61	60	35	48	56
7	111	183	356	157	178	173	55	59	51	58	73	37	48	56
8	78	164	354	89	105	117	70	78	52	60	63	33	48	56
9	141	202	323	98	120	139	77	82	58	70	68	40	54	62
10	97	173	371	164	180	179	53	54	47	54	64	39	47	57
AVG	139	198	366	170	180	195	78	81	50	60	66	38	50	59
MAX	217	238	408	230	235	276	140	129	58	70	73	46	57	68
MIN	78	149	302	89	105	117	53	54	47	54	60	33	46	55
STDDEV	52	32	34	49	43	49	26	22	3	4	4	4	4	4

5.2 Scenario 2 Outputs

Figure 5-3 highlights the queue counter locations via a pink line across a lane or lanes. Table 5-4 shows the length of the queue buildup at each queue counter over ten simulations, the average queue over all ten simulations, the maximum queue length, the minimum queue length, and the standard deviation among measurements.

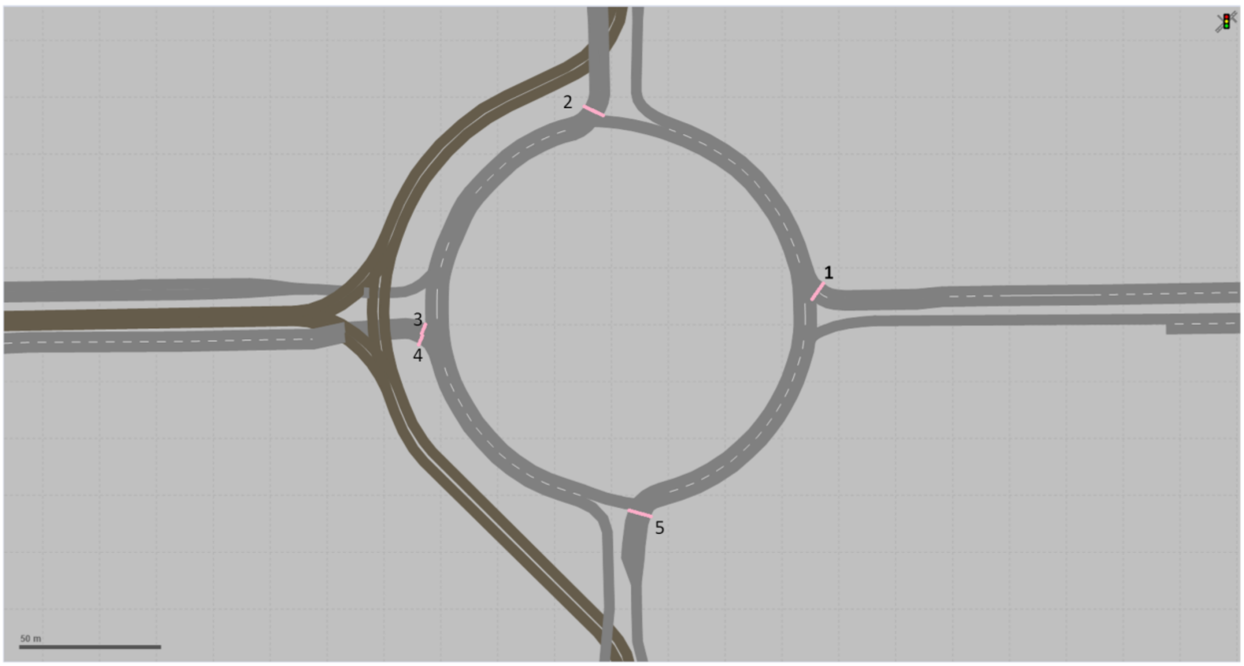

Figure 5-3: Queue Counter Locations for Scenario 2

Table 5-5 shows the average travel time for each travel counter over ten simulations, the average over all ten simulations, the maximum travel time, the minimum travel time, and the standard deviation among measurements. The geometry of Scenario 1 and Scenario 3 allow for the right lane of the eastbound approach to exit using the right lane of the eastbound exit, while the geometry of Scenario 2 does not. This restriction of vehicle behavior is why Vehicle Travel Time Counter 8 has measurements for Scenario 1 and Scenario 3 but no measurements for Scenario 2.

Table 5-4: Scenario 2 Queue Length Output Values

Queue Length	**Queue Counter**				
Sim. Run	1	2	3	4	5
1	6.8	68.9	3.8	3.6	1.6
2	7.7	22.7	4.1	3.3	2.5
3	7.8	36.7	5.7	4.0	2.4
4	8.7	103.9	4.4	2.2	2.5
5	7.7	21.6	5.5	3.5	1.9
6	13.9	105.9	2.8	2.1	2.6
7	8.2	25.7	3.4	2.8	3.8
8	13.2	76.9	7.3	4.9	2.1
9	7.1	28.5	11.4	2.2	1.5
10	13.1	54.5	2.3	2.6	1.7
AVG	9.4	54.5	5.1	3.1	2.3
MAX	13.9	105.9	11.4	4.9	3.8
MIN	6.8	21.6	2.3	2.1	1.5
STDDEV	2.8	32.8	2.7	0.9	0.7

Table 5-5: Scenario 2 Travel Time Output Values

Travel Time	**Travel Time Counter**													
Sim. Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	51	65	82	107	118	73	58		73	85	98	50	62	70
2	50	66	80	66	84	70	59		71	84	93	50	62	70
3	51	66	83	67	93	74	62		71	83	94	49	62	70
4	51	69	87	127	146	73	63		70	83	93	50	62	73
5	50	67	83	67	82	70	61		70	83	89	48	62	71
6	52	71	84	128	154	72	55		67	79	86	50	62	71
7	52	67	83	70	83	71	60		69	80	99	52	63	71
8	49	74	91	106	129	72	64		69	80	100	49	61	72
9	51	67	81	73	91	74	70		66	82	90	49	61	71
10	52	71	90	101	107	68	55		67	83	93	50	61	70
AVG	51	68	85	91	109	72	61		69	82	94	50	62	71
MAX	52	74	91	128	154	74	70		73	85	100	52	63	73
MIN	49	65	80	66	82	68	55		66	79	86	48	61	70
STDDEV	1	3	4	26	27	2	4		2	2	5	1	1	1

5.2 Scenario 3 Outputs

Figure 5-4 highlights the queue counter locations via a pink line across a lane or lanes. Table 5-6 shows the length of the queue buildup at each queue counter over ten simulations, the average queue over all ten simulations, the maximum queue length, the minimum queue length, and the standard deviation among measurements.

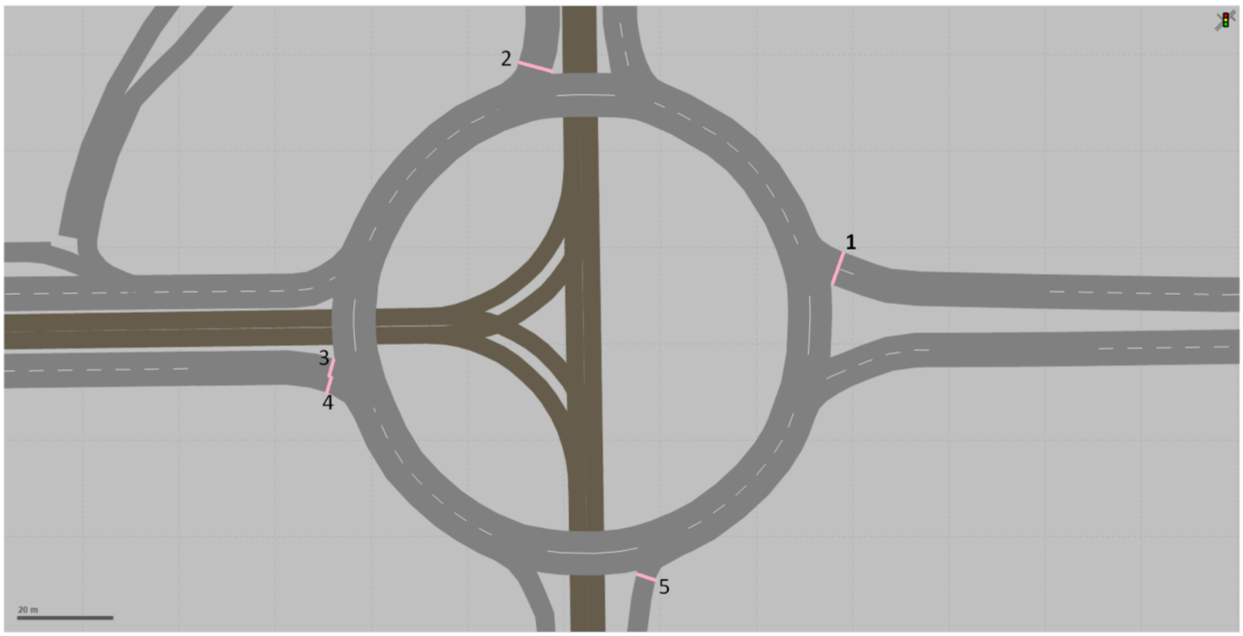

Figure 5-4: Queue Counter Locations for Scenario 3

Table 5-5 shows the average travel time for each travel counter over ten simulations, the average over all ten simulations, the maximum travel time, the minimum travel time, and the standard deviation among measurements.

Table 5-6: Scenario 3 Queue Length Output Values

Queue Length	Queue Counter				
Sim. Run	1	2	3	4	5
1	303.8	28.1	0.5	2.7	6.5
2	251.3	18.9	0.6	4.4	7.0
3	259.0	19.0	1.4	6.1	5.7
4	318.5	27.8	1.1	3.2	13.2
5	182.4	21.7	0.8	3.4	4.2
6	300.6	41.0	0.4	2.0	11.9
7	206.4	35.9	1.4	4.7	7.6
8	393.9	12.0	0.6	2.4	9.8
9	285.9	37.1	1.1	3.4	6.2
10	388.7	12.4	0.5	3.7	6.9
AVG	289.1	25.4	0.8	3.6	7.9
MAX	393.9	41.0	1.4	6.1	13.2
MIN	182.4	12.0	0.4	2.0	4.2
STDDEV	68.9	10.3	0.4	1.2	2.9

Table 5-7: Scenario 3 Travel Time Output Values

Travel Time	Travel Time Counter													
Sim. Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	48	127	312	78	85	68	43	54	59	69	78	43	58	66
2	64	135	327	65	73	68	44	54	62	74	84	43	61	66
3	55	126	309	61	75	71	44	55	62	73	82	44	59	66
4	62	137	339	77	84	68	44	54	60	72	79	47	62	70
5	54	108	248	73	78	68	45	54	60	70	81	42	57	64
6	54	141	318	87	94	70	44	54	57	68	78	49	63	70
7	62	130	297	83	90	67	44	55	61	72	83	48	61	66
8	51	155	375	61	69	67	45	54	59	68	76	47	61	68
9	50	133	319	76	93	66	44	54	59	69	80	45	59	66
10	51	144	342	57	71	66	44	55	62	73	81	47	59	66
AVG	55	134	319	72	81	68	44	54	60	71	80	46	60	67
MAX	64	155	375	87	94	71	45	55	62	74	84	49	63	70
MIN	48	108	248	57	69	66	43	54	57	68	76	42	57	64
STDDEV	6	12	33	10	9	2	0	1	2	2	3	2	2	2

Chapter 6: Evaluation of Results

This chapter analyzes and evaluates the Vissim simulation outputs. The first part of the analysis focuses on the variations of queue lengths between scenarios. The second part of the analysis focuses on the variations of average travel time between scenarios.

6.1 Evaluation of Queue Length

Queue length refers to the length of a queue of vehicles (in meters) at a given queue counter. Table 6-1 shows the average queue lengths per scenario. Scenario 1 has on average the longest queue lengths. Scenario 3 sees some improvement regarding average queue lengths compared to Scenario 1 in the westbound and eastbound directions, the most significant improvement occurring in the southbound direction. Scenario 2 has dramatic improvements compared to Scenario 1 and Scenario 2, especially in handling high vehicle input heading eastbound. However, Scenario 2 has a slightly higher average queue length heading southbound compared to Scenario 3. This increase is due to Scenario 2 having to yield to trams crossing the southbound approach whereas vehicles heading southbound in Scenario do not interact with trams at the entrance to the roundabout. Figure 6-1 demonstrates the largest improvements in queue length between Scenario 1 and Scenario 2. The trends seen with average queue length are also seen regarding maximum queue lengths (Table 6-2) and minimum queue lengths (Table 6-3).

Table 6-1: Summary of Average Queue Lengths

AVG	Eastbound	Southbound	Westbound (Left)	Westbound (Right)	Northbound
Scenario 1	319	164	31	24	9
Scenario 2	9	55	5	3	2
Scenario 3	289	25	1	4	8

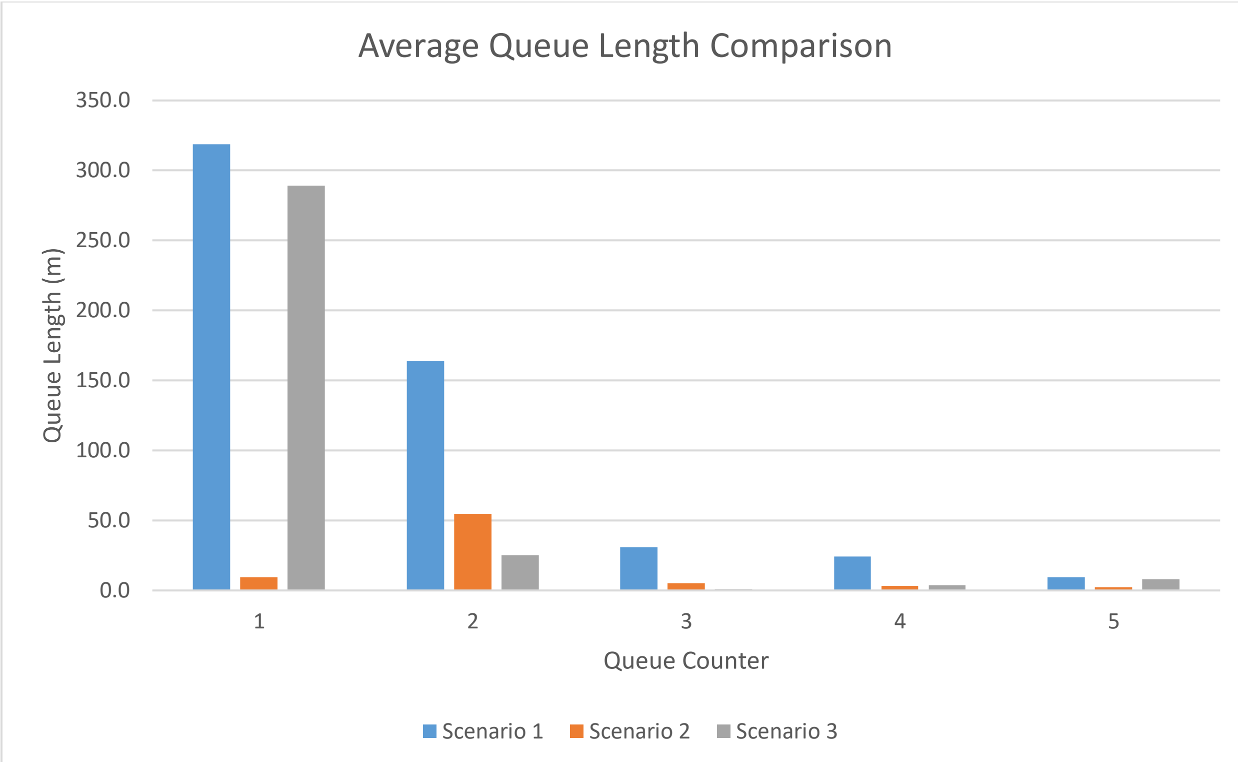

Figure 6-1: Average Queue Length Comparison

Table 6-2: Summary of Maximum Queue Lengths

MAX	Eastbound	Southbound	Westbound (Left)	Westbound (Right)	Northbound
Scenario 1	418	291	90	84	15
Scenario 2	14	106	11	5	4
Scenario 3	394	41	1	6	13

Table 6-3: Summary of Minimum Queue Lengths

MIN	Eastbound	Southbound	Westbound (Left)	Westbound (Right)	Northbound
Scenario 1	256	72	10	4	6
Scenario 2	7	22	2	2	1
Scenario 3	182	12	0	2	4

Table 6-4 shows the standard deviation between values of all ten simulations. Scenario 1 sees the most variation with values compared to Scenario 2 and Scenario 3, which is likely attributed to the difficulty in merging into the roundabout due to congestion within the roundabout. Scenario 2 has the most deviation in the southbound direction, while Scenario 3 has the most deviation in the eastbound direction. These variations are likely due to the arrival rate of vehicles to the roundabout, as well as how the arrival rate of trams heading southbound or northbound affect vehicles heading southbound in Scenario 2.

Table 6-4: Summary of the Standard Deviation of Queue Lengths

STDDEV	Eastbound	Southbound	Westbound (Left)	Westbound (Right)	Northbound
Scenario 1	44	65	24	24	3
Scenario 2	3	33	3	1	1
Scenario 3	69	10	0	1	3

6.2 Evaluation of Travel Times

Travel time refers to the length in time it takes to get from one point in the traffic network to another point. Vissim calculates the average travel time per vehicle travel time counter. In Vissim, the measurement begins when vehicle crosses over a set starting point and the measurement ends when the vehicle crosses the corresponding ending point. If a vehicle crosses over the starting point but does not cross the ending point, it is not considered in the calculations of the average travel time. Table 6-5 shows the average travel time per scenario. Scenario 1 has significant higher travel times than both Scenario 2 and Scenario 3 in all routes originating in the westbound and southbound directions; however, it has comparable (or slightly lower) travel times in the eastbound and northbound directions. Scenario 2 has the most consistent travel times across all directions, its longest travel time being 109 seconds (entering southbound and exiting southbound) and its shortest travel time being 50 seconds (entering northbound and exiting eastbound). Scenario 3 always has a shortest travel time in all routes originating in the eastbound or northbound directions (by a couple seconds up to 17 seconds) compared to Scenario 2. The geometry of Scenario 2 creates a lot of intersection points between vehicles entering/exiting the western half of the roundabout and the tram; as vehicles must yield to tram due to priority rules, this can cause increased delay. However, Scenario 3 has drastically longest travel times in some westbound originating routes when compared to Scenario 2. The westbound approach has the highest vehicle input out of all four approaches, so the congestion can cause increased delay. These differences are emphasized in Figure 6-2.

Table 6-5: Summary of Average Travel Time

Starting Direction	**Westbound (WB)**			**Southbound (SB)**			**Eastbound (EB)**					**Northbound (NB)**		
Exiting Direction	**NB**	**WB**	**SB**	**WB**	**SB**	**EB**	**SB**	**EBR**	**EBL**	**NB**	**WB**	**EB**	**NB**	**WB**
Counter Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Scenario 1	139	198	366	170	180	195	78	81	50	60	66	38	50	59
Scenario 2	51	68	85	91	109	72	61	-	69	82	94	50	62	71
Scenario 3	55	134	319	72	81	68	44	54	60	71	80	46	60	67

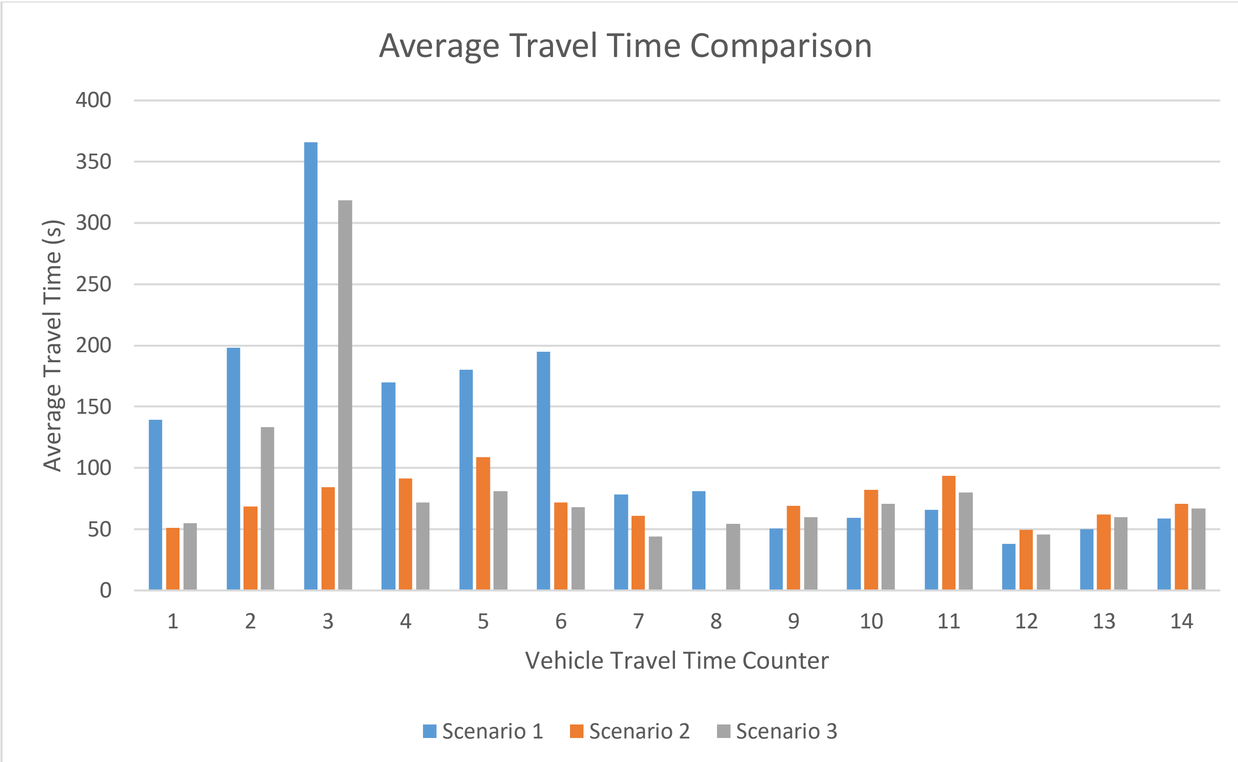

Figure 6-2: Average Travel Time Comparison

The trends seen with average queue length are also seen regarding maximum queue lengths (Table 6-6) and minimum queue lengths (Table 6-7). It is important to note that the maximum travel times for Scenario 1 is much more pronounced than the maximum travel times for Scenario 2 and Scenario 3.

Table 6-6: Summary of Maximum Travel Time

Starting Direction	Westbound (WB)			Southbound (SB)			Eastbound (EB)					Northbound (NB)		
Exiting Direction	NB	WB	SB	WB	SB	EB	SB	EBR	EBL	NB	WB	EB	NB	WB
Counter Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Scenario 1	217	238	408	230	235	276	140	129	58	70	73	46	57	68
Scenario 2	52	74	91	128	154	74	70	-	73	85	100	52	63	73
Scenario 3	64	155	375	87	94	71	45	55	62	74	84	49	63	70

Table 6-7: Summary of Minimum Travel Time

Starting Direction	Westbound (WB)			Southbound (SB)			Eastbound (EB)					Northbound (NB)		
Exiting Direction	**NB**	**WB**	**SB**	**WB**	**SB**	**EB**	**SB**	**EBR**	**EBL**	**NB**	**WB**	**EB**	**NB**	**WB**
Counter Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Scenario 1	78	149	302	89	105	117	53	54	47	54	60	33	46	55
Scenario 2	49	65	80	66	82	68	55	-	66	79	86	48	61	70
Scenario 3	48	108	248	57	69	66	43	54	57	68	76	42	57	64

Table 6-8 shows the standard deviation between values of all ten simulations. Scenario 1 sees the most variation with values compared to Scenario 2 and Scenario 3, especially for Traffic Counters 1 through 8. This is likely attributed to the difficulty in merging into the roundabout due to congestion within the roundabout, as well as difficulty in merging to get to the outer exit lane. Scenario 2 has the most deviation in the southbound directions exiting westbound or southbound (as the vehicles must yield to any trams wanting to cross the roadway infrastructure); the deviation for vehicles entering southbound and exiting eastbound is low due to the low number of traffic wanting to take this route.

Table 6-8: Summary of Standard Deviation of Travel Times

Starting Direction	Westbound (WB)			Southbound (SB)			Eastbound (EB)					Northbound (NB)		
Exiting Direction	**NB**	**WB**	**SB**	**WB**	**SB**	**EB**	**SB**	**EBR**	**EBL**	**NB**	**WB**	**EB**	**NB**	**WB**
Counter Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Scenario 1	52	32	34	49	43	49	26	22	3	4	4	4	4	4
Scenario 2	1	3	4	26	27	2	4	-	2	2	5	1	1	1
Scenario 3	6	12	33	10	9	2	0	1	2	2	3	2	2	2

Chapter 7: Conclusion

This chapter concludes the thesis by providing a summary of findings, encountered challenges, recommendations for the Vítězné Náměstí roundabout, and suggestions for future research building off the work done within this thesis.

7.1 Summary of Findings

Vítězné Náměstí is a busy roundabout with multiple modes of transportation interacting with one another. The focus of this research was to understand the factors that influence the current state of the roundabout and how they affect users of the intersection. After a review of the history of the area and the transportation planning decisions that were made, three geometrical arrangements were chosen to investigate how to best manage the traffic congestion that affects traffic operations. Three different designs of the intersection were investigated: the current design in practice, a turbo roundabout design by the design group Pavel Hnilička Architekti that was submitted to an international design competition, and a design in alignment with the 2009 Manual for Uniform Traffic Control Devices. These three designs were created within the microscopic, multimodal traffic simulation program Vissim, simulated, and results analyzed.

Certain parameters of this intersection cannot be changed, such as the built infrastructure surrounding the square (i.e., the university campus, the government building, and other multipurpose buildings). Additionally, the public transit system (i.e., the metro station stop, the tram stop, and the bus stops) cannot be removed as they are an integral part of the Prague transportation system – only the location of the stops and the infrastructure that supports the public transit (e.g., the paved tram lines) can be altered. This work focused on how to best manage the traffic, as it can affect other users of the area (e.g., public transit users, bicyclists, and pedestrians).

The scope of this work did not include the modeling of pedestrians or bicyclists, as the data was not available – this is one suggestion for future work that will be discussed in more detail later on in this chapter.

7.2 Challenges

Several challenges arose during this research. First, as the focus of this work is a roundabout located in the Czech Republic, most of the documents discussing the development of Vítězné Náměstí, the public transit system, and the traffic survey of the roundabout were in Czech and therefore had to be translated. The timetables regarding public transit information (refer to Figure 4-1) were not intuitive to a non-native resident and had to be explained on how to interpret. Additionally, as three modes of transportation all converge at or in the roundabout (buses, trams, and vehicles), accurately modeling their behaviors was challenging and took much time to correct. The most difficult behaviors to model was ensuring that vehicles entering the roundabout yielded to those already in the roundabout, that public transit got priority (e.g., vehicles stopped in the roundabout to allow the trams to continue their route), and that vehicles would follow the correct path depending on what approach and exit they wanted to follow.

7.3 Recommendations

This section provides recommendations at the Vítězné Náměstí roundabout based on results obtained in the previous chapter.

Given the current situation of Vítězné Náměstí, some change needs to happen. Current data and the results from Scenario 1 indicate that the current transportation infrastructure is not able to sufficiently handle the capacity of vehicles entering and exiting the roundabout during peak hour times. Of the three scenarios, Scenario 2 performed more consistently and had significantly shorter queue lengths and travel times than Scenario 1 and Scenario 2 from several approaches. However, it does require much more work to be done to change the infrastructure than compared to Scenario 1 (the "do-nothing" selection) and Scenario 3. A cost-benefit analysis would be helpful in selecting the appriate design in regards to funding.

7.4 Suggestions for Future Research

This thesis has simulated three different geometries with only buses, trams, and vehicles as users. However, this area is also used by bicyclists and heavily used by pedestrians. These models could be extended by modeling interactions between bicyclists and pedestrians in the area and the impact that the operations of the roundabout have on their movements. Figure 7-1 highlights current crosswalk locations; only two crosswalks (A and B in the figure) are signalized. Scenario 1 and Scenario 3 could be expanded to model these crosswalks. Scenario 2 could be expanded to model by four pedestrian crosswalks (refer to Figure 2-6) that connects the plaza featured in the International Competition Winning design to the surrounding areas.

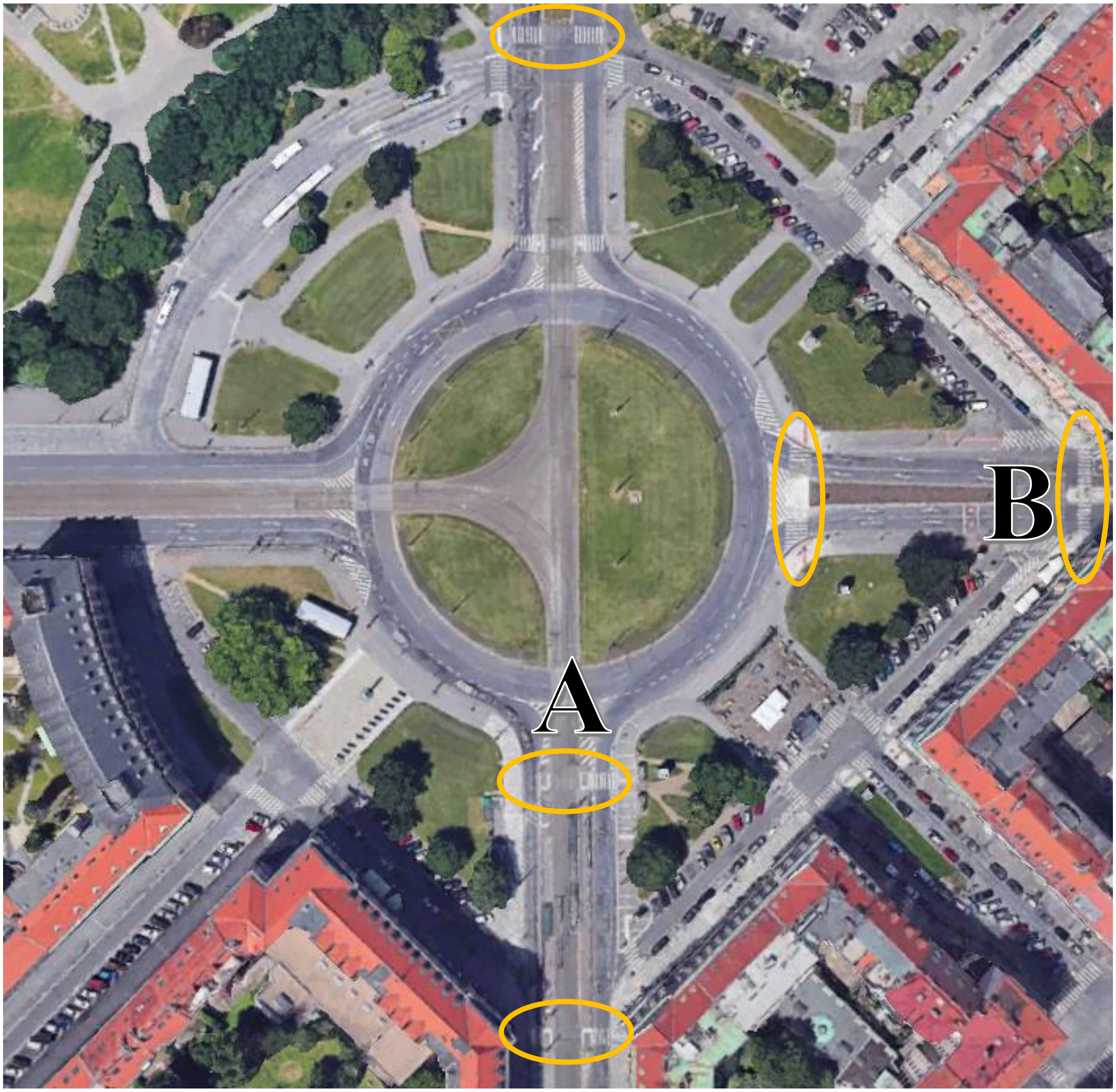

Figure 7-1: Pedestrian Crosswalk Locations

Given the original intentions of the area by Antonín Engel's design, Vítězné Náměstí should prioritize pedestrians and public transit. Another areas of research could be to make the area a vehicle free zone, only allowing for public transit, bicyclists, and pedestrians to use the area. In this scenario, the roundabout could be modeled to see how the surround transportation network would be able to handle the rerouting of vehicles from the roundabout and their impact on the network.

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Vita

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