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A Microsimulation of Novel Intersection Designs

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A Microsimulation of Novel Intersection Designs

BY

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My thanks and appreciations also go to all people who have willingly helped me out with their abilities.

ABSTRACT

The focus of this project is to see how a turbo roundabout and a protected intersection designs behave when they are applied on two study sites in Portland, OR. PTV VISSM is used to model, analyze and compare the performances of these designs with the existing intersection. In addition, the best features of the protected intersection and the turbo roundabout were combined to create a new intersection design that is safer for the bicyclists and also performs better than the existing intersection.

The analysis is conducted for five different volume scenarios for both the study sites. The results of the analysis show that both the proposed designs perform better than the existing intersection at both study sites. In addition, study site-II, which is the intersection of SE 92nd Ave & SE Flavel St, was examined for the combination of a protected intersection with a turbo roundabout at the intersection. Both the safety features and the performance of the intersection were improved significantly with the treatment.

The results in this project shows promise at reducing traffic crashes and increasing performance at intersections. At NW 23 Ave & NW Vaughn St Intersection, the existing signalized intersection was transformed into a turbo roundabout, this resulted in the average delay being reduced by 85.43%, the average speed increased by 52.5%, and the total travel time being reduced by 31.68%. At SE 92nd Ave & SE Flavel St, the existing signalized intersection was transformed into a protected intersection design, which resulted in the average delay being reduced by 10.11%, the average speed increased by 3.09%, and the total travel time being increased by 10.05%. Again on SE 92nd Ave & SE Flavel St Intersection, the existing design was transformed into a turbo roundabout, which is incorporated with a

protected intersection: the average delay was reduced by 32.69%; the average speed increased by 24.72%; and the total travel time was reduced by 26.02%. However, these are just simulation results assuming all road users will follow the road rules, which in the real world is not always true. Therefore, further studies using different simulation software, performance parameters and even by implementing them on different representative sites should be done in the future.

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1.0 Introduction

The subject of the project described in this document is regarding intersection improvements. In particular, this project aims to indicate the usefulness of adopting a well-practiced intersection design approach from other part of world and study how they perform here in the United State at a typical signalized intersection.

For this project, a turbo roundabout and a protected intersection design (Dutch's bike friendly intersection) were chosen for study. These intersection designs were modeled and simulated using PTV VISSM traffic simulation software. Simulation results were compared with the simulation results of a typical signalized intersection that is widely used here in the United States with respect to average delay, average speed and total travel time.

The concept of roundabouts and their hierarchical relationship with other intersection solutions will be addressed on chapter 2 of this paper. This introduction will address the initiative of improving intersection and intersection approaches, the problem statement, the methodologies used, the research questions, and finally, the structure for the remainder of this report will be introduced, logically following from the research questions.

1.1. Motivations And Objectives

Roundabouts have gained attention in the US in recent years, while other countries like Europe have already benefited from their use for a long time. Moreover, most of the United States transportation infrastructure was initially designed to accommodate and serve motorized vehicles only, but in recent years, people's way of life and transportation mode choice have begun to change rapidly. Studies show that one of the fastest growing choice of transportation modes is bicycle. Bicyclists are also one of the most vulnerable road users to any hazards. And unlike motorized vehicles, most of the bicycles are energized by the rider itself.

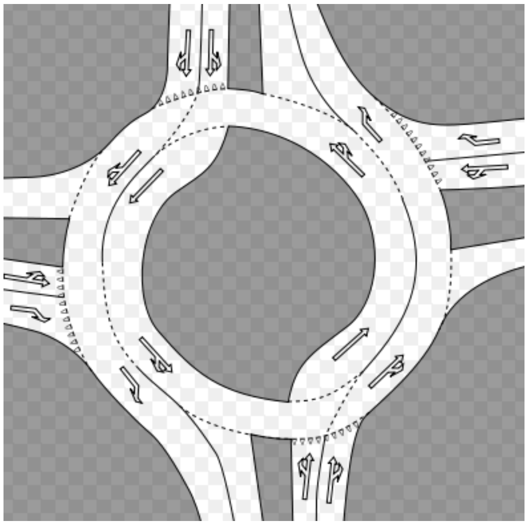
The other reason for doing this intersection improvement project is because, most traffic crashes happens at intersections and intersection approaches. According to the "US intersection accident statistics-2012" done by Hardwick & Pendergast from the University of Kentucky, about 35 percent of all crashes take place at intersections (4). So these factors forced transportation engineers and planners including me to come up with a safer and most energy efficient transportation infrastructure especially intersections.

This project aims to contribute to this need by adopting and examining the performance of the turbo roundabout and the protected intersection designs at two intersections in Portland, OR: "NW 23 Ave & NW Vaughn St" and "SE 92nd Ave & SE Flavel St". The overview of the study sites and the chosen intersection designs will be discussed in the following figures. Figure-1 will illustrate the study sites and Figure-2 will illustrate the intersection designs that are chosen for study.

Study site-I: NW 23 Ave & NW Vaughn St **Study site-II: SE 92nd Ave & SE Flavel St**

Figure-1 Study sites

The above pictures show the study sites in Portland, Oregon. At "NW 23 Ave & NW Vaughn St" intersection there is no bicycle facilities or bicycle traffic. So, in this study site the turbo roundabout will be simulated and the results will be compared with the simulation results of the existing intersection. However, on the "SE 92nd Ave & SE Flavel St" intersection, there are bicycle facilities and bicycle traffic. The protected intersection will be simulated and performance comparison will be made with the existing intersection. Then, the turbo roundabout will be incorporated with the protected intersection and the performance of the new intersection will be evaluated at this intersection.



Turbo roundabout

Protected intersection

Figure-2 Intersection designs chosen for study

The above pictures show the intersection designs chosen to be studied on the previously mentioned study sites. In this project the turbo roundabout is considered for performance reason, while the protected intersection is considered to enhance the safety features of the bicycle facilities at the intersection.

1.2.Problem Statement

This project explores the hypothesis made in the previous section: to adopt the turbo roundabout and the protected intersection approach on two intersections in Portland, and to investigate whether the performance of the intersections improves. After adopting the design, the performance of the intersections will be evaluated. Regarding the protected intersection design: if no changes in performance are observed, the results may be considered as an improvement since the protected intersection is not intended to enhance performance, but instead to provide safer passage for bicycle traffic. In order to indicate the influence of adopting turbo roundabout and the protected intersection approach, the existing conditions and the newly adopted designs will be compared by means of PTV VISSM simulation models.

1.3. Methodology

First, two study sites were selected in Portland, Oregon. One that has bicycle facilities and another without. Then for both study sites PTV VISSM traffic simulation software was used to model and simulate the experimental designs, and study their results.

At “NW 23 Ave & NW Vaughn St” intersection, since there are no bicycle facilities or bicycle traffic in this study site, the performance of the turbo roundabout was studied without the addition of bicycle traffic. However, on “SE 92nd Ave & SE Flavel St” intersection, since there are bicyclists and bicycle facilities at the intersection, the study in this site also involves the safety of bicyclists.

Second, the intersections were modeled, first by just adopting the protected intersection and comparing the performance with the existing intersection. Then, the protected intersection was incorporated with the turbo roundabout and again the performance of the new design was compare with the existing signalized intersection.

Finally, the results were analyzed and discussions were made based on the results regarding which features are improved and which features failed to improve based on the performance parameters. The performance parameters used in this project to compare intersection performances were: total travel time, average delay and average speed.

1.4. Research Question

The aim of this research questions is to structure all the research needed to be done in order to accomplish the main goal of this project. The first main research question that will be addressed is, whether or not the adopted intersection designs perform better than the conventional signalized intersection? To answer this question, the new intersection designs were modeled and simulated on PTV VISSM for both study sites, and results were analyzed and compared with the existing infrastructures based on the performance parameters considered in this project.

The second research question that will be addressed in this project is, which infrastructure performs better in case of multimodal transportation system? Could we enhance the safety features of the bicycle facilities at the intersection without affecting the performance of the intersection? To answer these important research questions, the study site with the bicycle facility, study site-II, was considered for study. Again PTV VISSM traffic simulation software was used to model and simulate the protected intersection design and the protected intersection design that is incorporated with the turbo roundabout. The simulation results will be compared again based on the same performance parameters.

1.5. Report Structure

This paper starts with a brief introduction and overview of the study sites and the proposed designs. Chapter-2 will give a general background regarding roundabouts. Chapter-3 deals with literature review. In Chapter-4 the model development will be discussed briefly. In Chapter-5 the evaluation results will be presented and discussions will be made based on those results. Finally in Chapter-6, an overall brief discussion and conclusion will be made based on simulation results.

2. Background

For several years due to lack of sufficient information on roundabout operation and design under local U.S. agencies, roundabout intersections have seen only sporadic implementation in the U.S road networks. However, in the past few years the applications of roundabouts in the United States has received an increased attention by both the public and transportation professionals. On the other hand, roundabouts have been in widespread use in other countries for a number of years especially in the Europe countries.

A roundabout is a form of circular intersection in which traffic circulate around a central non-mountable island and in which entering traffic must yield to circulating traffic that is already inside the roundabout (2). Figure-7 shows a typical circular intersection with a single lane approach. It consists of a circulatory roadway containing one lane, around a non-mountable middle island.

In the early 1960s the single-lane roundabout was introduced, it was an innovative design with many social and economic benefits. The single-lane roundabout offers a capacity of 2000 - 2500 PCU (PCE)/h, which is similar to the conventional non-circular intersection (see Figure-11), which was the most common intersection(2).

2.1. Types of circular intersections

There are at least four distinct types of circulatory intersections (NCHRP report 672, 2010).

- **Rotary:** This type of circular intersection was common to the United States prior to the 1960s, and it is characterized by a large diameter, often greater than 300 ft. (100 m) (2). The large diameter in the rotary traffic circle allows traffic to weave on the road stretches between two legs. Lane changes within the rotary are also required for some turning movements in this intersection. See Figure-3

Figure-3 Rotary circular intersection. Fort Worth, Texas. (Source: NCHRP REPORT 672, 2010)

- **Signalized traffic circles**:

  Are one of the oldest type of circular intersections which are used in some cities in the United States where traffic signals are used to control one or more entry. See Figure-4

Figure-4 Signalized traffic circle. Cape Town, Western Cape, South Africa. (Source: NCHRP REPORT 672, 2010)

- **Neighborhood traffic circles:**

  These are usually built for traffic calming and for aesthetics at intersections of local streets. The intersection approaches may be uncontrolled or stop sign controlled. See Figure-5

Figure-5 Neighborhood Traffic circle.

- **Roundabouts:**

  Roundabouts are types of circular intersections that have specific designs and traffic control features. These features may include yield control of all entering traffic, channelized approaches, and geometric curvature and features to induce desirable vehicular speeds (2).

2.2. Categories of roundabouts

According to NCHRP report 672, roundabouts are categorized into three basic categories according to size and number of lanes to facilitate discussion of specific performance or design issues. These are mini-roundabouts, single-lane roundabouts, and multilane roundabouts. However, according to Lambertus G.H. Fortuijn, 2013 TRB report, a turbo roundabout is also mentioned as one of the classification.

I. **Mini-roundabouts:** Mini-roundabouts are small roundabouts with a fully mountable central and splitter island. They are most commonly used in low-speed urban intersections with average operating speeds of 30 mph (50 km/h) or less (2). Figure-6 illustrates the features of a typical mini roundabout.

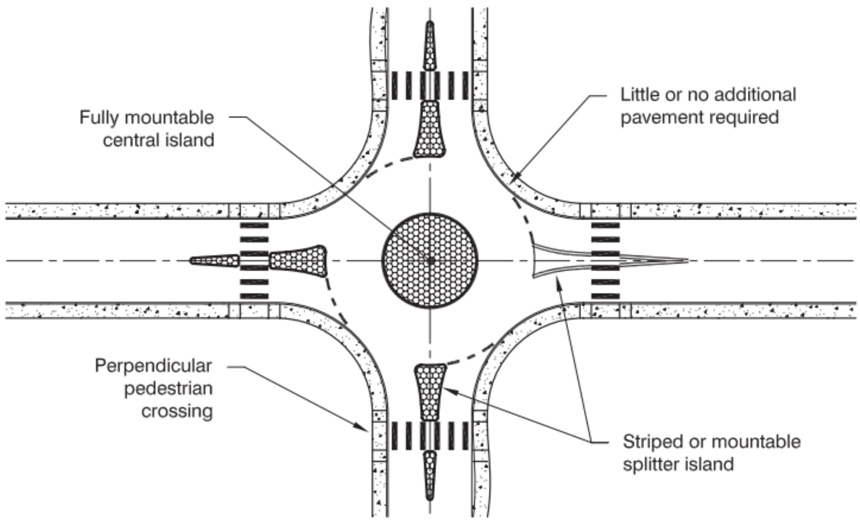


Figure-6 Features of Typical Mini-Roundabout. (Source: NCHRP REPORT 672, 2010)

II. **Single-lane roundabouts:** the difference between this types of roundabouts and traffic circles is the absence of weaving sections on the single-lane roundabouts. So, generally single-lane roundabouts are distinguished by not having a weaving sections. Figure-7 shows the features of a typical single-lane roundabout.

On single- lane round about due to the absence of weaving sections the roundabout can be constructed with a smaller radius, and because of its small diameter, traffic cannot queue on the roundabout i.e. right-hand rule cannot be applied on this roundabout.

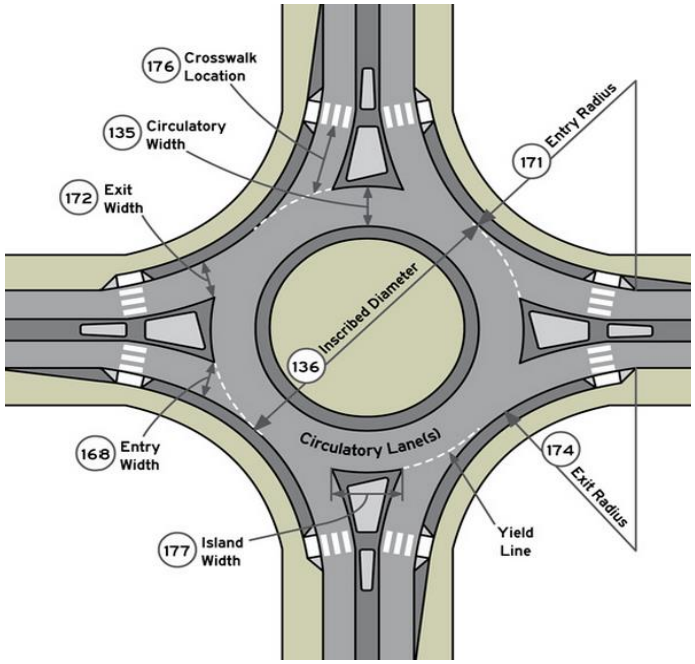


Figure-7 Features of a typical single lane roundabout

III. **Multilane roundabouts:** Multilane roundabouts have at least one entry with two or more lanes. In some cases, the roundabout may have a different number of lanes on one or more approaches. The multi-lane roundabout was implemented for intersections on which the traffic demand was so high, that the single-lane roundabout could not offer enough capacity. Figure-8 illustrates features of a typical two lane roundabout.

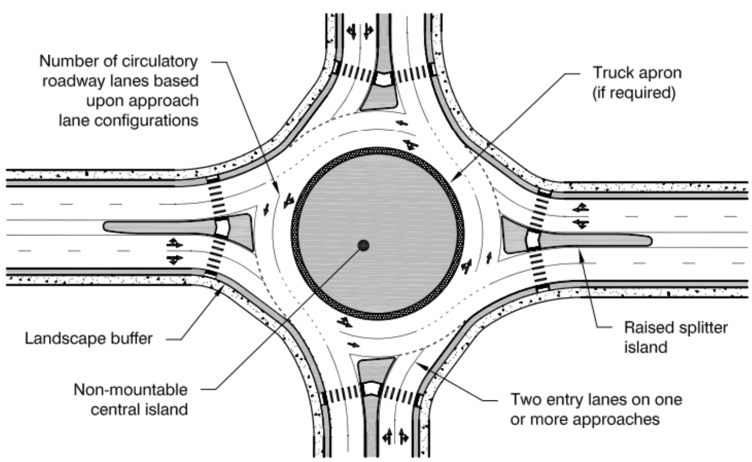


Figure-8 Features of a typical two-lane roundabout (Source: NCHRP REPORT 672, 2010)

IV. Turbo roundabout: this specific kind of spiraled round about is invented by Dr.ir. L.G.H. Fortuijn. It is an innovative arrangement of the two lane roundabout that has revolutionized roundabout design in the Netherlands by having about 25 – 35% higher capacity than a standard two lane roundabout. On the Turbo roundabout, many conflict points were removed by configuring the circulatory lanes in such a way that lane changes on the roundabout are not necessary (3). The figure below Figure-9 illustrates the typical characteristic features of a turbo roundabout.

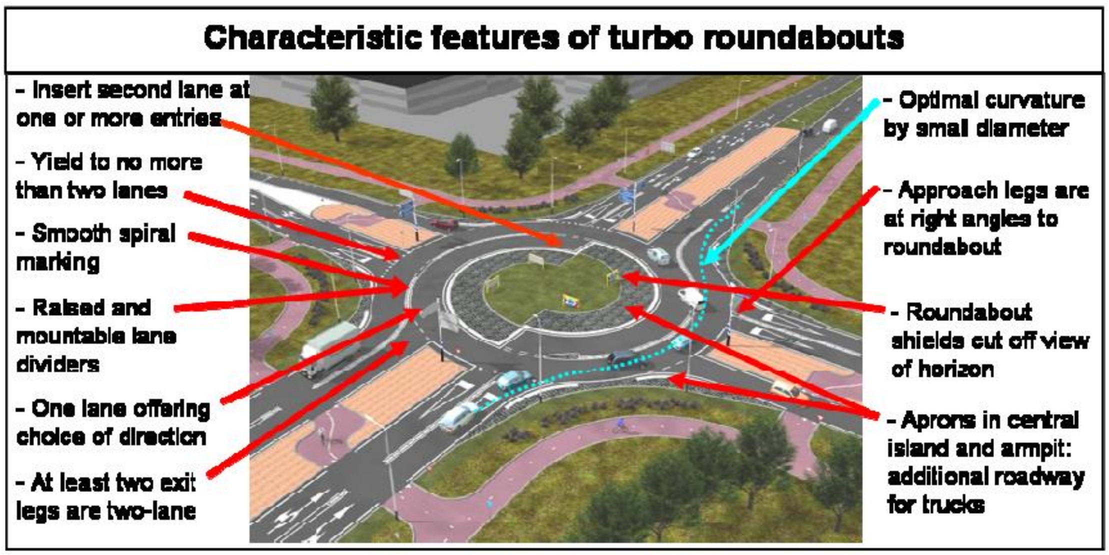


Figure-9 Characteristic features of a turbo roundabout. (Source: Fortuijn TRB Paper #09-2476)

- *Different Variants of the Turbo Roundabout*

According to L.G.H. Fortuijn, Different variants of the turbo roundabout are obtained by varying the number of lanes on the access and exit legs. The following figure illustrates the different variants of the turbo roundabout (see Figure-10).

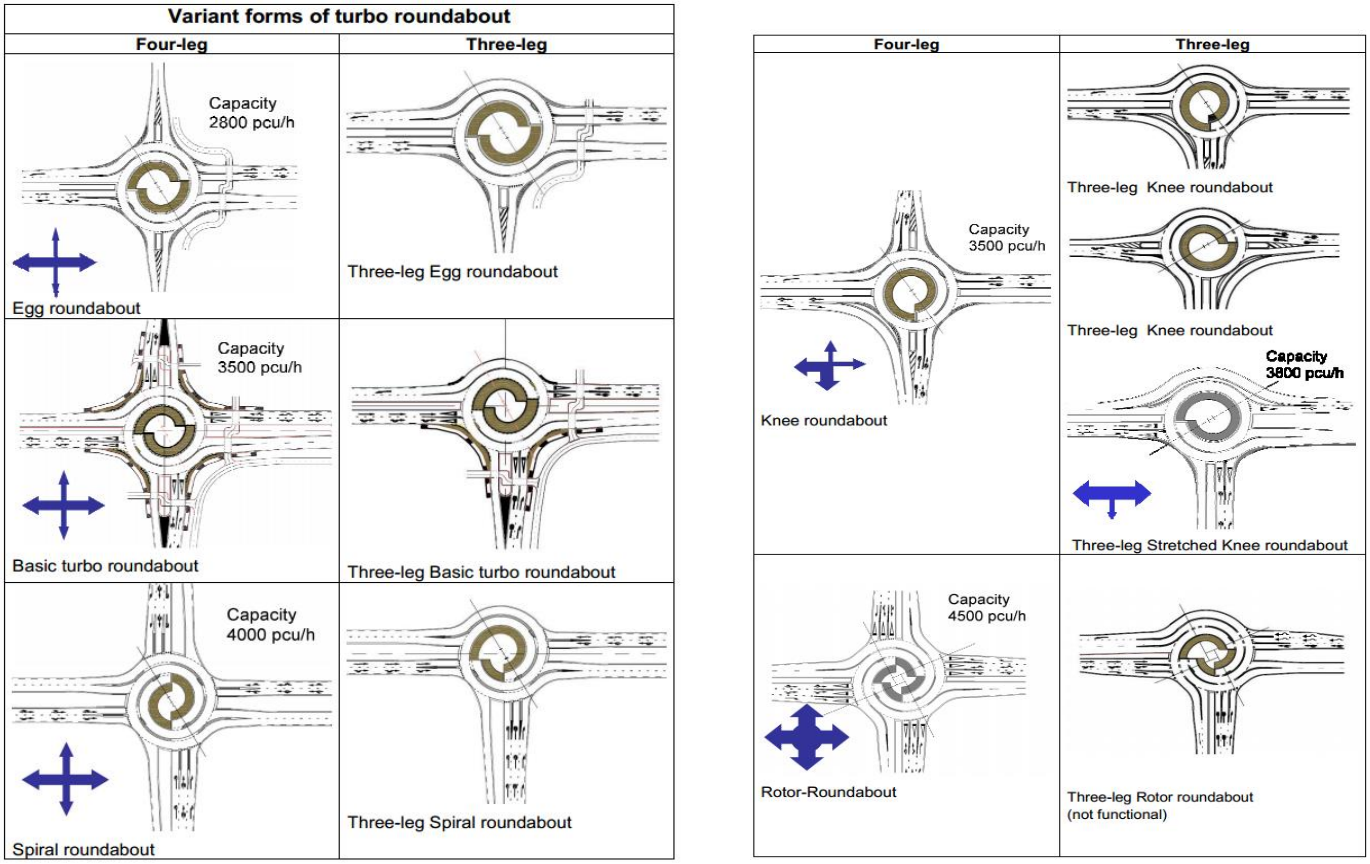


Figure-10 Different variant forms of turbo roundabout. (Source: Fortuijn TRB Paper #09-2476)

2.3. Non-circular intersection

Non-circular intersections were the most commonly used intersection solution until circular intersections gained popularity in 1960's. The figure below illustrates a typical non-circular intersection features (see Figure-11).

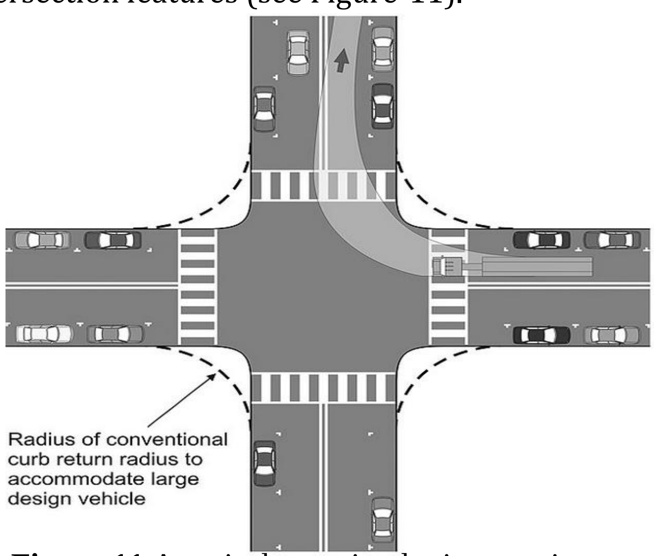


Figure-11 A typical non-circular intersection.

3. Literature Review

In this chapter all the knowledge already developed related to the topic of this project will be addressed. The first review is aimed at characteristic features of turbo roundabouts. In the second section, a study about the protected intersection approach is reviewed. Finally the third section presents the fundamentals of the model to be applied in this study: PTV VISSIM.

3.1. Characteristic features of turbo roundabouts

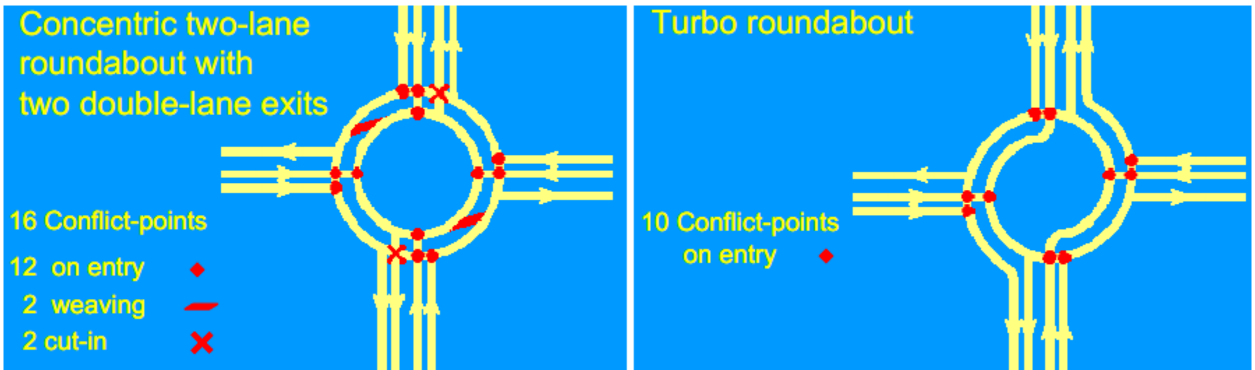
According Fortuijn, the basic characteristics of a turbo roundabout is classified into seven. In this section, the significance of the basic characteristics of the turbo roundabout will be discussed based on Fortuijin's TRB Paper #09-2476.

3.1.1. Pre-emption of traffic flows: is closely related to turbo roundabout features. Which are: traffic approaching the roundabout on at least one leg must yield to traffic in two and no more than two lanes on the roundabout; and smooth flow on roundabout by well applied spiral alignment.

3.1.2. Limited number of circulatory lanes: vehicles at approach yield to no more than two lanes. Studies have been done for expanding the roundabout from two lanes to three. However, results show that only a lesser capacity benefit can be achieved from expanding the turbo roundabout from two lane to three lane than expanding the roundabout from one lane to two lanes.

3.1.3. Smooth flow on roundabout by well applied spiral alignment: Figure-12 illustrates the difference in the number of conflicts between two-lane and turbo roundabout. In the figure we can observe that the concentric two-lane roundabout has 16 conflict points, and the turbo roundabout 10. The spiral alignment offers benefits as regards not only safety but also driving comfort. Figure-13 will illustrate that the turbo roundabout requires fewer steering movements than a concentric roundabout with spiral road markings.

Figure-12 Differences in conflict types between two-lane and turbo roundabouts (Source: Fortuijn TRB Paper #09-2476)



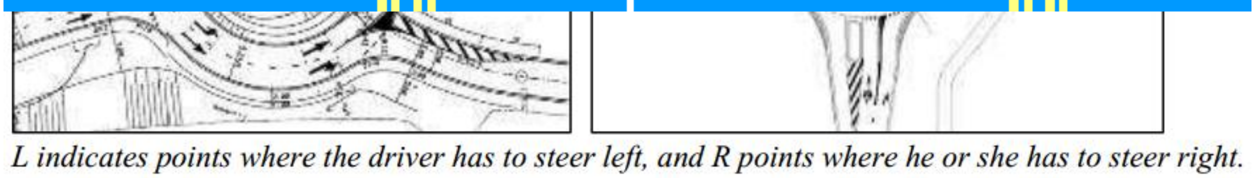


Figure-13 Difference in steering movements. Concentric roundabout markings (on left hand side) and spiral road "turbo roundabout (on right hand side)". (Source: Fortuijn TRB Paper #09-2476)

3.1.4. Division of lanes: Mainly the safety of a roundabout is largely determined by the speed at which vehicles pass through it. Figure-14 shows the relationship between speed through the roundabout and its internal diameter for three types of roundabouts. Usually in concentric two-lane roundabouts, drivers are strongly tempted to cut in the bends at times when traffic is low. One of the key features of turbo roundabout which is the raised lane dividers, plays an important role in curbing this behavior (3).

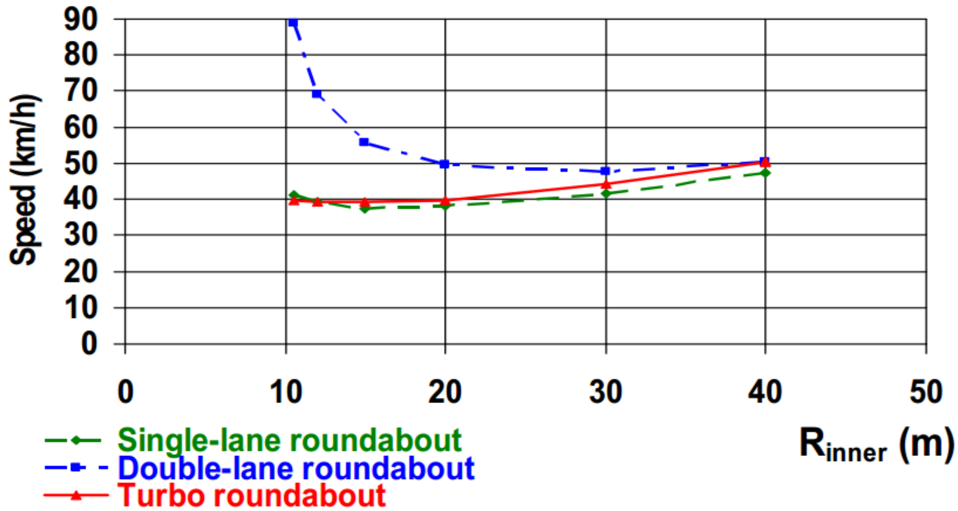


Figure-14 Relationship between Pass through Speed and Type of Roundabout (Single-lane, double lane and Turbo roundabout); Width of splitter island = 7 m (Source: Fortuijn TRB Paper #09-2476)

3.1.5. Robust pre-selection of entry lanes with dedicated exits: one of the features of a turbo roundabout is that each segment of the roundabout includes one lane on which traffic can choose whether to exit or to continue circulating the roundabout. According to Fortuijn, this idea has an important role in the development of the concept of the turbo roundabout, because the idea was to design a roundabout that is not just with a higher capacity than the single-lane roundabout but was also robust enough to handle appreciable variations in the loading pattern (3). The other important feature mentioned by Fortuijn, which is "At least two exit legs are two-lane" is required to give the roundabout the desired capacity.

3.1.6. Radial connection of entry lanes: Fortuijn listed "approach legs are at right angles to the roundabout" as one of the features of a turbo round about. However, according to him this principle should not be implemented without carefully understanding of the reason for it, since it could lead to a risk of more accidents instead of fewer. So, a collision-friendly traffic sign should be placed on the central island of the roundabout to block the view of the horizon in the direction of travel. Figure-15 shows a typical roundabout sign.

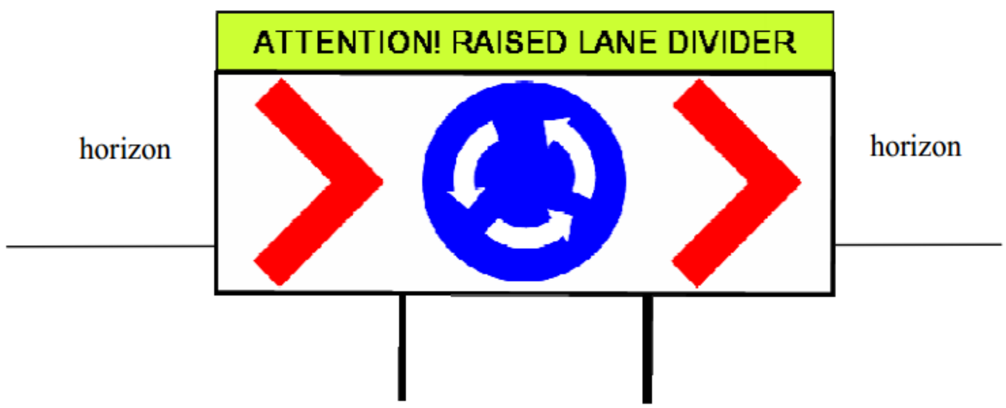


Figure-15 Roundabout shield (Source: Fortuijn TRB Paper #09-2476)

3.1.7. Rideability by long vehicle: Safety requirements call for narrow lanes since they force drivers to reduce speed, whereas trucks need plenty of room if they are to be able to share the roundabout. The following elements in the turbo roundabout design has a solution for this dilemmas:

- A 90-degree angle between approach leg and circulatory roadway, (safety requirement);
- limited width of circulatory roadway (safety requirement);

- central apron offering additional room for trucks using the inner lane (accessibility requirement);
- Aprons in the armpits between entrance and roundabout and exit and roundabout, which also offer additional room for trucks using the outer lane (accessibility requirement).

3.2.Protected intersection (Dutch Intersection Design with Cycle Tracks)

According to McIntyre and Murphy, the Dutch's and the US intersections have similar features except for the addition of cycle tracks at their intersections. Figure-16 illustrates both the US and the Dutch intersections.

Figure-16 Figure on the left hand side shows a typical Intersection with Bicycle Lanes in the US. And the figure on the right hand side shows Typical Dutch Intersection Design. (Source: reference5)

The differences in intersection design approach that include bicycle traffic is summarized in the following:

- On the protected intersection the cycle track is separated from the travel lane of motorized vehicles at all times. This differs from the American bicycle lanes since they are not physically separated from motorized vehicle traffic, but are just located on the sides of the road (5).

- From the above picture on Figure-16, we can observe the pavement markings that each intersection design approach receive across their intersection. In the Netherlands, when a cycle track reaches an intersection, the markings indicating the cycle track continue through the intersection to the cycle track on the far side of the intersection (see the figure on the right hand side). In the United States, when a bike lane reaches an intersection, typically the bike lane ends at the stop line and begins again at the far side of the intersection (5) (refer to the above picture on the left hand side).

So, according to McIntyre and Murphy, the protected intersection design offers various tools to make the intersection safer and more accessible for bicyclists than the US typical intersection.

3.2.1. Important design features of the protected intersection approach

- **Corner islands:** in Netherlands, corner islands are very common at intersections between the street and the cycle tracks. They provide additional physical barrier between where motorized vehicles will be traveling and where bicycles will be riding in the cycle tracks through raised islands (5). Figure-17 illustrates this feature.

Figure-17 Corner Island, the highlighted region. (5)

- **Stop line location:** one reason why automobiles and bicycles are able to operate together without much problem is their separation at intersections. Since the speed of bicycles is slower and also accelerate at a much slower rate from a stopped position compared to automobiles, many protected intersections push the stop line of automobiles behind cycle track crossings. So when the traffic signal light changes to green at the intersection, by the time an automobile arrives to the intersection, bicyclists have already passed through and are traveling at their desired speed (5).

- **Colored cycle tracks:** the color of motorized vehicle traffic lane is different from the bicycle path at the intersection. This helps to make operators of automobiles more aware of their surroundings and what modes of transportation are traveling around them. In Netherlands bicycle paths are usually painted red, but some other countries like the US use green paint to distinguish their bike lane. There are different ways to do this: paving the road with colored asphalt, painting the road, or using colored brick. The idea behind making the cycle tracks colored is so that they are easily distinguishable.

3.2.2. Conflicts within intersections

- **Conflicts between bicycles and automobiles:** at a four way intersection, a bicycle can make three possible moves; they can continue straight, turn right, or turn left. The easiest of these moves is to turn right while on the cycle track. As long as the cycle track remains off of the street, then there should be no conflict with automobiles. The real conflicts arise with continuing straight and making a left turn (5).

  Right Hook: is a very common conflict between motorized vehicle and bicycles at an intersection. This conflict happens when a bicyclist going straight through an intersection is side swiped by a motor vehicle turning right. This can occur when a bicycle lane crosses through an intersection where very little to no visibility is provided between the automobile and a bicyclist (5). The Dutch's on their protected intersection design addressed this issue by increasing the distance between the stop bar of motorized vehicles and the bicyclist. This distance gives a bicyclist enough time to move through the intersection before a right turning car could come in contact with it. So, during a steady green, the distance allows for both the bicyclist and the automobile to be able to see each other when looking straight ahead in the conflict zone, plus the corner islands also provide a physical barrier. Motorized vehicles must travel around when making a right turn, which allows bicyclists to be removed from automobiles at intersections. Additionally, corner islands push the bicyclists out farther from the curb. This also increases the visibility between the automobile and the bicyclist (5). Refer Figure-18 for visual illustration of the above statement.

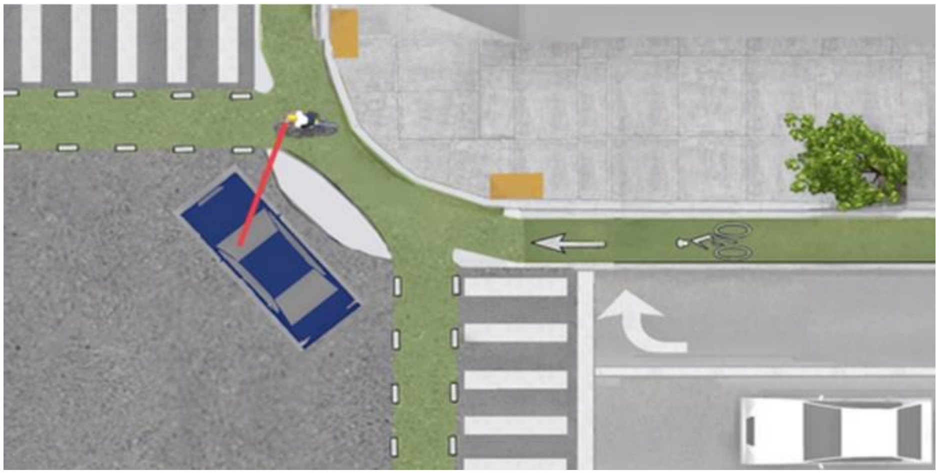


Figure-18 The sightlines in the conflict zone of a "right hook" (5).

Left Turn: according to the MUTCD typical signalized intersection with bicycle lanes, for the bicyclists in order to make a left turn either they have to merge the through automobile traffic or need to get off their bike and walk it across as a pedestrian. Neither one is immensely desirable, especially merging left into traffic, which can give rise to automobile and bicycle points of conflicts (5). On the other hand the Dutch's came up with a solution by two-phase left turn. Figure-19 shows a path that a bicyclist had to take to make a two phase left turn.

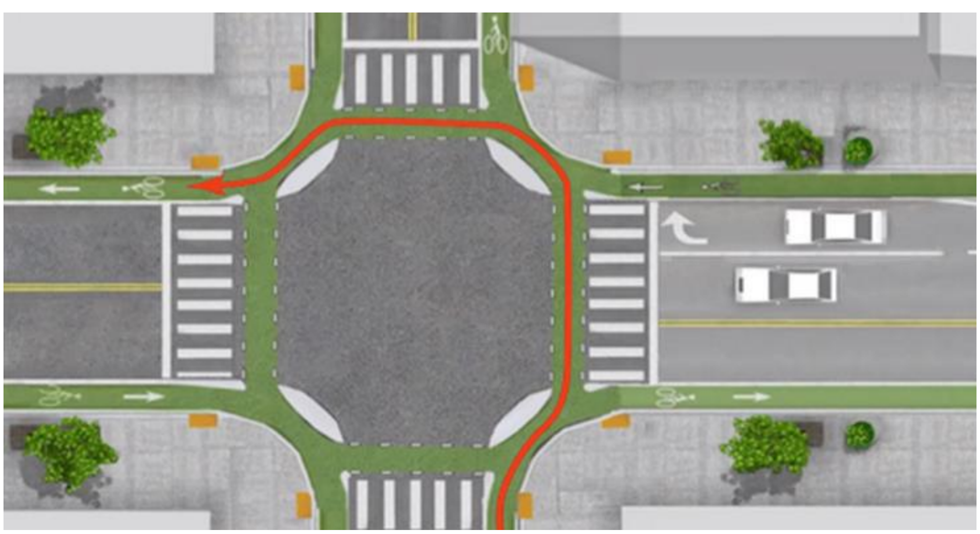


Figure-19 Two phase Left Turn for Bicyclists. (5)

3.3.Simulation model

There are several microscopic simulation tools available for evaluating the traffic flow on a random infrastructural network. PTV VISSIM, Paramics and Aimsun are some of the simulation tool that are widely used on microscopic modeling. In this project PTV VISSM is used for modeling and simulation. However, most microscopic simulation tools including PTV VISSM have similarities when it comes to the main input parameters to evaluate traffic flow. These are the infrastructural network, the traffic demand and microscopic behavioral models.

PTV VISSIM offers a graphical user interface that allows a user to input traffic and signal data on to the existing base maps of intersections and road layouts. Besides reducing the workload required for inputting data to the model, the quality of animation of traffic and transit operations has also been improved due to this unique capability of VISSM. In contrast to other traffic simulation software, VISSIM allows users to accurately model and analyze sophisticated traffic interactions such as weaving sections and merges (6).

A disadvantage of PTV VISSM simulation model is the computation time, which depends on the magnitude of the network, the desired output and the amount of random seeds to be applied. Coding the input data to the model also requires a fairly significant amount of time. The summary of strengths and weaknesses of PTV VISSM according to 'Boxill and Yu, 2000' is tabulated below (see Table-1).

Table-1. Strengths and weaknesses of PTV VISSIM. (Source: Sharon A. Boxill and Lei Yu, 2000)

PTV VISSM traffic simulation software	
Strength	**Weakness**
• Covers a wide range of traffic situations • Can be run on any personal computers • Continuously upgraded and hotline supported	• No assessment algorithms • Coding of input data is tedious and time consuming

The table below, Table-2, summarizes the important areas of applications of different traffic simulation models within the ITS framework.

Table-2 Summary of the application areas of selected models. (Source: Sharon A. Boxill and Lei Yu, 2000)

Traffic simulation models	Areas of applications
AIMSUN 2	Traffic control systems; evaluation of roadway alternatives; and route guidance.
CONTRAM	Traffic demand time series analysis; and design of urban traffic management options.
CORSIM	Assessment of advanced traffic control scenarios such as: adaptive traffic signal control and demand responsive ramp metering.
HUTSIM	Evaluation and testing of different signal control strategies and traffic arrangements; development of new traffic control systems; and evaluation of ITS applications.
INTEGRATION	Assessment of real time rout information and guidance; and corridor improvement strategies for HOV.
PARAMICS	For simulating: traffic signal impacts; ramp metering; in-vehicle route guidance; and in-vehicle network state display devices.
VISSM	Intersection design and operation; and Transit signal priority studies.

4. Model development

This chapter addresses the models made by means of a traffic simulation software called PTV VISSIM 6. This section is written in such a way, that a reader with basic knowledge of VISSIM should be able to reproduce the models used in this project.

The first section illustrates the elements within the network, such as links, nodes, priority rules, speed limit, and reduced speed areas and so on. The second section discusses about some basic features in the Base Data. Here, the behavior of vehicles in the network can be manipulated and customized. However in this project, the default setting of PTV VISSM is used. The third section explains how the traffic demand can be added to the simulation by means of a static assignment. And finally on the fourth section, the evaluation methods will be summarized.

4.1. Network

4.1.1. Links and connectors

In PTV VISSM 5 and earlier versions, before designing, the designer should load a graphic file into the VISSIM model on which one can draw the network. However, in this project since PTV VISSM6 is used and the graphic files are incorporated with the software, there is no need for loading graphical files. This file ensures that the geometrical dimensions of the roundabout are correctly modelled.

Study site-I: *NW 23 Ave & NW Vaughn St*

I. **Existing design:** Figure-20 shows a drawing of the existing signalized intersection, the links are the solid gray lanes and the connectors are the lanes with an atomic green border line. The connectors at the intersection are set to have a lane changing behavior that vehicles are supposed to change lane 200m from the connector. The cross walks are the lanes drown by white color.

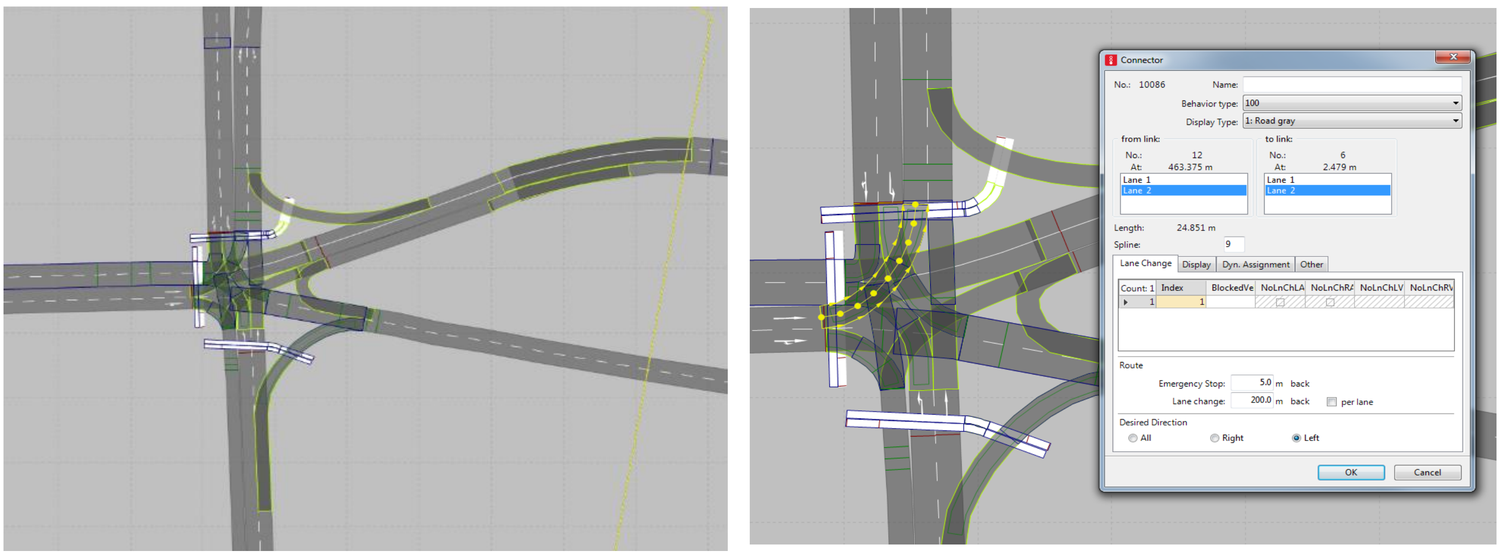


Figure-20 links and connectors of the existing signalized intersection design.

II. **Turbo roundabout:** Figure-21 shows a drawing of the turbo roundabout with the links and connectors forming the structure of the roundabout. The circulatory roadways are modelled by means of links, connected by short connectors at each of the decision points. The connectors at the entrance approaching legs of the roundabout are set to have a lane changing behavior that vehicles are supposed to change lane 200m from the connector. The divided segment entrance legs accommodate each direction on a separate lane. The links are the solid gray lanes and the connectors are the lanes with an atomic green border line.

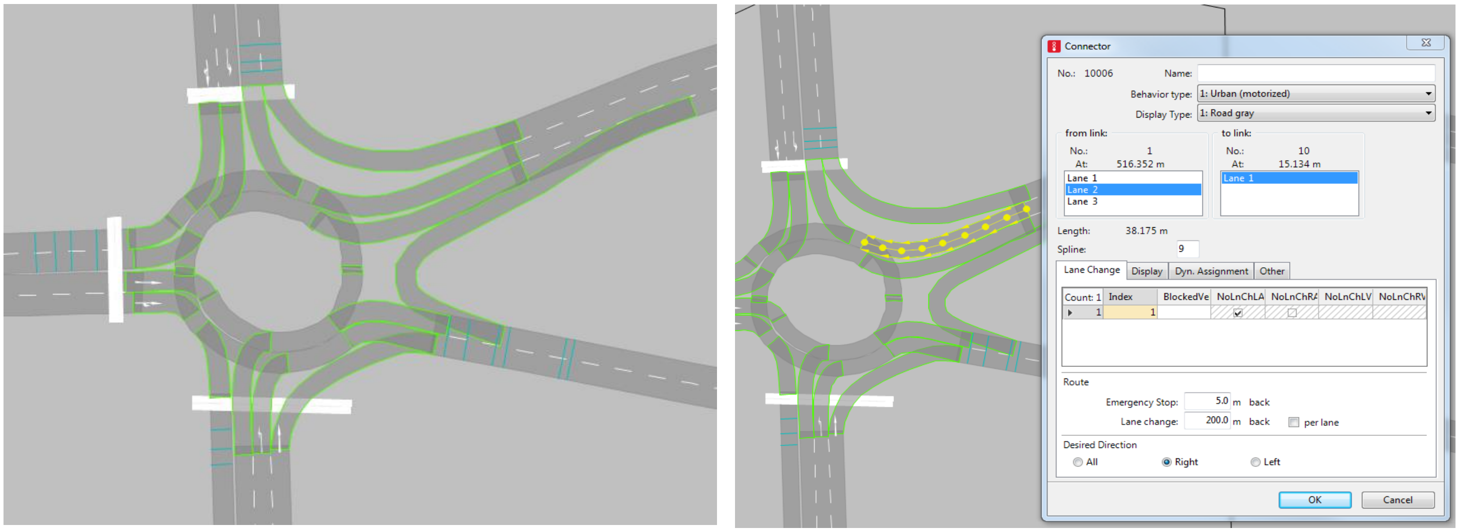


Figure-21 links and connectors of the turbo roundabout design.

Study site-II: *SE 92nd Ave & SE Flavel St*

I. **Existing design:** Figure-22 shows a drawing of the existing signalized intersection at the study site-II, the links are the solid gray lanes and the connectors are the lanes within the red border line. The connectors at the intersection are set to have a lane changing behavior that vehicles are supposed to change lane 200m from the connector. In this study site there are also a bicycle facilities which are drawn in the green lane color. Even though it is a single lane bike track, the connectors have the same lane changing behavior as the road way connectors.

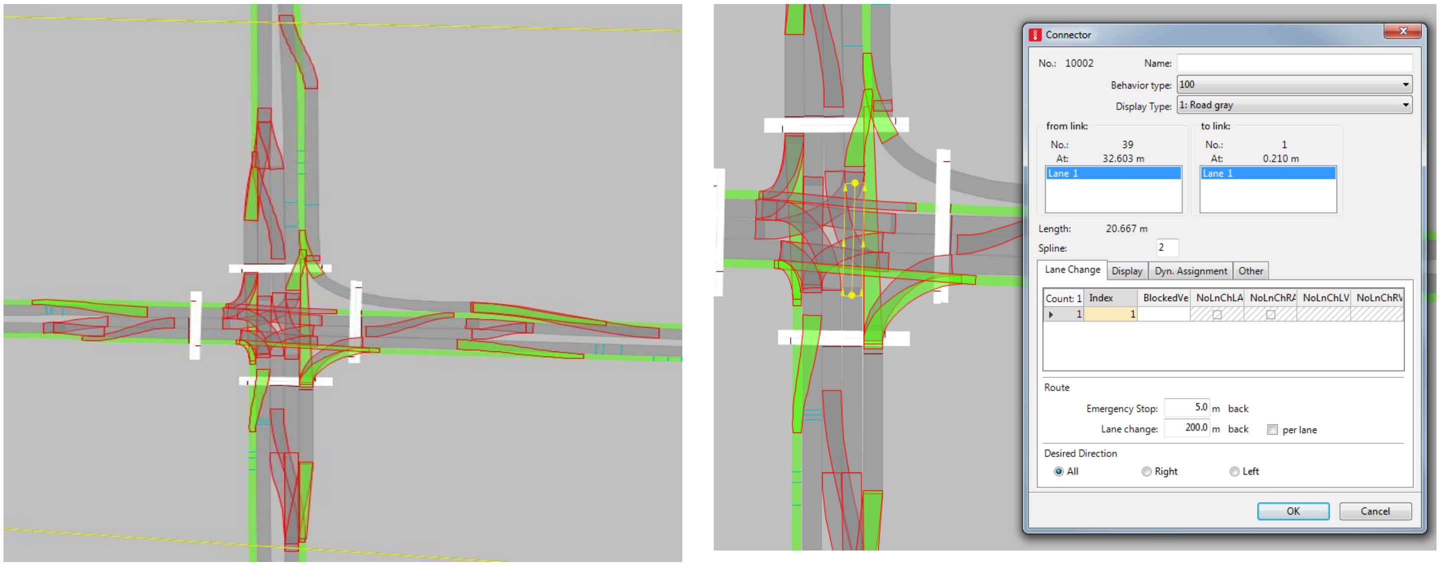


Figure-22 links and connectors of the existing signalized intersection design, at study site II.

II. Dutch's protected intersection: Figure-23 shows a drawing of the protected intersection at the study site-II, the links are the solid gray lanes and green lanes, and the connectors are the lanes within the red border line. The connectors at the intersection are set to have a lane changing behavior that vehicles are supposed to change lane 200m from the connector. As mentioned earlier the connectors connecting the bike lane links have the same lane changing behavior as the road way connectors.

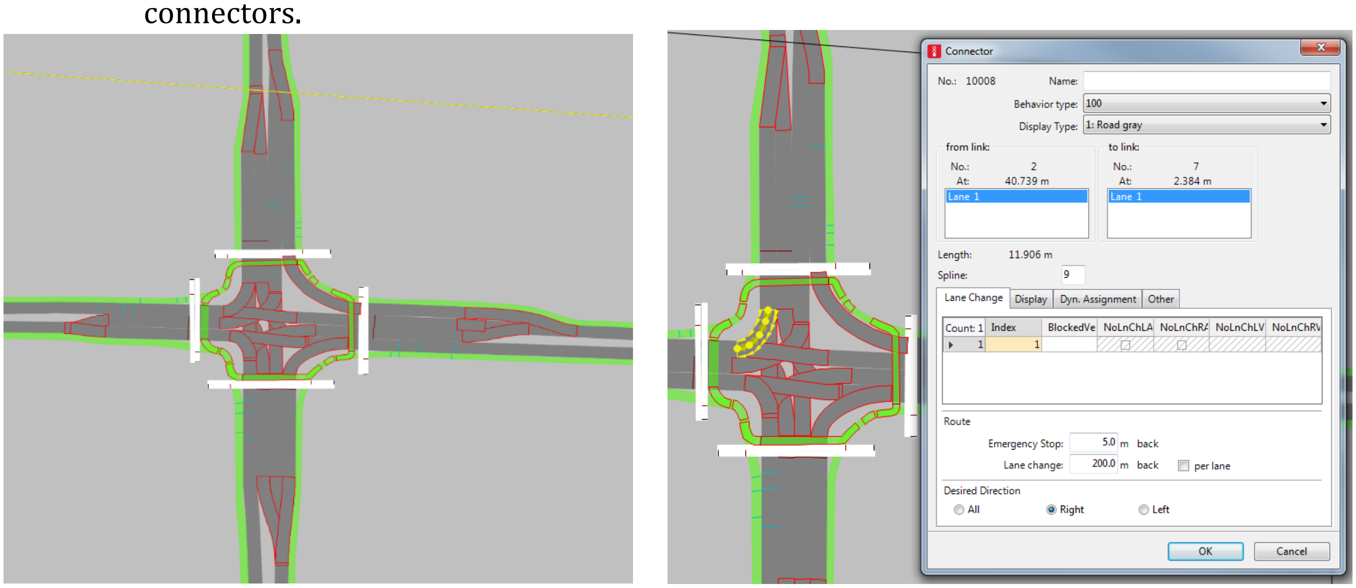


Figure-23 links and connectors of the protected intersection design, at study site II

III. The Dutch's protected intersection which is incorporated with a turbo roundabout: Figure-24 shows a drawing of the turbo roundabout with the links and connectors forming the structure of the roundabout. The circulatory roadways are modelled by means of links, connected by short connectors at each of the decision points. The connectors at the entrance approaching legs of the roundabout are set to have a lane changing behavior that vehicles are supposed to change lane 200m from the connector. The divided segment entrance legs accommodate each direction on a separate lane. The links are the solid gray and green lanes, and the connectors are the lanes within a red border line.

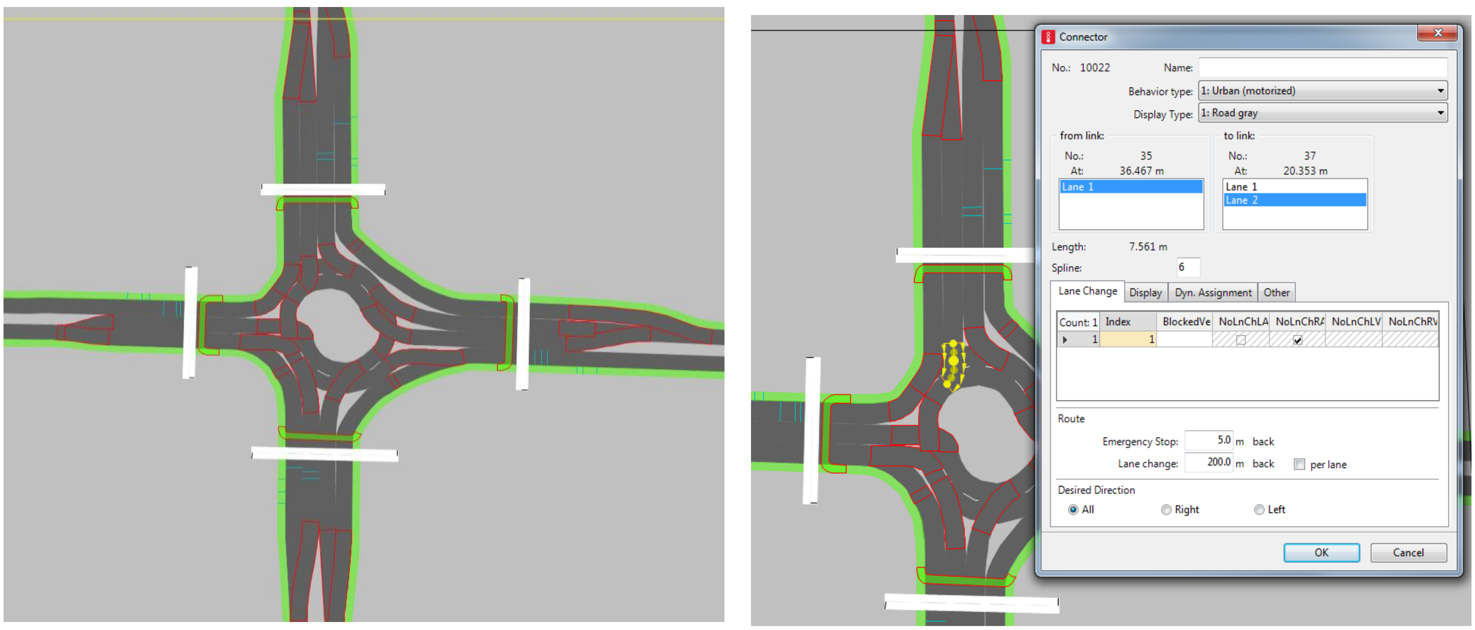


Figure-24 links and connectors of the protected intersection which is incorporated with a turbo roundabout, at study site II

4.1.2. Signal heads and signal timing

Figure-25 & 26 illustrates the position and signal group of each signal heads for study site I and II consecutively. In the picture the first number indicates the study site and the second number indicates signal group (for example: 1-2 means study site-I, signal group-2). Figure-27 and Figure-28 shows the signal timing distribution for each phases (signal groups). Since in the turbo roundabout traffic signals are not used, only the existing and the protected intersection designs are illustrated on the following figures.

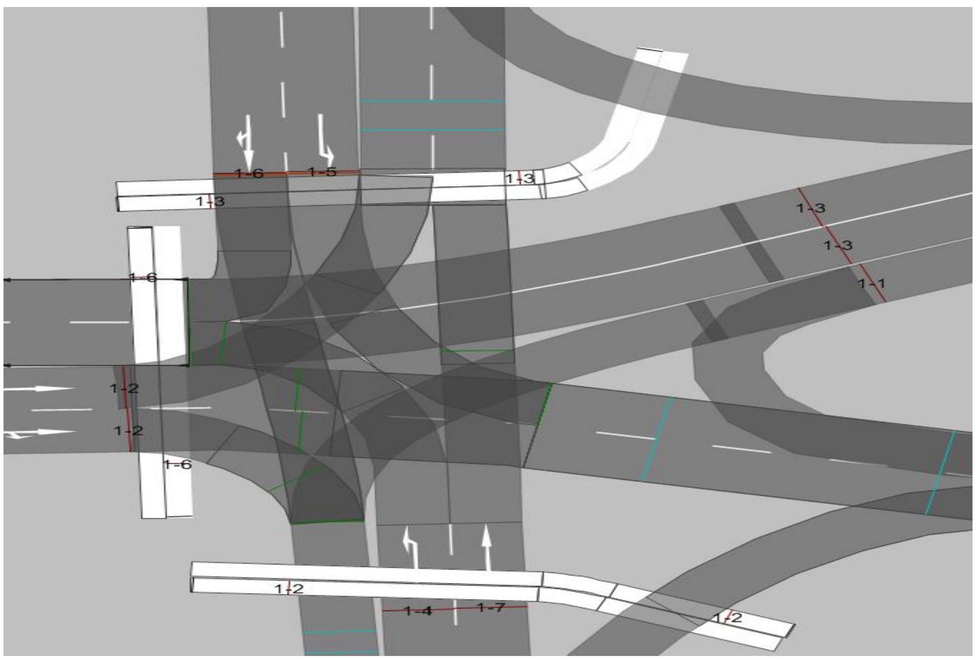


Figure-25 Positions of signal heads and signal groups of site-I. NW 23 Ave & NW Vaughn St.

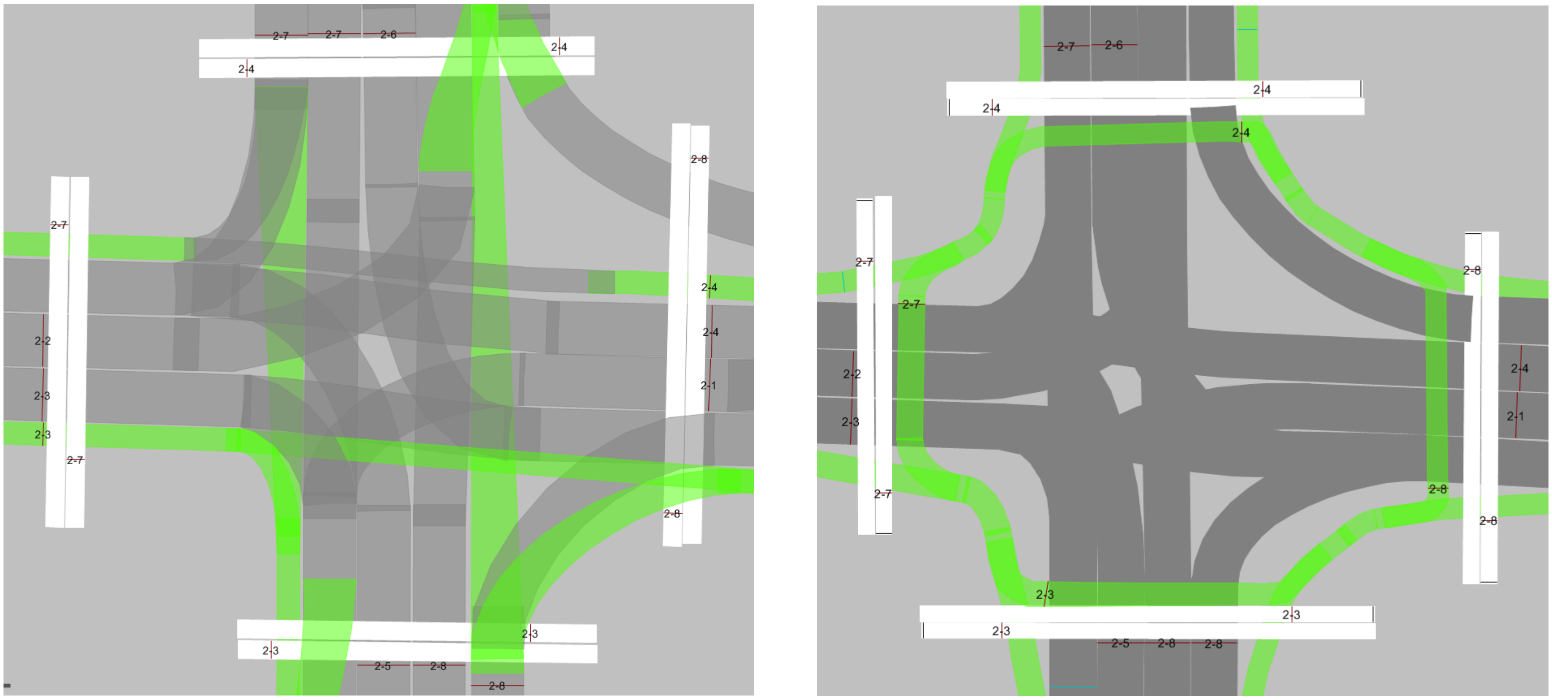


Figure-26 Positions of signal heads and signal groups of site-II. Existing design on the left hand side and the Dutch's bike friendly design on the right hand side. SE 92nd Ave & SE Flavel St.

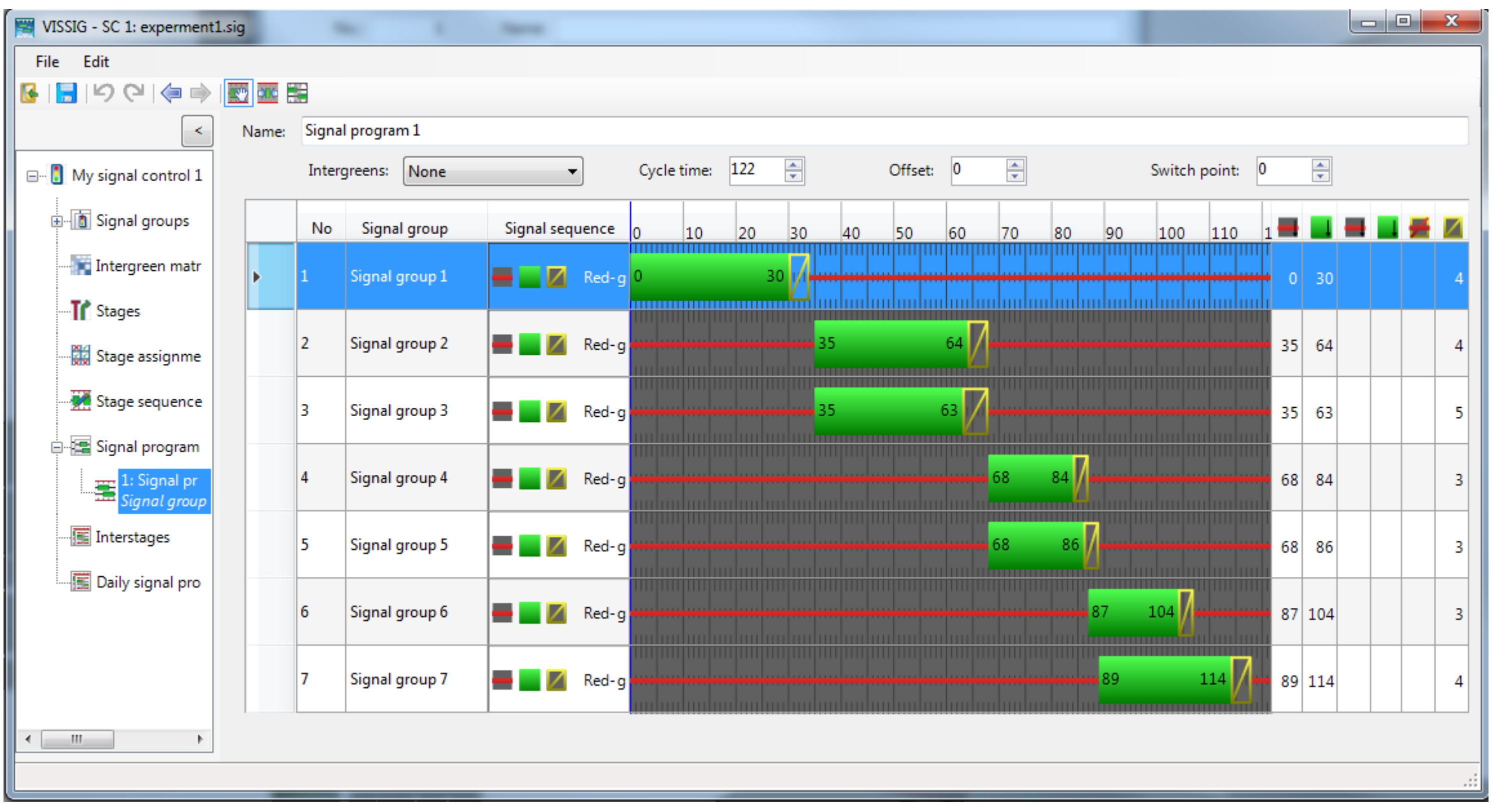


Figure-27 Signal timing distribution for each signal group. Site-I - NW 23 Ave & NW Vaughn St

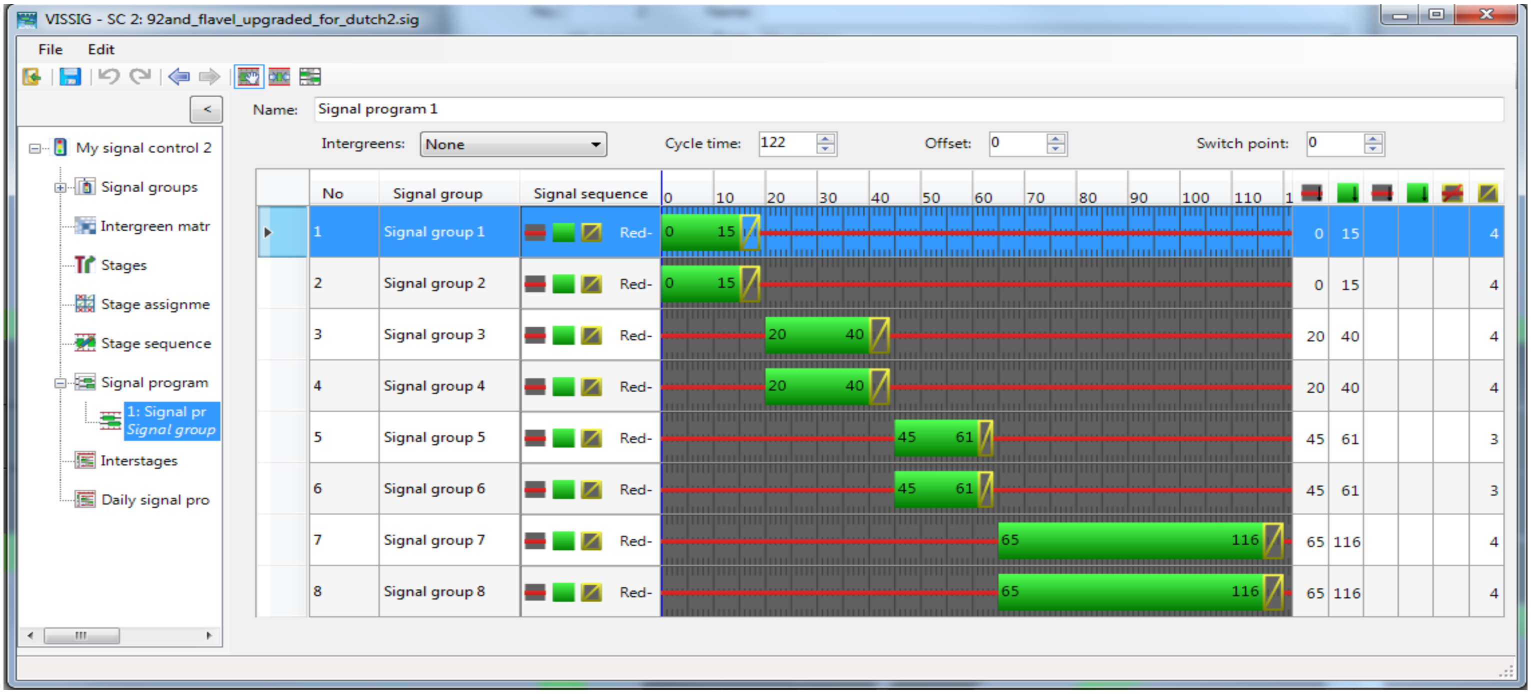


Figure-28 Signal timing distribution for each signal group. Site-II. SE 92nd Ave & SE Flavel St

4.1.3. Speed limits and reduced speed areas

The desired speeds for the links are copied from Portland maps data base. All vehicles arrive at the intersection with the desired speed of the link. However, the vehicles do not cross the intersection at that desired speed due to road curvature, priority, traffic signals, traffic calming, and several other factors. The following figures will illustrate the reduced speed areas and the reduced speeds. The reduced speed areas indicate the road stretches on which the desired speed is lower.

<u>Study Site-I. NW 23 Ave & NW Vaughn St</u>

Figure-29 shows the turbo roundabout on study site-I. In this design, on the right turning lanes the reduced speed is 20 km/hr. on the approaching legs and inside the turbo roundabout the speed is reduce to 25 Km/hr.

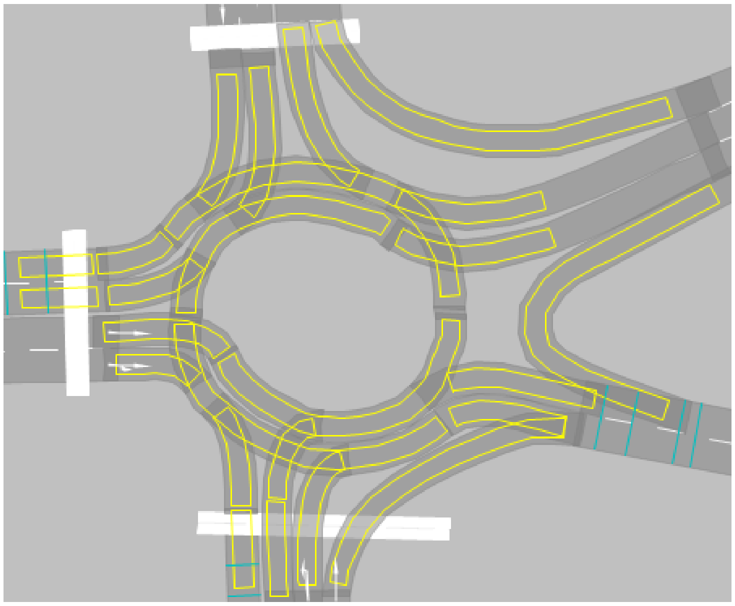


Figure-29 Reduce speed areas on the turbo roundabout design.

Figure-30 shows the reduced speed areas on the existing intersection. Here the right turning lanes have a reduced speed of 15 km/hr. and the left turning vehicle have a reduced speed of 20 Km/hr.

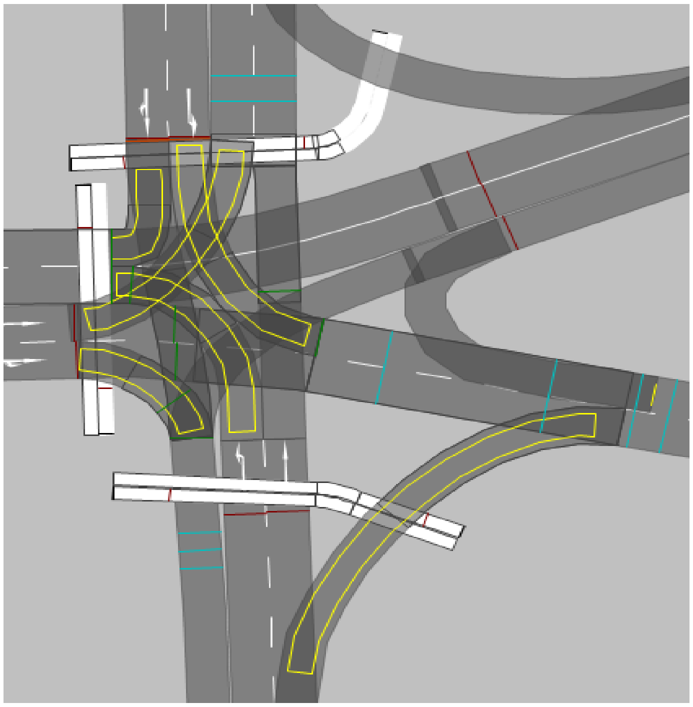


Figure-30 Reduce speed areas on the existing design.

Site-II. SE 92nd Ave & SE Flavel St

Figure -31 shows the reduced speed area on the existing signalized intersection at study site-II. Here the right turning lanes have a reduced speed of 15 km/hr and the left turning vehicle have a reduced speed of 20 Km/hr.

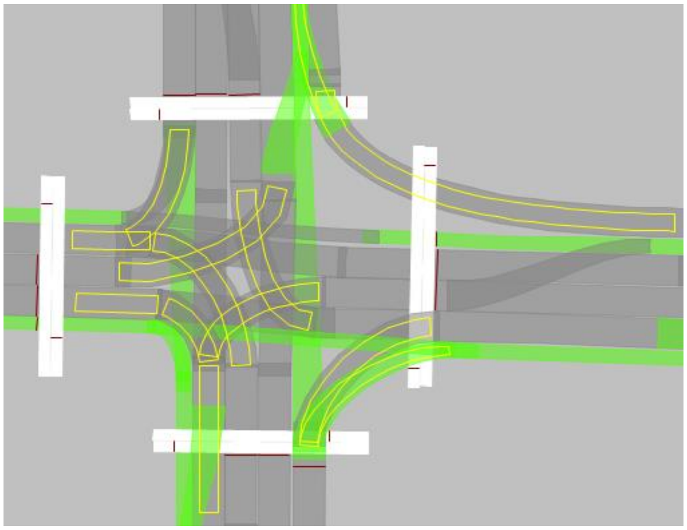


Figure-31 Reduce speed areas on the existing design.

Like the existing design, the right turning lanes on the protected intersection have a reduced speed of 15 km/hr and the left turning vehicle have a reduced speed of 20 Km/hr. Figure-32 shows the reduced speed area on the protected intersection at study site-II.

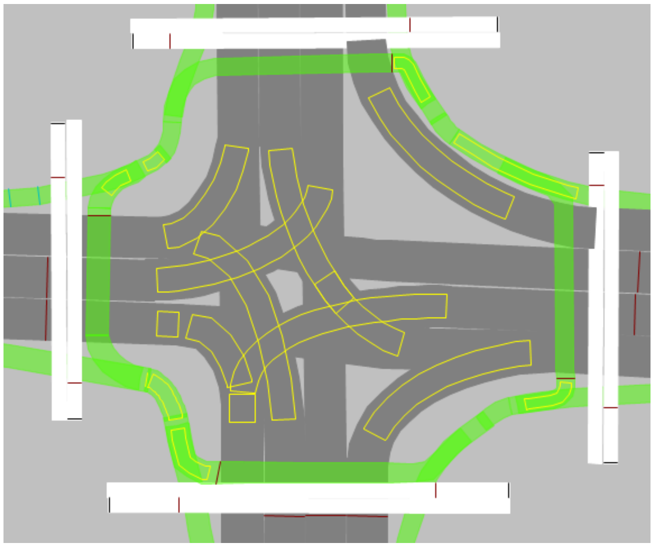


Figure-32 Reduce speed areas on the protected intersection design.

The figure below Figure-33 shows the reduced speed area on the protected intersection that is incorporated with the turbo roundabout. In this design, on the approaching legs and on the right turning lanes the reduced speed is 15 km/hr. And inside the turbo roundabout the speed is reduce to 25 Km/hr.

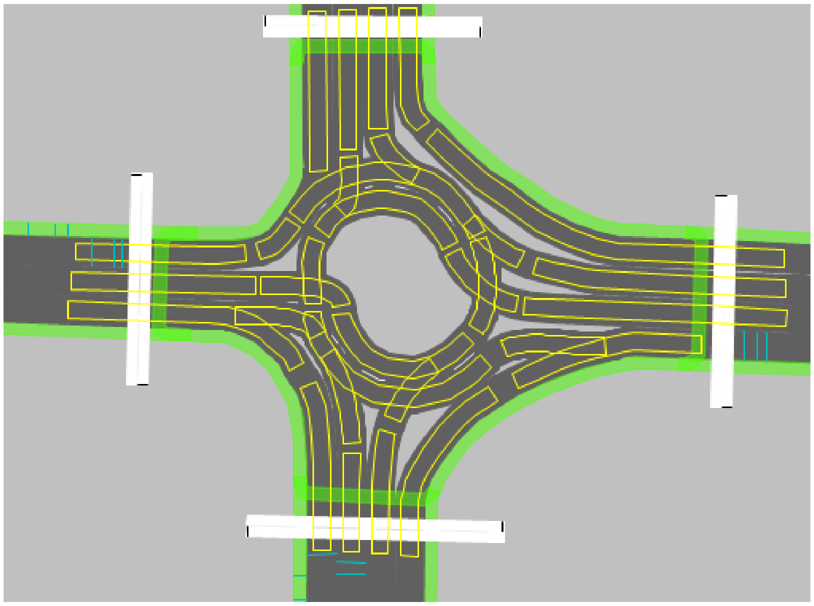


Figure-33 Reduce speed areas on the protected intersection that is incorporated with the Turbo roundabout intersection design.

4.2.Base data

On PTV VISSM tool bar from the drop down menu "Base data", the most important input variables with respect to the microscopic driving behavior can be defined in the form of functions and distributions. Since in this project the default settings are used, in this section only some of the important default setting features will be discussed. The online PTV Group web also offers some important description regarding this topic.

4.2.1. Vehicle type and vehicle class

In this dropdown menu, we can define the vehicles characteristics. In the VISSIM models of this project, the only relevant vehicle types used are Car, HGV, pedestrians and bikes. A vehicle class is a selection of the vehicle types, which together form a class. These classes can be assigned characteristics in a static assignment.

4.2.2. Distributions

In the dropdown menu under base data - Distributions, there are important parameters that influence the behavior of drivers in the model, and its output. One of the parameters is the desired speed distribution. The desired Speed distributions used in this project are: 15, 20, 25, 30, 40, and 60 Km/hr, which are applied in the reduced speed areas, on right turn and left turn lanes on the signalize intersections ,and on the approach links.

4.2.3. Link behavior types

In this menu, the driving behavior explained in the previous section can be applied to the road types in the model. In this project road type urban, cycle track and pedestrian area are used.

4.3.Traffic demand

The PTV VISSIM software offers two ways to generate traffic on a network, these are static and dynamic assignment. This project applies a static assignment.

4.3.1. Vehicle composition

There were no data regarding vehicle composition for the study sites. However, in this project a new vehicle composition is defined for cars, bikes and pedestrians unique to both study sites.

Site-I. NW 23 Ave & NW Vaughn St

Name	Vehicle type	Desired speed	Relative flows
CAR	1001: Car	60: 60 km/h	0.999
	1002: HGV	50: 50 km/h	0.001
PEDESTRIAN	1005: Man	5: 5 km/h	0.50
	1006: Woman	5: 5 km/h	0.50

Table-3 Vehicle compositions for study site-I VISSM model development

Site-II. SE 92nd Ave & SE Flavel St

Name	Vehicle type	Desired speed	Relative flows
CAR	1001: Car	60: 60 km/h	0.98
	1002: HGV	40: 40 km/h	0.01
	1003: Bus	40: 40 km/h	0.01
BIKE	1007: Bike	25: 25 km/h	1.00
PEDESTRIAN	1005: Man	5: 5 km/h	0.50
	1006: Woman	5: 5 km/h	0.50

Table-4 Vehicle compositions for study site-II VISSM model development

4.4. Evaluations

The evaluation of the intersection performance will be based on; travel time, average delay and average speed. PTV VISSM-6 offers all the above performance criteria to be measured from the model. A gradual increment in volume is done every 15 simulation minute to observe the performance of each intersection designs in different volume scenarios. The increment is done on the total volume of all legs that are feeding the intersection (in other words the in-volume) and then distributed to each intersection legs on their percentage contribution to the intersection which is driven from the existing condition that is obtained from Portland Maps. The following figure illustrates the volume distribution for the both study sites.

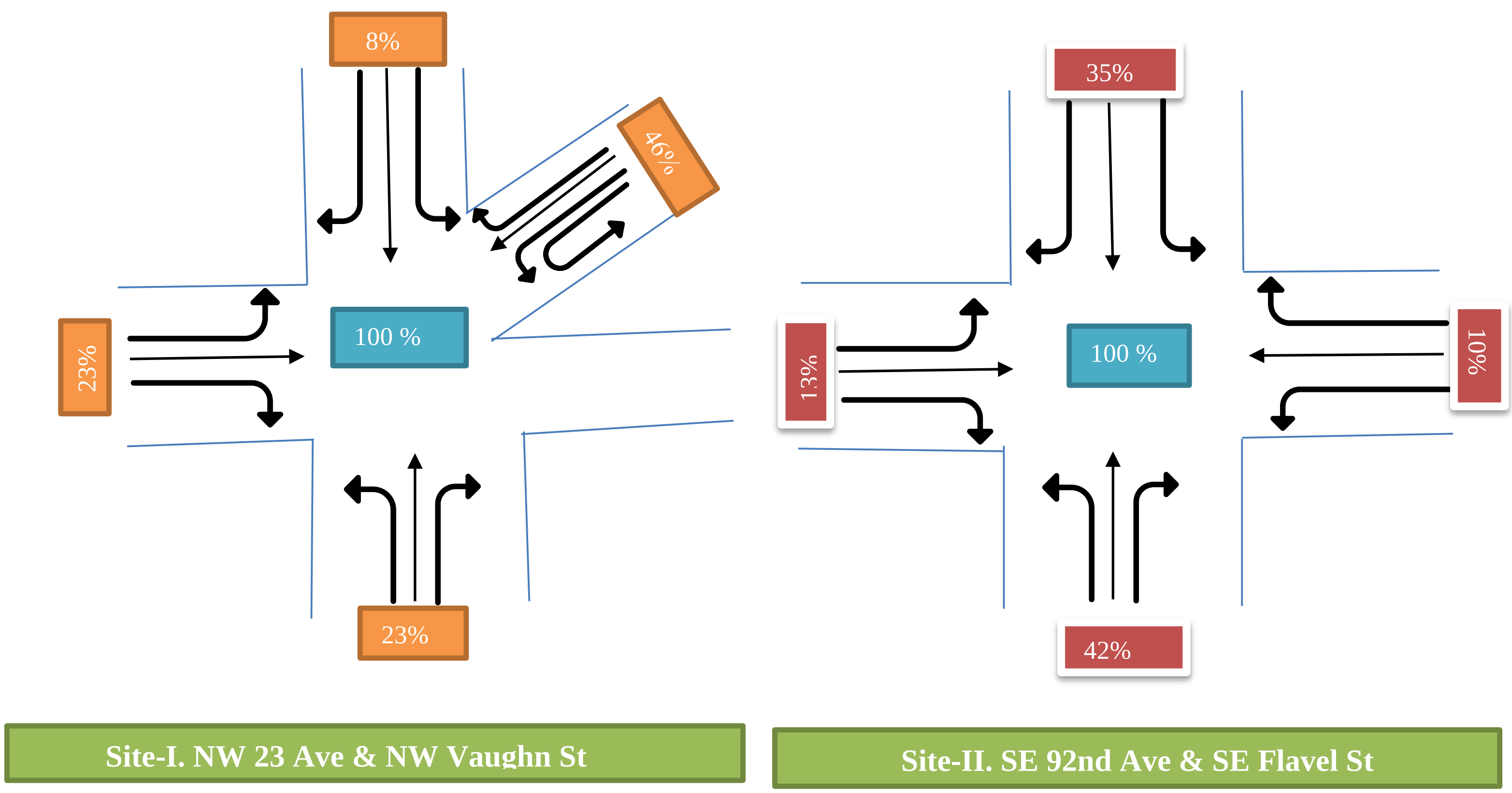
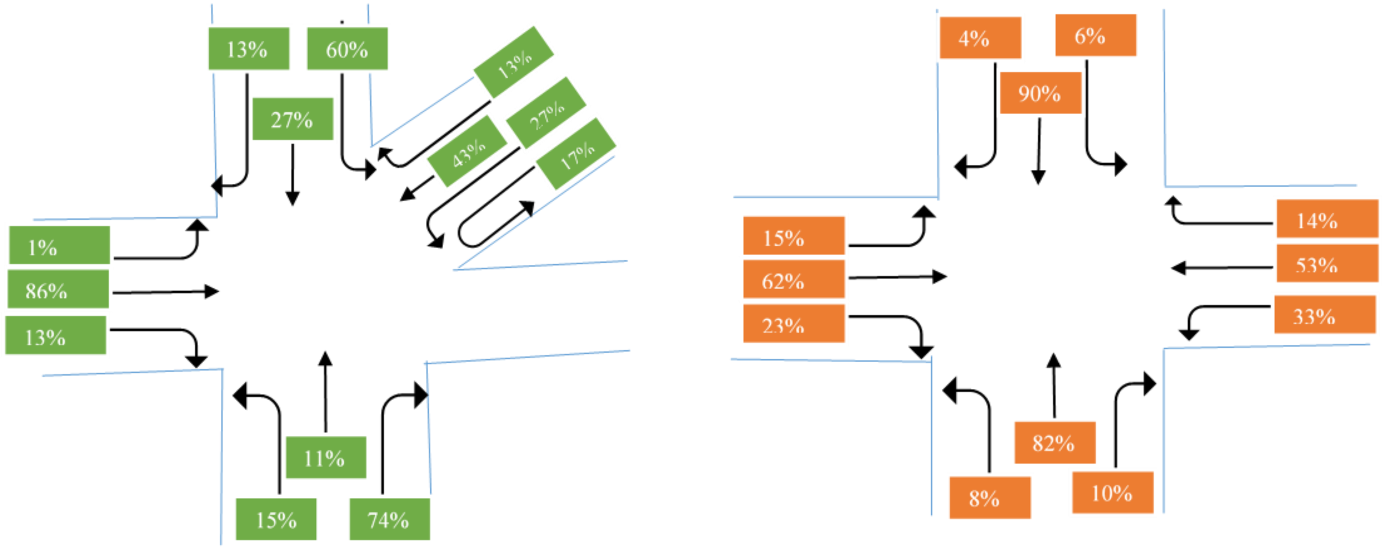


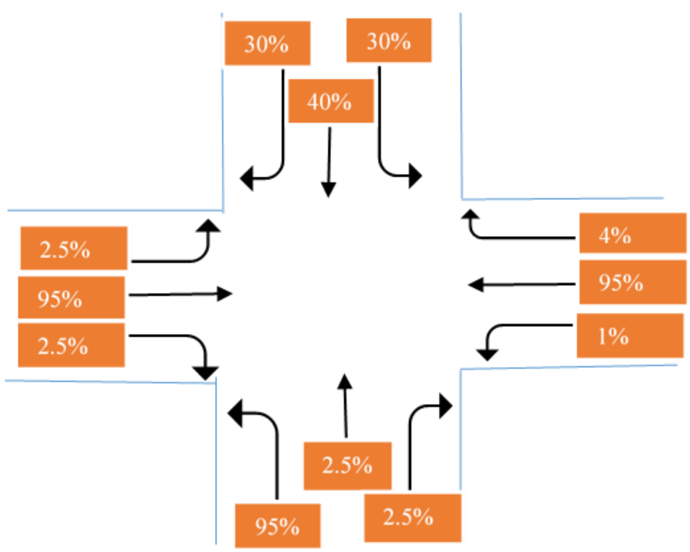
Figure-34 Percentage volume contribution of each approaches to their intersection.



Site-I. NW 23 Ave & NW Vaughn St

Site-II. SE 92nd Ave & SE Flavel St

Figure-35 Percentage volume distribution of all turning movements on each leg. For motor vehicles



Site-II. SE 92nd Ave & SE Flavel St

Figure-36 Percentage volume distribution of all turning movements on each leg. For bike traffic

4.4.1. Evaluation parameters

As mentioned earlier in this project the evaluation parameters used are total travel time, average delay and average speed. PTV VISSM-6 allows these performance criteria's to be measured from the model. In this project identical networks are used with the identical dimensions, volumes and, traffic and route behavior. Only the intersection designs are different for evaluation.

The travel time can be measured by defining starting and ending point on segments. By doing so, we can measure the time a vehicle on the link travel for the defined distance from the starting to the ending point. We can do this for all individual turning movements, inside and outside of interchanges. But studying the travel time on the individual link is not the intention of this project. That by itself can be a whole new project. The intent of this project is to study the impact of the different design types on a given network. So the total travel time is the travel time of all active and arrived vehicles in the network. The average speed is: the total distance / total travel time, where the total distance is the distance traveled by active and arrived vehicles in the network. The average delay per vehicle is: the total delay time / (active + arrived vehicles), where the total delay time of all active and arrived vehicles. The delay time is calculated by subtracting the quotient of the actual distance traveled and the desired speed from the length of the time step.

5. Evaluation results and discussions

5.1. Study site –I: NW 23 Ave & NW Vaughn St

5.1.1. Average delay

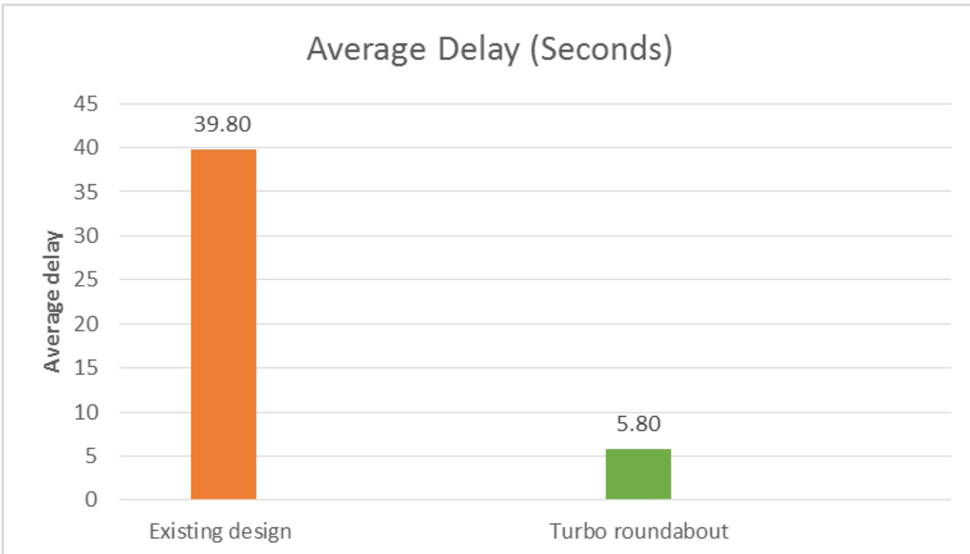
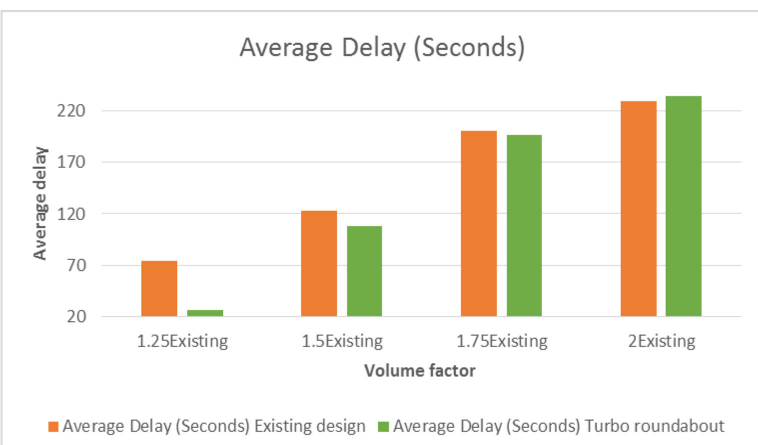


Figure-R1 Average delay comparison on the existing volume condition.



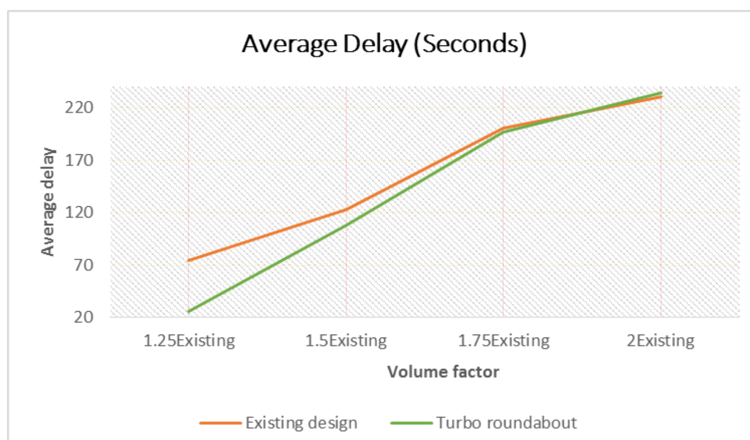


Figure-R2 Average delay comparison by progressive increment in volume.

Average delay is one of the performance parameters used in this study site. From Figure-R1 on the existing volume condition, we can clearly see that the turbo roundabout has a very low delay per car "average delay" compared to the existing signalized intersection. The turbo roundabout in this condition is significantly better than the existing design. There is around a 34 seconds average delay difference between the two designs. From Figure-R2, we can also see that the turbo roundabout is performing better than the existing signalized intersection even when the volume on the intersection is increased progressively until the point where the volume increment passed 75%. After that point the average delay on the turbo roundabout is greater. However, such volume conditions are highly unlikely to happen in the real world, since the existing volume used in this study is already the PM peak hour volume.

5.1.2. *Average speed*

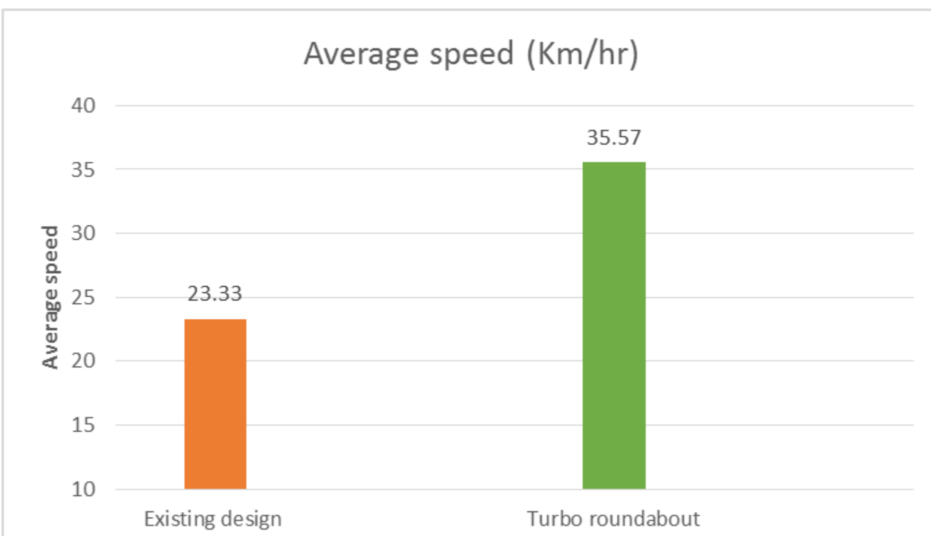
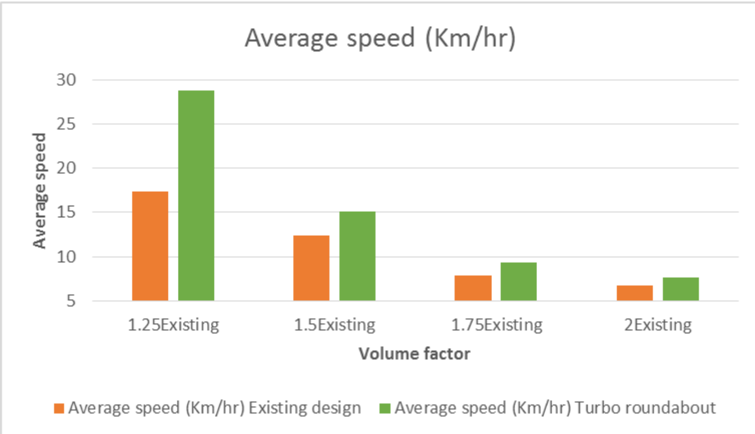


Figure-R3 Average speed comparison on the existing volume condition.



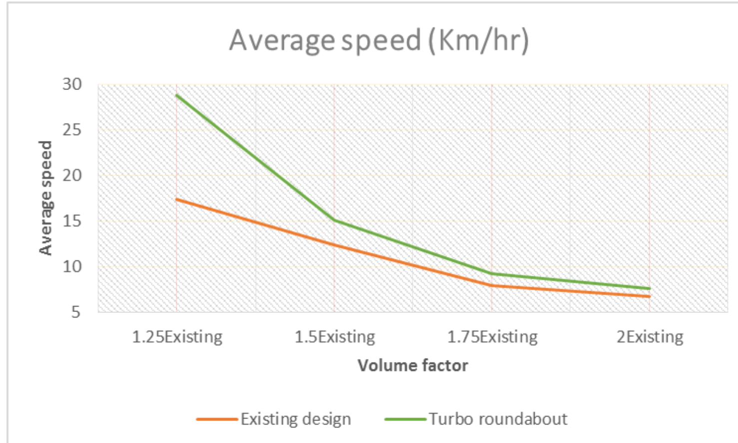


Figure-R4 Average speed comparison by progressively increasing the volume.

Average speed is another important comparison parameter use in this project. From the chart given on Figure-R3, we can see a comparison between the turbo roundabout and the existing signalized intersection by average speed using the existing volume condition. From the chart we can observe that the average speed on the turbo roundabout is significantly greater for the given scenario. Again on Figure-R4 we can also observe that the average speed on the turbo roundabout is greater than the existing signalized intersection in all different volume scenarios.

5.1.3. <u>Total travel time</u>

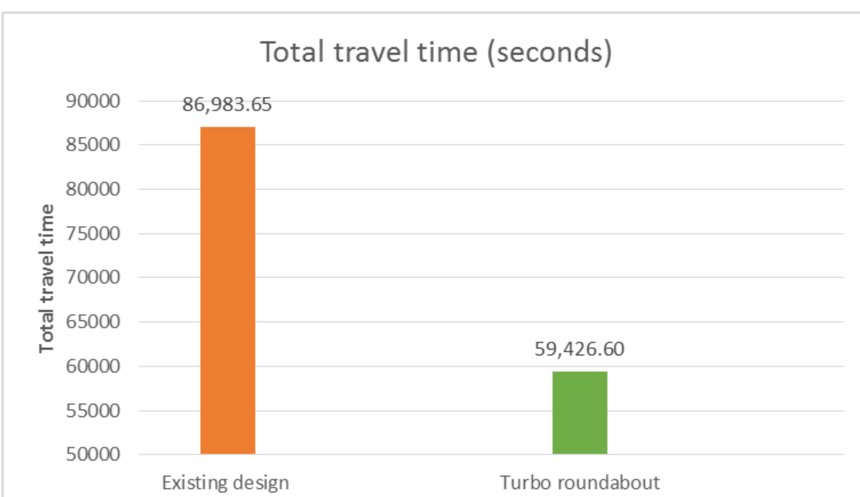
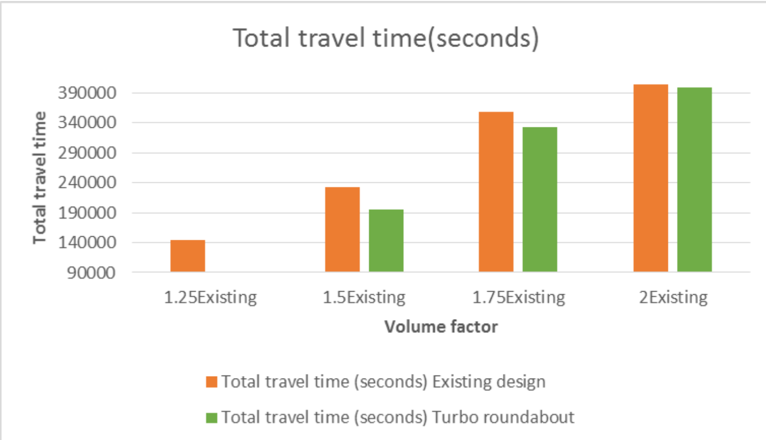


Figure-R5 Total travel time comparison on the existing volume condition.



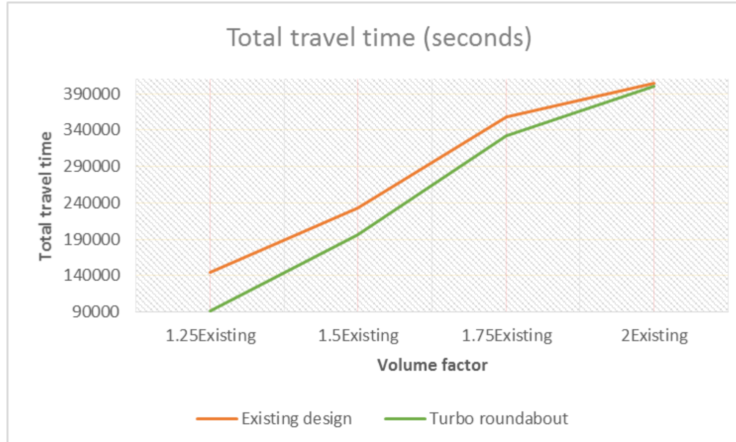


Figure-R6 Total travel time comparison by progressively increasing the volume.

The final performance comparison parameter used in this study site is the total travel time. The chart given on Figure-R5 shows a comparison of the turbo roundabout and the existing signalized intersection based on total travel time with the existing volume condition. From the chart we can observe that the total travel time under the turbo roundabout is much less than the existing signalized intersection. Again the charts given on Figure-R6 also show that the total travel time in the turbo roundabout under different volume scenarios is also less than the existing design at all time.

5.1.4. Results summary

Based on the simulation results given in this section and the above discussions, overall the turbo roundabout has shown a significant performance superiority over the existing intersection on different volume scenarios. The following summary shows the improved performances on the existing volume condition by transforming the existing signalized intersection into a turbo roundabout.

- ↓ Average delay is reduced by **85.43%** for the existing volume condition.
- ↑ Average speed is increased by **52.5%** for the existing volume condition.
- ↓ Total travel time is reduced by **31.68%** for the existing volume condition.

5.2. **Study Site-II:** SE 92nd Ave & SE Flavel St

As mentioned on the earlier sections of this paper, in this study site there are bike facility. So, the study in this site is not just only performance improvement but also a safety improvement. The Dutch's protected intersection design is adopted for the reason of safety only and then incorporated with turbo roundabout to improve its performance. First the performance of the different intersection design approaches will be discussed based on VISSM simulation results provided, then the safety improvement will be discussed in detail.

5.2.1. Average delay

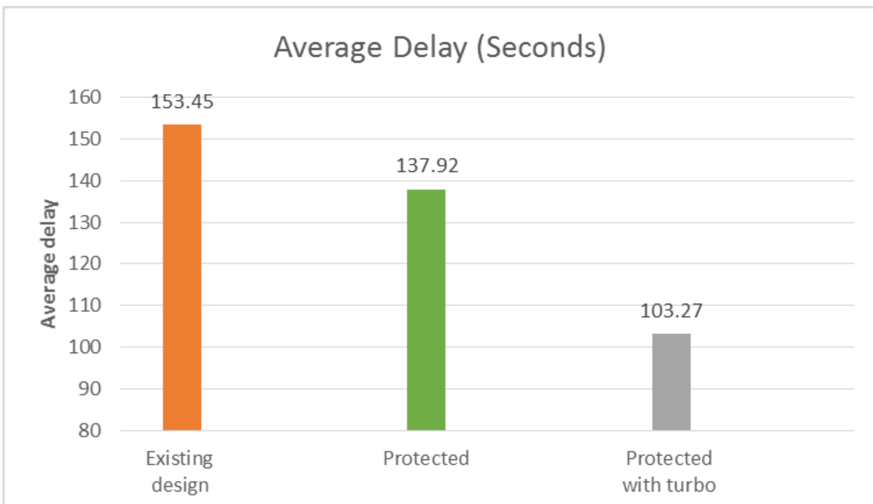
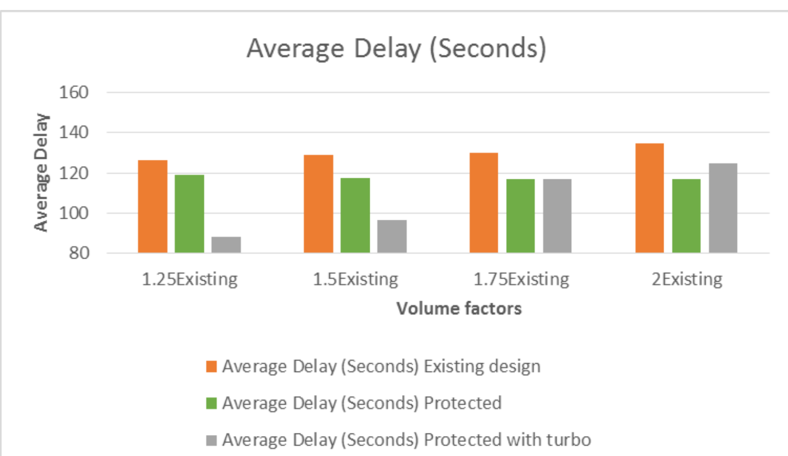


Figure-R7 Average delay comparison on the existing volume condition.



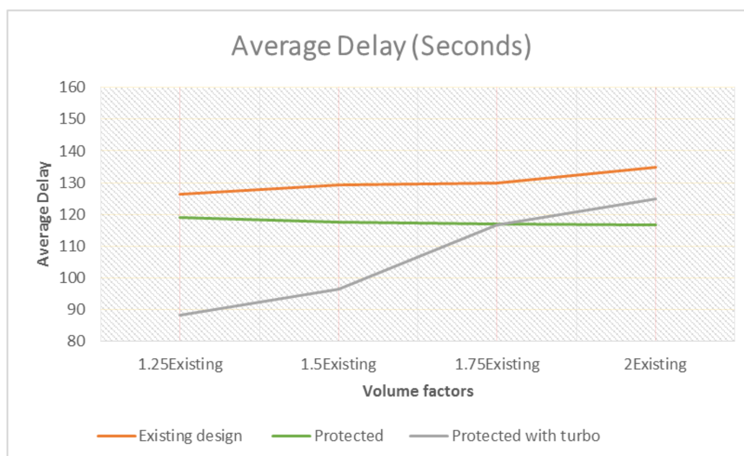


Figure-R8 Average delay comparison by progressive increment in volume.

The same as study site-I, average delay is also one of the performance comparison parameters used in this study site. Figure-R7 shows a comparison of the three intersection approaches (existing signalized intersection, the protected intersection and the turbo roundabout) on the existing volume condition. From the chart we can observe that the existing design has the highest average delay and the turbo roundabout has the lowest average delay at the intersection. In this results we can observe that the protected intersection is also performing better than the existing signalized intersection. Again the charts on Figure-R8 shows how these three intersections perform on different volume scenarios. From the charts, we can observe that the existing signalized intersection has the highest average delay on all scenarios. However, the turbo roundabout had the lowest average delay until the volume increment reach 75%. After that point the protected intersection has the lowest average delay. Another important observation in this chart is, unlike the existing signalized intersection and the turbo roundabout, on the protected intersection approach the average delay is rather decreasing as the traffic volume increases.

5.2.2. Average speed

Figure-R9 Average speed comparison on the existing volume condition.

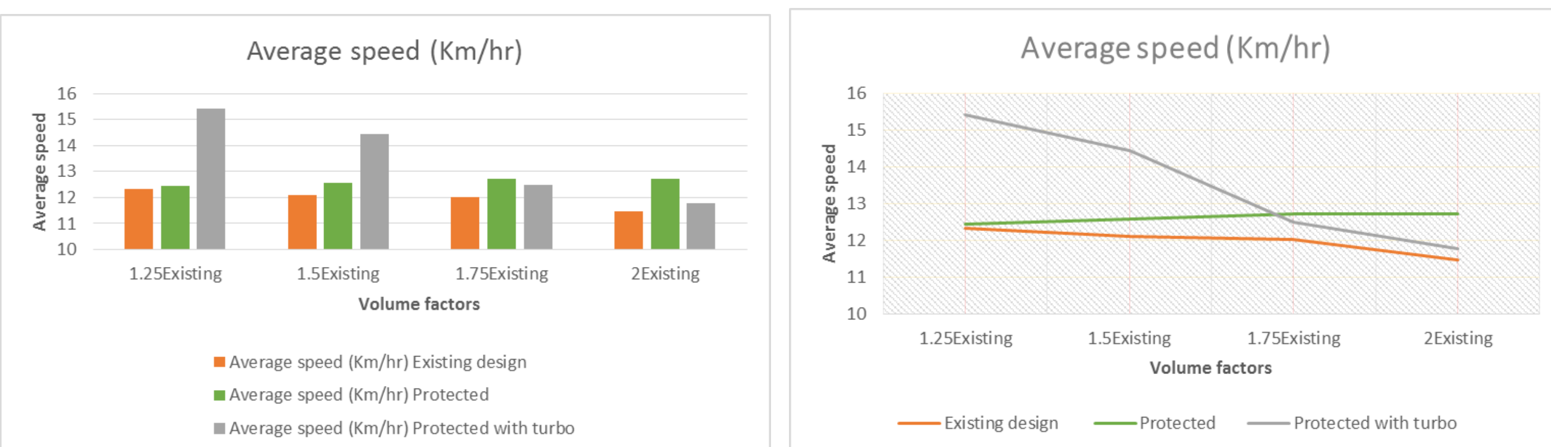


Figure-R10 Average speed comparison by progressively increasing the volume.

Average speed is also the other similar performance comparison parameter used in this study site. On Figure-R9, we can see that the turbo roundabout is performing better than the rest of the two intersection designs on the existing volume condition. The existing signalized intersection is still the lowest performing intersection in this scenario. In Figure-10, we can observe again that the existing signalized intersection has the lowest average speed at intersection on all volume scenarios. Regarding the turbo roundabout, it has the highest average speed until the volume increment reach right before 75%. After that point the protected intersection has the highest average speed at the intersection. Similarly here on the protected intersection, the average speed has shown increment as the volume at the intersection increases.

5.2.3. Total travel time

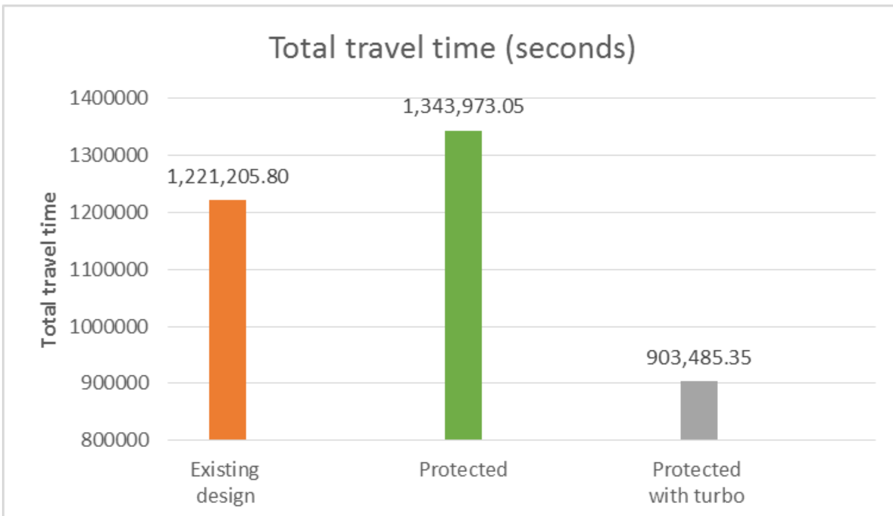
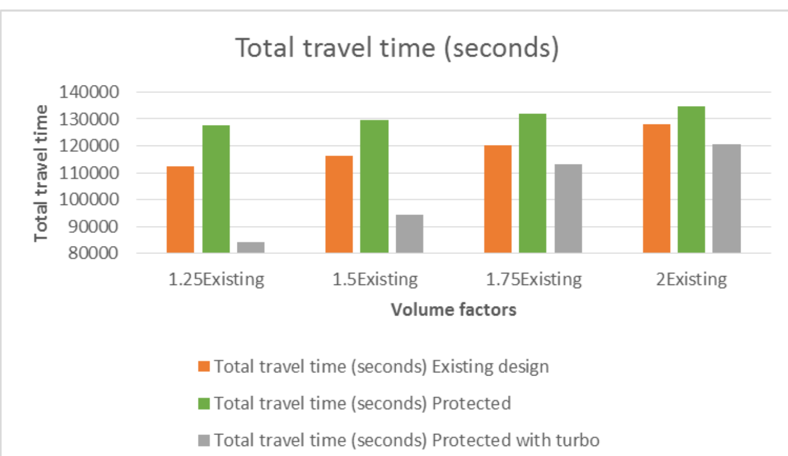


Figure-R11 Total travel time comparison on the existing volume condition.



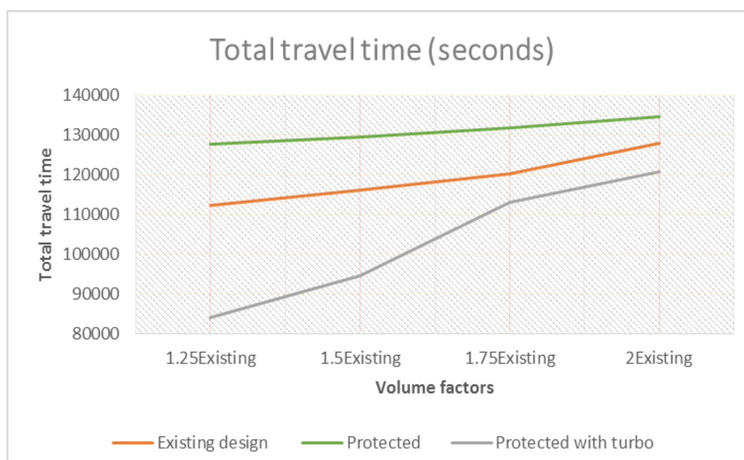


Figure-R12 Total travel time comparison by progressive increment in volume.

Finally, the total travel time is also the other similar performance parameter used in this study site. The charts in Figure-R11 and Figure-R12 shows the total travel time comparison between the three intersection approaches. In this performance parameter, the turbo roundabout has the all-time lowest total travel time and the protected intersection has the all-time highest total travel time at intersection on all volume scenarios.

5.2.4. <u>Results summary</u>

From the previous discussions and simulation results, the protected intersection with the turbo roundabout approach seems to have an overall greater performance. However, we have seen that the protected intersection design also perform very well on all performance parameters on all volume scenarios. More interestingly, the protected intersection approach seems to perform better on scenarios where the traffic volume is higher.

The following summary shows the improved performances on the existing volume condition by transforming the existing signalized intersection into a protected intersection design and into a protected intersection that is incorporated with the turbo roundabout consecutively.

<u>On the protected intersection</u>

- ↓ Average delay is reduced by **<u>10.11%</u>** for the existing volume condition.
- ↑ Average speed is increased by **<u>3.09%</u>** for the existing volume condition.
- ↑ Total travel time has increased by **<u>10.05%</u>** for the existing volume condition.

On the protected intersection that is incorporated with turbo roundabout

- ↓ Average delay is reduced by **32.69%** for the existing volume condition.
- ↑ Average speed is increased by **24.72%** for the existing volume condition.
- ↓ Total travel time is reduced by **26.02%** for the existing volume condition.

5.2.5. Discussion on safety improvement

5.2.5.1. Left-turn conflict

On the existing intersection approach, the bicyclist have to cross the motor way lane and join the far left lane of the motor way and stay on that lane until they finish making the left turn. This way of making a left turn puts the bicyclist at high risk because of the conflicting movements with the motor vehicles while joining the motor way and for sharing a high speed motor way. The following picture on Figure-R13 shows how bicyclists makes a left turn on the existing facility. The blue line on the picture is the path that a bicyclist takes to make a left turn.

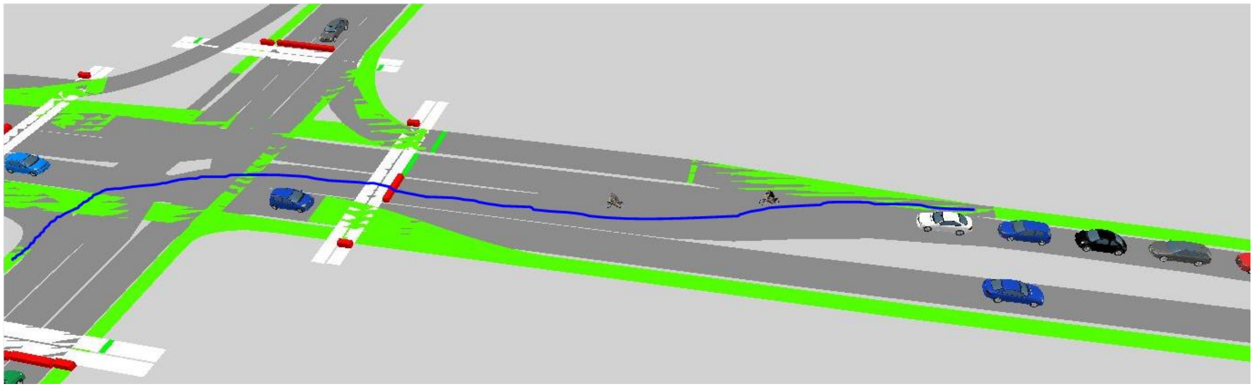
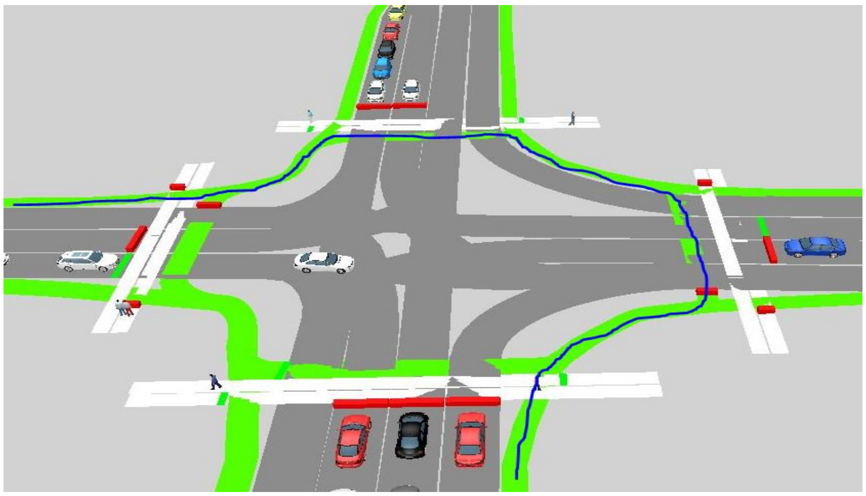


Figure-R13 Bicyclists making a left turn on the existing intersection.

However, on the protected intersection approach the bicyclists do not have to merge to the motorway to make a left turn. They just have to stay on their lane and make two left turns using the pedestrian phase. The following picture Figure-R14 illustrates how bicyclists make a left turn on the protected intersection approach. The blue line on the picture shows the path that bicyclists have to take to make a left turn on the protected intersection approach.

Figure-R14 A path that a left turning bicyclists have to take on the protected intersection.



So, in the protected intersection approach, the conflict between bicyclist and motor vehicles on merging zone to make a left turn is eliminated since, the bicyclist always stay on the bicycle lane.

5.2.5.2. Right-hook

As mentioned in the earlier sections, the protected intersection approach addresses the right-hook crash issue by increasing the visibility of bicyclists and increasing the sight distance at the intersection. The protected intersection design also provides a physical separation between motorway and bicycle way at intersection. The following pictures Figure-R15 and Figure-R16 will illustrates the above statement.

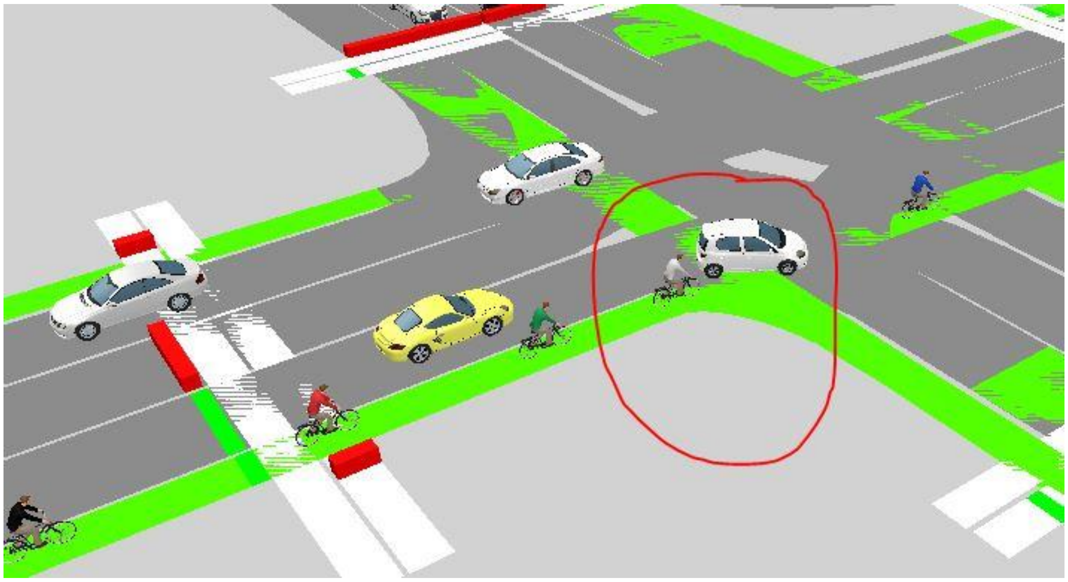


Figure-R15 Right hook issue at the existing signalized intersection

The above picture on Figure-R15 shows the conflicting movement between a right turning motorized vehicle and a bicyclist at the existing intersection.

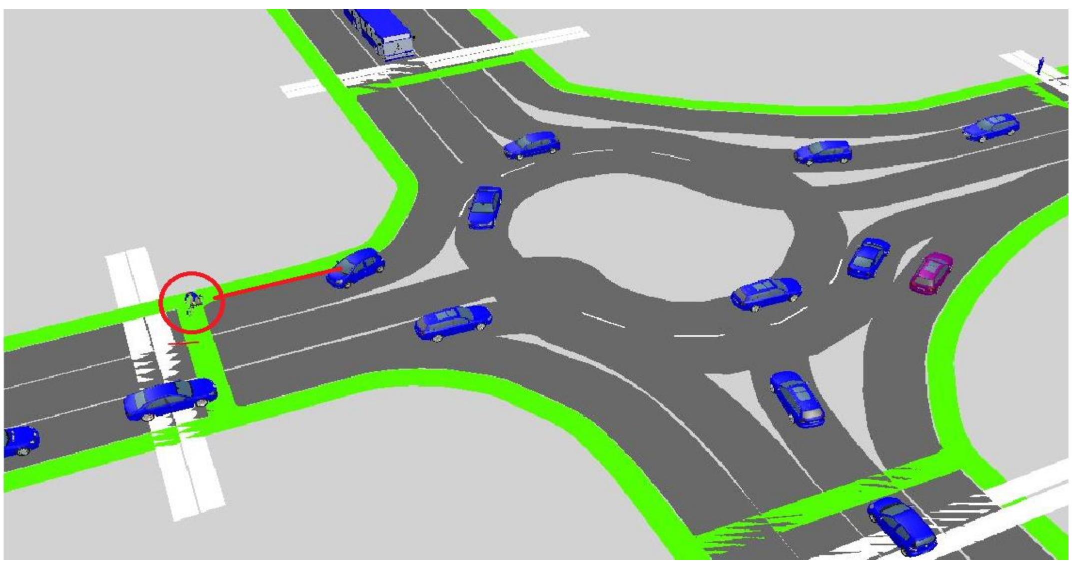


Figure-R16 Right hook issue addressed on the newly adopted protected intersection that is incorporated with a turbo roundabout.

The above picture on Figure-R16 shows the improved sight distance and increased visibility between right turning motorized vehicle and a bicyclist at the protected intersection which is incorporated with turbo roundabout.

6. CONCLUSIONS

From the simulation results, the turbo roundabout has shown a good potential in intersection performance improvement. However, it is debated by different academicians and professional that turbo roundabout is one of the intersection design approach that list accommodate pedestrians and bicyclists. The effort of incorporating the turbo roundabout with the protected intersection design in this project has raised from this point of view. On study site-II we have seen such a design performing well and even better than the existing infrastructure.

In this project we have learned that we can improve the safety features of intersections and intersection approaches without compromising their performance. And we have also seen that a better intersection design can be achieved by combining the best features of different intersection designs. On study site-I, which is the NW 23 Ave & NW Vaughn St Intersection, by transforming the existing signalized intersection into a turbo roundabout: the average delay has reduced by 85.43%; the average speed has increased by 52.5%; and the total travel time has reduced by 31.68%. On study site-II, which is the SE 92nd Ave & SE Flavel St Intersection, by transforming the existing signalized intersection into a protected intersection design: the average delay has reduced by 10.11%; the average speed has increased by 3.09%; and the total travel time has increased by 10.05%. Again on study site-II, by transforming the existing intersection in to the turbo roundabout which is incorporated with a protected intersection: the average delay has reduced by 32.69%; the average speed has increased by 24.72%; and the total travel time has reduced by 26.02%. However, these are just a PTV VISSM simulation results, further studies with different performance parameters and simulation tools should be done in the future since, there are indications from this project's simulation results that we can benefit from adopting this design approaches.

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<http://transportation.ce.gatech.edu/sites/default/files/files/vissim_5.1_tutorial_10132011.pdf >

Appendix A: Simulation results

- **Site-I. NW 23 Ave & NW Vaughn St**

Average delay results:

	Average Delay (Seconds)	
Volume	Existing design	Turbo roundabout
Existing	39.797346	5.795366

	Average Delay (Seconds)	
Volume	Existing design	Turbo roundabout
1.25Existing	74.537719	25.980766
1.5Existing	123.306854	107.62915
1.75Existing	200.916418	196.402891
2Existing	230.208542	234.568078

Average speed results:

	Average speed (Km/hr)	
volume	Existing design	Turbo roundabout
Existing design	23.3252	35.570633

	Average speed (Km/hr)	
volume	Existing design	Turbo roundabout
1.25Existing	17.429191	28.775609
1.5Existing	12.375476	15.146138
1.75Existing	7.89206	9.274269
2Existing	6.749889	7.61148

Total travel time results:

	Total travel time (seconds)	
volume	Existing design	Turbo roundabout
Existing design	86983.65	59426.6

	Total travel time (seconds)	
volume	Existing design	Turbo roundabout
1.25Existing	144052.1	91456.75
1.5Existing	233255.7	195888.65
1.75Existing	358104.85	332116.6
2Existing	404841.3	399789.55

- **Site-II. SE 92nd Ave & SE Flavel St**

Average delay results:

	Average Delay (Seconds)		
Volume	Existing design	Protected	Protected with turbo
Existing	153.447542	137.922428	103.273864

	Average Delay (Seconds)		
Volume	Existing design	Protected	Protected with turbo
1.25Existing	126.399393	118.897223	88.3596
1.5Existing	129.155217	117.569842	96.492976
1.75Existing	129.77168	116.855555	116.791376
2Existing	134.761148	116.805584	124.858677

Average speed results:

	Average speed (Km/hr)		
volume	Existing design	Protected	Protected with turbo
Existing	12.268398	12.647584	15.301091

	Average speed (Km/hr)		
Volume	Existing design	Protected	Protected with turbo
1.25Existing	12.338273	12.43304	15.408553
1.5Existing	12.104764	12.570516	14.438092
1.75Existing	12.028336	12.72692	12.488717
2Existing	11.469521	12.716088	11.78535

Total travel time results:

	Total travel time (seconds)		
Volume	Existing design	Protected	Protected with turbo
Existing	1221205.8	1343973.05	903485.3499

	Total travel time (seconds)		
Volume	Existing design	Protected	Protected with turbo
1.25Existing	112234.55	127669.15	84024.8
1.5Existing	116277.15	129523.35	94461.4
1.75Existing	120225.3	131791.3	113137.5
2Existing	127914.7	134708.35	120762.7

Appendix B: Available data and data used

- **Study site-I: NW 23 Ave & NW Vaughn St**

City of Portland
Office of Transportation
1120 SW 5th Ave, Rm 800
Portland, OR 97204

O'cast by: CDB For: Zhou

NW 23RD AVE/VAUGHN ST/I405 NB EX

File Name : 100407TOB
Site Code : 00000000
Start Date : 4/7/2010
Page No : 1

Groups Printed- VEHS PEDS

	NW 23RD AVE Southbound					I-405 NB EX Southwestbound						NW VAUGHN ST Westbound	
Start Time	Left	Thru	Right	Peds	App. Total	U-Turn	Left	Thru	Right	Peds	App. Total	Peds	App. Total
10:00	23	6	7	0	36	43	87	118	28	0	276	0	0
10:15	34	17	5	1	56	41	77	120	39	0	277	0	0
10:30	28	15	6	1	49	51	77	106	36	0	270	0	0
10:45	37	13	11	0	61	48	68	132	35	0	283	0	0
Total	122	51	29	2	202	183	309	476	138	0	1106	0	0
11:00	24	15	10	4	49	44	88	116	31	0	279	0	0
11:15	26	19	2	2	47	39	51	126	47	0	263	0	0
11:30	32	14	6	2	52	39	71	120	38	0	268	0	0
11:45	38	11	7	0	56	44	96	114	38	0	292	0	0
Total	120	59	25	8	204	166	306	476	154	0	1102	0	0
Grand Total	242	110	54	10	406	349	615	952	292	0	2208	0	0
Apprch %	59.6	27.1	13.3			15.8	27.9	43.1	13.2	0		0	
Total %	5	2.3	1.1		8.4	7.2	12.7	19.6	6	0	45.5	0	0

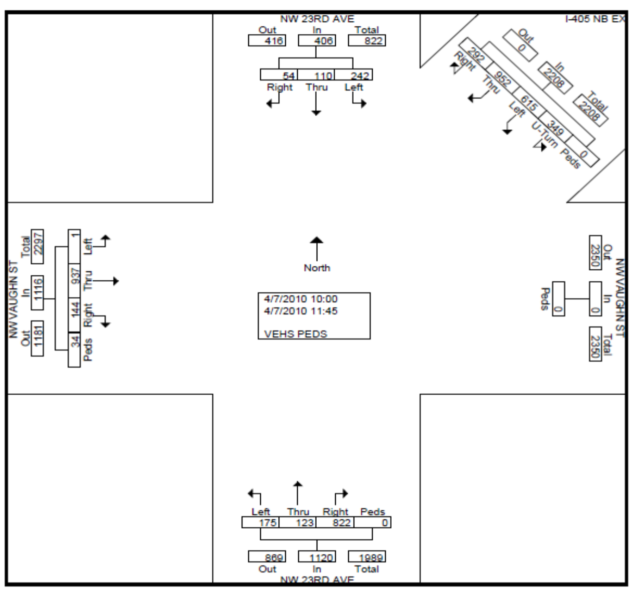
	NW 23RD AVE Northbound					NW VAUGHN ST Eastbound							
Start Time	Left	Thru	Right	Peds	App. Total	Left	Thru	Right	Peds	App. Total	Exclu. Total	Inclu. Total	Int. Total
10:00	8	10	88	0	106	0	107	12	4	123	0	541	541
10:15	24	15	130	0	169	0	96	10	0	106	1	608	609
10:30	20	13	95	0	128	0	112	21	1	134	1	581	582
10:45	22	22	89	0	133	0	128	18	7	153	0	630	630
Total	74	60	402	0	536	0	443	61	12	516	2	2360	2362
11:00	23	14	102	0	139	0	135	21	3	159	4	626	630
11:15	22	17	111	0	150	0	131	17	5	153	2	613	615
11:30	31	12	93	0	136	1	115	28	14	158	2	614	616
11:45	25	20	114	0	159	0	113	17	0	130	0	637	637
Total	101	63	420	0	584	1	494	83	22	600	8	2490	2498
Grand Total	175	123	822	0	1120	1	937	144	34	1116	10	4850	4860
Apprch %	15.6	11	73.4	0		0.1	84	12.9	3				
Total %	3.6	2.5	16.9	0	23.1	0	19.3	3	0.7	23	0.2	99.8	

City of Portland
Office of Transportation
1120 SW 5th Ave, Rm 800
Portland, OR 97204

O'cast by: CDB For: Zhou

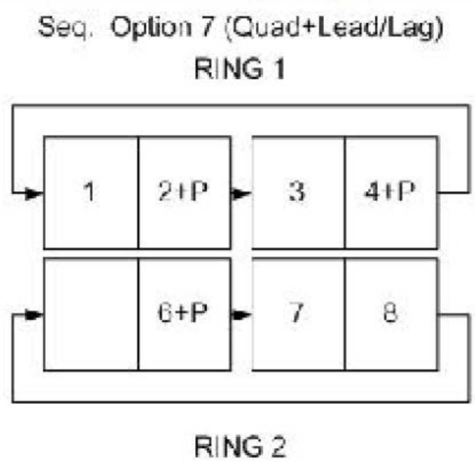
NW 23RD AVE/VAUGHN ST/I405 NB EX

File Name : 100407TOB
Site Code : 00000000
Start Date : 4/7/2010
Page No : 2



Signal timing data:

City of Portland			
Thursday, June 26, 2008 14:11			
Intersection Name	*1 - 3048--NW 23rd*	**Local ID**	*1*
Intersection Telephone Number			
System Name	*2 - NW Vaughn*	**System ID**	*2*
Controller Type	*Voyage - C1-C11 - MSA-C*		
Controller Serial Number		**Installation Date**	
Programmed by		**Programmed Date**	
Graphic Map Background		**Phase Rotation Diagram**	



Control Data

Controller Function and Timing (next/2/1, next/2/2)

Security, Sequence, Initialization

Security Code	****	0 = disabled, or 1000-9999
Sequence	*7*	0 = sequential, 1 = quad left turn, 2-6 = special A-E, 7 = lead lag

Lead Lag (next/2/2/3)			
Phases 1 - 2	**Phases 3 - 4**	**Phases 5 - 6**	**Phases 7 - 8**
2	*2*	*2*	*2*
0 = no reversal, 1 = reversal, 2 = by coord plan or clock			

Inialization and Flash (next/2/2/5)

	Initialization	**Flash Entry**	**Flash Exit**	
Ring 1 Phase	*1*	*0*	*2*	phase 1-8
Ring 2 Phase	*0*	*0*	*6*	phase 1-8
Interval	*0*	*0*	*2*	0 = red, 1 = yellow, 2 = green

Power up Flash	*0.0*	0.0 - 25.5 seconds	**First All Red**	*8.0*	0.0 - 25.5 seconds

Soft Flash (next/2/2/5)

Phase	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	0 = dark, 1=flash yel WIG, 2 = flash yel WAG, 3 = flash red WIG, 4 = flash red WAG				
	3	*4*	*3*	*4*	*3*	*4*	*3*	*4*					
Overlap	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	
	3	*4*	*3*	*4*	*3*	*4*	*3*	*4*	*3*	*4*	*3*	*4*	same as phase
Internal Logic Output	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	0 = normal, 1 = dark, 2 = flash WIG

Per Phase Functions (next/2/2/3, next/2/2/1)

	1	2	3	4	5	6	7	8	
Phases Used	X	X	X	X		X	X	X	X = on
Restricted Phases									
Yellow Lock		X	X			X		X	
Min Recall									
Max Recall									
Ped Recall									
Red Lock									
Max Out Recall Inhibit	X		X	X			X	X	
Soft Recall									
Free Walk Rest									
Conditional Ped									
Disable Inhibit Max Termination									

Dual Entry (next/2/2/7/3)

Mode	1	0 = off, 1 = on, 2 = Not Used, 3 = by coord plan, 4 = by time clock circuit 61

Dual Entry Phase -->	1	2	3	4	5	6	7	8	
Phase	0	6	0	8	0	2	0	4	0 = none, 1-8 = phase 1-8

Conditional Service, Five Section Head

Conditional Service (next/2/2/7/3)			5 Section Head Logic (next/2/2/7/4)						
			X Omits Y		Anti-Trap			Yellow Blanking LT	
	Mode	CS Max Time	X : Y		Trap Protected Phase		Next Phase	Phase	
Phase 1	0	0	6 : 1	0	1		< (5)	1	
Phase 3	0	0	8 : 3	0	3		< (7)	3	
Phase 5	0	0	2 : 5	0	5		< (1)	5	
Phase 7	0	0	4 : 7	0	7		< (3)	7	
0 = off, 1 = C.S.On. 2 = C.S. on by TOD circuit 57, 3 = N/A, 4 = C.S. and C.R. On, 5 = C.R. on by TOD circuit 57.			0=off, 1=side call, 2=no side call		X = On				

Phase Times (next/2/2/2, next/2/2/7/6)									
	1	2	3	4	5	6	7	8	
Movement	WBLT	EB	NBLT	SB		WB	SBLT	NB	
Minimum Green	3	8	3	5	0	10	3	5	0 - 255 sec.
Passage	2.5	1.6	0.5	1.0	0.0	3.1	0.5	1.0	0.0 - 25.5 sec.
Yellow	3.6	3.6	3.0	3.2	0.0	5.0	3.0	3.6	0.0 - 25.5 sec.
Red Clearance	1.0	1.0	0.0	1.0	0.0	1.0	1.0	1.0	0.0 - 25.5 sec. or 0 - 255 sec.
Max 1	35	35	16	21	0	35	22	30	0 - 255 sec
Max 2	45	35	16	21	0	35	22	30	0 - 255 sec
Walk	0	6	0	6	0	6	0	0	0 - 255 sec
Ped Clear	0	18	0	14	0	14	0	0	0 - 255 sec
Seconds Per Actuation	4.0	1.2	1.8	1.9	0.0	1.2	1.8	1.9	0.0 - 25.5 sec.
Time Before Reduction	15	0	0	0	0	0	0	0	0 - 255 sec
Time to Reduce	10	0	0	0	0	0	0	0	0 - 255 sec
Minimum Gap	1.0	2.7	0.0	0.0	0.0	2.7	0.0	1.0	0.0 - 25.5 sec.
Max Variable Initial	10	12	8	8	0	20	8	8	0 - 255 sec
Max Extend	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 25.5 sec.
Auto Max	0	0	0	0	0	0	0	0	0 - 255 sec
Inhibit Min Yellow					X				X = On
Red Decimal Off									X = On

Other Controller Functions (next/2/2/7)									
Phase -->	1	2	3	4	5	6	7	8	
Inhibit Simultaneous Gap Out	X		X	X			X	X	X = On
Last Car Passage	2	0 = recall phase, 1 = last car passage, 2 = NOT recall - Not last car passage							
Red Revert (+2seconds)	0.0	0 - 25.5 sec.							
Auto Ped Clear		X = On							
Flashing Don't Walk Thru Yellow		X = On							
Soft Recall Delay	0.0	0 - 25.5 sec.							
Change Sequence		X = On (After a download with a power on - off cycle)							
Phase -->	1	2	3	4	5	6	7	8	
Red Clear Extension Detector	0	0	0	0	0	0	0	0	0 = none 1 - 32 = detector 1 - 32
Red Clear Extension Red Time	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 - 25.5 sec.

- **Site-II. SE 92nd Ave & SE Flavel St**

Due to lack of adequate available data, the traffic data on this study site is adopted from the neighboring intersection.” SE 82ND AVE @ SE FLAVEL ST”.

CITY OF PORTLAND

Bureau of Transportation
1120 SW 5th Ave RM 800
503-823-5211

Collected by:
ALL TRAFFIC DATA

SE 82ND AVE @ SE FLAVEL ST

File Name : 060111TP_ATD7
Site Code : 00000000
Start Date : 1/11/2006
Page No : 1

Groups Printed- VEHICLES PEDS

	SE 82ND AVE From North					SE FLAVEL ST From East					SE 82ND AVE From South					SE FLAVEL ST From West							
Start Time	Rght	Thru	Left	Peds	App. Total	Rght	Thru	Left	Peds	App. Total	Rght	Thru	Left	Peds	App. Total	Rght	Thru	Left	Peds	App. Total	Exclu. Total	Inclu. Total	Int. Total
16:00	13	202	11	5	226	3	31	16	11	50	19	233	15	9	267	16	41	14	5	71	30	614	644
16:15	9	161	4	6	174	6	27	31	2	64	26	236	25	9	287	29	38	12	6	79	23	604	627
16:30	10	219	16	6	245	7	44	27	2	78	29	213	23	1	265	18	48	14	8	80	17	668	685
16:45	5	227	9	3	241	19	22	27	6	68	28	220	20	0	268	14	62	11	3	87	12	664	676
Total	37	809	40	20	886	35	124	101	21	260	102	902	83	19	1087	77	189	51	22	317	82	2550	2632
17:00	6	199	11	11	216	10	52	22	6	84	30	229	14	0	273	21	57	15	6	93	23	666	689
17:15	8	225	15	2	248	8	34	18	2	60	54	237	23	1	314	17	57	15	2	89	7	711	718
17:30	18	198	11	1	227	7	39	13	5	59	21	173	17	2	211	15	51	11	4	77	12	574	586
17:45	7	178	13	2	198	17	43	26	1	86	18	206	24	6	248	23	59	11	7	93	16	625	641
Total	39	800	50	16	889	42	168	79	14	289	123	845	78	9	1046	76	224	52	19	352	58	2576	2634
Grand Total	76	1609	90	36	1775	77	292	180	35	549	225	1747	161	28	2133	153	413	103	41	669	140	5126	5266
Apprch %	4.3	90.6	5.1			14	53.2	32.8			10.5	81.9	7.5			22.9	61.7	15.4					
Total %	1.5	31.4	1.8		34.6	1.5	5.7	3.5		10.7	4.4	34.1	3.1		41.6	3	8.1	2		13.1	2.7	97.3	

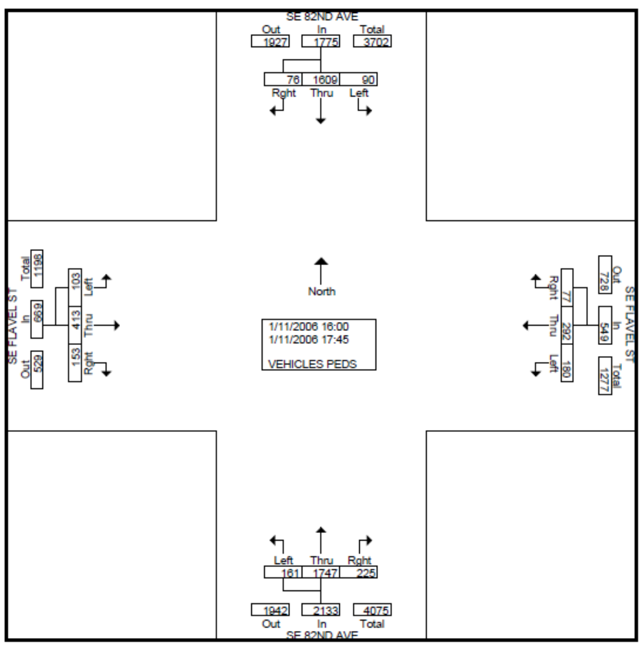
CITY OF PORTLAND

Bureau of Transportation
1120 SW 5th Ave RM 800
503-823-5211

Collected by:
ALL TRAFFIC DATA

SE 82ND AVE @ SE FLAVEL ST

File Name : 060111TP_ATD7
Site Code : 00000000
Start Date : 1/11/2006
Page No : 2



CITY OF PORTLAND

Bureau of Transportation
1120 SW 5th Ave RM 800
503-823-5211

Collected by:
ALL TRAFFIC DATA

SE 82ND AVE @ SE FLAVEL ST

File Name : 060111TP_ATD7
Site Code : 00000000
Start Date : 1/11/2006
Page No : 3

	SE 82ND AVE From North				SE FLAVEL ST From East				SE 82ND AVE From South				SE FLAVEL ST From West				
Start Time	Rght	Thru	Left	App. Total	Rght	Thru	Left	App. Total	Rght	Thru	Left	App. Total	Rght	Thru	Left	App. Total	Int. Total
Peak Hour Analysis From 16:00 to 17:45 - Peak 1 of 1																	
Peak Hour for Entire Intersection Begins at 16:30																	
16:30	10	219	16	245	7	44	27	78	29	213	23	265	18	48	14	80	668
16:45	5	227	9	241	19	22	27	68	28	220	20	268	14	62	11	87	664
17:00	6	199	11	216	10	52	22	84	30	229	14	273	21	57	15	93	666
17:15	8	225	15	248	8	34	18	60	54	237	23	314	17	57	15	89	711
Total Volume	29	870	51	950	44	152	94	290	141	899	80	1120	70	224	55	349	2709
% App. Total	3.1	91.6	5.4		15.2	52.4	32.4		12.6	80.3	7.1		20.1	64.2	15.8		
PHF	.725	.958	.797	.958	.579	.731	.870	.863	.653	.948	.870	.892	.833	.903	.917	.938	.953

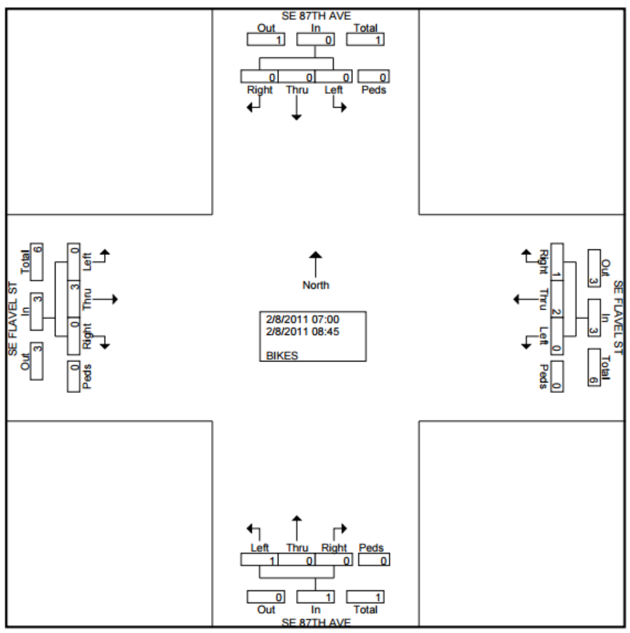
CITY OF PORTLAND

Bureau of Transportation
1120 SW 5th Ave RM 800
503-823-5211

By: RC For: Batson

SE 87TH AVE @ SE FLAVEL ST

File Name : 110208TAC
Site Code : 00000000
Start Date : 2/8/2011
Page No : 2



This bicycle volume is too small to evaluate or study any kind of intersection designs. So, for in this project 25 bikes/hr is used for all approaching legs.

Signal timing data: due to lack of adequate available data, a signal timing similar to study site-I is used for this study site.