Traffic and Environmental Impact Assessment of Partial Cloverleaf Interchange Junctions

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Abstract

An efficient working transportation system is necessary for every decent sized city. However the current infrastructure does not provide the people with enough possibilities to travel. The lack of enough infrastructure results in congestion which in turn leads to increased travel times, increased fuel consumption and decreased driver experience.

This study investigated a case study from Boca Raton, Florida where the transportation network does not perform very well. A model has been made using CORSIM and this model is calibrated with the current traffic counts and turning movements. Different alternatives have been designed and implemented and have been simulated multiple time with increasing traffic volumes to forecast future scenarios.

Finally an environmental assessment has been made to determine the effects of different alternatives on fuel consumption and air pollution. Nowadays it’s rather important to understand the effects on an environmental level because a future transportation system can only work if it’s a sustainable one that is not only user-friendly but eco-friendly as well.

For a low traffic volumes scenario the best alternative was the full cloverleaf configuration. This design decreases travel time by 10%. It loses ground however when traffic volumes increase. For medium traffic volumes the increase in lanes causes a reduction in travel time of almost 30%. These alternatives do not perform as good as the Turbo T-design in the high traffic volume scenario. The Turbo T-design combined with various pocket adjustments decreased travel time by over 20%. This design also decreases fuel consumption by 20% with these traffic volumes showing that it is a environmental sustainable solution.

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1. Introduction

Congestion is one of the single largest threats to the economy of the US. The economic impact of congestion is costing the US approximately $200 billion a year. Based on current trends, highway congestion is on its way toward becoming a major problem for existing traffic infrastructure in medium-sized cities within the next 10 years. Many heavily congested highways are frequently prone to and cause severe traffic flow problems. These traffic flow problems include loss of time, increased fuel consumption and decreased driving experience. Of course the congestion is not confined to the highway itself. Spillback often occurs on the off-ramps and on to the connecting arterial.

Interchanges are an important instrument to improve traffic flow on highways and surrounding arterials. A lot of different configurations are invented with each serving a different purpose or goal. Since a lot of interchanges were designed in the past for lower traffic volumes, interchanges are often a source of congestion and related problems.

The specific objectives of this study were as follows:

1. To examine the literature and learn the results of past studies on interchange characteristics and comparisons.

2. To analyze the specific problems regarding congestion on the interchanges along the I-95.

3. To forecast future problems on these interchanges by simulating different scenarios.

4. To improve the design of the interchange in different ways, such as the optimization of the surrounding traffic lights, minor design changes and a total design change.

5. To assess the impact a new design has on the environment by comparing environmental output parameters

In chapter 2 a literature review is performed on comparable studies and projects regarding congestion problems and interchanges. In chapter 3 the simulation software is discussed and the case study is presented. The analysis and results of all the simulation runs are given in chapter 4. The environmental assessment is discussed in chapter 5. Conclusions are presented in chapter 5. These include recommendations for further research as well.

2. Literature review

The first step in this study was to conduct a literature review on congestion problems on interchanges and especially regarding the partial cloverleaf configuration. First a brief introduction of the different interchanges is given. The problems with carrying capacity and weaving areas are addressed in section 2.2 and 2.3. Since changing the geometric layout of the T-junction is part of one of the alternatives, this topic is addressed in section 2.4. A partial cloverleaf is often used when a freeway intersects with an arterial. Congestions problems on the off-ramp can result in congestion on the freeway if the geometry doesn't allow for a buffer. These issues are covered in section 2.5.

2.1 Introduction

The American Association of State Highway and Transportation Officials [AASHTO[1], 1990] has identified several viable interchange types that can be used on interchanges. In figure 1 the different configurations are shown.

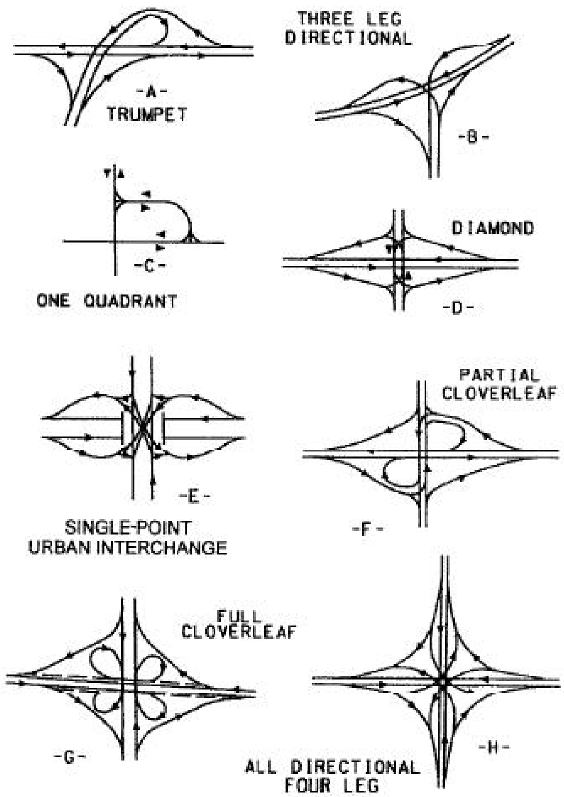

Figure 1: Layout of interchange types [AASHTO, 1990]

These interchanges can be categorized on certain parameters, such as their functional category, the type of intersecting facility and the number of legs at the interchange. Table 1: Interchange classification [Bonneson, Zimmerman and Jacobson, 2003] presents an overview of the categorized interchanges.

Table 1: Interchange classification [Bonneson, Zimmerman and Jacobson, 2003]

Functional Category	Type of Intersecting Facility	Interchange Legs	
		Three-leg Interchange	**Four-leg Interchange**
Service Interchange	Local Collector Arterial	Trumpet Diamond (Directional occasionally used)	One quadrant Diamond SPUI Partial Cloverleaf (parclo)
System Interchange	Freeway	Directional (Trumpet occasionally used)	Full Cloverleaf (rarely used today) All directional without loops All directional with loops

A survey by Garber and Fontaine[3] (1999) showed that diamond interchanges are used by far he most. SPUI's are hardly used as an interchange, which could be explained by the fact that it is a relative new way of designing an interchange.

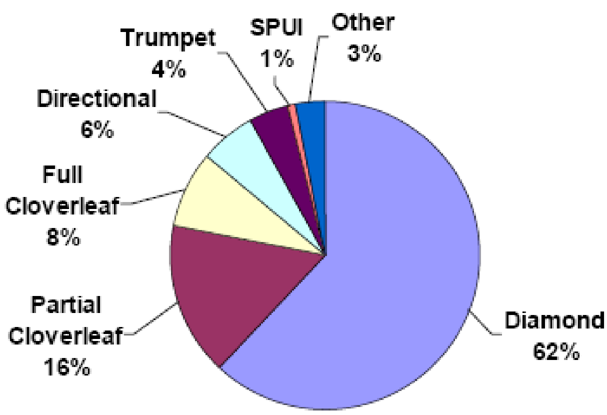

Figure 2: Distribution of interchange types in the US [Garber & Fontaine, 1999]

Partial cloverleaf configurations accounts for 16% of all the interchanges, twice as much as the full cloverleaf. The partial cloverleaf interchange is similar to a full cloverleaf, except that loop ramps are present in three quadrants or less. In figure 3 the partial cloverleaf interchange is shown. According the Garber & Fontaine (1999) partial cloverleaves are generally used where the right of way is not available in a quadrant or when the traffic making a particular movement is much smaller when compared to other movements.

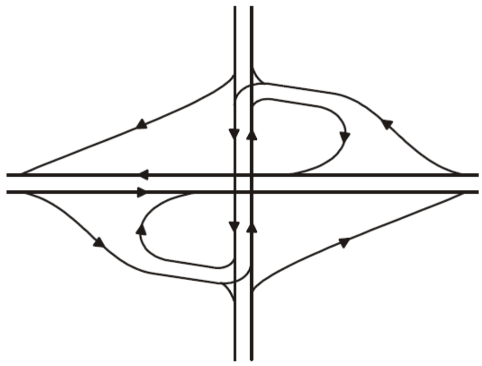

Figure 3: Partial cloverleaf interchange [Garber & Fontaine, 1999]

2.2 *Carrying capacity*

In order to increase traffic carrying capacity of an interchange the same survey of Garber & Fontaine (1999) showed that either a SPUI or a directional interchange are able increase capacity compared to the partial cloverleaf. The full cloverleaf configuration was able to handle the same amount of traffic as the partial cloverleaf.

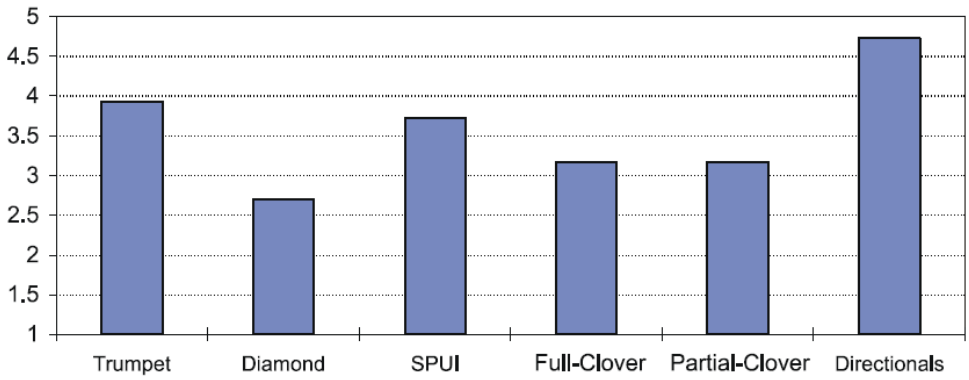

Figure 4: Ability to increase traffic carrying capacity [Garber & Fontaine, 1999]

A study by Milam & Choa[4] (1999) was performed to compare traffic operations of an existing full cloverleaf interchange with that of the partial cloverleaf configuration. The study was able to effectively demonstrate that the partial cloverleaf interchange configuration would improve system-wide traffic operations in the interchange corridor. It would increase average travel speeds and reduce delay and queuing, and increase the total number of vehicles served in nearly all cases. Figure 4 represents the outcome of a survey where engineers from different U.S. states had to rank the ability to increase traffic carrying capacity for different design on a scale of 1 to 5.

The following overview table was presented in the study of Garber & Fontaine (1999). These results provide guidelines for the selection process of interchanges. The study also recognizes the need for further transport studies to specific locations.

Table 2: Summary of interchange characteristics [Garber & Fontaine, 1999]

Interchange type	**Right of way required**	**Capacity**	**Cost**	**Notes**
Diamond	Low	Low	Low	Simplest interchange
SPUI	Low	Moderate	Low-moderate	Designed for urban use, problems accommodating pedestrians
Partial cloverleaf	Moderate	Moderate	Moderate	Loops should be arranged to serve largest left turning movements
Full cloverleaf	High	Moderate	High	Weaving areas are safety and capacity concerns
Trumpet	Moderate-high	Moderate	Moderate-high	Should be used when 3 legs are present
Directional	Very high	High	Very high	Preferred interchange for freeway to freeway connections

2.3 Weaving

One of the biggest problems interchange design faces is the implementation of weaving areas. Weaving is the undesirable situation where traffic must cross paths with each other within a limited distance to merge with traffic on the through lane. Weaving creates both safety and capacity problems. The impact of the weaving section depends on the spacing between interchanges, the traffic volumes and speeds of the weaving and the non-weaving movements and the number and type of lane changes [Texas Highway Operations Manual[5], 1992].

According to Garber & Fontaine (1999) weaving areas are the critical interchange component for partial and full cloverleaves, in terms of LOS. Operations at weaving areas degrade to LOS E/F as the weaving volume approaches 1000 vehicles per hour (vph). This indicates that full cloverleaves and partial cloverleaves are not suitable for roads with large weaving volumes. They don’t recommend the use of a full cloverleaf configuration without collector distributor roads.

2.4 T-junctions

3-way junction is a type of road junction with three arms. A Y-junction generally has 3 arms of equal size. A T-junction also has 3 arms, but one of the arms is generally a minor road connecting to a larger road. Some T-junctions are controlled by traffic lights but others rely upon drivers to obey right-of-way rules.

An experiment was done in Illinois, United States to allow going straight on red (like a right turn on red) when approaching a T-junction on the main road, with the intersecting road on the left. It was a failure because of the obvious problems with traffic safety and capacity when traffic volumes increase.

However, at some T-junctions where the main road includes at least two lanes on the side away from the intersecting road, the rightmost lane is given the right of way to proceed straight through the intersection at all times, denoted by a green arrow signal if a traffic light is installed at the intersection. In such cases, often that lane is also specially delimited with pavement markings or other lane separation devices, to keep left-turning traffic on the intersecting road from colliding with traffic proceeding through the intersection on the main road.

2.5 Queue spillback

The rapid growth of population and economic activities in many states has caused queues on the freeways off-ramps to spill back onto the freeway mainline. In 'Toolbox for Reducing Queues at Freeway Off-ramps' (Hagen, Lin & Fabregas[6], d.u.) the authors performed a research into the major causes for this event and different treatment methods. In table 3 the different causes are given and in figure 5 the corresponding frequencies are presented.

Table 3: Causes for queue spillback [Hagen, Lin and Fabregas, d.u.]

Ranked ID	Major causes of queue spillback
1	Capacity problems at the off-ramp terminal intersection
2	Not enough storage space at the off-ramps
3	Lane blockage problem of downstream intersections on the local artery
4	Inadequate signal spacing on the artery near the freeway off-ramp
5	Not enough green time allocated to off-ramps at the terminal intersection
6	Inefficient operation of off-ramp lane assignments at the terminal intersections
7	Frequent signal pre-emption at the off-ramp terminal intersection
8	Other

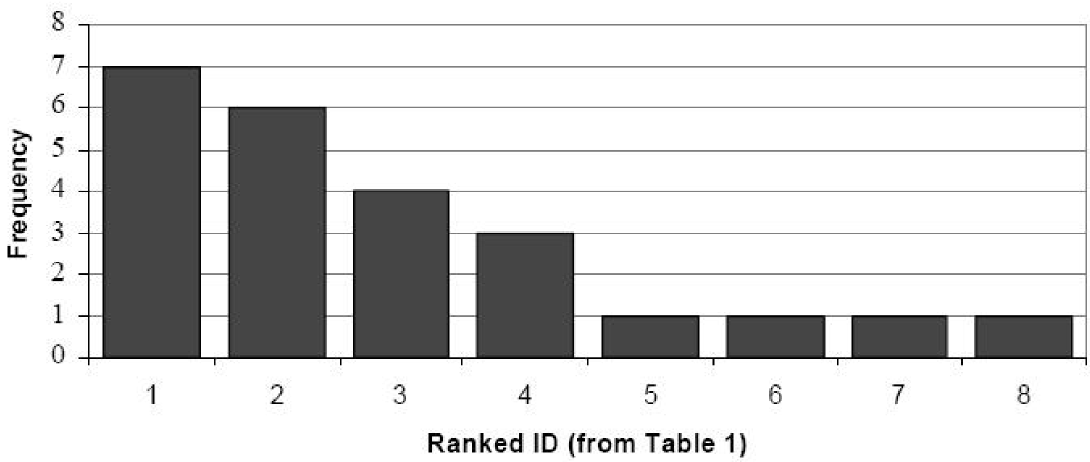

Figure 5: Frequency of causes for queue spillback [Hagen, Lin and Fabregas, d.u.]

The authors divide the most common and effective measurements in either the short-term or long-term category. Short-term measurements include for instance the optimization of traffic signals on the off-ramp terminal and along the arterial road as well. Geometric changes as adding lanes or lengthening them are suggested too. As a long-term solution major geometric changes are presented.

2.6 Summary

This section will include the findings of the literature review which are particularly useful for this study. One of the major conclusions that can be drawn from the literature review is that a full cloverleaf configuration does not increase the capacity of the traffic network. Weavings occurs on the arterial road as well and this will deteriorate traffic flow to Level of Serve E/F. These problems with weaving will occur with any design where the weaving volumes are greater than 1.000 vph.

Another conclusion can be drawn that there are possibilities to upgrade T-junctions. Typically these are controlled by lights or traffic rules but more free flowing options are available and might posses some problem solving content. Off-ramps of freeways are usually the minor road on a T-junction where the major road is the arterial road. Increasing traffic flow in this situation will probably influence the performance in a positive manner.

Finally there are several causes for queue spillback. Most of these causes are concerned with the capacity of either the turning movements or the storage space. Also the signal timing is a significant reason spillback occurs. These causes are identified in a study to queue spillback at freeway off-ramps. However these causes are major contributors to decreased performance for smaller intersections as well.

3. Simulation – case study

In this chapter the case study will be introduced.

3.1 CORSIM

CORSIM is chosen as the simulation tool for this particular study. CORSIM is a combination of the arterial model NETSIM and the freeway model FRESIM. The combination of the models allows users to conduct system-level analyses of networks including both freeways and arterials. CORSIM can be used for networks containing only freeway links or only arterial links, or combinations of the two; however, in reality, performance of one portion of the network often affects the other and necessitates a combined analysis. CORSIM is a microscopic simulation model that tracks the position and movement of each vehicle in the network once each second. The movement of vehicles is based on car following theory and random effects caused by differences in driver behavior and vehicle performance.

3.2 Model development

To develop a model of the traffic network detailed geometrics are required. The main focus is on the partial cloverleaf interchange between Glades Road and the I-95 freeway. The limits of the network extend from just west from St. Andrews Blvd and just east from NW 13th St. The freeway will be modeled approximately 2 miles north and 2 miles south of the interchange, not including any other interchanges. See figure 6 and 7 for detailed pictures of the area.

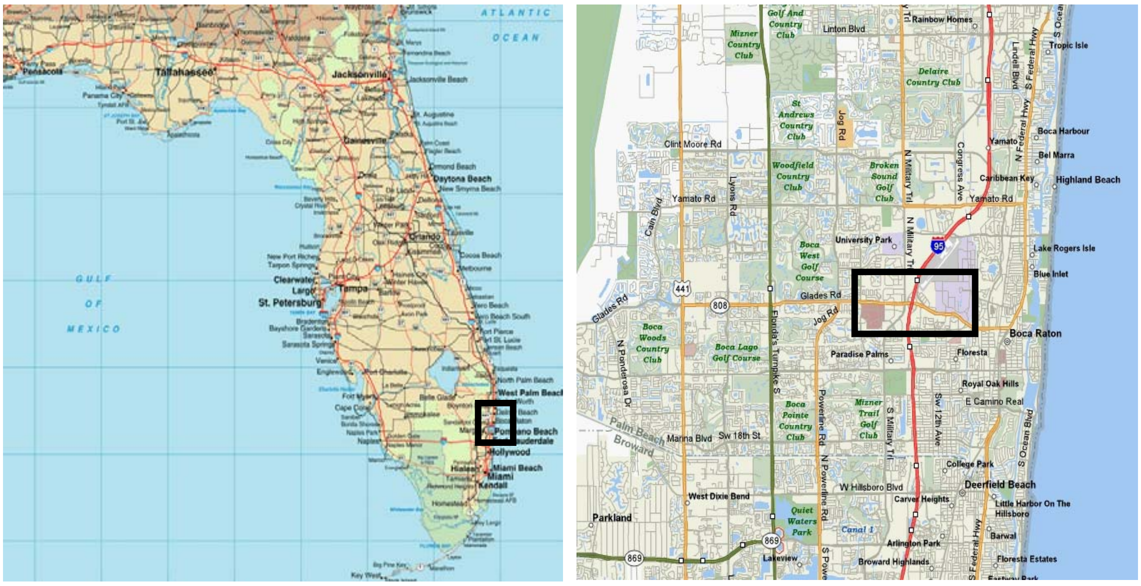

Figure 6: Map of Florida (left) and map of Boca Raton (right)

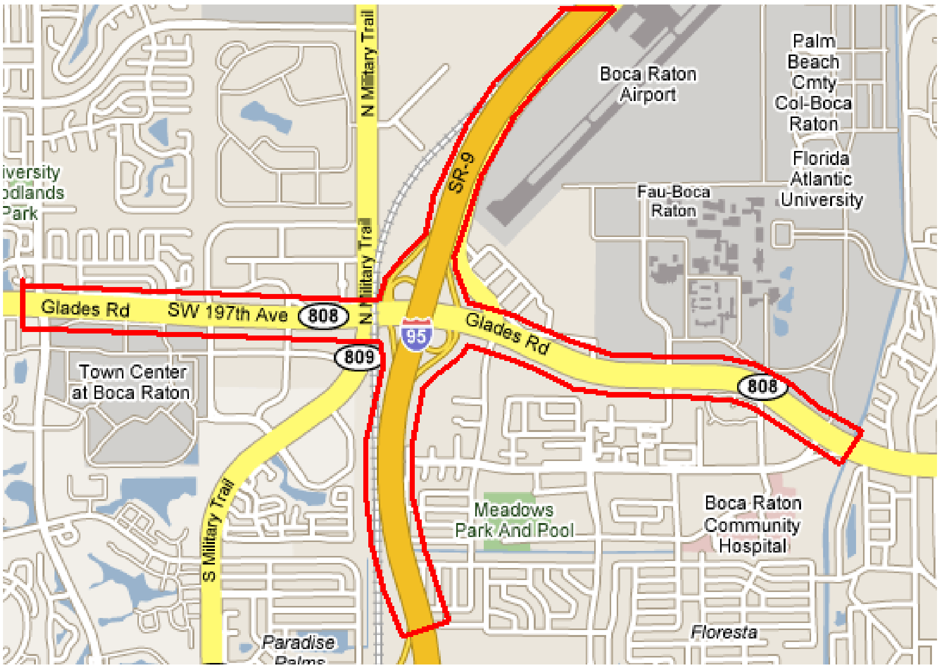

Figure 7: Geographical limits of research

Figure 6 shows the map of Florida and highlights the location of Boca Raton. The right picture also shows the map of Boca Raton. The geographical limits of the research are shown in figure 7.

Background layers from Google Earth[7] have been used to exactly match the geometry of the traffic network. In addition to the satellite images from Google Earth, extensive field research has taken place to accommodate for the recent changes to the geometry of different junctions.

The arterial road (Glades Road) has 9 semi-actuated controlled junctions. The signal phasing plans were obtained from the Municipal Services Department from the City of Boca Raton.

3.3 Data acquirements

As mentioned before Google Earth has been used to replicate to geometric conditions of the traffic network. However traffic counts are necessary as well to produce a working model. To accomplish this goal two datasets of traffic counts were acquired from Miller Consulting, a division of TranSystems Corporation. The first dataset specified the traffic counts on the on- and off-ramps of the I-95 on Glades Road. The second dataset introduced the turning and though movements along the Glades Road arterial. These datasets had to be combined since they both did not cover the entire network. Since these datasets were taken on two different dates traffic volumes did not match exactly. Nonetheless a complete traffic flow chart could be generated which showed all the turning movements on each particular intersection.

3.4 Model calibration and validation

The CORSIM model was calibrated to 2006 a.m. peak hour conditions. The validation of the model consisted of comparing output parameters with field observations and existing traffic counts. In their paper Oketch and Carrick[8] (2005) describe the process of calibrating and validating a traffic network based on model results and field data. For this particular research of a sub-urban network in the city of Niagara Falls the Paramics micro-simulation model is used. For the case study Glades Road / I-95 a different model is used (CORSIM) but the same methodology applies.

In order to validate the model the GEH statistic is defined. This GEH value is a modified chi-squared statistic that incorporates both relative and absolute differences, in comparison of modeled and observed volumes. Generally the GEH static should be used in comparing hourly traffic volumes only. It is represented by the equation as below:

Equation 1: GEH value as a function of M [vph] and O [vph] [Oketch and Carrick, 2005]

$$GEH = \sqrt{\frac{(M-O)^2}{0 \cdot 5 * (M+O)}}$$

Where:

M:	Simulated flows	(vph)
O:	Observed flows	(vph)

Various GEH values give an indication of a goodness-of-fit as outlined below:

GEH < 5	Flows may be considered a good flow
5 < GEH < 10	Flows may require further investigation
10 < GEH	Flows cannot be considered to be a good fit

Once the model has been calibrated for the existing situation it can then be used to model future scenarios. Since micro-simulation is a stochastic process a complete experiment consists of 8 simulation runs with random seeds and parameters. To compare the values an average of these 8 runs is taken. According to Oketch and Carrick (2005) a general rule for validation is that 80% of all link locations, approach and turning movements have a GEH value of 5.0 or less and that no significant link, intersection approach or turning movement flows has a GEH value greater than 10.0.

Table 4: Screen line validation for A.M. peak using GEH values

Screen line location	Direction	A.M. (08.00 – 10.00)		
		Observed flow [vph]	**Modeled flow [vph]**	**GEH [-]**
West of St. Andrews Blvd	EB	2996	2800	3.6
	WB	1300	1395	2.6
West of Butts Rd	EB	2936	3082	2.7
	WB	1195	1258	1.8
West of Commercial Trail	EB	2313	2525	4.3
	WB	1241	1340	2.8
West of Airport Rd	EB	2793	3053	4.8
	WB	1887	1696	4.5
West of Broward Ave	EB	2608	2514	1.9
	WB	1681	1485	4.9
West of NW 13th St	EB	1916	1778	3.2
	WB	1800	1970	3.9
I-95 NB Off-ramp	EB	960	934	0.8
	WB	640	650	0.4
I-95 SB Off-ramp	EB	720	741	0.8
	WB	480	520	1.8
I-95 SB On-ramp	EB	600	627	1.1
I-95 NB On-ramp	EB	600	511	3.8
I-95 SB On-ramp	WB	400	480	3.8
I-95 NB On-ramp	WB	400	336	3.3

From the above table we can conclude that every screen line location along the arterial road is correctly modeled since the GEH values are less than 5.0. Hence the traffic flows may be considered a good fit for the A.M. peak.

4. Analysis, results, discussion

In this chapter the analysis of the different simulation runs and alternatives will be described. In section 4.1 the current traffic performance will be shown using a variety of traffic parameters. In section 4.2 an analysis is made for different traffic volumes to forecast future scenarios. In sections 4.3 till section 4.10 different solutions are designed to improve traffic flow. Each alternative is analyzed using three different traffic parameters.

4.1 Current situation

Glades Road is one of the major arterial roads in Boca Raton, Florida. Many commuters have to experience significant amount of travel delay while driving through the Glades Road and I-95 interchange. Key factors to this congestion are the campus of the Florida Atlantic University, nearby shops and restaurants, the Towncenter Mall and the alignment of the Florida Turnpike with respect to Glades Road.

Table 5: Network wide traffic parameters of A.M. peak

Performance index	
Average Travel Time [min/veh]	3.75
Average Control Delay [min/veh]	1.57
Stops Ratio [%]	219.96

Table 5 presents an overview of the traffic parameters used in this analysis. These numbers are generated for all the traffic in the NETSIM-model of CORSIM. This means that traffic in I-95 will be disregarded until they take an off-ramp and join Glades Road. The choice has been made to concentrate on improving traffic performance on Glades Road and ignoring the effects of different solutions on I-95.

There are a few problem areas in the current situation. These will be described using screenshots from the TRAFVU animation software.

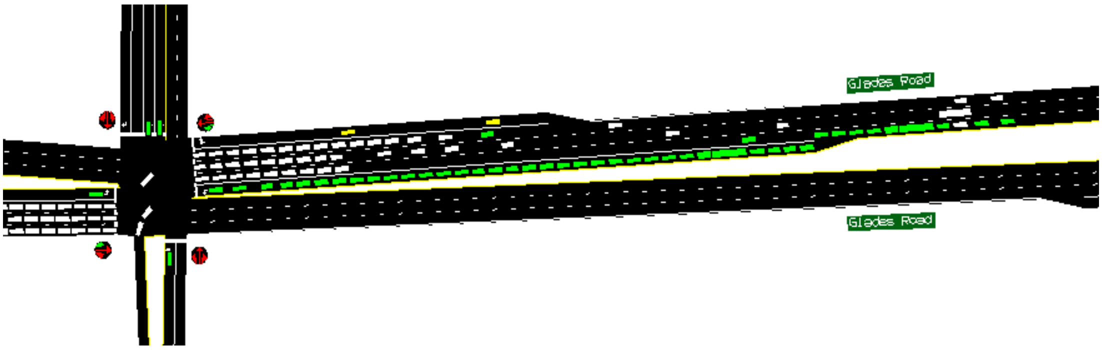

Figure 8: Backup in left-turn pocket for WB traffic on Glades Road – Commercial Drive

Figure 8 shows the backup on one of the through lanes caused by the lack of capacity for left-turning traffic. This results in a decreased capacity for though traffic as well and this is one of the reasons the traffic network does not perform well.

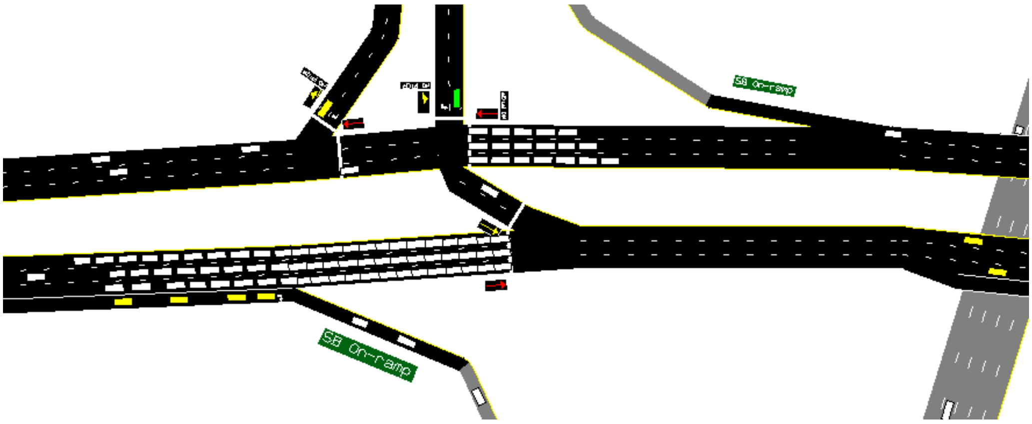

Figure 9: Traffic piling up behind I-95 controller in EB-direction

Figure 9 shows the pile-up of traffic in East direction. This is caused by the controller giving green for traffic coming from the I-95 off-ramp. Since the traffic flow in the A.M. peak on Glades Road is mostly going East-bound these backups frequently occur.

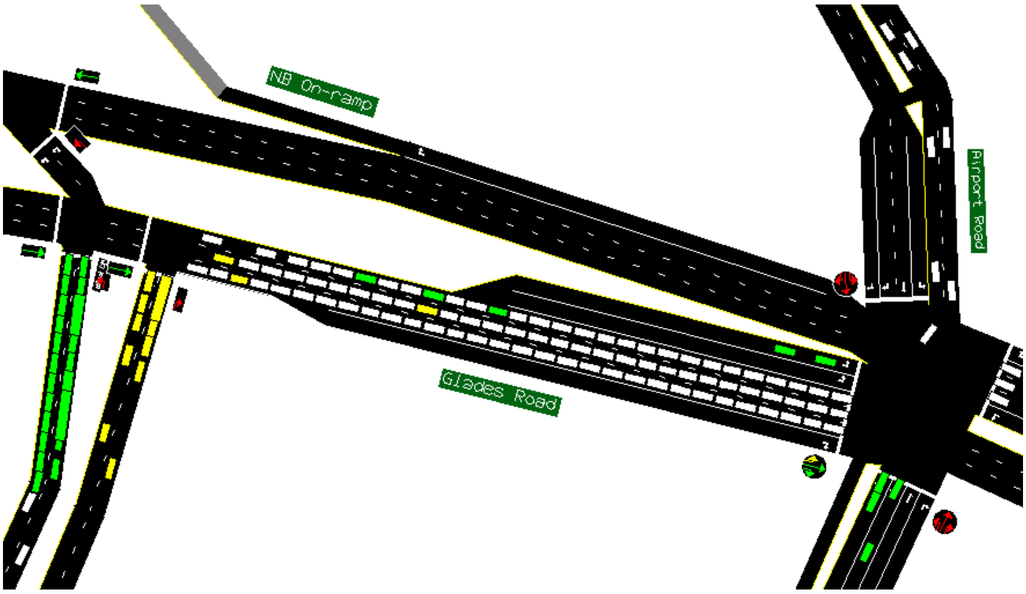

Figure 10: Traffic backup on Glades Road – Airport Road

Figure 10 shows the same situation as seen before. This time the location of the backup is after both the I-95 off-ramps. Also there is a lot of vehicles waiting to turn West on Glades Road.

4.2 Forecasted traffic volumes

Without improvements to the traffic network, conditions on the road will deteriorate since traffic volumes will increase. To analyze future problems simulation runs have been made with decreased and increased traffic volumes. As a performance indicator the Average Travel Time is taken. It should be clear that this indicator should increase when traffic volumes increase.

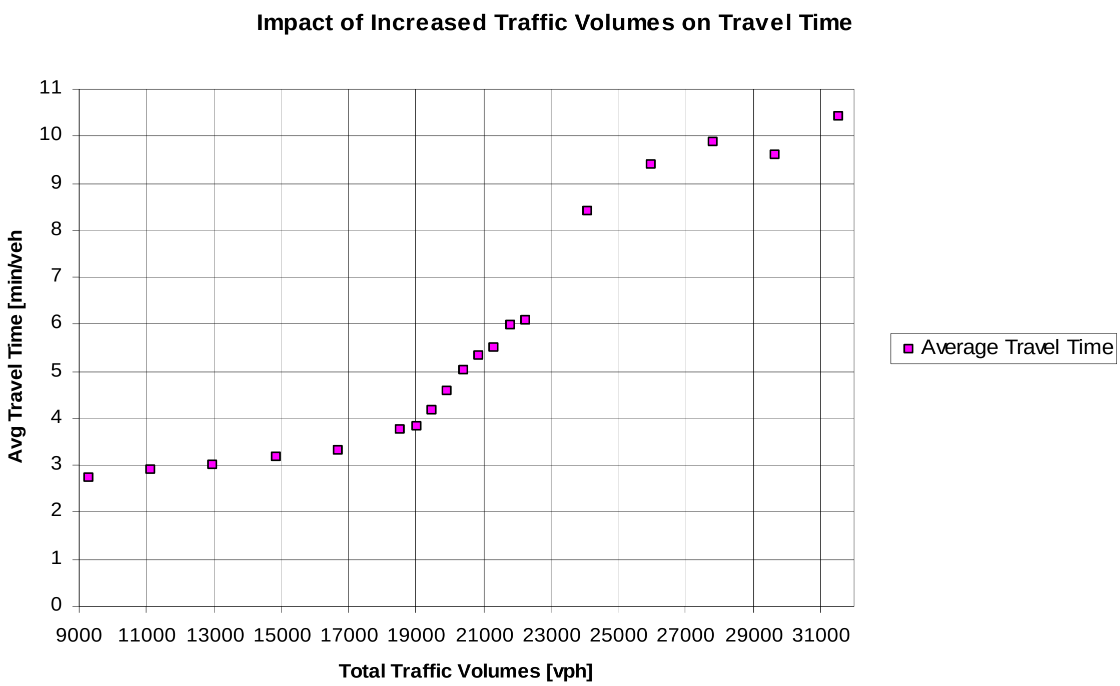

Figure 11: Impact of Increased Traffic Volumes on Average Travel Time

Figure 11 represents the relationship between increased traffic volumes and average travel time. The traffic volumes are the total traffic volumes entering the network per hour. The average travel time is computed as the time each vehicle remains in the traffic network. Travel time on I-95 does not count towards this performance indicator as Travel Time starts when a vehicle enters an exit ramp and stops when it enters an entry ramp to I-95.

With entering volumes of 19.000 vph and less the vehicles in the network are driving at more or less free flow speed. Between 19.000 and 27.000 vph the average travel time increases fast because of congestion. After 27.000 vph the traffic network is almost saturated and average travel time will not increase anymore because the network is already maximally congested. This is of course the worst-case scenario. The current situation in the traffic network corresponds with about 19.000 vph so at this point the traffic system performs normally.

Figure 11 has been generated under the assumption traffic volumes will increase at the same level at every entry point of the network. However certain scenarios can come up where traffic volume increases only happen at certain entry points. For instance traffic volumes can increase with 15% on I-95 without directly increasing the entry volumes on Glades Road. To examine these scenarios simulation runs have been made with different growth factors for Glades Road and the I-95. See table 6 for the results.

Table 6: Average travel time for different traffic volumes increases

		I-95			
		0%	15%	30%	45%
Glades Road	0%	3.70	4.06	4.46	4.60
	15%	4.37	4.90	5.38	6.50
	30%	4.82	5.12	6.35	6.52
	45%	5.57	6.94	6.56	7.54

Table 6 gives an overview of the different growth possibilities for Glades Road and I-95. An increase of the traffic volume on Glades Road has more effect on the average travel time than an increase of traffic volume on I-95.

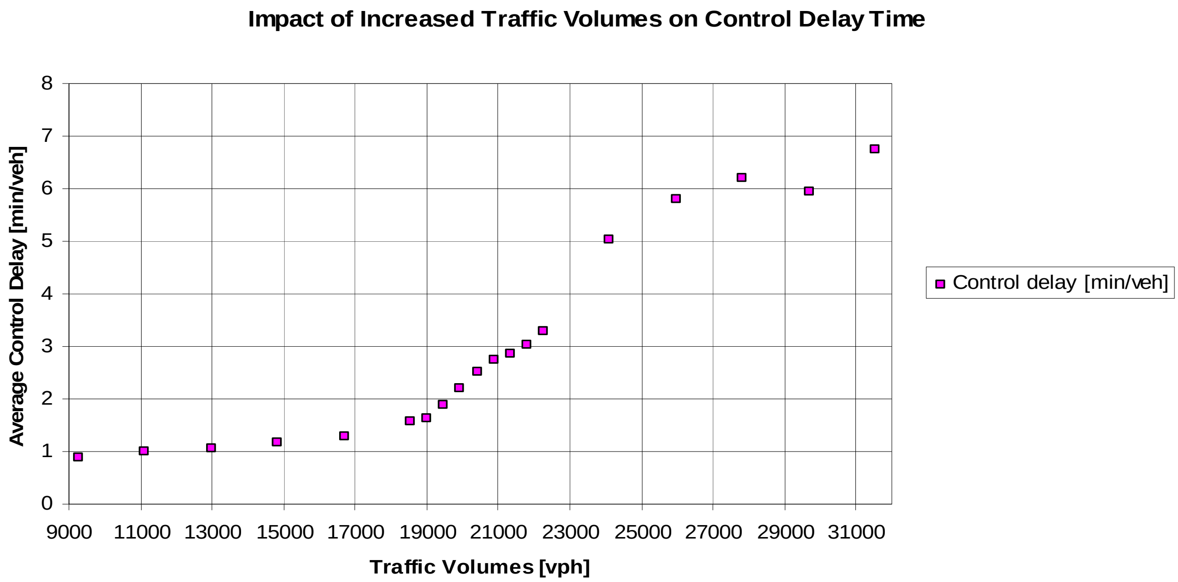

Figure 12: Impact of Increased Traffic Volumes on Control Delay

In figure 12 the relationship between increased traffic volumes and the average control delay is shown. Control delay includes initial deceleration delay, queue move-up time, stopped delay and final acceleration delay [CORSIM Help[9], *"NETSIM MOE's"*, 2002]. It is a Measure of Effectiveness (MOE) which measures the level of optimization for the traffic signals. When traffic volumes are smaller than 20.000 vph average control delay is around 30% - 40% of the average travel time. When volumes increase this percentage will increase to as high as 65%. Therefore optimizing the traffic signals is a very important contribution to the traffic network performance, especially with high volumes of traffic.

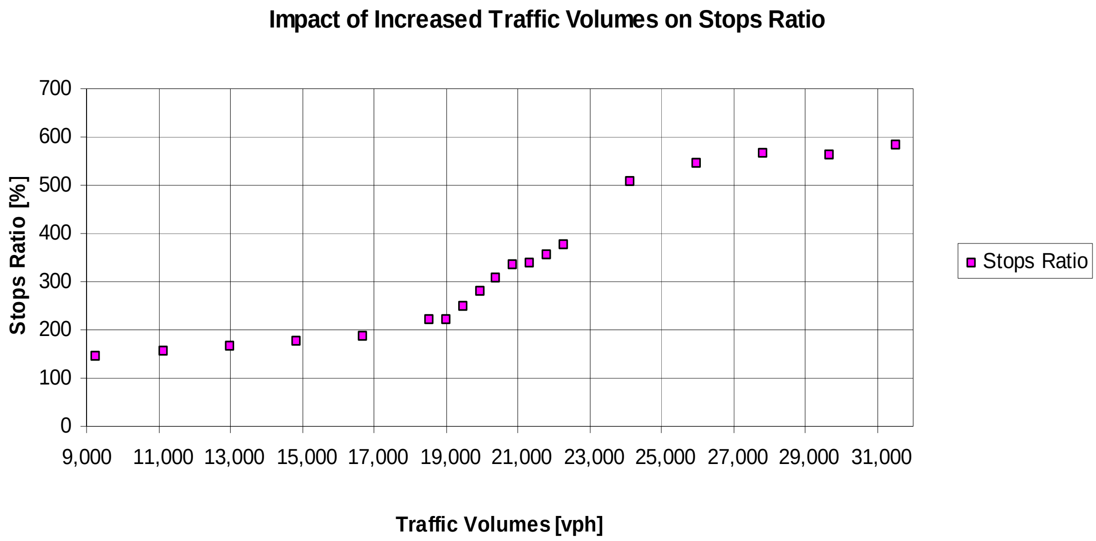

Figure 13: Impact of Increased Traffic Volumes on Stops Ratio

In figure 13 the relationship between traffic volumes and ratio of stops is shown. CORSIM defines the ratio of stops as the number of vehicles that have stopped at least once to the total number of trips. A ratio of stops of 200% means that every vehicle has to stop twice during that particular simulation run. For low traffic volumes the average trip consists of about 2 stops. While traffic volumes increase the ratio of stops increases as well. For high traffic volumes the ratio of stops is almost 600% which means that at every controller a stop has to be made and no free flowing traffic occurs.

4.3 Traffic signal optimization

The research area has 9 signalized intersections. These traffic signals are semi-actuated which means that detectors are used to improve traffic flow conditions. Note that during peak hours congestion can throw of any type of coordination normally present. A simple and cost-effective measure to improve traffic conditions is to optimize the traffic lights along the arterial road.

Since no traffic signals optimizing add-on was available in the CORSIM software package a different methodology is chosen. Optimization is performed using brute force logic by changing the signal phasing one at a time. By only continuing when the results show improved traffic conditions worse traffic signal settings are ignored. This method will make sure that a local minimum will be reached. These signal settings are of course not the global solution to this problem since there are so many different combinations possible. This optimization process took place under the current conditions.

The logic behind this brute force methodology was to give more green time to the through traffic on Glades Road. The majority of traffic on Glades Road flows from West to East in the 8 AM peak so priority has been given to this direction. This results in more free flowing traffic in the main direction and less green time for crossing streets with less dense traffic volumes.

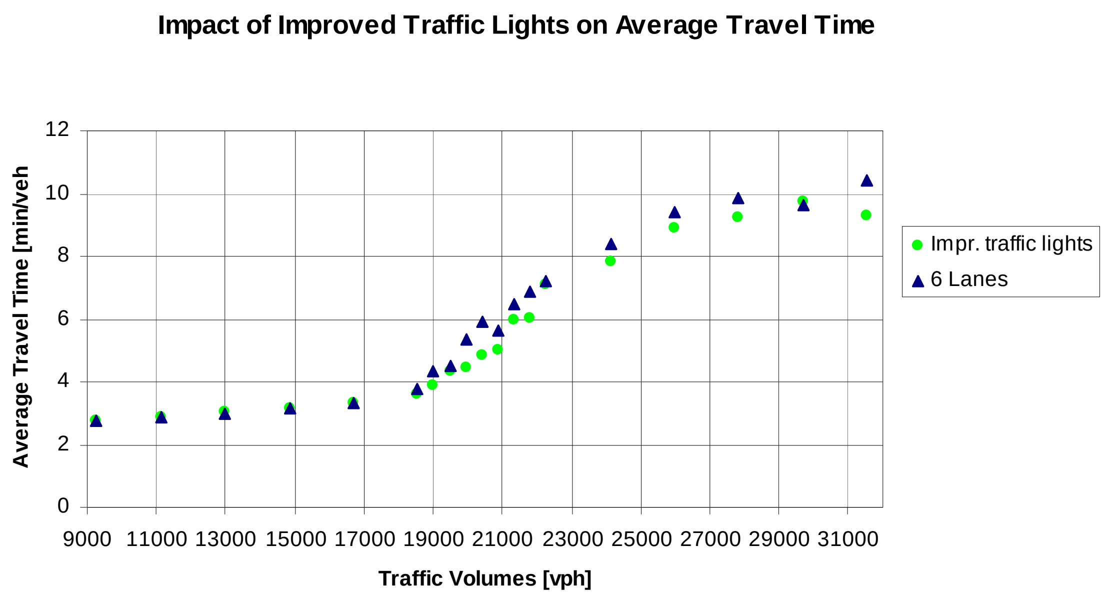

Figure 14: Impact of improved traffic lights on Average Travel Time

Figure 14 shows the relationship between traffic volumes and average travel time. It can be seen that for traffic volumes less than 19.000 vph there is no difference between the current situation and the improved situation. This can be explained by the fact that there is so little traffic that it results in a state of free flow and traffic signals can't change this. By increasing traffic volumes the importance of well optimized traffic signals increase as well. With the improved signal timings a reduction of the average travel time of about 8% can be maintained. The last data point seems strange but can be explained by the random seeds used in the simulation software.

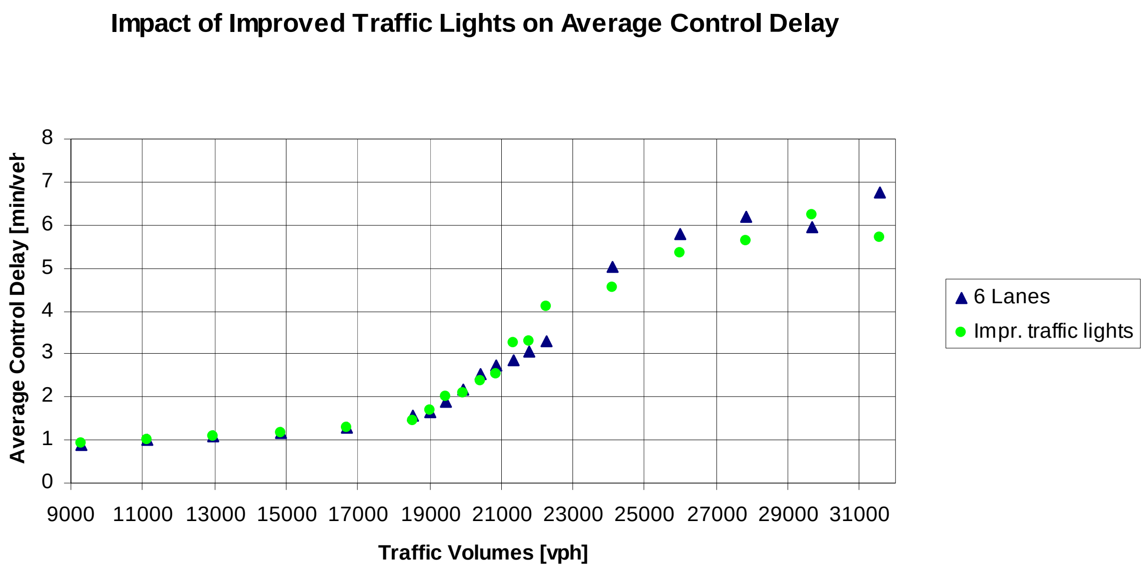

Figure 15: Impact of improved traffic lights on Control Delay

Figure 15 shows the relationship between increased traffic volumes and the control delay time. This indicator measures the delay time caused by controllers in the simulation. Since the goal was to optimize the traffic signals and thereby decreasing control delay this parameter should be lower than in the original scenario. For traffic volumes smaller than 21.000 vph the curve is similar. This can be explained by the fact that the system is in a state of free flow already and the controllers in the simulation are not hindering the flow at all. For traffic volumes between 21.000 and 23.000 vph the control delay time is actually higher than in the original scenario. An explanation could be that the level of service decreases in a way that it distorts traffic flow conditions around controllers. By increasing traffic volumes even more the level of service will degrade further but this improves the relative control delay time. In this graph the last data point seems out of place as well. This could have happened for the reasons previously described.

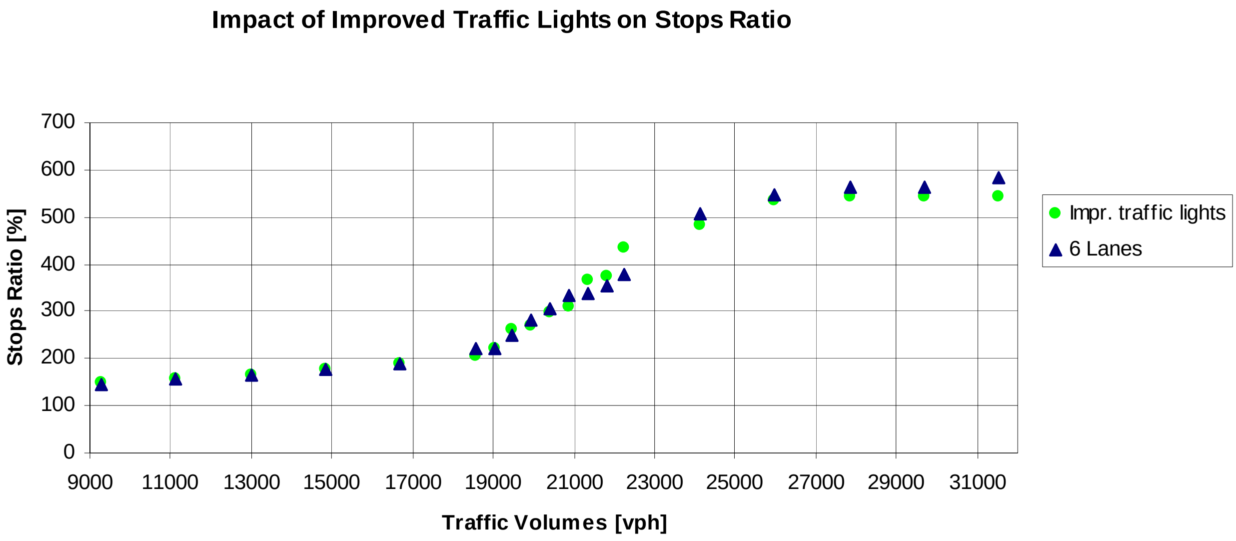

Figure 16: Impact of improved traffic lights on Stops Ratio

Figure 16 shows the relationship between increased traffic volumes and the stops ratio for two different alternatives. Both the curves are quite similar with slight changes which can be explained by the random seeds used in the simulations. The graph shows there is no significant change in the ratio of stops with the improved traffic lights compared to the original situation.

4.4 Various pocket adjustments

While examining the current situation certain bottlenecks are identified. By adjusting the length of certain turning pocket traffic flow can be increased. Also new pocket are added to locations where turning movements are blocking the through traffic. These geometric changes are minor adjustments since traffic can still use the entire infrastructure and only limited right of way is needed for the upgrades. The costs of these constructions are low compared to a major re-design such as the Turbo T or the full cloverleaf.

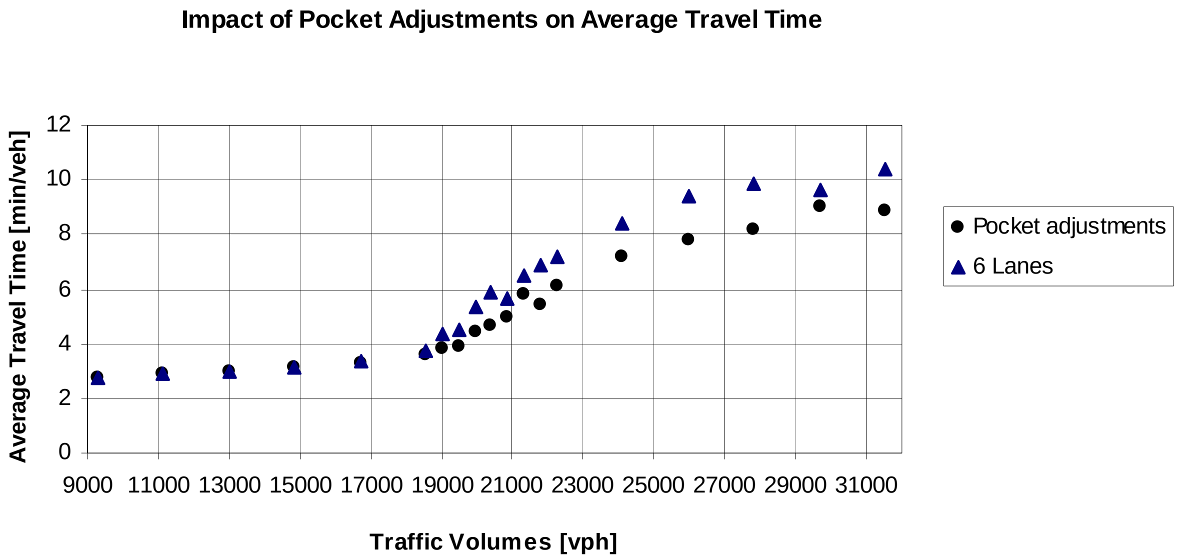

Figure 17: Impact of pocket adjustments on average travel time

Figure 17 shows the effects of the pocket adjustments on the average travel time. For low traffic volumes this alternative does not change the travel time significantly. When traffic volumes increase however there is a significant decrease of 15% in the travel time. This can be mostly contributed to the decrease in control delay, which is showed in the next figure.

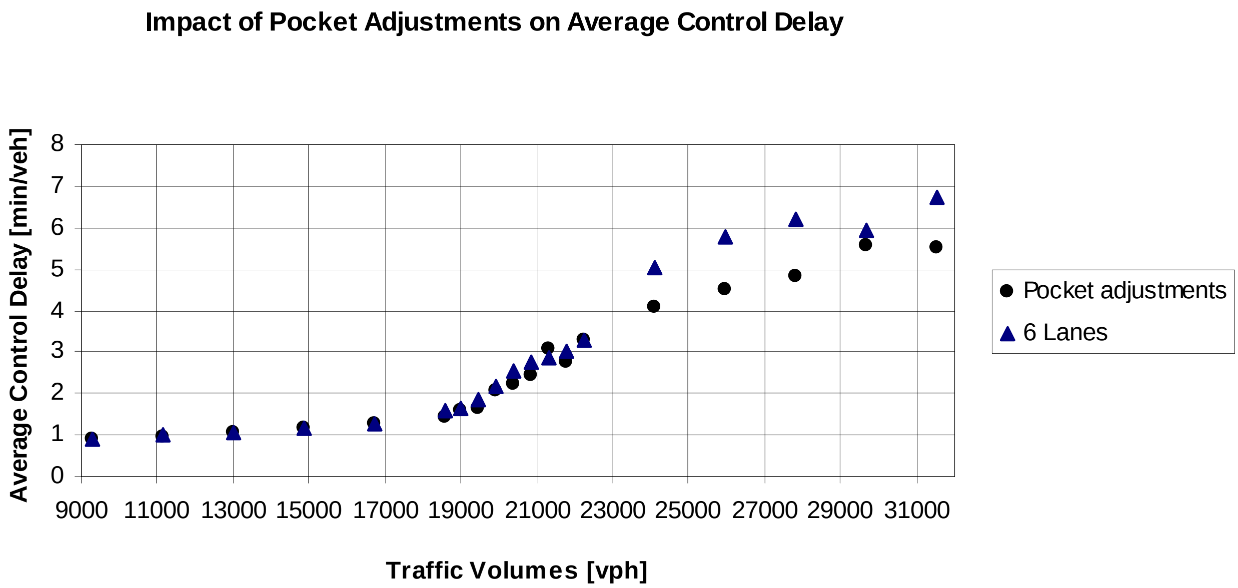

Figure 18: Impact of pocket adjustments on average control delay

Figure 18 shows the relationship between increased traffic volumes and average control delay. The curve is quite similar to figure 16. For low traffic volumes the pocket adjustments don’t improve the network since it is already in a free flow state. However when traffic volumes increase and space on the road is limited the adjusted pockets are performing quite well. This causes a reduction in the average control delay of more than 17% in the high volume scenario. For a medium traffic volume scenario the decrease of 6% is less but still significant.

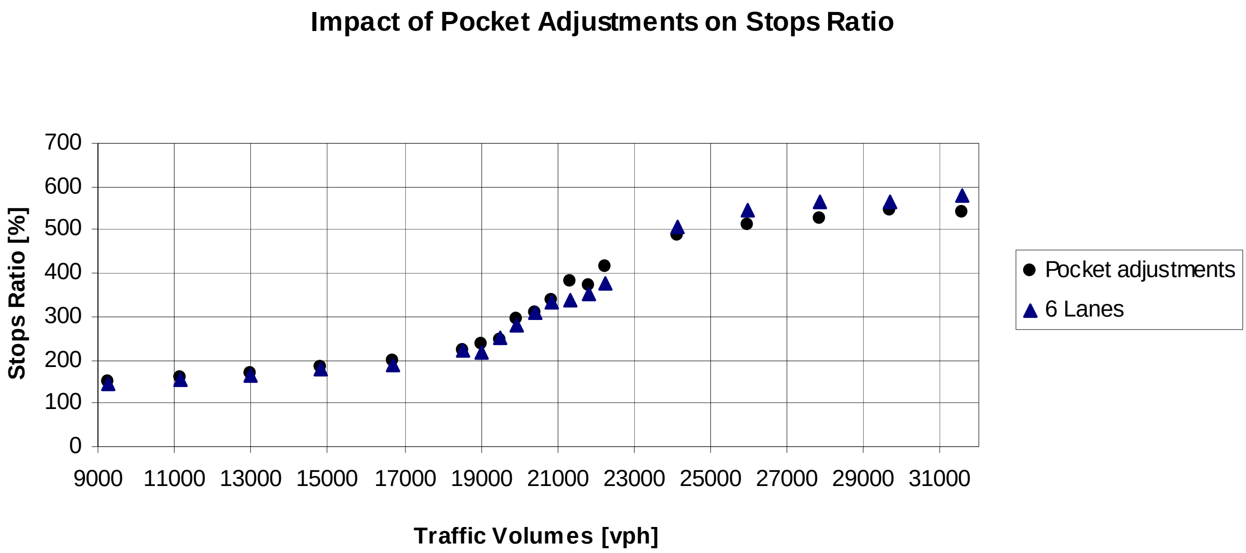

Figure 19: Impact of pocket adjustments on stops ratio

Figure 19 shows the stops ratio as a function of traffic volumes. For low traffic volumes the difference between the two alternatives is quite small. However for medium traffic volumes the stops ratio increases with about 6%. The stops ration decreases with the same percentage for high traffic volumes so in general the difference is small.

4.5 Increase Glades Road to 8 lanes

One of the alternatives to improve traffic conditions is to increase Glades Road from 6 lanes to 8 lanes. Either direction will have 4 through lanes in this configuration. Left or right turning pockets will remain in the same place and traffic signals haven’t changed as well. After this analysis the same runs will be simulated with the improved traffic signals from section 4.3.

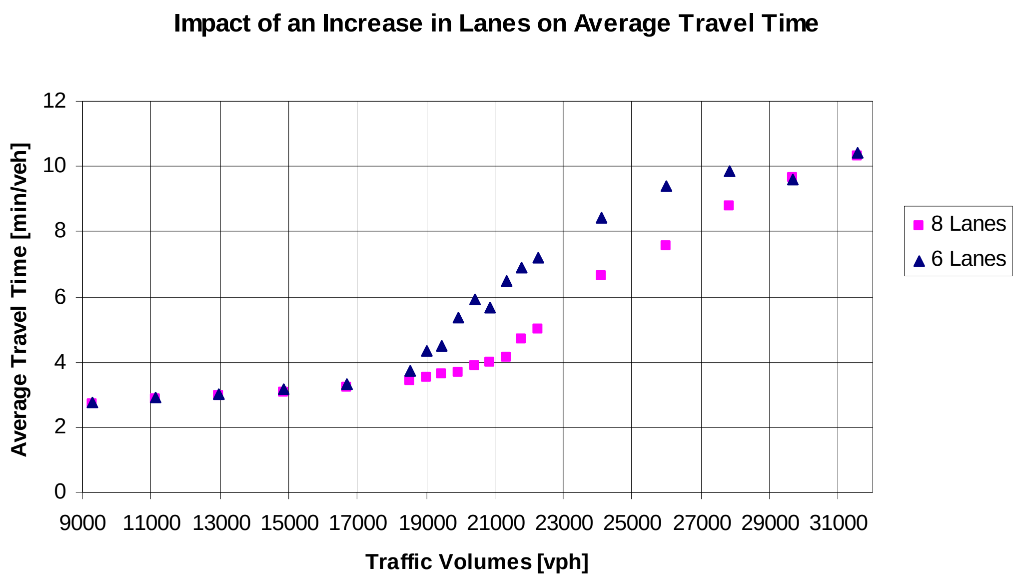

Figure 20: Impact of an increase in lanes on Average Travel Time

Figure 20 clearly shows that for traffic volumes between 19.000 vph and 29.000 vph average travel time on Glades Road with 8 lanes is less than on Glades Road with 6 lanes. For traffic volumes less than 19.000 the network was already in a free flow state because of low traffic volumes. These average travel times are the same in both cases since the average travel distance has not changed. For volumes greater then 29.000 vph the difference in average travel time between 6 lanes and 8 lanes is hardly visible. Glades Road with 8 lanes has a slightly higher saturation rate compared to the 6 lanes alternative. A higher traffic volume is required to reach this saturation rate though.

Impact of an Increase in Lanes on Average Control Delay

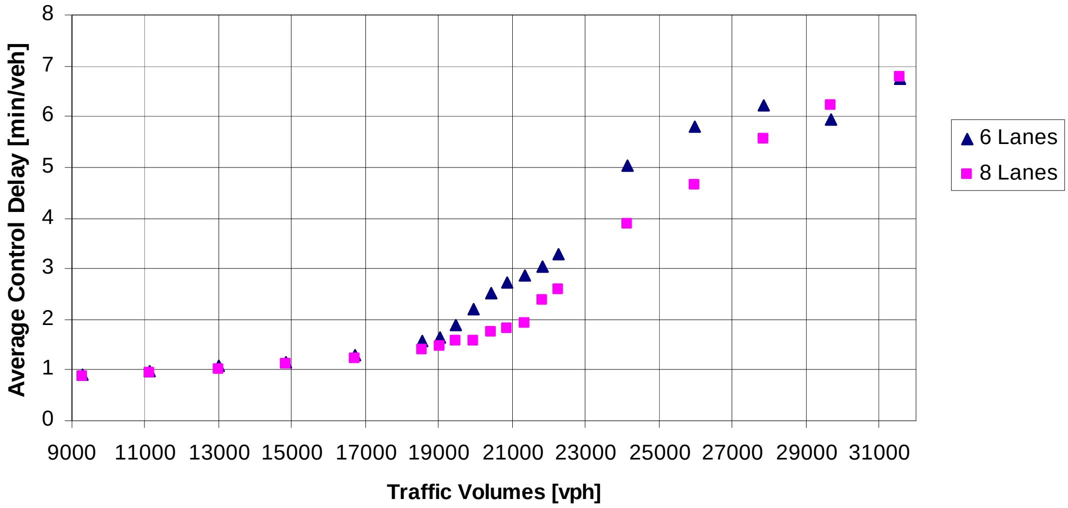

Figure 21: Impact of an increase in lanes on Average Control Delay

In figure 21 the same relationship is found between the traffic volumes and average control delay as previously. With low traffic volumes (< 19.000 vph) the traffic is almost free flowing and does not incur a lot of congestion. Control delay times are therefore the same as the current situation. When traffic volumes increases control delay times are less than the current situation. This is explainable by the fact that there is more space available to withstand the increase in traffic. As traffic volumes increase to more than 31.000 vph the control delay time exceeds the current situation to reach a higher saturation rate.

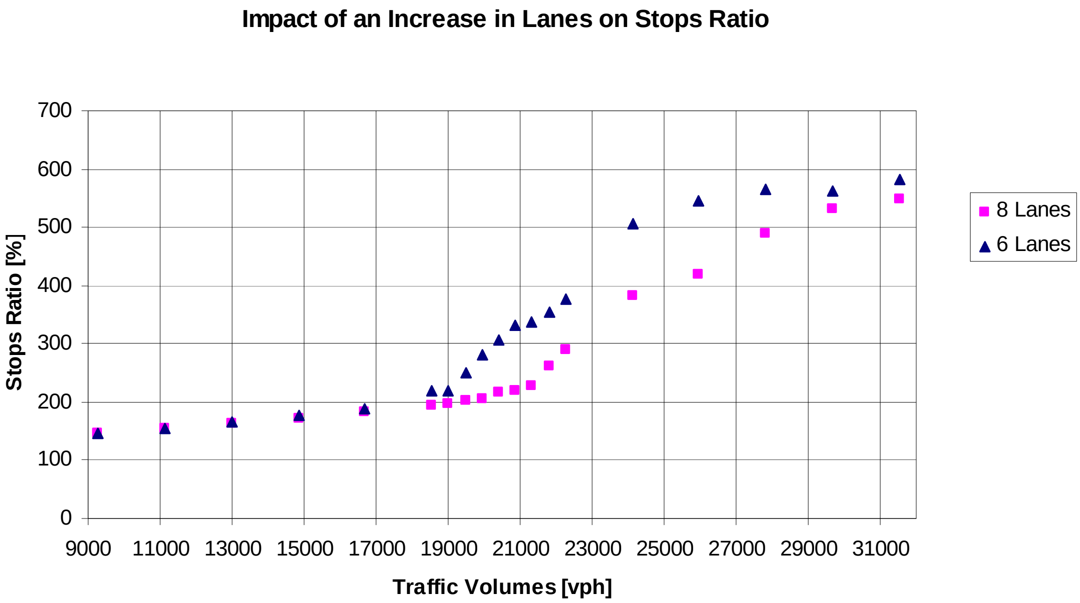

Figure 22: Impact of an increase in lanes on Stops Ratio

Figure 22 shows the relationship between increased traffic volumes and the ratio of stops. The curve is somewhat similar to the previous ones. For low traffic volumes the ratio of stops is the same in both situations. With medium traffic volumes the alternative with 8 lanes has a clear advantage over the current situation. But in the end with traffic volumes nearing the saturation rate of the system the ratio of stops will be constant and more or less the same on both situations.

4.6 Traffic signal optimization + 8 lanes

From the previous sections can be concluded that increasing Glades Road to 8 lanes does not have increase traffic flow performance for higher traffic volumes. It is more or less a quick fix to solve the current problems. Traffic signal optimization proved to improve traffic conditions by on average 8%. This improvement is valid for low, medium and high traffic volumes. In this section these alternatives will be combined.

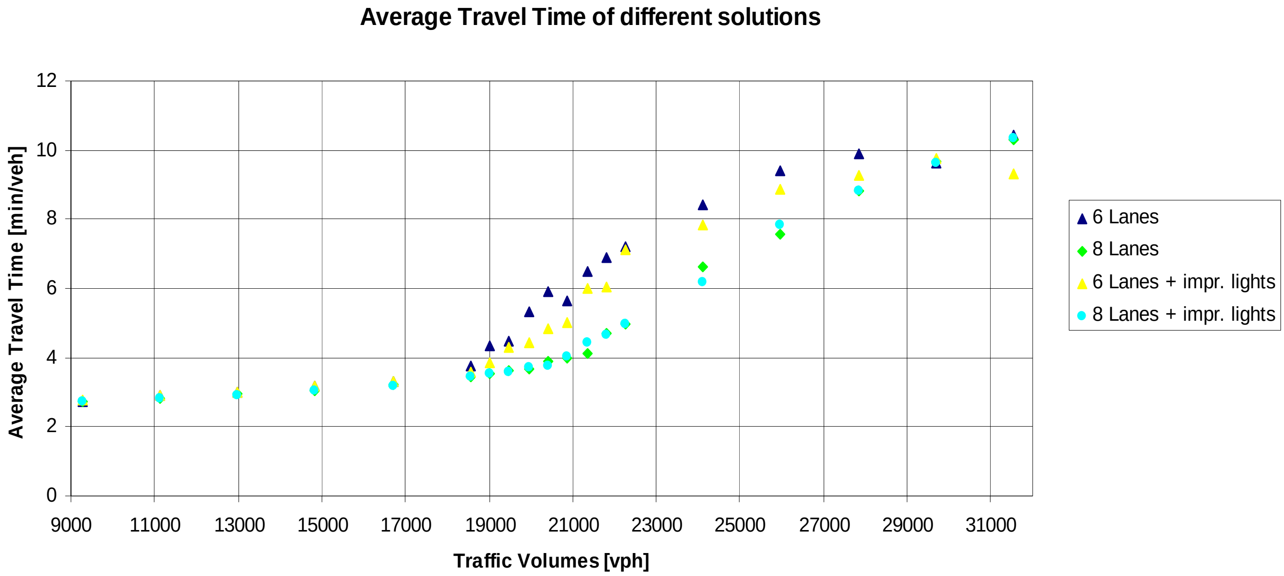

Figure 23: Average travel time of different solutions

Figure 23 shows the relationship between the combination of different alternatives and the average travel time. The curves are quite similar though both the alternatives with improved traffic signals have a shorter travel time than their respective counterparts. Apparently the influence of the improved signals on the increase of lanes is minimal. Also for higher traffic volumes the influence of both an increase in lanes and improved traffic signals is minimal. The saturation rate seems to be stable in all four alternatives.

Since both the Control Delay Time and Stops Ratio show similar results as seen in figure 23 these will not be explored any further.

4.7 Turbo T

One of the ways to improve traffic flow is to reduce the number of controllers along the arterial road. The density of controllers along the arterial road is quite high. By removing some of these controllers the traffic flow performance will increase. Removing a controller can be done in various ways. In this section the Turbo T will be explained in more detail.

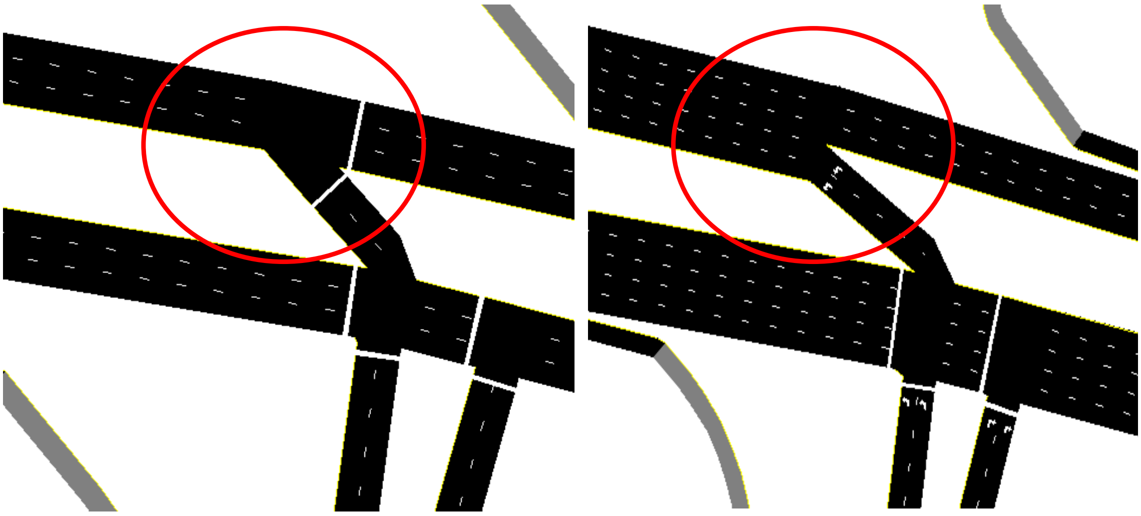

Figure 24: Current situation (left) and Turbo T-design (right)

As shown in figure 24 the design of the Turbo T is such that it removes the controller for the through traffic going West-bound. The two lanes are safely merged with Glades Road so traffic from both roads can weave properly. Since it is expected that this change will dramatically change the traffic flow the traffic signal phasing will remain the same as in the current situation as to not increase the number of variables for this simulation run. CORSIM does not allow proper lane reductions for links in the NETSIM-model so the design is such that the extra two lanes will be used as turning lanes in the next intersection and thereby removing the extra lanes after the intersection.

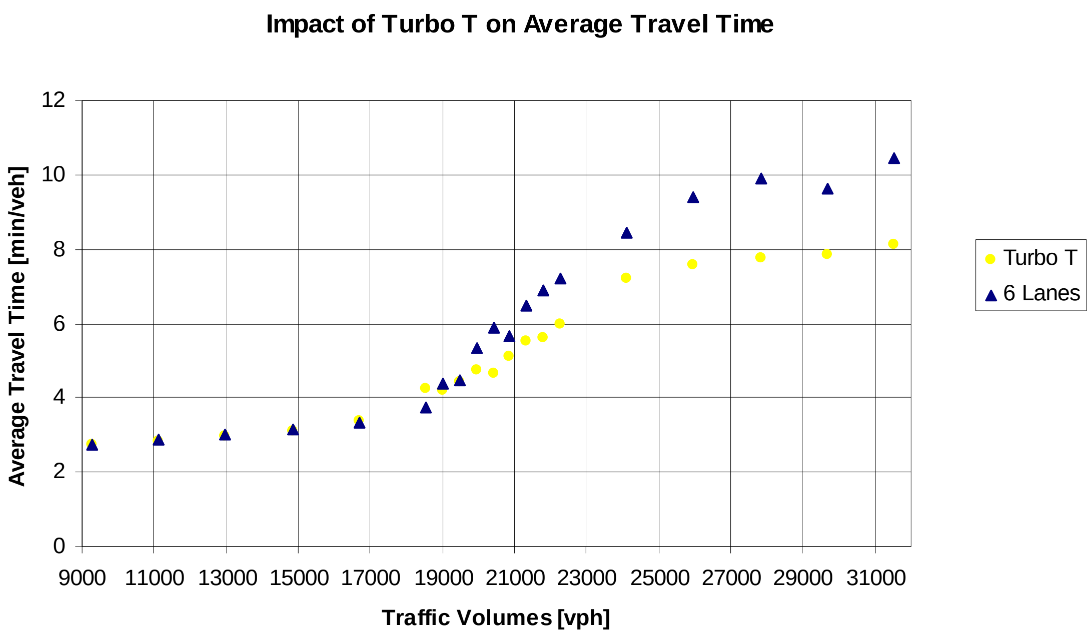

Figure 25: Impact of 'Turbo T' on Average Travel Time

In figure 25 the relationship between increased traffic volumes and average travel time is shown for the Turbo T and the original situation. For low traffic volumes the design change doesn't make a difference in travel time. The system is already in a state of free flow hence there is no decrease in travel time. For medium traffic volumes of 19.000 – 23.000 vph the effects of the Turbo T start to show. The average travel time with medium traffic volumes is on average 15% lower than in the original situation. For even higher traffic volumes of 25.000 vph and more the average travel time has decreased with almost 20% compared to the original situation. The curve seems to stabilize around a maximum of 8 min/veh which is significantly lower than the saturation rate of the original system, which is around 10 min/veh.

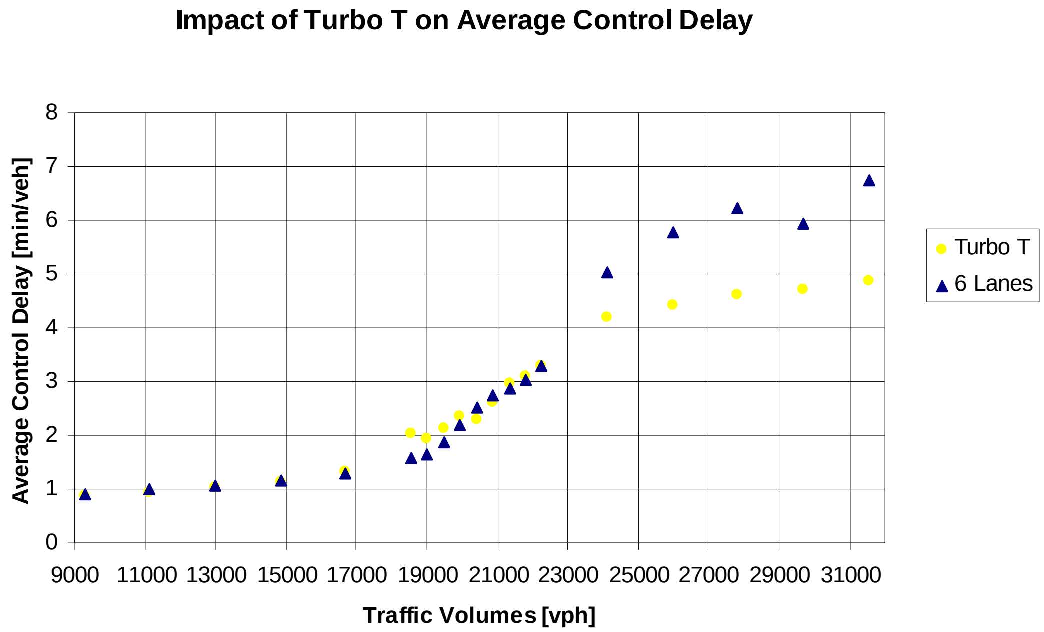

Figure 26: Impact of 'Turbo T' on Average Control Delay

The curve of the Control Delay Time is pretty similar to the previous graph. Figure 26 shows that for low and medium traffic volumes the differences between the Turbo T and the original situation are marginal. Only when traffic volumes exceed 23.000 vph a difference is shown in the Control Delay Time. The Turbo T design decreases Control Delay Time by 2 min/veh (approx. 20%) and therefore is the single most contributing factor to the decrease in Average Travel Time.

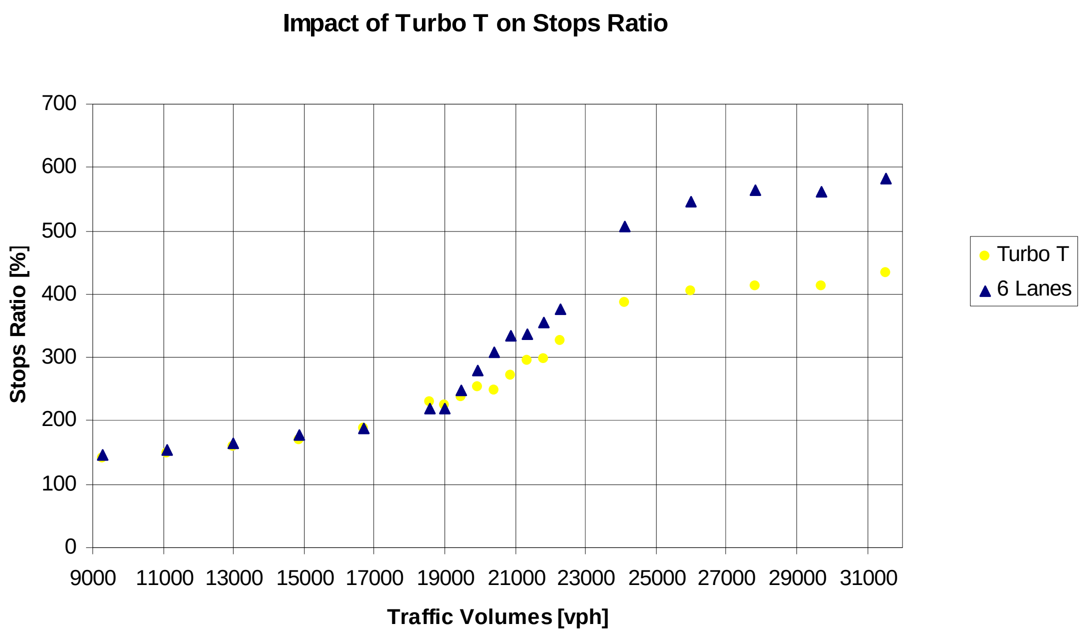

Figure 27: Impact of 'Turbo T' on Stops Ratio

Figure 27 shows the relationship between increased traffic volumes and the ratio of stops. The graph is similar to previous figures. For low traffic volumes there is little to no difference in the ratio of stops. For medium traffic volumes the ratio of stops decreases slightly while for higher traffic volumes the ratio of stops decreases by almost 25%. The decrease in the ratio of stops seems to be sustainable in the long run as well.

4.8 Various pocket adjustments + Turbo T

This alternative will present the combination of the Turbo T-design with various adjustments to turning pockets. These adjustments include the lengthening of the existing pockets as well as increasing the number of pockets in some cases. Together with the Turbo T-design this should improve the traffic flow in the major directions for higher traffic volumes as well.

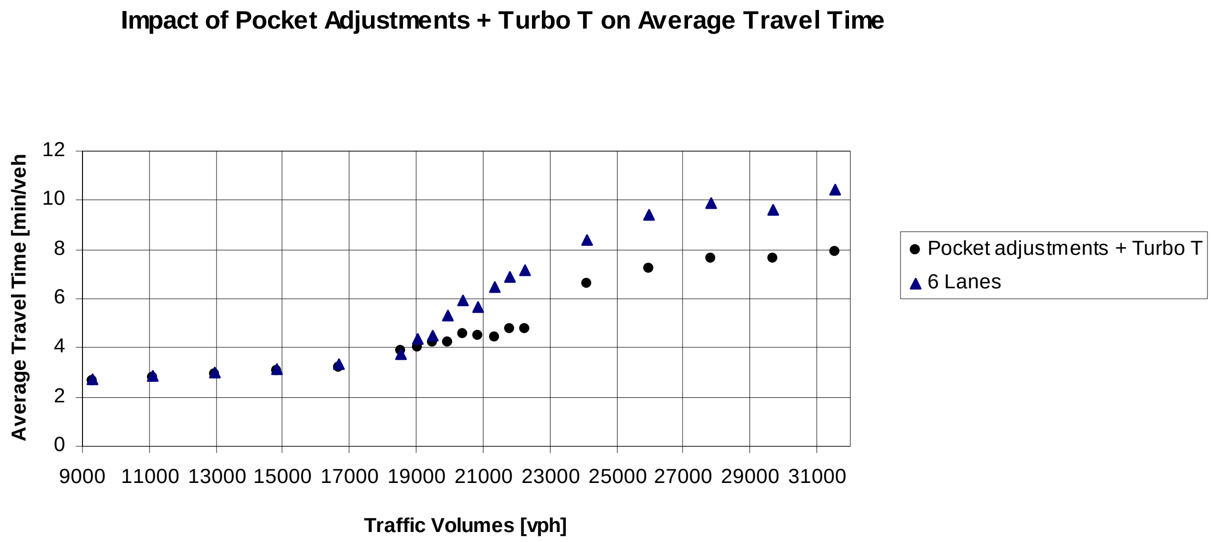

Figure 28: Impact of Pocket Adjustments + Turbo T on Average Travel Time

Figure 28 shows the average travel time plotted for various traffic volumes. For low traffic volumes these changes don’t cause a major difference in travel time. For medium and high traffic volumes however this new design heavily influences the average travel time. With travel time reductions of over 20% this alternative seems to be a sustainable way to improve traffic flow conditions. The curve of the graph suggests that there is room for even more traffic as well.

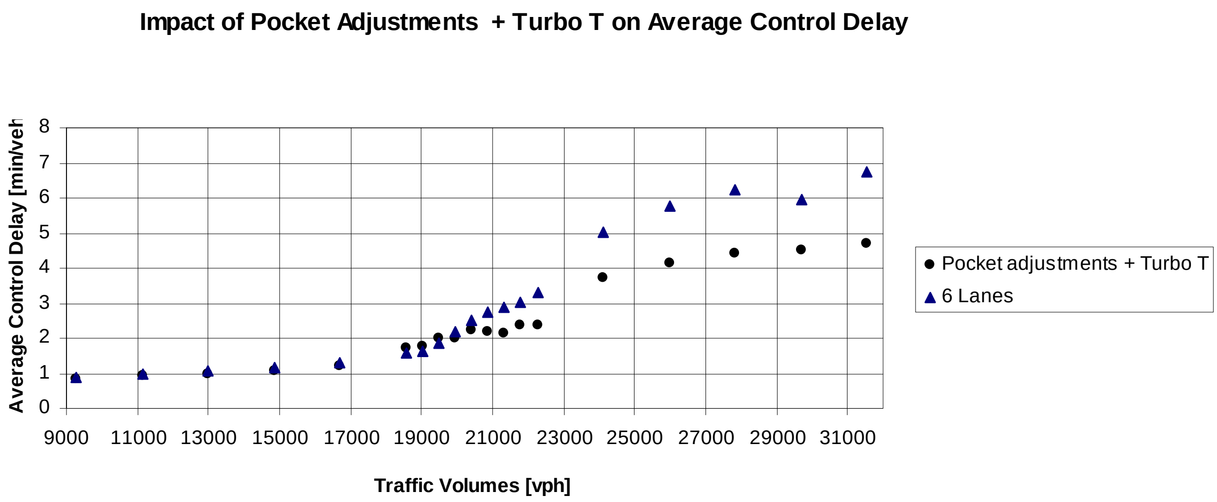

Figure 29: Impact of Pocket Adjustments + Turbo T on Average Control Delay

This design also greatly reduces the delay caused by the controllers in the network as can be seen in figure 29. Especially for high traffic volumes the increased capacity for turning movements on important intersections causes an average reduction of 27% for this scenario. For medium traffic volumes the reduction in average control delay is still almost 10%.

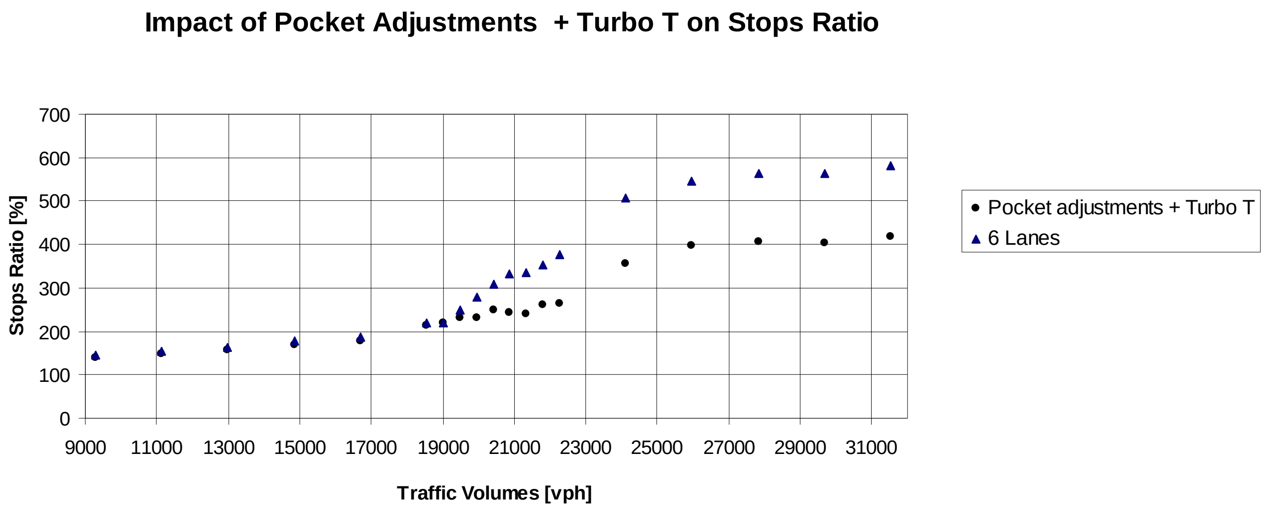

Figure 30: Impact of Pocket Adjustments + Turbo T on Stops Ratio

The design also greatly reduces the number of stops per vehicle. Figure 30 shows the relationship between the traffic volumes and the stops ratio. For low traffic volumes the stops ratio does not significantly change but for medium and especially high traffic volumes this design causes a reduction in the number of stops of almost 30%. Apparently the flow of the traffic is improved in such a way that it is more continuous and doesn't require as much stops as previously which probably reduces fuel consumption as well.

4.9 Increase in lanes + Turbo T

From section 4.5 about the increase in lanes one could draw the conclusion that lane increasing is only profitable for low and medium traffic volumes. For higher traffic volumes the system will deteriorate and end up in a slightly higher saturation rate. In section 4.7 about the Turbo T the opposite is true. For low and medium traffic volumes the differences are quite small. For higher traffic volumes however the difference in travel time increases and seems quite sustainable as well. In this section both these alternatives will be combined in one design to see if this can be a solution for both low and high traffic volumes.

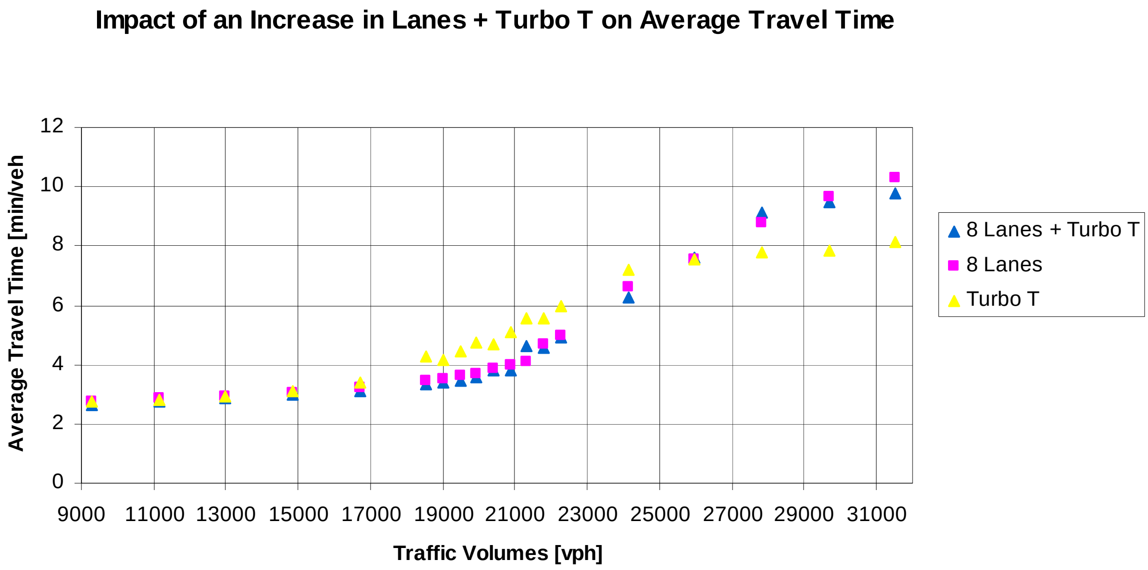

Figure 31: Impact of an Increase in Lanes + Turbo T on Average Travel Time

Figure 31 shows the relationship between traffic volumes and travel time for three different alternatives. This graph shows that for low and medium traffic volumes the Turbo T is not the optimal solution. Both the 8 lanes-alternative and 8 lanes + Turbo T-alternative perform between 15% - 20% better. For higher traffic volumes of around 26.000 vph and more the Turbo T is the best alternative though. Even the Turbo T combined with 8 lanes performs worse which seems strange. One would expect a decrease in travel times when the number of lanes increases. Apparently the increase in lanes causes some sort of dynamic situation with the Turbo T-design where traffic is delayed even more.

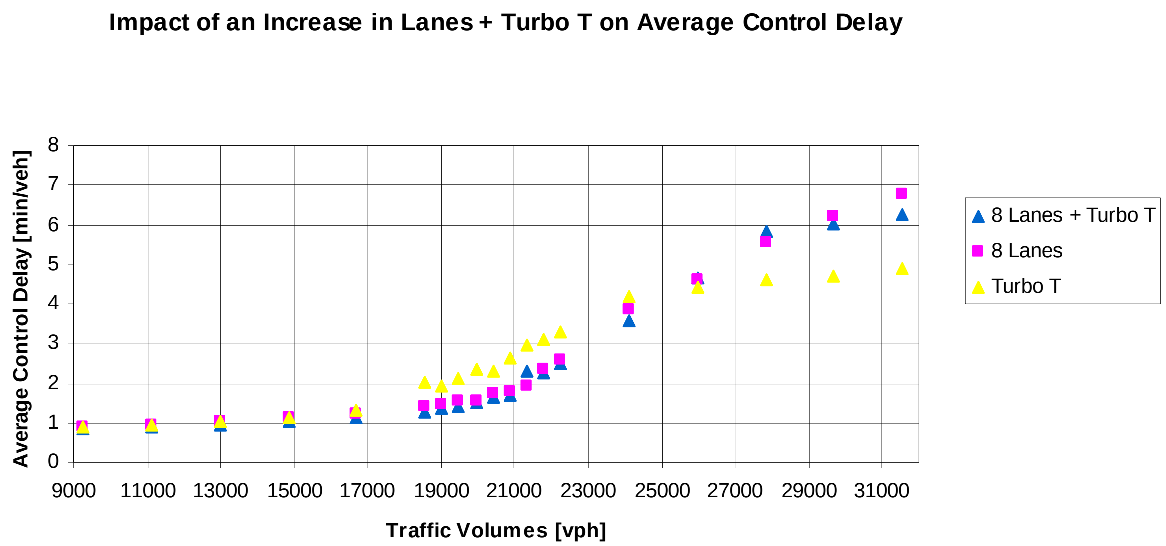

Figure 32: Impact of an Increase in Lanes + Turbo T on Average Control Delay

Figure 32 shows more or less the same relationship for the three alternatives as seen before. For low traffic volumes there is hardly any difference in control delay time. For medium traffic volumes the increase in lanes causes a reduction in travel time of about 20%. For higher traffic volumes the Turbo T without an increase in lanes is still the best solution.

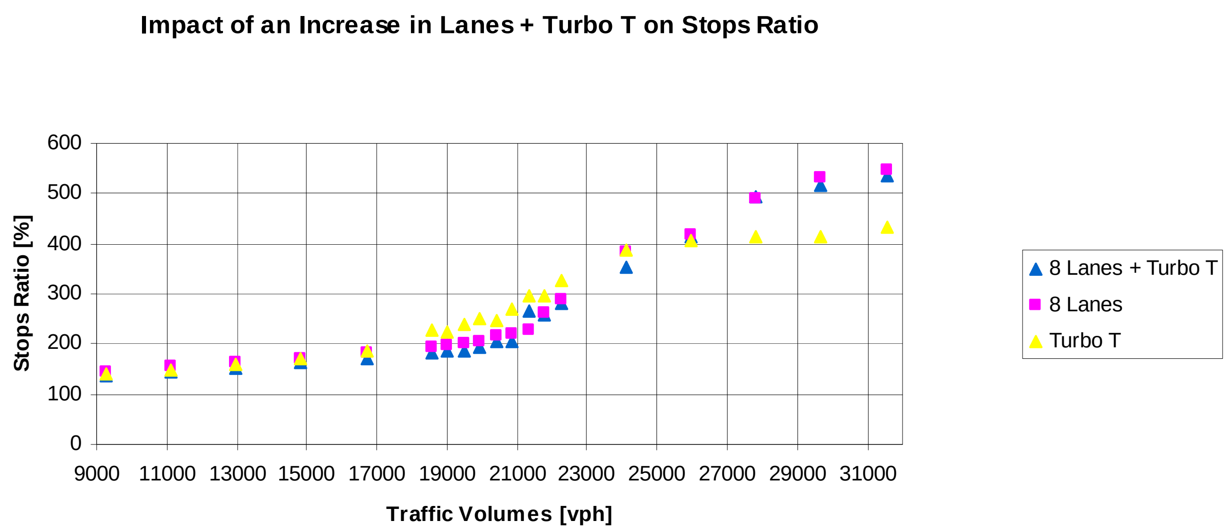

Figure 33: Impact of an Increase in Lanes + Turbo T on Stops Ratio

Figure 33 shows the stops ratio as a function of traffic volumes for the different alternatives. As previously described the Turbo T without an increase in lanes is far more beneficial to the stops ratio compared to any alternative with an increase in lanes on Glades Road.

4.10 Full cloverleaf

In order to improve traffic flow conditions the partial cloverleaf configuration currently in place can be upgraded to a full cloverleaf. The right of way in the case study is limited in both the North-Eastern and South-Western quadrant. The construction costs of this alternative would be immense considering the overpasses that probably need to be built as well. Still, the full cloverleaf is simulated to compare this design with the partial cloverleaf on the different traffic parameters.

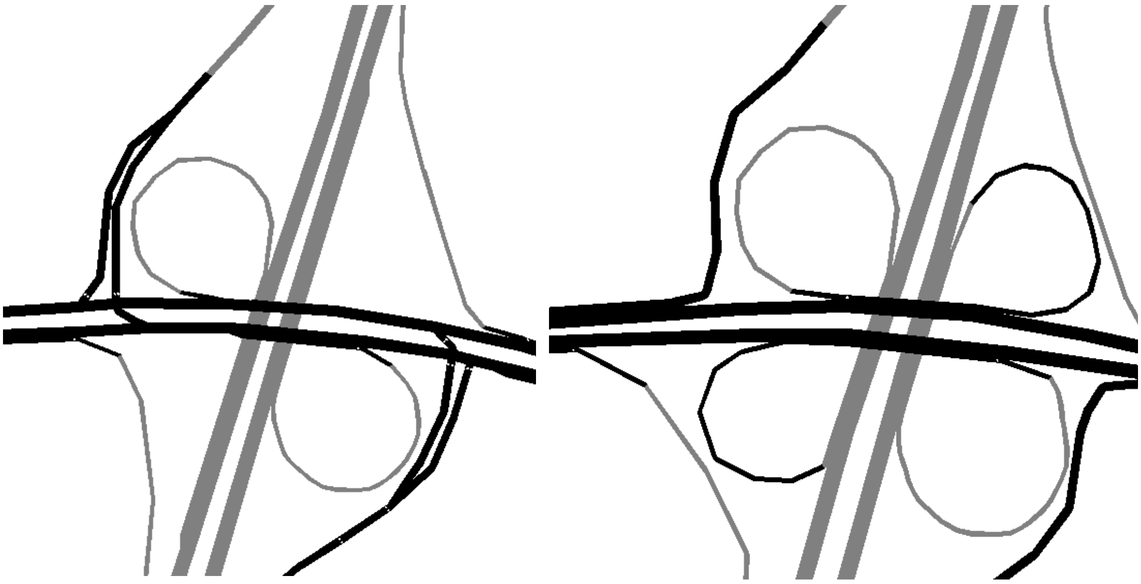

Figure 34: The original situation (left) and the proposed full cloverleaf configuration (right)

Figure 34 shows the differences between the current partial cloverleaf interchange and the proposed full cloverleaf interchange. Two loops are added to replace the left-turning movements which interfere with the through traffic in Glades Road. The Southbound I-95 On-Ramp for traffic going Eastbound on Glades Road had to be replaced to make room for the new loop in the South-West quadrant.

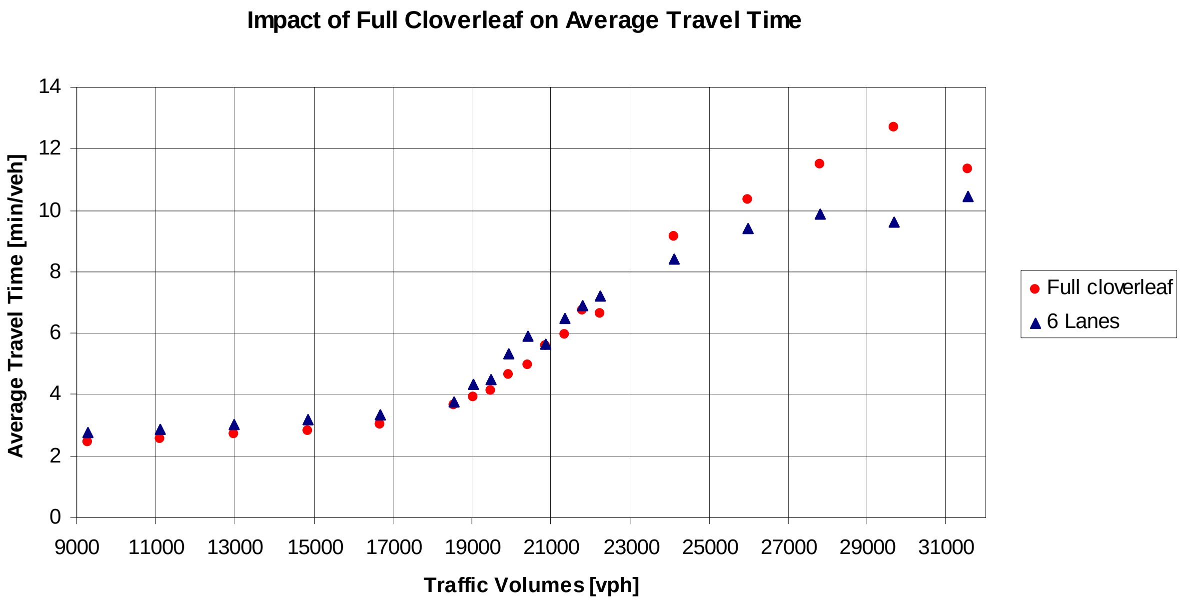

Figure 35: Impact of Full Cloverleaf on Average Travel Time

In figure 35 the relationship between increased traffic volumes and average travel time is shown for the original situation as well as the full cloverleaf configuration. For low and medium traffic volumes the full cloverleaf decreased average travel time with 9%. But when traffic volumes increase to 24.000 vph the performance of the full cloverleaf starts to decrease. For this high traffic volume the average travel time has increased with 15% compared to the original situation.

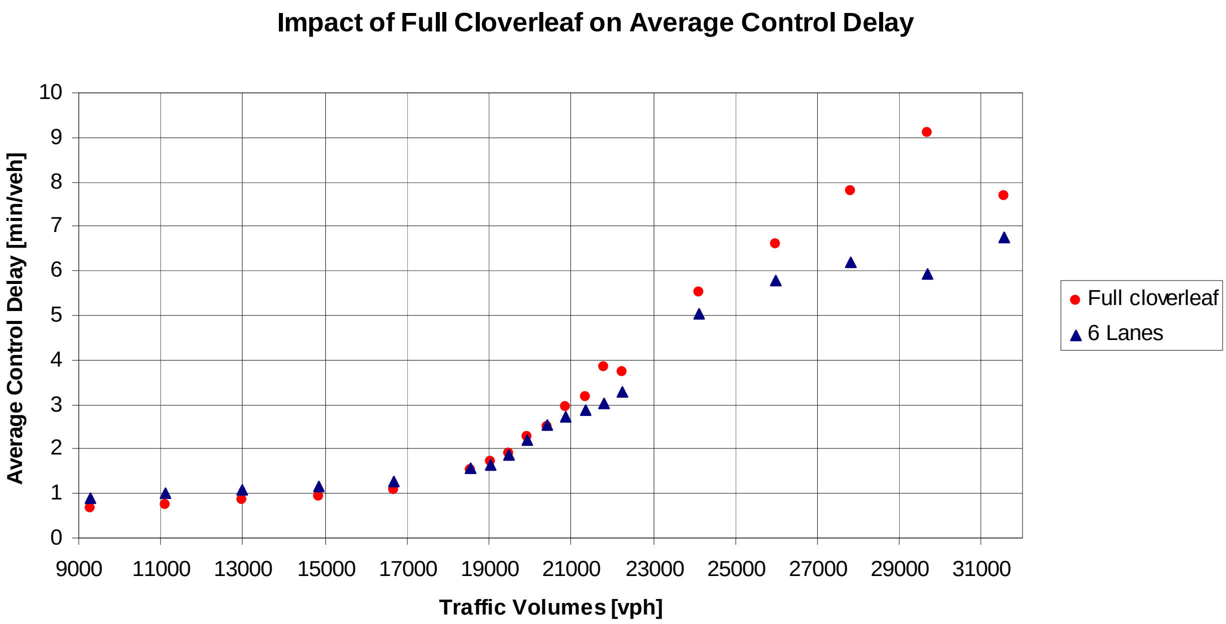

Figure 36: Impact of Full Cloverleaf on Average Control Delay

In figure 36 the average control delay as a function of the traffic volumes can be seen. For low traffic volumes of 9.000 – 17.000 vph the full cloverleaf configuration decreased the control delay time by almost 20%. This due to the fact that the two controllers on Glades Road have been eliminated which causes increased traffic flow along the arterial. For medium and higher traffic flow this performance cannot be sustained. With traffic flows of around 21.000 vph the control delay time is actually higher than in the original situation. The explanation for this could be that traffic from I-95 has to weave on the arterial road. In the current design there is probably not enough space to properly weave. Currently the weaving occurs quite close to the adjacent controllers which may be the cause for the deteriorated performance for higher traffic volumes.

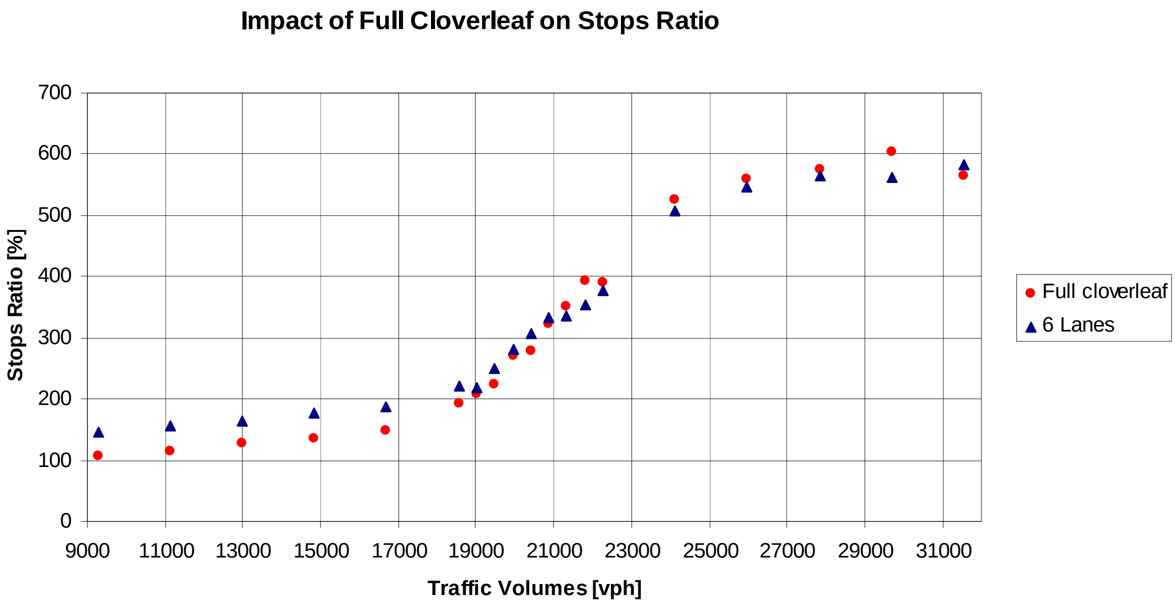

Figure 37: Impact of Full Cloverleaf on Stops Ratio

In figure 37 the relationship between the increased traffic volumes and the stops ratio is shown. Again, for low traffic volumes the full cloverleaf configuration causes the stop ratio to decrease with about 25%. When traffic volumes increase the performance decreases. The decrease is not as big compared to the travel time and control delay time but the relationship is quite similar.

5. Environmental assessment

It's rather important in today's society and environment to think about what influence certain measures or (lack of) actions could have on different environmental systems. The transportation system and more specifically the cars and trucks using the roads are causing a lot of air pollution. To solve this problem and leave a better place for future generations it's important to investigate this issue in traffic analysis studies such as this one.

Fuel consumption or fuel economy is the amount of fuel required to move a vehicle over a certain distance. While the fuel efficiency of automobile engines has improved markedly in the last decades, total fuel usage is still increasing. As parts of the world develop car ownership increases. In already developed parts of the world people tend to buy bigger and heavier cars thus resulting in increased fuel consumption.

Besides the technical developments there are a few ways to improve efficiency and decrease fuel consumption while driving. One of the most important is to drive at constant and lawful speeds. Unnecessary acceleration and deceleration increases fuel consumption and should be avoided. Therefore the traffic network should be designed such that it's possible to maintain a healthy speed.

For every alternative in chapter 4 the total fuel consumption has been calculated. These numbers should give insights as to which design is environmentally more sustainable. The traffic volumes have been split in three categories, namely low, medium and high traffic volumes.

Table 7: Fuel consumption for low, medium and high traffic volumes

		Low volume *[-50%, -10%]*	Medium volume *[0%, 20%]*	High volume *[30%,70%]*
Fuel Consumption *[Liters/vehicle]*	6 Lanes	0.20 (-)	0.27 (-)	0.32 (-)
	Impr. traffic lights	0.21 *(+2%)*	0.28 *(+3%)*	0.30 *(-7%)*
	Pocket adjustments	0.21 *(+1%)*	0.27 *(+0%)*	0.31 *(-5%)*
	8 Lanes	0.20 *(+0%)*	0.24 *(-6%)*	0.34 *(+12%)*
	Turbo T	0.20 *(+0%)*	0.26 *(-6%)*	0.26 *(-20%)*
	Pocket adjustments + Turbo T	0.20 *(-1%)*	0.24 *(-12%)*	0.27 *(-15%)*
	8 Lanes + Turbo T	0.20 *(-3%)*	0.24 *(-12%)*	0.32 *(+0%)*
	Full Cloverleaf	0.19 *(-5%)*	0.28 *(+4%)*	0.32 *(+0%)*

Table 7 shows us that for low traffic volumes it hardly matters which alternative will be chosen. The full cloverleaf configuration decreases fuel consumption by 5% with low traffic volumes. For medium traffic volumes the Turbo T-design combined with either an increase in lanes or various pocket adjustments are causing less fuel consumption. For higher traffic volumes however the increase in lanes isn't worth it anymore since it increases fuel consumption by 12% compared to the original situation. For this high volume of traffic the only worthwhile solutions are the Turbo T (-20%) and pocket adjustments combined with the Turbo T (-15%).

The Turbo T-design decreases fuel consumption by 20% in the high traffic volume scenario. This equals a reduction in the emission of CO_2 of around 7.000 ton per year. This is about 5% of the annual emission of CO_2 for a traditional power factory.

6. Conclusion and recommendations

In each of the designs of chapter 4 three variables are investigated for different traffic volumes. Of course the list of alternatives is never ending but due to obvious time constraints not every combination or new design could be tested. In this chapter an overview of the results will be given to finalize the research.

6.1 Overview of results

Table 8 presents the % change in average travel time for the different solutions. The percentage is based on the increase or decrease of the average travel time compared to the current design. The current traffic volumes are set to 0%. The low traffic volumes therefore represent a decrease in the number of vehicles while the medium and high scenarios represent a growth in traffic volumes.

Table 8: % Change in Average Travel Time

		Low volume *[-50%, -10%]*	Medium volume *[0%, 20%]*	High volume *[30%,70%]*
% Change in Average Travel Time	Impr. traffic lights	0%	-10%	-6%
	Pocket adjustments	0%	-14%	-14%
	8 Lanes	-2%	-27%	-11%
	Impr. traffic lights + 8 lanes	-3%	-26%	-11%
	Turbo T	-1%	-9%	-19%
	Pocket adjustments + Turbo T	-3%	-19%	-22%
	8 Lanes + Turbo T	-5%	-28%	-12%
	Full Cloverleaf	-11%	-8%	15%

For low traffic volumes it is clear that a full cloverleaf configuration improves the traffic conditions. The rest of the alternatives are somewhat close to 0% which means that the changes are not influencing the travel time measured by CORSIM.

For medium traffic volumes an improvement is seen with every alternative. The best ranking alternatives are mostly the alternatives which include an increase in lanes.

However for high traffic volumes these alternatives lose ground to the Turbo T-design. This design improves traffic flow by creating a weaving area to reduce the number of controllers along the arterial. Especially combined with various pocket adjustments this design improves traffic conditions with over 20%. The conclusion can be drawn that in order to improve the traffic flow it’s not just about laying more asphalt. It is important to identify the bottlenecks in the network and provide for enough storage space in turning pockets else queue spillback will occur on the mainline.

Table 9: % Change in Average Control Delay

		Low volume *[-50%, -10%]*	Medium volume *[0%, 20%]*	High volume *[30%,70%]*
% Change in Average Control Delay	Impr. traffic lights	0%	3%	-7%
	Pocket adjustments	-1%	-6%	-17%
	8 Lanes	-3%	-23%	-10%
	Impr. traffic lights + 8 lanes	-4%	-23%	-10%
	Turbo T	-2%	7%	-23%
	Pocket adjustments + Turbo T	-8%	-10%	-27%
	8 Lanes + Turbo T	-10%	-26%	-12%
	Full Cloverleaf	-22%	7%	23%

Table 9 gives an overview of the change in the average control delay. As defined previously the control delay is the sum of the initial deceleration delay, queue move-up time, stopped delay and final acceleration delay. The numbers per scenario are quite similar to table 8.

For a low traffic volume the full cloverleaf configuration is the best option considering the control delay time. All the alternatives show signs of improvement except for the improved traffic lights. This alternative is obviously designed to decrease the control delay time. The method used to improve traffic signals was not optimal but showed a decrease in control delay time for the current situation. Apparently for traffic volumes smaller than the current volumes the new traffic lights do not change the performance at all.

For medium traffic volumes the alternatives which include an increase in lanes are the best options. These alternatives show a decrease of around 25% which is certainly good. Some alternative even increase the control delay time such as the improved traffic lights, Turbo T and the full cloverleaf. Apparently the first two do not perform as well with medium traffic volumes since they do show signs of improvement for the higher volumes.

In this high traffic volume scenario the Turbo T-design is the best choice again. Especially combined with various pocket adjustments the change in control delay time is quite high. Note that the new traffic lights finally showed signs of improvement although it still is not as good as other alternatives.

Table 10: % Change in Stops Ratio

		Low volume *[-50%, -10%]*	Medium volume *[0%, 20%]*	High volume *[30%,70%]*
% Change in Stops Ratio	Impr. traffic lights	1%	2%	-4%
	Pocket adjustments	3%	5%	-6%
	8 Lanes	-2%	-24%	-14%
	Impr. traffic lights + 8 lanes	-2%	-24%	-11%
	Turbo T	-3%	-10%	-26%
	Pocket adjustments + Turbo T	-5%	-18%	-28%
	8 Lanes + Turbo T	-7%	-26%	-17%
	Full Cloverleaf	-24%	-3%	2%

The stops ratio has been defined as the chance that a complete stop must be made during an average trip in the network. The explanation of table 10 is similar to the other overview tables in this chapter.

For low traffic volumes the full cloverleaf configuration performs great though when traffic volumes increase the performance deteriorates. For medium traffic volumes an alternative which includes an increase in lanes is again one of the best options. The Turbo T-design performs also performs quite well. For higher traffic volumes this design combined with various pocket adjustments decreases the stops ratio by almost 30%.

In chapter 5 about the fuel consumption it was concluded that the Turbo T design caused less emission of air pollution as well. Besides that the alternative improves the traffic conditions network wide it also is a very eco-friendly solution.

There are a few options to summarize all of the above. The conclusions that can be drawn are dependant of the vision the city of Boca Raton has on this problem. If they expect a massive growth in vehicles the solution would be different than if they don't expect any growth at all. Also what do they think is an acceptable level of service? Is the current transportation system working as it should be? Some may agree that it's not working efficiently but the numbers suggest that the network is still more or less in a good state and growth in the future will cause real congestion problems.

6.2 Recommendations

This study has primarily been focused on solving or relieving some of the congestion problems that exist in traffic heavy scenarios. The solutions brought up are all infrastructural options. Only the new traffic signals didn't require the construction of new lanes, new pockets or some other new constructional design.

Of course there are a lot more options one could investigate in this matter. Probably one of the most important solutions is to get people out of their cars and in public transportation of any form. Currently the service level of public transportation in Boca Raton is quite low. It could be interesting to see the effects that a completely renewed public transportation system has on the traffic network. The same goes of course for using a bicycle. It's really important for a sustainable way of living that eco-friendly solutions to transportation problems arise.

Another important key to solving this puzzle is zonal planning and management. The transportation sector is usually regarded as a lagging sector. All sorts of expansions are built like shops, restaurants, cinemas or stadiums. The transportation department only gets involved after a certain problem arises and then is asked to solve it. The key of a good solution is the integral approach of the projects by combining everyone involved in a broad solution beforehand, not after.

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