
Modelling the impact of vehicle type knowledge on actuated/adaptive traffic management

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A dissertation submitted in partial fulfilment of the requirements of the MSc in Control Engineering

April 2019

Evidence of Ethics



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Applicant:

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Project Title:

Modelling the impact of vehicle type knowledge on actuated/adaptive traffic management

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Acknowledgement

During the period of the development of my Master's project, I received help and support from many people who I would like to show my gratefulness. First of all, I would like to thank my supervisor, Olivier Haas. His help and support were essential to beat this great challenge. I really appreciate that he answered all my questions and guided my ideas throughout this research process. In addition, I would like to show my appreciation to Dina Laila, the module leader, for her comprehension and for letting me do my dissertation during the second semester. Not to forget my tutor from Spain for accepting this project and validate it.

Secondly, I would like to thank Nigel Goodison for helping me with Aimsun.

Furthermore, I would like to show my appreciation to my friends who supported and understood me during the period in which I worked in this dissertation.

Finally, I would like to extend my love and thanks to my parents and brother, who are the most important pillar to my achievement and success.

Last but not least, I would also like to thank the International Offices of Faculty of Engineering, Environment and Computing and "Escuela Técnica Superior de Ingenieros Industriales" of the Polytechnic University of Valencia for making my Erasmus possible.

Abstract

The aim of this project was to develop a traffic management system that can be adapted to traffic condition knowing different information about vehicles approaching a junction.

The purpose of setting this control system was minimizing traffic jams and waiting time of vehicles staying in the junction.

The controlled junction belongs to the road A52 and it is placed in Nottingham, United Kingdom.

The information about the number and type of vehicles was collected by the infrastructure, this is, by the loop and cameras located on the traffic lights.

A traffic simulation model was designed through Aimsun micro-simulator and it was used to generate the traffic data, which was collected and analyzed. Later, an algorithm in Python language was developed to transfer these data and deal with them.

Using Visual Studio Code, as second software, a traffic controller was modelled for managing the traffic light's behavior. This controller is adaptive based on vehicle count (information collected by the infrastructure).

At the end, the performance has been compared between using the controller and not using it to assess its effectiveness.

List of terminology and abbreviations

API	Application Programming Interface
CP	Control Plan
MCP	Master Control Plan
MOTION	Method for the Optimization of Traffic signals In Online controlled Networks
MOVA	Microprocessor Optimised Vehicle Actuation
RHODES	Real-time Hierarchical Optimized Distributed and Effective System
SCATS	Sydney Coordinated Adaptive Traffic System
SCOOT	Split Cycle Offset Optimisation Technique
TCMS	Traffic Control Management Systems
TRANSYT	TRAffic Network StudY Tool
UTMCS	Urban Traffic Management and Control Systems
UTOPIA	Urban Traffic Optimization by Integrated Automation

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1. Introduction

1.1. Background and justification

The junction in which a traffic management control is going to be implemented belongs to the primary road A52. It is located in the south-east of Nottingham (postcode NG12 2LT), United Kingdom. Here, the A52 crosses with Stragglethorpe Road and a small unpaved road, which will not be taken into account in this project because its traffic could be consider null.

Currently, the traffic control plan of the A52 intersection is fixed. This means that the duration of the green time of the traffic lights is always the same and the switching sequence too.

The reason of choosing this junction to change its traffic management and make it adaptive is that this is a road through which a high quantity of trucks travels every day. Trucks, as a heavy vehicle type can incur in a long and slow queue when they have to stop in a red traffic light and start moving again. This is why it will be taken into account when a truck approaches the junction to let it go, as far as possible, through the crossroad without forcing it to stop.

Although trucks will be the main vehicle type considered to adapt the traffic lights green time, other vehicles, such as car and public transport buses will be also taken into account to extend the green time or give them priority.

With those changes, traffic jams and waiting times will be reduced, especially in peak times of week days.

1.2. Aim and Objectives

The aim of this project is to develop an algorithm used as an adaptive controller that can be applied to the traffic light management of a junction located in the city of Nottingham, United Kingdom. With this controller it will be possible to reduce waiting times and queues taking into account various information about the vehicles approaching the intersection.

The objectives that have to be completed to reach the aim of this thesis are:

1. To make a Literature Review explaining which other methods exist and can be applied to achieve our goal.
2. To use a software called Aimsun to model the junction including detectors, stop lines, traffic lights, bus stops, etc. As well as generate traffic data including public transport lines.
3. To formulate a code in Python language to develop a controller for the junction.
4. To implement the algorithm in Aimsun to monitor its actuation.
5. To extract results and conclusions comparing the adaptive traffic management in the junction with making the traffic lights work with a fixed behavior (make them work always with the same time interval).

1.3. Methodology

Before the start of the project, a wide research has been carried out on the subject of traffic management. The literature review of this work is focused on collecting information about the different existing approaches to create traffic management systems, their applications and controlling methods.

The designing part of the project was effectuated by Aimsun Next, a software for transportation networks modelling from a single intersection to an entire region (in this case, just an intersection). It also served for analysis of the project results. The control part of the work was developed by Visual Studio Code, a code editing software able to handle different types of programming language, such as JavaScript, C ++, Python, SQL, Swift, HTML, TypeScript, etc. In our case, the code was written using Python.

Parameter and setting information for the implementation of the A52 modelling in Aimsun were found in the 'Help' section of this software. Support from other members of the project team and the tutor was also received.

The learning of the use of Python language has been acquired of videos coming from meetings of the project's supervisor with the technical support of Aimsun, of examples of code provided by the supervisor and of the Python's official website.

1.4. Deliverables

The deliverables that will be included in the submission of this project are:

1. An Aimsun file containing the A52 junction modelling and including:
 - Control plans
 - Vehicle types interacting in the simulations
 - Traffic demands
 - Scenarios
 - Infrastructure (detector locations, lane types and road types)
 - Turns
 - Public transport lines
2. A Python code file, which could be opened with Visual Studio Code for example, including the developed algorithm for the adaptive controller implementation.
3. This report.
4. A log book proving that the student and the supervisor met during the development of the project.

After the submission of the project, some days before its VIVA, a poster will be also submitted as a guide for the presentation and some further purposes, such as exhibitions.

1.5. Outline of Thesis

This subchapter is dedicated to present a summary and to explain the distribution of the thesis. This dissertation focuses on the study of how to minimize waiting times and queues length in an intersection located in Nottingham. It deals with real traffic data to model the behavior of the vehicles approaching the junction. For this purpose, a model of the crossroads has been developed using Aimsun as a micro-simulator. Then a controller coded in Python language has been created to take into consideration the trucks approximating the intersection. The trucks, which are the slowest type of vehicles that rides along the road that will be studied, usually incurs in very long traffic jams due to their slow burst of speed. For this reason, the developed controller will extend the green times in the traffic lights when possible, taking into account several considerations.

To enhance this research, this dissertation is distributed into six parts or chapters.

The second chapter discusses the latest developments in Traffic Control Management Systems (TCMS) as a Literature Review. It focuses in the presentation of some practical examples of TCMS approaches given by different authors.

The third part explains how the model of the studied intersection has been implemented in Aimsun and also how the traffic data has been handled.

Chapter 4 presents the first part of the experimental setup. Thus it exposes the details of the control part of the junction implemented in Aimsun, this is, the Control Plans in which the green times and detector configurations are set, the Master Control Plans and the Dynamic Scenarios that will be run to simulate the behavior of the junction with and without applying control.

Chapter 5 is about the second part of the experimental setup, it is dedicated to the explanation of how the code for the controller has been developed and structured. It also itemizes the functions that it contains and the outputs they generate.

In chapter 6 the analyzed results obtained from the different Dynamic Scenario simulations will be presented. Several comparisons between their will be carried out.

The last chapter ends the thesis making some conclusions about the milestone achieved during the development of this dissertation. Additionally, it identifies the research gaps and considerations left that could be implemented in the future.

1.6. Timetable and plan

The next timetable shows the phases in which this project has been decomposed with the assigned period to complete each of them. It also includes the real completion time interval.

Table 1. Project plan.

Project plan	Assigned completion time interval	Real completion time interval
Project choice	21/01/2019 - 27/01/2019	21/01/2019 - 27/01/2019
Ethics application	28/01/2019 - 25/02/2019	06/02/2019 - 25/02/2019
Literature review	07/02/2019 - 15/02/2019	07/02/2019 - 15/02/2019
Familiarization with Aimsun	07/02/2019 - 08/02/2019	07/02/2019 - 08/02/2019
To assign necessary data to the existing A52 model	09/02/2019 - 25/03/2019	09/02/2019 - 25/03/2019
Familiarization with Python	25/03/2019 - 29/03/2019	25/03/2019 - 29/03/2019
Controller modelling and implementation	27/03/2019 - 15/04/2019	27/03/2019 - 17/04/2019
To obtain results	16/04/2019 - 17/04/2019	22/04/2019 - 28/04/2019
To write the report	05/04/2019 - 29/04/2019	05/04/2019 - 29/04/2019
Dissertation submission	29/04/2019	29/04/2019
PowerPoint slides / poster preparation	29/04/2019	-
VIVA Presentation	14/05/2019	-

2. Literature Review

2.1. Evolution of Traffic Control Management Systems

Nowadays, traffic jam congestions are becoming an important issue mostly in big cities all around the world. The population growth and technological advances are leading to the contribution of the appearance of many factors that incur to traffic jams. Some of those factors are the high traffic density, inadequate road capacity, bad driving behaviors and ineffective traffic light setting. (Rosyadi et al. 2016)

To try to solve this important problem, during the last years, significant advances have been developed in terms of vehicle detection and communications technologies, enabling changes from fixed plans to modern integrated systems. In order to understand such evolution, it is necessary to look back to the origin and development of the Traffic Control Management Systems (TCMS).

The first phase to consider covers from 1868 to 1920. It is during these years the first traffic lights appeared. The original models were gas powered and did not have automatic control installed on them, reason why police officers had to manually activate them.

In the 1920s, the electric powered traffic lights were invented to accomplish two main objectives. The first one was relieving police officers of traffic management, whereas the second one was obtaining an economical benefit.

The second phase spans from 1920 to 1980. It corresponds to the period at which TCMS started to gain real importance in traffic control. During the late 1950s, due to the increment of traffic congestion and the need reducing the delay and enable a local coordination, several projects were developed to change the original fixed plans by coordinating traffic signals. This was achieved by means of the use of optimized signals, which were improved in terms of the split, cycle and offset times.

In this second phase, TRANSYT (from TRAffic Network StudY Tool) played an important role. It is one of the most significant control design systems which considers that the traffic is constant and known during a certain interval of time.

The third phase includes from 1970s up to the presents days. This phase arose after the congestion was still meaning a problem and new technological solutions were sought. This phase proposed the addition of inductive loops in the junctions, so that the signals could be triggered. The way this system works is provoking a constant frequency in the resonant loop. Thus, every time that a vehicle passes through the magnetic field generated by such resonance, its frequency increases and the detector recognises its position. It is important to outline that these loops are generally placed before the junction of interest, so that there is enough time to react.

One of the optimising actuator used in this third phase is the MOVA (Microprocessor Optimised Vehicle Actuation), which performs an analysis lane by lane and minimises both the delays and the stops. This is the system that has been installed in the studied intersection.

However, it is not able to deal with the high traffic volume in it, especially in peak hours of weekdays.

Phase four is coetaneous to the previous one. It consists of vehicle actuated systems, which uses on-line detector measurements in order to optimise the timing of the signals in a certain cycle to cycle basis. One of the most commonly used TCMS in the world is the SCOOT (Split Cycle Offset Optimisation Technique) (Hamilton et al. 2013), which makes use of traffic data in live in order to fairly determine the signalling time that best suits the requirements. They gather and process a huge amount of information at the same time.

Another option for a TCMS is the SCATS (Sydney Coordinated Adaptive Traffic System). It works with coordinated vehicle actuation combined altogether with fixed time plans, working at two basic levels: the “upper level” “lower level”. It operates in live, making use of smaller libraries of offset. One of the advantages of this system is that it is able to change the cycle time after every cycle if the conditions of the road are different enough from the initial ones. Other advantage that can be found in the use of this system is that it can be configured to give priority to public transport.

Urban Traffic Optimization by Integrated Automation (UTOPIA) is a different TCMS developed the last years. It focuses on the minimisation of the total time lost by vehicles although it gives priority to public vehicles so that they do not need to stop at traffic lights. It can be applied to a single junction and also to a whole network; what leads to its three tiered hierarchical architectural system:

- Local level: a microscopic model to estimate the state of the intersection is applied.
- Area level: it monitors the state of the whole controlled network.
- Town Supervisor Level: it integrates the congestion information given by UTOPIA with data from other systems, such as bus travel times (Hamilton et al. 2013). This is, it is able to set macroscopic models.

UTOPIA uses loop detectors at key locations in the network which are just downstream of the previous junction (Gardner et al., 2009).

Real-time Hierarchical Optimized Distributed and Effective System (RHODES) is very similar to UTOPIA, as it also has a three tiered hierarchy architecture. Its highest level determines levels of traffic whereas the lowest one determines the signal timings. RHODES is composed by two main processes: ‘estimation and prediction’ and the ‘decision system’ process.

The last most commonly used system is the Method for the Optimization of Traffic signals In Online controlled Networks (MOTION). It has two components: Central and Local. The central function creates plans which can then be adjusted by the local element (Gardner et al., 2009). It operates using four functional levels:

1. Data acquisition
2. Dynamic traffic model
3. Optimizing control variables
4. Decision

Many other used Traffic Control Management Systems have introduced important improvements on fixed plans. Some of them are Green Link Determining (GLIDE) used in Singapore and the Universal Traffic Management System (UTMS) applied in Japan traffic management which uses infra-red technology to detect and communicate with vehicles (Hamilton et al. 2013).

Comparing the different existing TCMS can be a big challenge as there very few studies of comparison of two commercial systems. At the same time, every country, city and area has different requirements. But the next table can be taken as a guide when there is a necessity of choosing an appropriate system:

Table 2. Comparison between TMCS

Traffic Signal System	Advantages	Disadvantages	Technology
Fixed Time	<ol style="list-style-type: none"> 1) Cheaper to install and maintain 2) Can be implemented using non-centrally controlled equipment 3) Familiarity with settings for regular users 4) Green Waves more easily implemented 	<ol style="list-style-type: none"> 1) Large amount of data to be collected and updated 2) Signal plans will require updating 3) Disruption caused when plans change 4) Operator needs to respond to incidents 5) Cannot deal with short term traffic fluctuations 	<p><i>Sensing:</i> Offline</p> <p><i>Communications:</i> None</p>
Responsive plan selection (e.g. SCATS, MOVA)	<ol style="list-style-type: none"> 1) Can deal with some day to day fluctuations 2) Could benefit arterial routes more 3) Cheaper than fully responsive systems 	<ol style="list-style-type: none"> 1) Require more data than fixed time 2) Detector failures can cause problems 3) Discussions are required on when to change a plan 4) The plan could change for a wrong reason if automated 5) Difficult to foresee all eventualities 	<p><i>Sensing:</i> Current road state</p> <p><i>Communications:</i> System Dependent</p>
Fully responsive (e.g. SCOOT, UTOPIA)	<ol style="list-style-type: none"> 1) Less data required in advance 2) Plan evolves with time so no updating required 3) Can deal with short and long term fluctuations (better at long) 4) Automatic reaction to incidents 5) Live traffic information available 	<ol style="list-style-type: none"> 1) Detector failure can cause significant loss of efficiency 2) More expensive to install, comparable for maintenance 3) Requires some central control 4) Maintenance is critical 	<p><i>Sensing:</i> Current Road State</p> <p><i>Communications:</i> Minimum of local level</p>

The fifth phase extends from 1997 to the present and corresponds to the integration of TCMS with Intelligent Transport Systems: Urban Traffic Management and Control Systems (UTMCS). These links are designed to allow different applications used within traffic management

systems to communicate and share information with each other (Department of transport, 2009).

One of the advantages of using UTMCS is that the operators can inform road users of congestion of accidents in the network and re-route them accordingly, or inform motorist of available parking facilities in the city centres (Hamilton et al. 2013).

In the future phases, new communications technologies could be applied to change the impact on urban traffic control systems. One of the solutions that could be applied would be the communication between vehicles to quickly share information about congestions.

If we continue developing technology advances towards the decrease of human help, the future will be based on TCMS more intuitive and which will run without human assistance.

Developing intelligent automated systems, computers will be able to make decisions about how to best control the traffic signals if the average delay per vehicle could be monitored. This type of control system is based on Logistic Regression and Neural Networks.

2.2. Different proposed approaches to solve traffic congestions problems

Different approaches have been investigated during this literature review to examine how several authors propose a solution for the problem we want to solve in this thesis.

First, (Basconcello et al. 2017) proposes the use of NetLogo, a multi-agent programmable modelling environment to create a traffic model and simulation environment to simulate and test a developed fuzzy logic system.

A Fuzzy Logic controller implements real life commands to work as humans would think. It is applied to make decisions when it receives the estimated number of pedestrians and vehicles approaching the studied junction and it gives priority to the one with bigger density.

The duration of the traffic lights green times are calculated as a combination of the densities of pedestrians and vehicles and with the combination of both of them, the Fuzzy Logic generates different outputs to create the signals.

The second studied paper advocates for the use of Intelligent Traffic Light Control with Collaborative Q-Learning Algorithms to optimize the waiting time in junctions. For the simulation process, the authors have used Green Light District Simulator.

For this study, the applied method considers traffic states in an intersection and its adjacent ones.

Q-learning is one method from reinforcement learning with a model-free approach (Rosyadi et al. 2016). Q-learning does not need to have access to the real traffic demand; it applies statistical estimated input values called Q-values to make decisions. Thus, it is not necessary the use of detectors for the application of this method.

Next analysed work applies an adaptive traffic light system based on wireless communication between vehicles and fixed controller nodes deployed in intersections (Gradinescu et al. 2007).

This method assumes that the vehicles are equipped with a wireless communication device and also the controller node located in the controlled intersection. Then with an Intelligent Transportation System, the vehicles exchange information about road conditions.

The aim of this study is to minimize the delay of vehicles approaching the junction, reducing the queue length and reducing the fuel consumption and emissions.

The simulation run in this work focuses on the comparison between two different scenarios: a fixed controlled one and the proposed adaptive strategy using communication between the controller and vehicles.

Last but not least, (Sinha et al. n.d.) proposes a design process nearly equal to the method that will be used in this dissertation. Their approach combines Aimsun as a micro-simulator with the difference that they take Simulink to develop the control modelling, instead of Python language.

This paper exposes the use of Simulink to create a SCATS controller and Aimsun micro-simulator to model a multi intersection network. Then a link between these two structures is made by applying Aimsun API extensions.

3. Modelling of A52 intersection in Aimsun

After analyzing the different approaches to duplicate a network and control its traffic system management, Aimsun was the chosen software for modelling the A52 intersection. Thus, it will be used to generate traffic data and analyzing the results of the control implementation.

This chapter is about how the A52 junction has been replicated. It will explain which roads it contains and turns, where the detectors are located. It also contains the vehicle types that are going to be used in the simulation and in which quantity and time intervals.

The A52 junction object of this project is an intersection in which the A52 crosses with Stragglethorpe Rd. and an unpaved road (not taken into account). The A52 is a two-lane, two-way road which splits in a third lane just before the junction of the west part to allow the south turn (towards Stragglethorpe Rd.). This last road is a single-lane, two-way road that also splits in a third lane for the west turn.

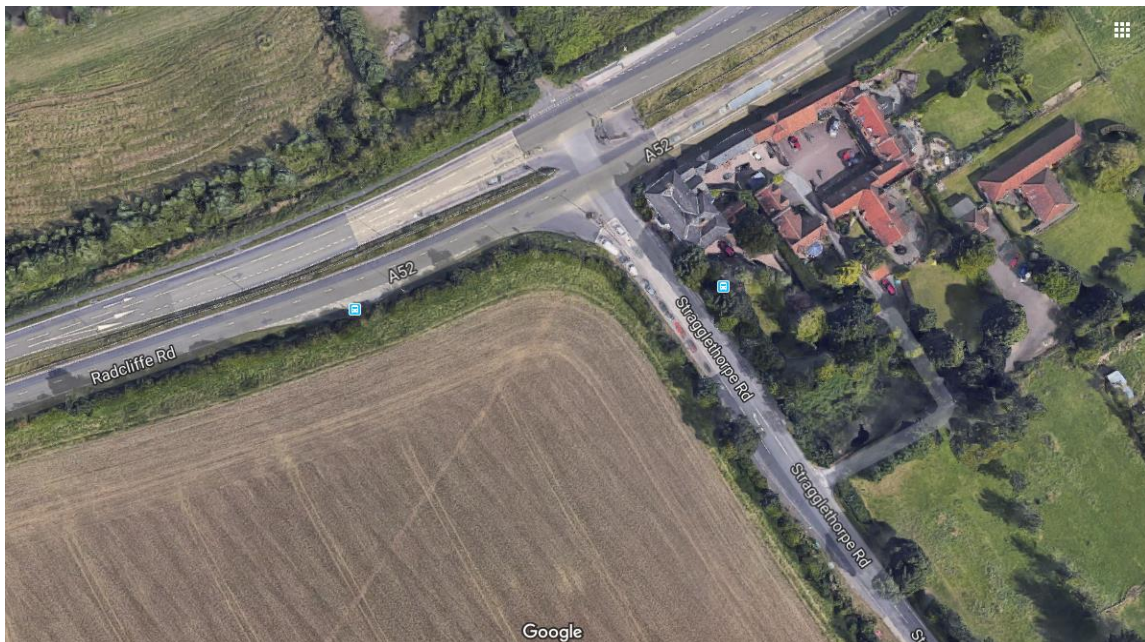


Figure 1. Aerial View of the A52 junction

The allowed turns in this junction are:

- East – South
- East – West
- West – East
- West – South
- South – East
- South – West

3.1. Infrastructure

As this is a project developed by a team, the steps for this part of the modelling process were taken other colleagues.

First of all, a picture from the intersection map was exported to the software to take it as a guide.

Then, with the tool called “Create a Section”, all of the lanes were created. After that, with the option “Create a Junction”, three of them were created: the main one and two more for the lanes that split. This is, a junction to link a lane with the two lanes in which it is divided to allow turns.

Once the roads and the junctions were set, the adjustments for their shape and turns were done.

The next step was creating the centroids: ‘points’ to set the origin and/or destinations of trips in the network. They are three (one for each destination) and are connected to the sections. They are called: West, East and South.

The next part of the infrastructure to set was the detectors. They are going to be used to know some information about traffic and also to take the some decision when controlling the traffic lights. They are eight: five near the stop lines and three far away from them. The nearest ones are used to actuate (by Aimsun) and the furthest ones for extending green times (by the controller).

Last, the three existing bus stops were also placed in their corresponding lanes.

Next tables show data corresponding to the junctions, sections and detectors.

Table 3. Junctions with their connected sections

JUNCTIONS	
ID	Connections (Sections)
927	870 - 871 - 876 - 877 - 879 - 880 - 881 - 882
201064	870 - 871 - 872
885	881 - 882 - 884

Table 4. Sections

SECTIONS	
ID	Description
870	From West to East (West side of the junction)
871	From West to South (West side of the junction)

872	From West to East and South (West side of the junction)
876	To East (East side of the junction)
877	From East (East side of the junction)
879	To West (West side of the junction)
880	To South (South part of the junction)
881	From South to East (South part of the junction)
882	From South to West (South part of the junction)
884	From South to East and West (South part of the junction)

Table 5. Detectors

Detectors	
ID	Description
1049	From South to East 2 nd detector
1051	From South to West 2 nd detector
1052	From South 1 st detector
1053	A52 from East to West and South 2 nd detector
1054	A52 from East to West and South 1 st detector d1
13242835	A52 from East to West and South 1 st detector d2
201063	A52 West East South detector 1
201105	A52 West East detector 2
201106	A52 West South detector 2

The next table shows the distances between the detectors and the stop lines:

Table 6. Distance from the loop to the stop line

Distance from the loop to the stop line					
West loops		East loops		South loops	
A52 West East South detector 1	126.5 m	A52 from East to West and South 1st detector d1	36 m	From South 1st detector	83.2 m
A52 West East detector 2	42.5 m	A52 from East to West and South 1st detector d2	48 m	From South to West 2nd detector	31.7 m
A52 West South detector 2	40 m	A52 from East to West and South 2nd detector	12 m	From South to East 2nd detector	31.85 m

3.2. Vehicle types

For the time being, just two types of vehicles are interacting in our simulation: cars and trucks. For the future work, public transport lines and some other types of vehicles as motorbikes and trucks with different dimensions will be used.

3.2.1. Cars

The name given to this vehicle type in Aimsun is 'Car'.

Their dimensions are set as follows:

Table 7. Car specifications

	Average	Deviation	Minimum	Maximum
Length	4,00 m	0,5 m	3,50 m	4,50 m
Width	2,00 m	0,00 m	2,00 m	2,00 m
Maximum Desired Speed	110,00 km/h	10,00 km/h	80,00 km/h	150,00 km/h

For emission vehicle type, it was selected as Car.

The 'Slope velocity affected by the weight' was selected so the weight of the car is:

Table 8. Car weight

	Average	Deviation	Minimum	Maximum
Weight	1202 kg	454 kg	839 kg	2291 kg

3.2.2. Trucks

As in the future it will be desired to add other truck vehicle types with different dimensions, for the time being the truck that is being used is called 'LongTruck'.

The next table shows the given dimensions for trucks:

Table 9. Truck specifications

	Average	Deviation	Minimum	Maximum
Length	12,00 m	0,00 m	12,00 m	12,00 m
Width	2,50 m	0,00 m	2,50 m	2,50 m
Maximum Desired Speed	90,00 km/h	10,00 km/h	70,00 km/h	100,00 km/h

For emission vehicle type, it was selected as Heavy Goods Vehicle (HGV). And its fuel type is 100% Diesel.

This type of vehicle speed is also set as affected by its weight in slopes so the weight parameters are:

Table 10. Truck weights

	Average	Deviation	Minimum	Maximum
Weight	13608 kg	4536 kg	11340 kg	18144 kg

3.3. OD Matrices

OD matrices are used to calculate the traffic demand. Each one of these matrices gives the number of trips from every origin centroid to every destination centroid for a time interval and a vehicle type.

In this case, the data was taken from files of the real vehicles counting in the junction for calculating our matrices.

Three matrices were calculated:

- Monday 7-9am (Monday 7:00 to 9:00 Total)
- Monday 12-14pm (Monday 12:00 to 14:00 Total)
- Sunday 7-9am (Sunday 7:00 to 9:00 Total)

The next line shows an example of the data taken from the junction detectors:

12/ 8 7:00 TOTIN= 415 TOTX= 424 XFL= 139 33 168 13 42 24 5

The 'XFL' part corresponds to the vehicle counting and it shows the number of vehicles that passed through the detectors the 12/08/2018 from 7am to 8am.

The first two numbers are the vehicles going from east to west and south; the following two numbers are vehicles going from west to east; then, the next one belongs to the west to south turn; next one is from south to west and last one, south to east.

For Monday, which is the day of the week that that is going to be simulated in this project, the data for the 3rd of September of 2018 (as a sample day) has been selected from 7am to 9am and the vehicle count of both time intervals has been added for each detector.

As the data from first and second detector take into account vehicles going East-West and East-South. Approximately 15% of them were considered as East-South.

Then this OD Matrix was rounded, being:

Table 11. Total OD matrix

	West	South	East	Total
West	0	420	2100	2520
South	650	0	25	675
East	1000	200	0	1200
Total	1650	620	2125	4395

Once introduced this matrix in Aimsun, it was split into two sub-matrices: for cars and trucks, considering the number of trucks as the 20% of the total number of vehicles. Then, they were rounded too, being the next one for cars:

Table 12. Truck OD matrix

	West	South	East	Total
West	0	336	1680	2016
South	520	0	20	540
East	1200	320	0	1520
Total	1720	656	1700	4076

And the next one for trucks:

Table 13. Car OD matrix

	West	South	East	Total
West	0	84	420	504
South	130	0	5	135
East	200	40	0	240
Total	330	124	425	879

3.4. Traffic demand

In order to create a traffic demand, a set of OD Matrices for the types of vehicles desirable to run in our scenarios has been selected, being possible to set several time intervals with different vehicle types and quantities.

For this work, as the simulation desirable to run belongs to a Monday morning differentiating between peak and off-peak hours, the traffic demand contains four OD Matrices:

1. Cars from 6:30 to 9:00. 125% factor of increment in the number of cars.
2. Trucks from 6:30 to 9:00. 125% factor of increment in the number of trucks.
3. Cars from 9:00 to 12:00. 105% factor of increment in the number of cars.
4. Trucks from 9:00 to 12:00. 105% factor of increment in the number of trucks.

Note that the time interval from 6:30 to 9:00 is considered as peak and from 9:00 to 12:00 is off-peak.

Here, in the traffic demand, some assumptions have been done. For both peak and off-peak hours, the percentage of increment has been applied because of the following reasons:

- The same OD Matrices have been used for both time intervals, but the percentage in peak is bigger than in off-peak to take into account that there is more traffic at the early morning.
- The real data were measured from 7am instead of 6:30, so this half hour has also been taken into account increasing that percentage in peak hours.
- During the first simulations, there was not enough traffic coming to the junction, so the decision of increasing the number of vehicles was taken to have a better appreciation of the controller performance.

The name of the traffic demand is *1.1. Monday 6:30 - 12:00 20%Trucks EAST REDUCED* and the following figure shows a summary of it:

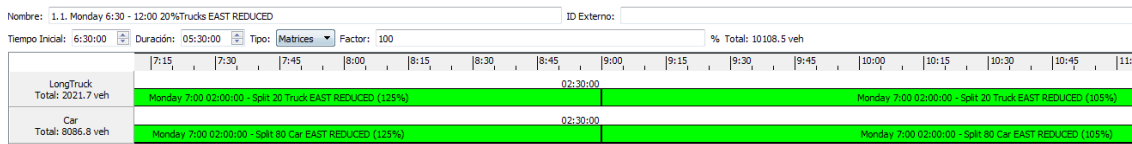


Figure 2. Traffic demand

The next figure shows the overall view of the intersection modelling:

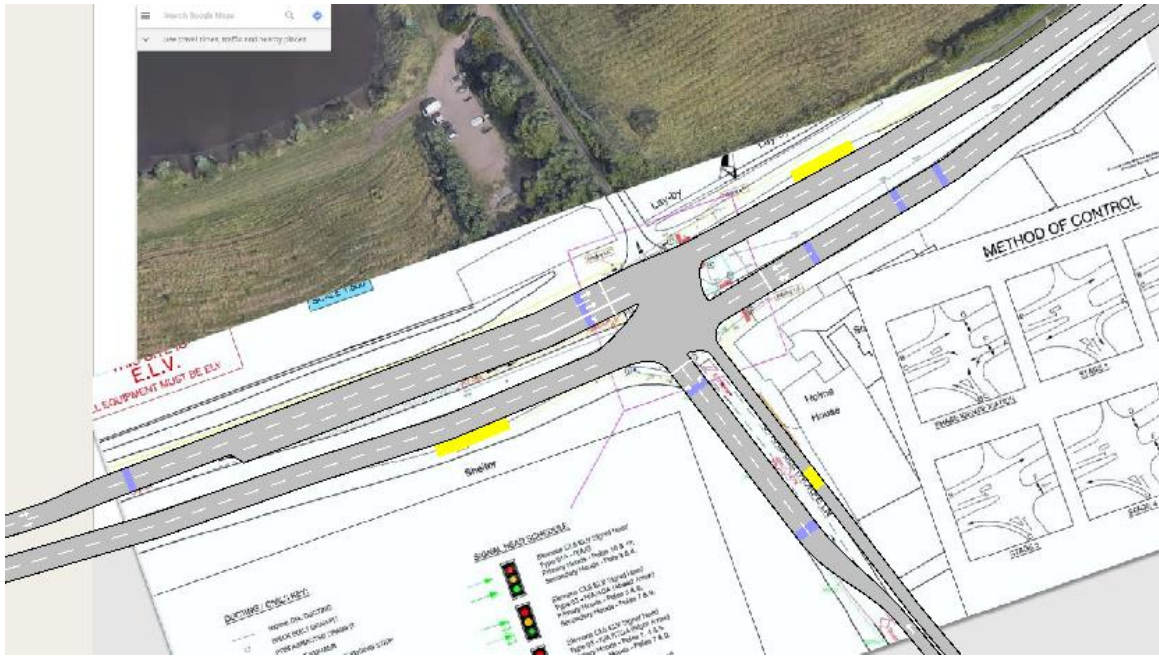


Figure 3. A52 junction modelled in Aimsun

Once the infrastructure of our junction has been set and the information about the type and quantity of users interacting in it has been introduced, the next chapter can be explained. Along it, the creation of the control set up and also the scenarios will be presented, which will use the settings from chapter 3 to generate an environment for our simulations.

4. Control Plans and signalized intersection modelling and control

Thanks to the data introduced in Aimsun that has been explained in the previous chapter, it is possible to set the control settings for our case of study.

The fourth chapter is dedicated to the explanation of the number of control plans that have been created with their characteristics and how they are combined to form master plans.

The last part of the chapter corresponds to the scenarios set to run the simulations for this project.

4.1. Control Plans

A Control Plan is set to specify the control parameters applied to the junction. The main parameters used in a Control Plan for a junction are:

- Control type: unspecified, uncontrolled, fixed control, external or actuated.
- Offset: this is for the case in which several junctions are controlled at the same time. This does not apply to our case.
- Phases: different time periods of green signal corresponding to each turn.

In this case, five different Control Plans will be set: three fixed and two actuated ones.

The difference between fixed and actuated Control Plans is that in the fixed ones the green time of a phase is always the same for the whole simulation period; however, an actuated control plan can change its green times depending on some specific parameters and settings.

The allowed turns for the phases of the A52 junction are:

- Phase 1: East – West and West – East.
- Phase 2: West – East and West – South.
- Phase 3: West – East and South – West.
- Phase 4: South – West.
- Phase 5: South – West and South – East.

The number of phases changes in the Control Plan settings because an interphase is introduced between each of them. The interphase is used to clear the junction from vehicles to avoid crashes when there are different turns between phases.

Thus, there will be ten phases; phase 1 will be still called the same, then phase 2 is a 5 seconds interphase, phase 2 becomes phase 3, phase 4 is a 4 seconds interphase, phase 3 becomes phase 5, phase 6 is a six seconds interphase, phase 4 becomes phase 7, phase 8 is a 4 seconds interphase, phase 5 becomes phase 9 and finally, there is a 6 seconds interphase (phase 10). Hereinafter, the phases will be called as they appear in the Control Plans. Next figure shows an example of a Control Plan, in which the dark green phases are the interphases.

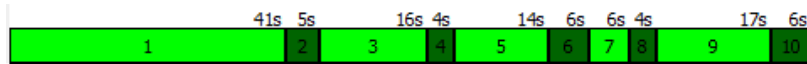


Figure 4. Example of a CP

All the simulations that are going to be run for this project belong to a Monday morning from 6:30 to 12:00 because the weekdays are the busier ones in the junction. The time interval is set to differentiate between peak hours (6:30 to 9:00) and off-peak hours (9:00 to 12:00). To calculate the green times, an average of green times from several Mondays in 2018 has been used.

As for the traffic demand, the data for the green times has been collected from the detectors placed in the A52 junction.

All of the CP set for this project have the same yellow time (3 seconds) and the same red percentage (60%), which is the percentage of yellow time considered as red.

The specific characteristics and configuration of each of the Control Plans are:

1. 1. FIXED Control Plan A52 Peak hours

This Control Plan is fixed. To create it, an average of the green times data for each phase has been done from 6:30 to 9:00. The green times of each phase are:

- Phase 1: 42 seconds
- Phase 3: 16 seconds
- Phase 5: 15 seconds
- Phase 7: 6 seconds
- Phase 9: 17 seconds

Consequently, the cycle time of the Control Plan is 121 seconds.

As this is a Fixed Control Plan, no more parameter settings are necessary.

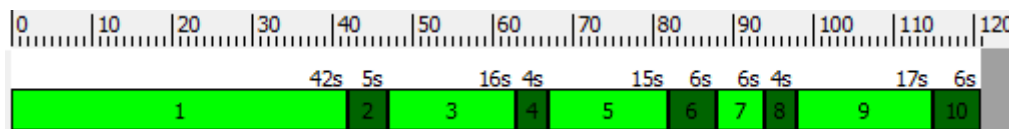


Figure 5. Fixed CP peak hours

2. 2. FIXED Control Plan A52 Off Peak hours

This Control Plan is the complementary to the previous one; it sets the green times for the interval between 9:00 and 12:00.

- Phase 1: 41 seconds
- Phase 3: 16 seconds

- Phase 5: 13 seconds
- Phase 7: 6 seconds
- Phase 9: 17 seconds

The cycle time becomes 118 seconds.

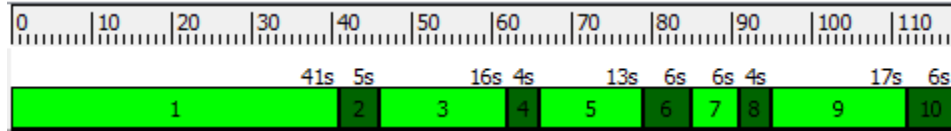


Figure 6. Fixed off-peak hours

3. 3.d1 ACTUATED Control Plan A52 Peak hours

This Control Plan will be used for adapting the phases' green times according to the traffic volume during peak hours.

The green times of each phase are the same as for the second CP. But the differences between them are the actuated parameters and the use of detectors for this case.

A summary of how the detector configuration should be done in actuated CP is shown below.

1. Far detectors: to extend green time.

Always LOCKING (Locking = YES). The detector counts the number of vehicles crossing it during the yellow and red time of its phase. This mode can be useful to take the decision of extending the minimum green time. Locking mode is for detectors placed far from the stop line.

Extend green time: When it is set to YES, the detector signal is considered if its associated phase is running. If controlling the phase by API= YES. If not = NO.

Call phase: When it is set to YES, the detector signal is considered if its associated phase is not the running one. Always YES.

2. Near detectors: to actuate.

Always NON - LOCKING (Locking = NO).

Extend green time: NO

Call phase: NO

The settings for each of the phases are as follows:

- Phase 1

This phase will be used in the API to take the decision of control.

Actuated parameters:

- Minimum Recall, the phase will be activated at least for its minimum green time.
- Minimum Green: the phase will always stay green for at least 7 seconds.
- Max-Out: the green time can be extended up to 42 seconds. Note that this can vary when an API to control the junction is used.
- Passage Time: the maximum allowed time difference between detector actuations is 3 seconds, which is the time needed to reach the stop line from the detector.

Detectors:

Table 14. 3d1 Actuated control plan A52 peak hours phase 1 detector setting

ID	Locking	Delay	Extension	Extended Green Time	Call Phase
201063	YES	0	0	YES	YES
201105	NO	0	0	NO	NO
1054	YES	0	0	YES	YES
1053	NO	0	0	NO	NO

- Phase 3

Actuated parameters:

- No Recall, it will be only activated if a demand has been detected, if not, it will be skipped.
- Minimum Green: 7 seconds.
- Max-Out: 16 seconds.
- Passage Time: 3 seconds.

Detectors:

Table 15. Actuated control plan A52 peak hours phase 3 detector setting

ID	Locking	Delay	Extension	Extended Green Time	Call Phase
201063	YES	0	0	NO	YES
201106	NO	0	0	NO	NO
201105	NO	0	0	NO	NO

- Phase 5

Actuated parameters:

- No Recall.
- Minimum Green: 7 seconds.
- Max-Out: 15 seconds.
- Passage Time: 3 seconds.

Detectors:

Table 16. Actuated control plan A52 peak hours phase 5 detector setting

ID	Locking	Delay	Extension	Extended Green Time	Call Phase
1052	YES	0	0	NO	YES
201063	YES	0	0	NO	YES
201105	NO	0	0	NO	NO
1051	NO	0	0	NO	NO

- Phase 7

Actuated parameters:

- No Recall.
- Minimum Green: 6 seconds.
- Max-Out: 6 seconds.
- Passage Time: 3 seconds.

Detectors:

Table 17. Actuated control plan A52 peak hours phase 7 detector setting

ID	Locking	Delay	Extension	Extended Green Time	Call Phase
1052	YES	0	0	NO	YES
1051	NO	0	0	NO	NO

- Phase 9

This phase will be used in the API to take the decision of control.

Actuated parameters:

- No Recall.
- Minimum Green: 7 seconds.
- Max-Out: 17 seconds.
- Passage Time: 3 seconds.

Detectors:

Table 18. Actuated control plan A52 peak hours phase 9 detector setting

ID	Locking	Delay	Extension	Extended Green Time	Call Phase
1052	YES	0	0	YES	YES
1051	NO	0	0	NO	NO
1049	NO	0	0	NO	NO

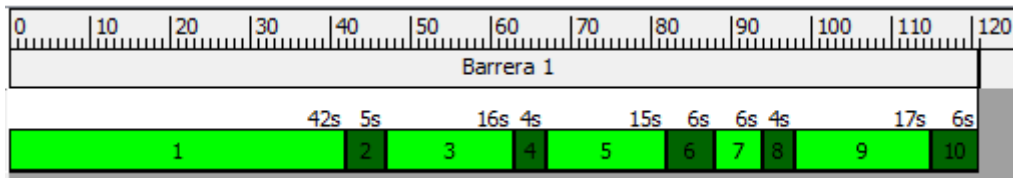


Figure 7. Actuated control plan A52 peak hours

4. 4.d1 ACTUATED Control Plan A52 Off Peak hours

This last CP is the complementary to the third one. They have the same actuated and detector parameters but with different green times, which are the same as the second Control Plan.

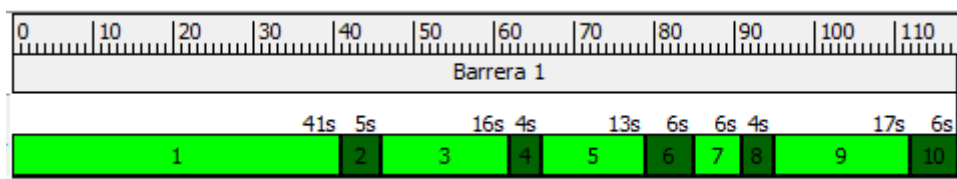


Figure 8. ACTUATED Control Plan A52 Off Peak hours

Two additional Control plans called 3.d2 ACTUATED Control Plan A52 Peak hours 4.d2 ACTUATED Control Plan A52 Off Peak hours and have also been created to investigate the traffic management system performance with different detector positions. The only difference between them and the two previous ones are the replacement of the detector 1054 in phase 1 by the detector 13242835, which is located further.

3.d2 ACTUATED Control Plan A52 Peak hours:

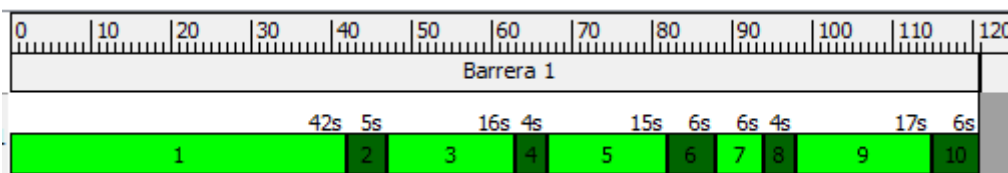


Figure 9. 3.d2 ACTUATED Control Plan A52 Peak hours

4.d2 d2 ACTUATED Control Plan A52 Off Peak hours:

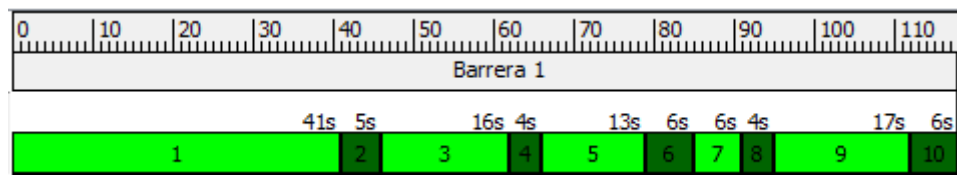


Figure 10. ACTUATED Control Plan A52 Off Peak hours

5. 3.d1 ACTUATED Control Plan A52 Peak hours - For normal

This CP will be used for the case in which the phases green times will be actuated but the APIs will not be used. So, the CP settings are very similar to the ones of *3.d1 ACTUATED Control Plan A52 Peak hours* but with different Max-Out for phases 1 and 9. These two phases will be the ones that will be extended (if necessary).

The Max-Out for these two phases is 80 seconds.

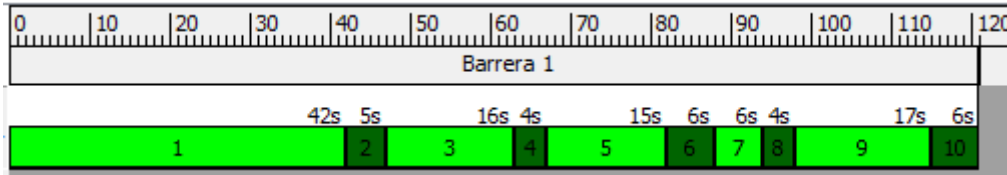


Figure 11. The Max-Out for these two phases is 80 seconds.

6. 4.d1 ACTUATED Control Plan A52 Off Peak hours - For normal

This CP is set as *d1 ACTUATED Control Plan A52 Off Peak hours* but changing the Max-Out of phases 1 and 9 to 80 seconds.

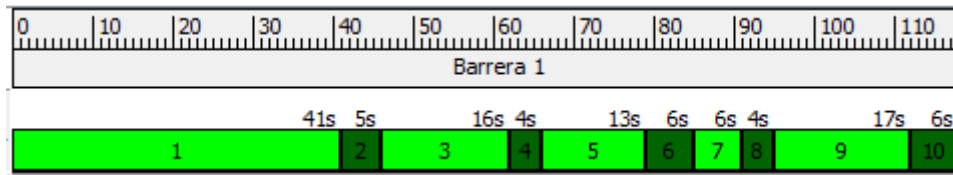


Figure 12. ACTUATED Control Plan A52 Off Peak hours - For normal

4.2. Master Control Plans

A Master Control Plan is a series of Control Plans that are assigned to a scenario and used to control the signals in that scenario (*Aimsun Help Section n.d.*). A Master Control Plan is useful when it is necessary to create a scenario with several Control Plans.

For this project, three Master Control Plans have been created:

1. 1.Master Control Plan FIXED

This MCP starts at 6:30 and lasts 5:30 hours. It contains two CP:

- 1. FIXED Control Plan A52 Peak hours
- 2. FIXED Control Plan A52 Off Peak hours

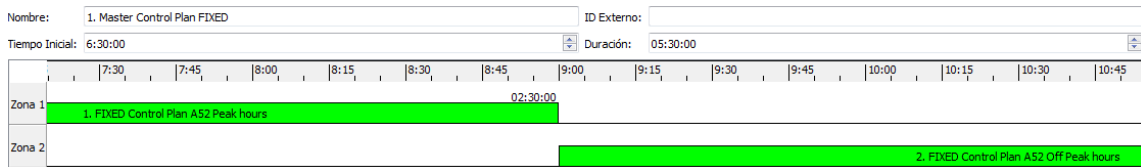


Figure 13. 1. Master Control Plan FIXED

2. 2.Master Control Plan ACTUATED Normal

This MCP starts at 6:30 and lasts 5:30 hours. It contains two CP:

- 3. d1 ACTUATED Control Plan A52 Peak hours - For normal
- 4. d1 ACTUATED Control Plan A52 Off Peak hours - For normal

It will be used in a simulation in which extensions in green times will be performed but without an API interaction.

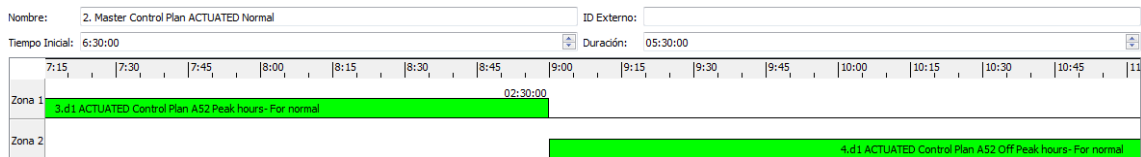


Figure 14. 2. Master Control Plan ACTUATED Normal

3. 3.d1 Master Control Plan ACTUATED Python

This MCP is similar to the second one, but it contains the third and the fourth Control Plans. It will be used for the dynamic scenario in which the API will be applied taking data from the detector position 1.

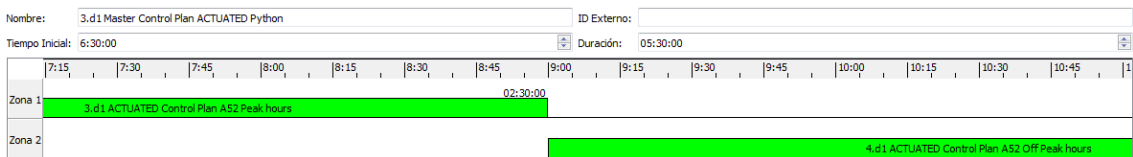


Figure 15. 3.d1 Master Control Plan ACTUATED Python

4. 3.d2 Master Control Plan ACTUATED Python

This MCP is composed by the *3.d2 ACTUATED Control Plan A52 Peak hours* *4.d2 ACTUATED Control Plan A52 Off Peak hours* Control Plans and it will be also run with an API. But in this case, the detector for extension will be the one in second position.

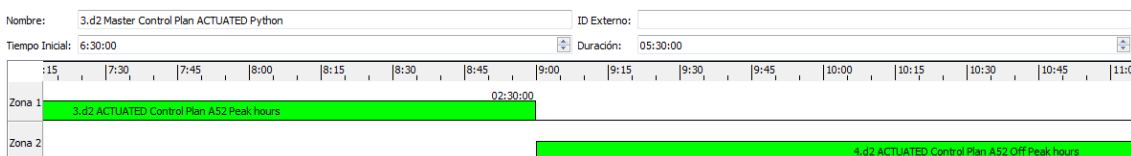


Figure 16. 3.d2 Master Control Plan ACTUATED Python

4.3. Dynamic Scenarios

A Dynamic Scenario is a set of traffic conditions and Control parameters used to simulate experiments. It assembles all the needed conditions during a simulation to generate the desired data or outputs.

The minimum requirement for create one of them is a transport network and a traffic demand. Then, it can also contain a Public Transport Plan, a Master Control Plan, Traffic Management Actions, APIs, etc.

Three Dynamic Scenarios have been created to be able to collect data in order to develop this project. For each of them, ten replications will be run, what means ten simulations with different random traffic display (but always with the same vehicle quantity set in the traffic demand). Then an average of the ten replications will be calculated to obtain results.

These are the four Dynamic Scenarios with their settings:

1. 1 LF

The traffic demand used will be 1.1. Monday 6:30 – 12:00 20% Trucks. The MCP will be 1. Master Control Plan FIXED. The results will be saved on the Data Base using SQLite with an interval of 10 minutes.

As the CP used in this scenario is fixed, no API will be used for the simulation.

2. 1 LAn

The traffic demand for this scenario is the same as the fixed one. The MCP considered for the simulations will be 2. Master Control Plan ACTUATED Normal. And none API will be used for this case.

The results will be also saved on the Data Base using SQLite with an interval of 10 minutes.

3. 1 LApd1

This Dynamic Scenario will be run with the same traffic demand as the previous one and the data will be stored in the same way. The MCP used will be 3.d1 Master Control Plan ACTUATED Python.

Then, as this is an actuated experiment, an Aimsun Next API will be used. Its name is *A52_change_passagetime_pd1.py* and it will be explained in the next chapter.

4. 1 LApd2

The last Dynamic Scenario is set as the third one but the MPC and the API are different ones. The MCP used is 3.d2 Master Control Plan ACTUATED Python. The API's name is *A52_change_passagetime_pd2.py* and it will also be explained in chapter 5.

Once all the scenarios and inputs for our cases of study and simulations have been set and explained, it is only necessary to specify which are the APIs that will take part in the two last scenarios. The explanation of them will be developed in chapter 5. Then, it will be possible to obtain the results for chapter 6.

5. Modelling of API in Python language

The last two Dynamic Scenarios explained in the previous chapter use APIs in their simulation parameters. This means that an external traffic controller is going to be applied when their corresponding replications are run.

An API is a set of routines, protocols and tools used for the aim of accessing to functions of a certain software (*What Is API - Application Program Interface? Webopedia Definition 2019*). What an API does is specifying how to different software components should interact.

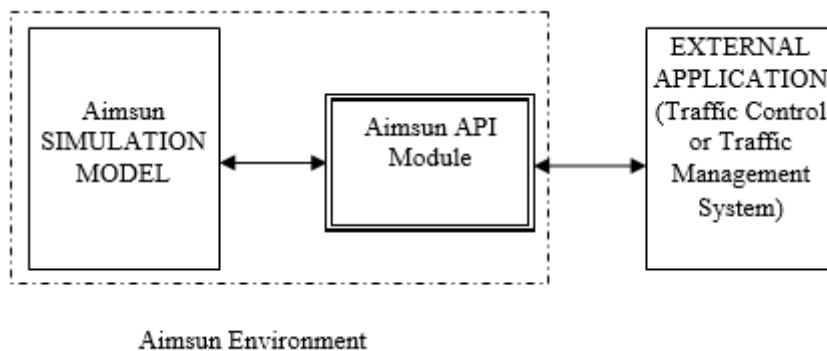


Figure 17. Aimsun API External Controller

The aim of using APIs in our simulations is to program operations to adapt the green times of selected phases to traffic conditions.

For our case of study, the use of APIs will be coding two Python language scripts using Visual Studio Code as software.

A Python script should define the fourteen high level functions: `AAPILoad()`, `AAPILoadInit()`, `AAPIManage(...)`, `AAPIPostManage(...)`, `AAPIFinish()`, `AAPILoadUnLoad()`, `AAPIPreRouteChoiceCalculation(...)`, `AAPILoadEnterVehicle(...)`, `AAPILoadExitVehicle(...)`, `AAPILoadEnterPedestrian(...)`, `AAPILoadExitPedestrian(...)`, `AAPILoadEnterVehicleSection(...)` and `AAPILoadExitVehicleSection(...)`. All high level functions must be defined in the file for it to be run successfully (*Aimsun Help Section* n.d.). So, these thirteen functions will appear in both of our codes.

This chapter is about to explain these controllers, the functions they contain and the behavioral changes they cause in our Traffic Management System.

5.1. Change Passage time pd1

The API script applied to the third Dynamic Scenario is called `A52_change_passagetime_pd1.py`.

The purpose of coding this controller is changing the passage time, this is the time needed to reach the stop line from the detector. This control action will be only applied to trucks, which are the slow vehicles driving along the network. This passage time will be calculated taking into account the speed of these vehicles when they cross the detector. For the time being, actuations will be only applied to phase 1 and 9.

Below, the most important lines of the code are explained.

1. Import of the necessary libraries.
2. *AAPILoad()*
3. *AAPIInit()*. This high level function is used to store the network variables and it contains:
 - Declaration of variables that are going to be used in the program.
 - Activation of the model.
 - Setting of the path for the creation of a simulation data document.
 - Setting variables for vehicles detected and controlling the junction to False.
 - Setting the normal phase duration to 7 seconds + 3 seconds (1 green time + 1 passage time).
 - Setting the maximum phase duration to 80 seconds. This will be the maximum time that a phase will be extended in case of actuation.
 - Setting the percentage of speed reduction before the stop line to 40%. This means that it will be considered that the vehicles will reduce their speed by 40% when they arrive to the junction to turn.
 - Truck length: 12 meters.
 - Setting the ID of the junction that is aimed to be control (927), the phases that are aimed to actuate and their corresponding detectors, sections that vehicle will use to exit and enter the junction.
 - Several functions created by Aimsun to find the detectors and their positions.
 - Two functions plus a 'for' loop to find the index of the junction.
 - Several functions plus a 'for' loop to find the name and the position of the LongTruck between all the vehicles.
4. Function to move to the next phase of the control plan.
5. *AAPIManage(...)*.
6. *AAPIPostManage(...)* This function is used to modify everything inside it, this is, to apply the control itself.
 - Declaration of variables.
 - Setting variables for detected vehicles to False.
 - Getting the current phase from point 4.
 - Setting that the detector has detected presence to False.
 - Creation of an array to store the future extra time needed.
 - 'For' loop to track vehicles in the sections where the detectors are placed and to obtain various information about them, such as speed and position.

'If' to check if the current green phase is some of the ones that are being controlled, with another 'if' inside checking if the tracked vehicle is in the

section in green. Then it checks if the vehicle has passed the detector + 2 meters (+ the truck length to ensure that even a truck crossed), if so, the variable for the detector has detected presence becomes true.

'If' function to calculate the extra time needed to let the vehicle cross the junction depending on its speed. 'If' to create a string with the color of the phase. Last function to write in the output file: time, ID of the tracked vehicle, its type, speed, its position in the section, the color of the phase and the actual phase.

- 'If' to skip everything in the case that the current green phase is not any of the phases to be controlled.
- Functions to find the associated detector to the current phase and to check that the vehicle crossing this detector is a truck.
- 'If' function to print and write in the output file that the phase detector had truck presence.
- 'If' checking that the phase that is aiming to be controlled is not active, what it means that it is just about to start. Then it calculates the end time of the phase as the current time plus the normal phase duration, and the start time of the phase as the current time. Then it sets the phase as active.
- 'If' checking that the phase that needs to be controlled is active, that the detector had presence and the detected vehicle is a truck.
 - a) 'If' truck detected:

'If' the current time + the extra time needed is less than the start time of the phase + the normal phase duration, then it prints in Aimsun and also writes in the output file that the truck has plenty of time to pass.

'elif' the current time + the extra time needed is higher or equal than the start time of the phase + the normal phase duration and the current time + the extra time needed is less than the start time of the phase plus the maximum phase duration, then it calculates the end time of the phase as the current time plus the extra time needed. It also prints in Aimsun and writes in the output file the next statement: "Controlling the junction. The time to give control back to Aimsun is 'the end time of the phase' at this time phase will have been for 'end time of the phase – start time of the phase'. Reason TRUCK. Extratime: 'extra time according to this speed'".

Controlling the junction variable set to True.

- b) 'Else': printing and output file writing that there has not been presence detected, so the end time still will be the end time of the phase.
- 'If' the phase to be controlled is active and 'if' the time is higher than the end time of the phase and the junction is being controlled:

Printing and writing that control back to Aimsun is being given at the current time.

Calling to 'the getting next phase' function.

Controlling the junction set to False and also the phase that is being controlled.

7. AAPIFinish()
8. AAPIUnLoad()
9. AAPIPreRouteChoiceCalculation(...)
10. AAPIEnterVehicle(...)
11. AAPIExitVehicle(...)
12. AAPIExitPedestrian(...)
13. AAPIEnterVehicleSection(...). This function is called every time a vehicle enters a section. It starts tracking a vehicle when it enters one of the entrance sections and stops tracking it when it enters one of the exit sections.
14. AAPIExitVehicleSection(...)

5.2. Change Passage time pd2

This script is exactly equal as the previous one but changing the detector for phase one to be able to run a simulation with a different position for the extension detector. Its name is *A52_change_passagetime_pd2.py*.

The explanation of the two python scripts that are going to be used for the APIs of the actuated Dynamic Scenarios of our simulations have been developed in this chapter.

A comparison of their performance will be hold in the next chapter and also a comparison of the use of these APIs with running fixed control plans and actuating them but without their interaction.

6. Simulation of Studies

After modelling the junction, setting the control parameters and configurations and developing the code for the controller, four simulations have been run.

Each of these simulations belongs to the scenarios configured in Aimsun. The way of running them was: to simulate the ten replications set for each scenario and then calculate the average results.

This chapter is divided in two subchapters, the first one is dedicated to the presentation of the simulations' results and the second one is about to make comparisons between them.

6.1. Results

6.1.1. 1 LF

The results corresponding to the Fixed Dynamic Scenario are:

Table 19. LF results

Time Series	Value	Standard Deviation	Units
CO2 - All	0	ND	g/km
CO2 - Car	0	ND	g/km
CO2 - LongTruck	0	ND	g/km
Mean Queue - All	11,1	0,64	veh
Mean Queue - Car	8,93	0,53	veh
Mean Queue - LongTruck	2,17	0,14	veh
Max. Virtual Queue - All	4,5	0,85	veh
Max. Virtual Queue - Car	3,2	0,42	veh
Max. Virtual Queue - LongTruck	3,4	0,7	veh
Mean Virtual Queue - All	0,09	0,01	veh
Mean Virtual Queue - Car	0,02	0	veh
Mean Virtual Queue - Truck	0,07	0	veh
Fuel Consumption - All	0	0	l
Fuel Consumption - Car	0	0	l
Fuel Consumption - LongTruck	0	0	l
Input Count - All	10159,2	ND	veh
Input Count - Car	8100,3	ND	veh
Input Count - LongTruck	2058,9	ND	veh
Density - All	7,23	0,18	veh/km
Density - Car	5,62	0,14	veh/km
Density - LongTruck	1,62	0,05	veh/km
Total Travelled Distance - All	11057,4	124,04	km

	2		
Total Travelled Distance - Car	8817,09	99,74	km
Total Travelled Distance - LongTruck	2240,33	60,83	km
Total Travelled Distance (Vehicles Inside) - All	18,9	3,76	km
Total Travelled Distance (Vehicles Inside) - Car	14,91	3,23	km
Total Travelled Distance (Vehicles Inside) - LongTruck	3,99	1,21	km
Flow - All	1846	20,41	veh/h
Flow - Car	1471,67	16,2	veh/h
Flow - LongTruck	374,33	10,23	veh/h
Input Flow - All	1847,13	20,73	veh/h
Input Flow - Car	1472,78	16,32	veh/h
Input Flow - LongTruck	374,35	10,38	veh/h
Missed Turns - All	61,2	17,68	
Missed Turns - Car	35,4	11,17	
Missed Turns - LongTruck	25,8	7,55	
NOx - All	0	ND	g/km
NOx - Car	0	ND	g/km
NOx - LongTruck	0	ND	g/km
Number of Lane Changes - All	2007,25	32,45	#/km
Number of Lane Changes - Car	1707,36	29,48	#/km
Number of Lane Changes - LongTruck	299,89	11,53	#/km
Number of Stops - All	0,08	0	#/veh/k m
Number of Stops - Car	0,09	0	#/veh/k m
Number of Stops - LongTruck	0,08	0	#/veh/k m
Total Number of Lane Changes - All	11403,2	184,37	
Total Number of Lane Changes - Car	9699,5	167,48	
Total Number of Lane Changes - LongTruck	1703,7	65,48	
Total Number of Stops - All	4852,8	177,1	
Total Number of Stops - Car	3924,27	138,32	
Total Number of Stops - LongTruck	928,53	45,26	
Delay Time - All	29,01	1,04	sec/km
Delay Time - Car	28,53	1,09	sec/km
Delay Time - Truck	30,94	1,09	sec/km
Waiting Time Virtual Queue - All	0,19	0,01	sec
Waiting Time Virtual Queue - Car	0,06	0	sec
Waiting Time Virtual Queue - LongTruck	0,69	0,04	sec
Total Travel Time (Waiting Out) - All	0	0	h
Total Travel Time (Waiting Out) - Car	0	0	h
Total Travel Time (Waiting Out) - LongTruck	0	0	h
Stop Time - All	19,19	0,88	sec/km
Stop Time - Car	19,34	0,93	sec/km
Stop Time - LongTruck	18,61	0,93	sec/km

Travel Time - All	72,72	1,03	sec/km
Travel Time - Car	70,77	1,05	sec/km
Travel Time - LongTruck	80,39	1,09	sec/km
Total Travel Time - All	225,82	5,43	h
Total Travel Time - Car	175,35	4,18	h
Total Travel Time - LongTruck	50,46	1,67	h
Total Travel Time (Vehicles Inside) - All	0,74	0,24	h
Total Travel Time (Vehicles Inside) - Car	0,56	0,19	h
Total Travel Time (Vehicles Inside) - LongTruck	0,18	0,07	h
Vehicles Inside - All	39,4	9,56	veh
Vehicles Inside - Car	30,9	7,89	veh
Vehicles Inside - LongTruck	8,5	2,55	veh
Vehicles Waiting to Enter - All	0	0	veh
Vehicles Waiting to Enter - Car	0	0	veh
Vehicles Waiting to Enter - LongTruck	0	0	veh
Vehicles Outside - All	10153	112,28	veh
Vehicles Outside - Car	8094,2	89,09	veh
Vehicles Outside - LongTruck	2058,8	56,29	veh
Vehicles Lost Inside - All	0,1	0,32	veh
Vehicles Lost Inside - Car	0,1	0,32	veh
Vehicles Lost Inside - LongTruck	0	0	veh
Vehicles Lost Outside - All	61,1	17,63	veh
Vehicles Lost Outside - Car	35,3	11,09	veh
Vehicles Lost Outside - LongTruck	25,8	7,55	veh
Speed - All	57,3	0,45	km/h
Speed - Car	58,98	0,46	km/h
Speed - LongTruck	50,69	0,39	km/h
Harmonic Speed - All	49,51	0	km/h
Harmonic Speed - Car	50,87	0	km/h
Harmonic Speed - LongTruck	44,78	0	km/h

6.1.2. 1 LAn

The obtained results from the normal actuated Dynamic Scenario are:

Table 20. LAn results

Time Series	Value	Standard Deviation	Units
CO2 - All	0	ND	g/km
CO2 - Car	0	ND	g/km
CO2 - LongTruck	0	ND	g/km
Mean Queue - All	16,61	0,54	veh
Mean Queue - Car	13,59	0,45	veh

Mean Queue - LongTruck	3,02	0,14	veh
Max. Virtual Queue - All	4,1	0,88	veh
Max. Virtual Queue - Car	2,9	0,57	veh
Max. Virtual Queue - LongTruck	3,5	0,97	veh
Mean Virtual Queue - All	0,09	0,01	veh
Mean Virtual Queue - Car	0,02	0	veh
Mean Virtual Queue - Truck	0,07	0,01	veh
Fuel Consumption - All	0	0	l
Fuel Consumption - Car	0	0	l
Fuel Consumption - LongTruck	0	0	l
Input Count - All	10085	ND	veh
Input Count - Car	8081,9	ND	veh
Input Count - LongTruck	2003,1	ND	veh
Density - All	8,3	0,11	veh/km
Density - Car	6,54	0,09	veh/km
Density - LongTruck	1,76	0,05	veh/km
Total Travelled Distance - All	10973,2	5	62,79 km
Total Travelled Distance - Car	8798,9		56,94 km
Total Travelled Distance - LongTruck	2174,35		38,45 km
Total Travelled Distance (Vehicles Inside) - All	17,71		4,37 km
Total Travelled Distance (Vehicles Inside) - Car	14,92		3,71 km
Total Travelled Distance (Vehicles Inside) - LongTruck	2,79		1,57 km
Flow - All	1834,2		10,62 veh/h
Flow - Car	1469,82		9,31 veh/h
Flow - LongTruck	364,38		6,58 veh/h
Input Flow - All	1833,64		9,56 veh/h
Input Flow - Car	1469,44		9,18 veh/h
Input Flow - LongTruck	364,2		6,36 veh/h
Missed Turns - All	127,8		25,99
Missed Turns - Car	80		17,49
Missed Turns - LongTruck	47,8		9,6
NOx - All	0	ND	g/km
NOx - Car	0	ND	g/km
NOx - LongTruck	0	ND	g/km
Number of Lane Changes - All	2038,64		24,98 #/km
Number of Lane Changes - Car	1746,51		26,21 #/km
Number of Lane Changes - LongTruck	292,13		6,06 #/km
Number of Stops - All	0,1		0 #/veh/k m
Number of Stops - Car	0,1		0 #/veh/k m
Number of Stops - LongTruck	0,1		0 #/veh/k m
Total Number of Lane Changes - All	11581,5		141,9

Total Number of Lane Changes - Car	9921,9	148,9	
Total Number of Lane Changes - LongTruck	1659,6	34,43	
Total Number of Stops - All	5912,09	149,44	
Total Number of Stops - Car	4810,54	126,24	
Total Number of Stops - LongTruck	1101,55	43,44	
Delay Time - All	40,41	1,02	sec/km
Delay Time - Car	40,34	1,05	sec/km
Delay Time - Truck	40,69	1,02	sec/km
Waiting Time Virtual Queue - All	0,18	0,01	sec
Waiting Time Virtual Queue - Car	0,05	0	sec
Waiting Time Virtual Queue - LongTruck	0,7	0,04	sec
Total Travel Time (Waiting Out) - All	0	0	h
Total Travel Time (Waiting Out) - Car	0	0	h
Total Travel Time (Waiting Out) - LongTruck	0	0	h
Stop Time - All	29,15	0,89	sec/km
Stop Time - Car	29,71	0,92	sec/km
Stop Time - LongTruck	26,92	0,9	sec/km
Travel Time - All	84,11	1,01	sec/km
Travel Time - Car	82,58	1,03	sec/km
Travel Time - LongTruck	90,26	1,03	sec/km
Total Travel Time - All	259,26	3,31	h
Total Travel Time - Car	204,34	2,58	h
Total Travel Time - LongTruck	54,92	1,39	h
Total Travel Time (Vehicles Inside) - All	0,74	0,31	h
Total Travel Time (Vehicles Inside) - Car	0,6	0,26	h
Total Travel Time (Vehicles Inside) - LongTruck	0,14	0,08	h
Vehicles Inside - All	35,9	10,02	veh
Vehicles Inside - Car	30,3	8,77	veh
Vehicles Inside - LongTruck	5,6	2,55	veh
Vehicles Waiting to Enter - All	0	0	veh
Vehicles Waiting to Enter - Car	0	0	veh
Vehicles Waiting to Enter - LongTruck	0	0	veh
Vehicles Outside - All	10088,1	58,43	veh
Vehicles Outside - Car	8084	51,2	veh
Vehicles Outside - LongTruck	2004,1	36,18	veh
Vehicles Lost Inside - All	0	0	veh
Vehicles Lost Inside - Car	0	0	veh
Vehicles Lost Inside - LongTruck	0	0	veh
Vehicles Lost Outside - All	127,8	25,99	veh
Vehicles Lost Outside - Car	80	17,49	veh
Vehicles Lost Outside - LongTruck	47,8	9,6	veh
Speed - All	52,68	0,4	km/h
Speed - Car	54,05	0,42	km/h
Speed - LongTruck	47,17	0,4	km/h
Harmonic Speed - All	42,8	0	km/h

Harmonic Speed - Car	43,59	0	km/h
Harmonic Speed - LongTruck	39,89	0	km/h

6.1.3. 1 LAdp1

The results corresponding to the average of the simulation of the Actuated Dynamic Scenario using the detector located in position 1 are:

Table 21. LAdp1 results

Time Series	Value	Standard Deviation	Units
CO2 - All	0	ND	g/km
CO2 - Car	0	ND	g/km
CO2 - LongTruck	0	ND	g/km
Mean Queue - All	15,16	0,61	veh
Mean Queue - Car	12,25	0,48	veh
Mean Queue - LongTruck	2,91	0,17	veh
Max. Virtual Queue - All	4,1	0,74	veh
Max. Virtual Queue - Car	2,9	0,32	veh
Max. Virtual Queue - LongTruck	3,2	0,42	veh
Mean Virtual Queue - All	0,09	0,01	veh
Mean Virtual Queue - Car	0,02	0	veh
Mean Virtual Queue - Truck	0,07	0,01	veh
Fuel Consumption - All	0	0	l
Fuel Consumption - Car	0	0	l
Fuel Consumption - LongTruck	0	0	l
Input Count - All	10116	ND	veh
Input Count - Car	8089,1	ND	veh
Input Count - LongTruck	2026,9	ND	veh
Density - All	8,03	0,19	veh/km
Density - Car	6,28	0,15	veh/km
Density - LongTruck	1,75	0,06	veh/km
Total Travelled Distance - All	11008,27	147,54	km
Total Travelled Distance - Car	8805,46	115,01	km
Total Travelled Distance - LongTruck	2202,81	59,27	km
Total Travelled Distance (Vehicles Inside) - All	18,59	4,62	km
Total Travelled Distance (Vehicles Inside) - Car	14,84	3,9	km
Total Travelled Distance (Vehicles Inside) - LongTruck	3,75	1,78	km
Flow - All	1838,98	24,93	veh/h
Flow - Car	1470,51	19,25	veh/h
Flow - LongTruck	368,47	10,2	veh/h
Input Flow - All	1839,27	24,62	veh/h
Input Flow - Car	1470,75	19,07	veh/h

Input Flow - LongTruck	368,53	10,07	veh/h
Missed Turns - All	106,8	20,12	
Missed Turns - Car	63,6	14,85	
Missed Turns - LongTruck	43,2	6,51	
NOx - All	0	ND	g/km
NOx - Car	0	ND	g/km
NOx - LongTruck	0	ND	g/km
Number of Lane Changes - All	2039,08	35,44	#/km
Number of Lane Changes - Car	1738,83	35,4	#/km
Number of Lane Changes - LongTruck	300,25	8,98	#/km
Number of Stops - All	0,1	0	#/veh/k m
Number of Stops - Car	0,1	0	#/veh/k m
Number of Stops - LongTruck	0,09	0	#/veh/k m
Total Number of Lane Changes - All	11584	201,31	
Total Number of Lane Changes - Car	9878,3	201,11	
Total Number of Lane Changes - LongTruck	1705,7	51,02	
Total Number of Stops - All	5693,78	166,54	
Total Number of Stops - Car	4617,37	125,11	
Total Number of Stops - LongTruck	1076,41	49,37	
Delay Time - All	37,43	0,96	sec/km
Delay Time - Car	37,03	0,91	sec/km
Delay Time - Truck	39,04	1,32	sec/km
Waiting Time Virtual Queue - All	0,18	0,01	sec
Waiting Time Virtual Queue - Car	0,05	0	sec
Waiting Time Virtual Queue - LongTruck	0,69	0,05	sec
Total Travel Time (Waiting Out) - All	0	0	h
Total Travel Time (Waiting Out) - Car	0	0	h
Total Travel Time (Waiting Out) - LongTruck	0	0	h
Stop Time - All	26,49	0,77	sec/km
Stop Time - Car	26,73	0,73	sec/km
Stop Time - LongTruck	25,53	1,09	sec/km
Travel Time - All	81,14	0,95	sec/km
Travel Time - Car	79,28	0,91	sec/km
Travel Time - LongTruck	88,54	1,36	sec/km
Total Travel Time - All	250,75	5,99	h
Total Travel Time - Car	196,13	4,62	h
Total Travel Time - LongTruck	54,61	1,95	h
Total Travel Time (Vehicles Inside) - All	0,75	0,33	h
Total Travel Time (Vehicles Inside) - Car	0,56	0,26	h
Total Travel Time (Vehicles Inside) - LongTruck	0,19	0,12	h
Vehicles Inside - All	36,5	10,32	veh
Vehicles Inside - Car	29,5	9,01	veh

Vehicles Inside - LongTruck	7	3,16	veh
Vehicles Waiting to Enter - All	0	0	veh
Vehicles Waiting to Enter - Car	0	0	veh
Vehicles Waiting to Enter - LongTruck	0	0	veh
Vehicles Outside - All	10114,4	137,12	veh
Vehicles Outside - Car	8087,8	105,86	veh
Vehicles Outside - LongTruck	2026,6	56,1	veh
Vehicles Lost Inside - All	0	0	veh
Vehicles Lost Inside - Car	0	0	veh
Vehicles Lost Inside - LongTruck	0	0	veh
Vehicles Lost Outside - All	106,8	20,12	veh
Vehicles Lost Outside - Car	63,6	14,85	veh
Vehicles Lost Outside - LongTruck	43,2	6,51	veh
Speed - All	53,72	0,37	km/h
Speed - Car	55,22	0,38	km/h
Speed - LongTruck	47,77	0,47	km/h
Harmonic Speed - All	44,37	0	km/h
Harmonic Speed - Car	45,41	0	km/h
Harmonic Speed - LongTruck	40,66	0	km/h

6.1.4. 1 LAdp2

The following results belong to the simulation of the Actuated Dynamic Scenario using the detector located in position 2:

Table 22. 1 LAdp2 results

Time Series	Value	Standard Deviation	Units
CO2 - All	0	ND	g/km
CO2 - Car	0	ND	g/km
CO2 - LongTruck	0	ND	g/km
Mean Queue - All	15,21	0,42	veh
Mean Queue - Car	12,45	0,31	veh
Mean Queue - LongTruck	2,76	0,16	veh
Max. Virtual Queue - All	4,7	0,95	veh
Max. Virtual Queue - Car	2,9	0,57	veh
Max. Virtual Queue - LongTruck	3,6	0,7	veh
Mean Virtual Queue - All	0,09	0,01	veh
Mean Virtual Queue - Car	0,02	0	veh
Mean Virtual Queue - Truck	0,07	0,01	veh
Fuel Consumption - All	0	0	l
Fuel Consumption - Car	0	0	l
Fuel Consumption - LongTruck	0	0	l
Input Count - All	10116,5	ND	veh

Input Count - Car	8089,4	ND	veh
Input Count - LongTruck	2027,1	ND	veh
Density - All	8,03	0,1	veh/km
Density - Car	6,31	0,06	veh/km
Density - LongTruck	1,72	0,05	veh/km
Total Travelled Distance - All	11010,0 4	86,58	km
Total Travelled Distance - Car	8810,22	80,34	km
Total Travelled Distance - LongTruck	2199,82	51,22	km
Total Travelled Distance (Vehicles Inside) - All	20,5	6,75	km
Total Travelled Distance (Vehicles Inside) - Car	15,54	6,31	km
Total Travelled Distance (Vehicles Inside) - LongTruck	4,96	2,32	km
Flow - All	1839,55	14,38	veh/h
Flow - Car	1470,96	13,4	veh/h
Flow - LongTruck	368,58	8,57	veh/h
Input Flow - All	1839,36	14,79	veh/h
Input Flow - Car	1470,8	13,7	veh/h
Input Flow - LongTruck	368,56	8,52	veh/h
Missed Turns - All	106,6	21,13	
Missed Turns - Car	62,1	16,49	
Missed Turns - LongTruck	44,5	9,91	
NOx - All	0	ND	g/km
NOx - Car	0	ND	g/km
NOx - LongTruck	0	ND	g/km
Number of Lane Changes - All	2018,18	28,14	#/km
Number of Lane Changes - Car	1723,64	25,07	#/km
Number of Lane Changes - LongTruck	294,54	8,39	#/km
Number of Stops - All	0,1	0	#/veh/k m
Number of Stops - Car	0,1	0	#/veh/k m
Number of Stops - LongTruck	0,09	0	#/veh/k m
Total Number of Lane Changes - All	11465,3	159,85	
Total Number of Lane Changes - Car	9792	142,45	
Total Number of Lane Changes - LongTruck	1673,3	47,64	
Total Number of Stops - All	5601,92	92,66	
Total Number of Stops - Car	4553,57	76,46	
Total Number of Stops - LongTruck	1048,35	35,77	
Delay Time - All	37,42	0,74	sec/km
Delay Time - Car	37,34	0,72	sec/km
Delay Time - Truck	37,73	1,14	sec/km
Waiting Time Virtual Queue - All	0,19	0,01	sec
Waiting Time Virtual Queue - Car	0,06	0,01	sec
Waiting Time Virtual Queue - LongTruck	0,73	0,04	sec

Total Travel Time (Waiting Out) - All	0	0	h
Total Travel Time (Waiting Out) - Car	0	0	h
Total Travel Time (Waiting Out) - LongTruck	0	0	h
Stop Time - All	26,52	0,66	sec/km
Stop Time - Car	27,09	0,67	sec/km
Stop Time - LongTruck	24,28	1	sec/km
Travel Time - All	81,14	0,72	sec/km
Travel Time - Car	79,6	0,68	sec/km
Travel Time - LongTruck	87,31	1,18	sec/km
Total Travel Time - All	251,02	3,03	h
Total Travel Time - Car	197,25	1,99	h
Total Travel Time - LongTruck	53,77	1,65	h
Total Travel Time (Vehicles Inside) - All	0,76	0,28	h
Total Travel Time (Vehicles Inside) - Car	0,54	0,26	h
Total Travel Time (Vehicles Inside) - LongTruck	0,22	0,12	h
Vehicles Inside - All	35,9	7,36	veh
Vehicles Inside - Car	27,3	7,21	veh
Vehicles Inside - LongTruck	8,6	3,89	veh
Vehicles Waiting to Enter - All	0	0	veh
Vehicles Waiting to Enter - Car	0	0	veh
Vehicles Waiting to Enter - LongTruck	0	0	veh
Vehicles Outside - All	10117,5	79,08	veh
Vehicles Outside - Car	8090,3	73,69	veh
Vehicles Outside - LongTruck	2027,2	47,11	veh
Vehicles Lost Inside - All	0	0	veh
Vehicles Lost Inside - Car	0	0	veh
Vehicles Lost Inside - LongTruck	0	0	veh
Vehicles Lost Outside - All	106,6	21,13	veh
Vehicles Lost Outside - Car	62,1	16,49	veh
Vehicles Lost Outside - LongTruck	44,5	9,91	veh
Speed - All	53,86	0,22	km/h
Speed - Car	55,3	0,23	km/h
Speed - LongTruck	48,11	0,35	km/h
Harmonic Speed - All	44,37	0	km/h
Harmonic Speed - Car	45,23	0	km/h
Harmonic Speed - LongTruck	41,23	0	km/h

6.2. Comparison

This subchapter is divided into two parts. The first one makes three comparisons in percentage between the results of two simulations: 1 LAPd1 and 1 LAPd2, 1 LAPd1 and 1 LAn, 1 LF and 1 LAPd1.

The second one uses five graphs to contrast the value of some of the most important results between the fourth Dynamic Scenarios.

6.2.1. 1 LApd1 - 1 LApd2

The percentage for this comparison has been calculated as the difference between the results of 1 LApd1 minus 1 LApd2 divided by 1 LApd1 and multiplied by 100 $((1 \text{ LApd1} - 1 \text{ LApd2}) / 1 \text{ LApd1} * 100)$.

Table 23. 1 LApd1 – 1 LApd2 comparison

Time Series	Difference (%)
Mean Queue - All	-0,329815303
Mean Queue - Car	-1,632653061
Mean Queue - LongTruck	5,154639175
Max. Virtual Queue - All	-14,63414634
Max. Virtual Queue - Car	0
Max. Virtual Queue - LongTruck	-12,5
Mean Virtual Queue - All	0
Mean Virtual Queue - Car	0
Mean Virtual Queue - Truck	0
Input Count - All	-0,004942665
Input Count - Car	-0,003708694
Input Count - LongTruck	-0,009867285
Density - All	0
Density - Car	-0,477707006
Density - LongTruck	1,714285714
Total Travelled Distance - All	-0,016078821
Total Travelled Distance - Car	-0,054057369
Total Travelled Distance - LongTruck	0,135735719
Total Travelled Distance (Vehicles Inside) - All	-10,27434104
Total Travelled Distance (Vehicles Inside) - Car	-4,716981132
Total Travelled Distance (Vehicles Inside) - LongTruck	-32,26666667
Flow - All	-0,030995443
Flow - Car	-0,030601628
Flow - LongTruck	-0,029853177
Input Flow - All	-0,004893246
Input Flow - Car	-0,003399626
Input Flow - LongTruck	-0,00814045
Missed Turns - All	0,187265918
Missed Turns - Car	2,358490566
Missed Turns - LongTruck	-3,009259259
Number of Lane Changes - All	1,024972046
Number of Lane Changes - Car	0,87357591
Number of Lane Changes - LongTruck	1,901748543
Number of Stops - All	0

Number of Stops - Car	0
Number of Stops - LongTruck	0
Total Number of Lane Changes - All	1,024689227
Total Number of Lane Changes - Car	0,873632103
Total Number of Lane Changes - LongTruck	1,899513396
Total Number of Stops - All	1,613339469
Total Number of Stops - Car	1,381738955
Total Number of Stops - LongTruck	2,606813389
Delay Time - All	0,026716538
Delay Time - Car	-0,83715906
Delay Time - Truck	3,355532787
Waiting Time Virtual Queue - All	-5,555555556
Waiting Time Virtual Queue - Car	-20
Waiting Time Virtual Queue - LongTruck	-5,797101449
Stop Time - All	-0,113250283
Stop Time - Car	-1,346801347
Stop Time - LongTruck	4,896200548
Travel Time - All	0
Travel Time - Car	-0,403632694
Travel Time - LongTruck	1,38920262
Total Travel Time - All	-0,107676969
Total Travel Time - Car	-0,571049814
Total Travel Time - LongTruck	1,538179821
Total Travel Time (Vehicles Inside) - All	-1,333333333
Total Travel Time (Vehicles Inside) - Car	3,571428571
Total Travel Time (Vehicles Inside) - LongTruck	-15,78947368
Vehicles Inside - All	1,643835616
Vehicles Inside - Car	7,457627119
Vehicles Inside - LongTruck	-22,85714286
Vehicles Outside - All	-0,030649371
Vehicles Outside - Car	-0,030910754
Vehicles Outside - LongTruck	-0,029606237
Vehicles Lost Outside - All	0,187265918
Vehicles Lost Outside - Car	2,358490566
Vehicles Lost Outside - LongTruck	-3,009259259
Speed - All	-0,260610573
Speed - Car	-0,144875045
Speed - LongTruck	-0,711743772
Harmonic Speed - All	0
Harmonic Speed - Car	0,396388461
Harmonic Speed - LongTruck	-1,401869159

Most of the results of the difference in percentage are negatives, what means that the values of 1 LApd2 are higher than 1 LApd1. This makes the 1 LApd1 Dynamic Scenario the best approach in comparison with 1 LApd2.

6.2.2. 1 LApd1 - 1 LAn

Due to the fact that the best option between the two previous compared scenarios is 1 LApd1, this is the one that will be compared with 1 LAn in the next table.

The difference in percentage in this case has been calculated as follows:

$$(1 \text{ LApd1} - 1 \text{ LAn}) / 1 \text{ LApd1} * 100$$

Table 24. 1 LApd1 – 1 LAn comparison

Time Series	Difference (%)
Mean Queue - All	-9,564643799
Mean Queue - Car	-10,93877551
Mean Queue - LongTruck	-3,780068729
Max. Virtual Queue - All	0
Max. Virtual Queue - Car	0
Max. Virtual Queue - LongTruck	-9,375
Mean Virtual Queue - All	0
Mean Virtual Queue - Car	0
Mean Virtual Queue - Truck	0
Input Count - All	0,306445235
Input Count - Car	0,089008666
Input Count - LongTruck	1,174206917
Density - All	-3,362391034
Density - Car	-4,140127389
Density - LongTruck	-0,571428571
Total Travelled Distance - All	0,318124465
Total Travelled Distance - Car	0,074499231
Total Travelled Distance - LongTruck	1,291986145
Total Travelled Distance (Vehicles Inside) - All	4,733727811
Total Travelled Distance (Vehicles Inside) - Car	-0,539083558
Total Travelled Distance (Vehicles Inside) - LongTruck	25,6
Flow - All	0,259926698
Flow - Car	0,046922496
Flow - LongTruck	1,109995386
Input Flow - All	0,306099703
Input Flow - Car	0,089070202
Input Flow - LongTruck	1,174938268
Missed Turns - All	-19,66292135
Missed Turns - Car	-25,78616352
Missed Turns - LongTruck	-10,64814815

Number of Lane Changes - All	0,021578359
Number of Lane Changes - Car	-0,4416763
Number of Lane Changes - LongTruck	2,704412989
Number of Stops - All	0
Number of Stops - Car	0
Number of Stops - LongTruck	-11,11111111
Total Number of Lane Changes - All	0,021581492
Total Number of Lane Changes - Car	-0,441371491
Total Number of Lane Changes - LongTruck	2,702702703
Total Number of Stops - All	-3,834183969
Total Number of Stops - Car	-4,183550376
Total Number of Stops - LongTruck	-2,33554129
Delay Time - All	-7,961528186
Delay Time - Car	-8,938698353
Delay Time - Truck	-4,226434426
Waiting Time Virtual Queue - All	0
Waiting Time Virtual Queue - Car	0
Waiting Time Virtual Queue - LongTruck	-1,449275362
Stop Time - All	-10,0415251
Stop Time - Car	-11,14852226
Stop Time - LongTruck	-5,44457501
Travel Time - All	-3,660340153
Travel Time - Car	-4,162462159
Travel Time - LongTruck	-1,942624802
Total Travel Time - All	-3,393818544
Total Travel Time - Car	-4,185999082
Total Travel Time - LongTruck	-0,5676616
Total Travel Time (Vehicles Inside) - All	1,333333333
Total Travel Time (Vehicles Inside) - Car	-7,142857143
Total Travel Time (Vehicles Inside) - LongTruck	26,31578947
Vehicles Inside - All	1,643835616
Vehicles Inside - Car	-2,711864407
Vehicles Inside - LongTruck	20
Vehicles Outside - All	0,26002531
Vehicles Outside - Car	0,046984347
Vehicles Outside - LongTruck	1,110233889
Vehicles Lost Outside - All	-19,66292135
Vehicles Lost Outside - Car	-25,78616352
Vehicles Lost Outside - LongTruck	-10,64814815
Speed - All	1,935964259
Speed - Car	2,118797537
Speed - LongTruck	1,256018422
Harmonic Speed - All	3,538426865
Harmonic Speed - Car	4,007927769
Harmonic Speed - LongTruck	1,893753074

For this comparison, the differences show that the results of the 1 LAn simulation are larger than the API applied simulation. This makes the 1 LAPd1 case a better choice than the normal actuated one.

6.2.3. 1 LF - 1 LAPd1

The last table for analyzing the results will take into account the fixed scenario and the best of the actuated with API ones. The difference in percentage has been calculated this way:

$$(1 \text{ LF} - 1 \text{ LAPd1}) / 1 \text{ LF} * 100$$

Table 25. 1 LF – 1 LAPd1

Time Series	Difference (%)
Mean Queue - All	-36,57657658
Mean Queue - Car	-37,17805151
Mean Queue - LongTruck	-34,10138249
Max. Virtual Queue - All	8,888888889
Max. Virtual Queue - Car	9,375
Max. Virtual Queue - LongTruck	5,882352941
Mean Virtual Queue - All	0
Mean Virtual Queue - Car	0
Mean Virtual Queue - Truck	0
Input Count - All	0,425230333
Input Count - Car	0,138266484
Input Count - LongTruck	1,554227986
Density - All	-11,06500692
Density - Car	-11,74377224
Density - LongTruck	-8,024691358
Total Travelled Distance - All	0,444497903
Total Travelled Distance - Car	0,131902929
Total Travelled Distance - LongTruck	1,674753273
Total Travelled Distance (Vehicles Inside) - All	1,64021164
Total Travelled Distance (Vehicles Inside) - Car	0,469483568
Total Travelled Distance (Vehicles Inside) - LongTruck	6,015037594
Flow - All	0,38028169
Flow - Car	0,078822019
Flow - LongTruck	1,565463628
Input Flow - All	0,425525004
Input Flow - Car	0,137834571
Input Flow - LongTruck	1,554694804
Missed Turns - All	-74,50980392
Missed Turns - Car	-79,66101695
Missed Turns - LongTruck	-67,44186047

Number of Lane Changes - All	-1,58575165
Number of Lane Changes - Car	-1,843196514
Number of Lane Changes - LongTruck	-0,120044016
Number of Stops - All	-25
Number of Stops - Car	-11,11111111
Number of Stops - LongTruck	-12,5
Total Number of Lane Changes - All	-1,585519854
Total Number of Lane Changes - Car	-1,843393989
Total Number of Lane Changes - LongTruck	-0,11739156
Total Number of Stops - All	-17,32978899
Total Number of Stops - Car	-17,66188361
Total Number of Stops - LongTruck	-15,92624902
Delay Time - All	-29,02447432
Delay Time - Car	-29,79320014
Delay Time - Truck	-26,17970265
Waiting Time Virtual Queue - All	5,263157895
Waiting Time Virtual Queue - Car	16,66666667
Waiting Time Virtual Queue - LongTruck	0
Stop Time - All	-38,04064617
Stop Time - Car	-38,21096174
Stop Time - LongTruck	-37,18430951
Travel Time - All	-11,57865787
Travel Time - Car	-12,02486929
Travel Time - LongTruck	-10,13807688
Total Travel Time - All	-11,03976619
Total Travel Time - Car	-11,85058455
Total Travel Time - LongTruck	-8,224336108
Total Travel Time (Vehicles Inside) - All	-1,351351351
Total Travel Time (Vehicles Inside) - Car	0
Total Travel Time (Vehicles Inside) - LongTruck	-5,555555556
Vehicles Inside - All	7,360406091
Vehicles Inside - Car	4,530744337
Vehicles Inside - LongTruck	17,64705882
Vehicles Outside - All	0,380183197
Vehicles Outside - Car	0,079068963
Vehicles Outside - LongTruck	1,564017874
Vehicles Lost Outside - All	-74,79541735
Vehicles Lost Outside - Car	-80,16997167
Vehicles Lost Outside - LongTruck	-67,44186047
Speed - All	6,247818499
Speed - Car	6,375042387
Speed - LongTruck	5,760505031
Harmonic Speed - All	10,38174106
Harmonic Speed - Car	10,7332416
Harmonic Speed - LongTruck	9,200535954

Once again, negative results have been obtained for most of the values, which means that the actuated scenario seems to be a worse idea than a fixed one. This cannot be possible as one of the aims of this research was to improve the traffic congestion in the A52 junction actuating in the green time of the phases. The continuation of this research will get these results better.

6.2.4. Graphical comparisons

a) Mean Queue – All

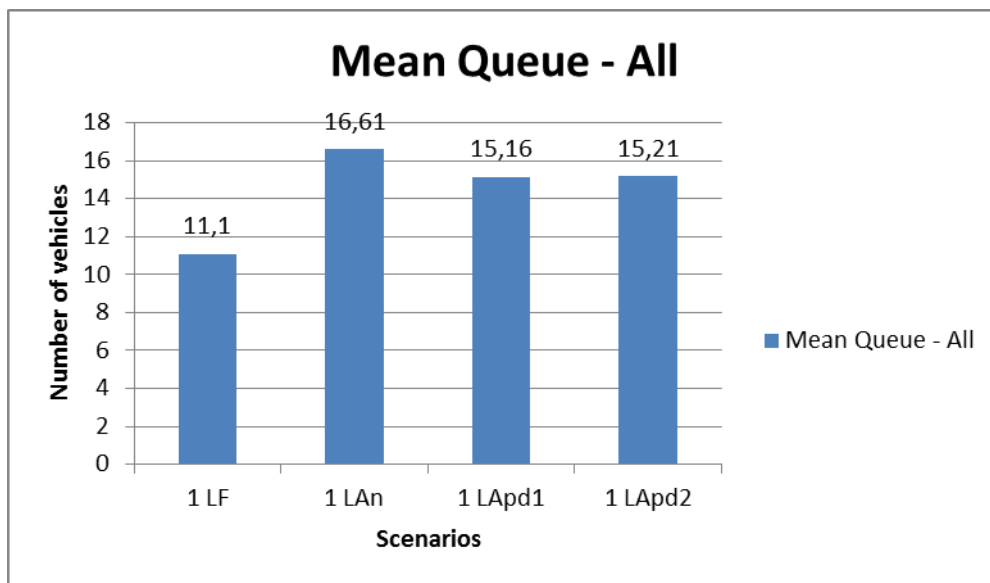


Figure 18. Mean Queue - All

The mean number of vehicles in queue is lower for the fixed simulation, but if they are compared to the actuated ones, it can be assured that:

- The detector position 1 makes a more efficient extension than the detector position 2.
- The controller coded in Python language generates a shorter queue than the normal actuated one. Being the 1 LApd1 the best result of the actuated scenarios.

b) Stop Time – All

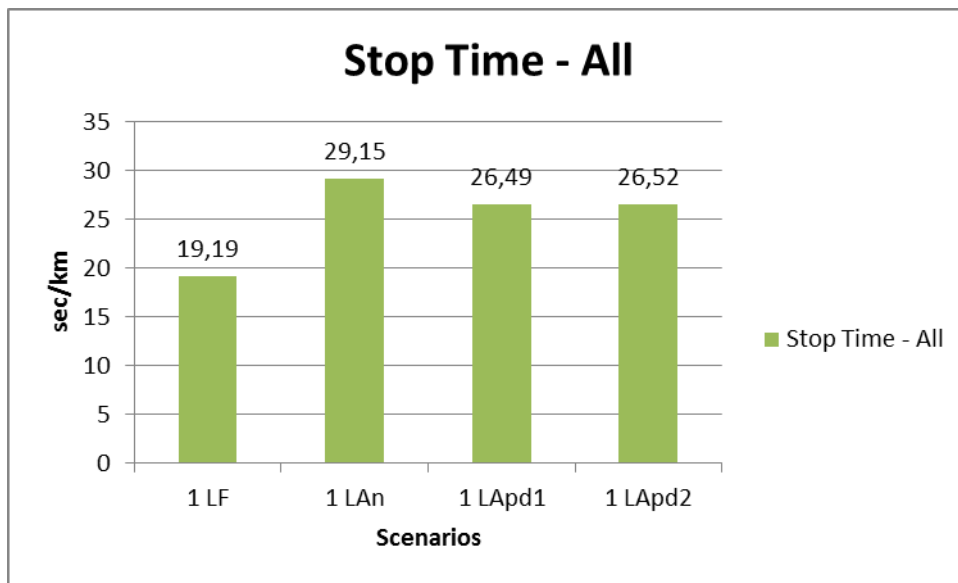


Figure 19. Stop Time - All

The stop time in seconds per km is the same in the actuated with API scenarios, but less than the normal actuated one. Nevertheless, the fixed scenario generates a lower value than for the three actuated cases.

c) Total Travel Time (Vehicles Inside) – All

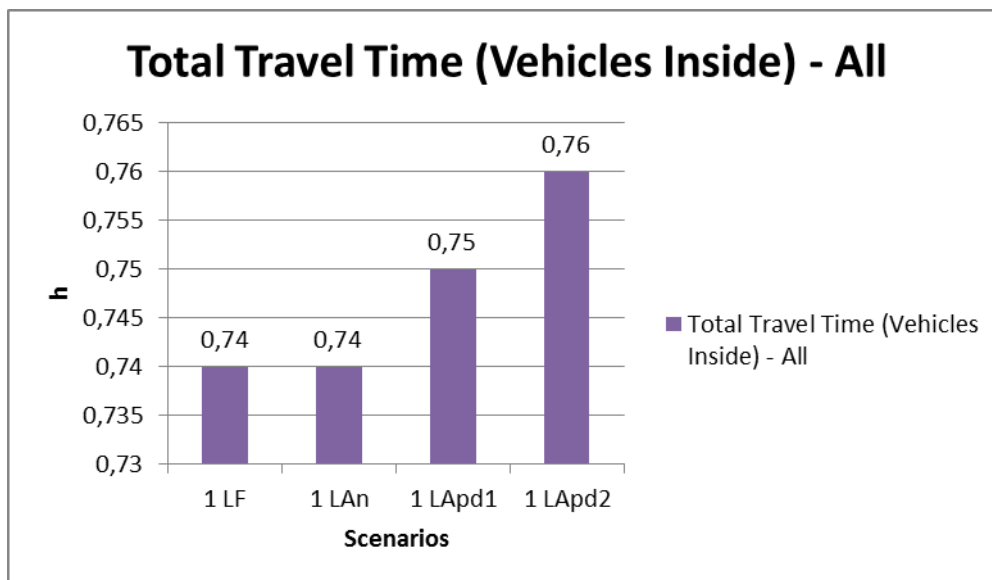


Figure 20. Total Travel Time (Vehicles Inside) - All

In this case, the worst values for the total travel time of vehicles inside the junction belong to the actuated with API scenarios. The fixed and normal actuated scenarios gave the same total travel time. Nonetheless, the results are very similar in the four simulations.

d) Delay Time – All

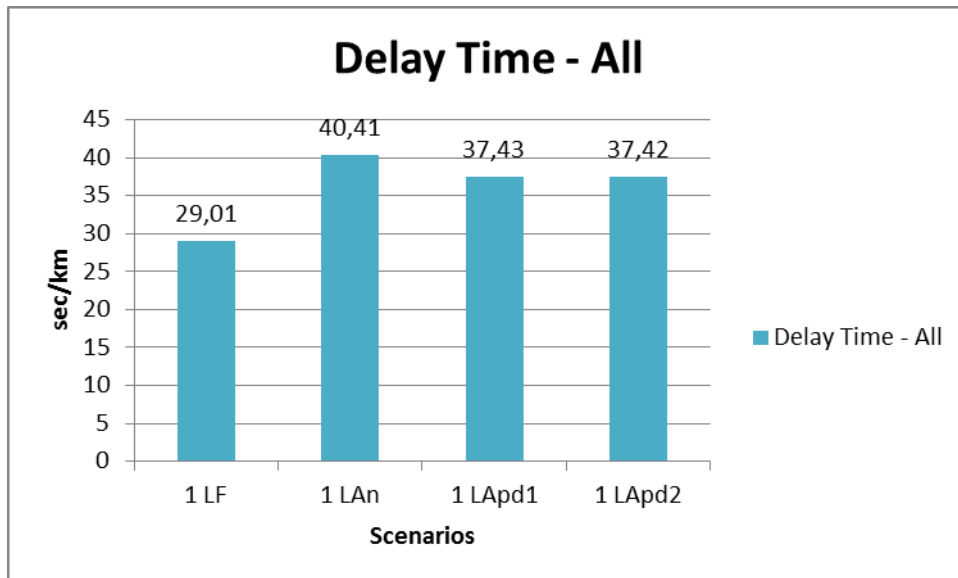


Figure 21. Delay Time - All

The best value of delay time is obtained after running the fixed simulation. However, if the actuated simulations are compared, the best performance is reached with the 1 LApd1 Dynamic Scenario.

e) Number of Stops – All

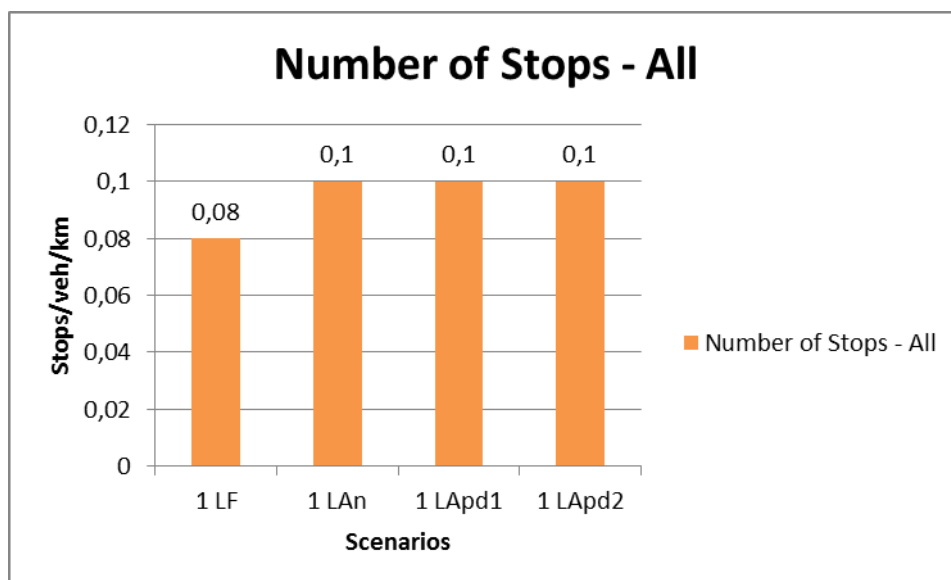


Figure 22. Number of Stops - All

The number of stops in the fixed scenario is less than in the actuated ones, being for these ones the same value: 0.1 stops/vehicle/km.

As it has been seen, the results of this thesis are not as good as desired. The actuated Dynamic Scenarios should have provided better results as the fixed one but this goal was not reached. The possible reasons to this fact that the author suggests are:

- Not all the phases of the CP have been taken into account to extend the green time, being possible that the traffic volume in other phases is large enough to consider increasing their green times too. This could explain why the normal actuated case of study is also worse than the fixed.
- The micro-simulator obtained the results considering the complete set of sections, not only the actuated ones. This means that when a phase is been extended, it provokes a queue in other phases that are not going to be actuated. This is, as the TCMS improves the waiting time and the queue in a phase with increased green time, it aggravates a not extended one.
- The code used for controller could be improved with the use of more complex functions.

Nevertheless, it has been able to resort to the simulations results to make comparisons between the different actuated Dynamic Scenarios. These findings show that the first detector position is better than the second one to detect vehicle presence and make the decision of increasing the green time of phase 1.

They also prove that the actuated control plan integrated with an API performs better than the normal actuated one (just using Aimsun).

7. Conclusions and future work

7.1. Conclusions

The purpose of this research was to develop an algorithm used as an adaptive controller to make the green light duration of the traffic lights at an intersection change. Those changes are made according to the vehicle information collected by the detectors located at the junction. The crossroads in which this traffic management system was desired, is located in Nottingham.

Throughout the previous chapters, a model of the intersection object of this work has been developed, the traffic data for the simulations has been entered into the software and the control cases for the different studies have been created. Four Dynamic Scenarios or cases of study have been set to compare their performance: a fixed one and three actuated ones (the first just using Aimsun and the others, applying an external controller).

In addition, the adaptive controller to be used as an API has been coded in Python language. Later, a research has been carried out among the results of four Dynamic Scenarios that have been run.

Nevertheless, the results show that the best case of study is the fixed scenario followed by the actuated one in which an API has been applied placing the extension detector in the first position. These results are not good as desired due to the aim of this project was to prove that an actuated control system could improve the waiting time and queue length generated with the fixed plan.

7.2. Future work

With the continuation of this research, if we keep investigating, we will be able to get a better code for more accurate management system performance. So that, the system will reach 100% of efficiency and the desired results will be obtained. One of the first changes that we should apply to the setup would be the application of the method to the rest of the phases.

Once the actuated controller performs properly, we could also add more vehicle types to the traffic demands and we could also take into account the call of the pedestrians. We could also add more truck types with different dimensions to actuate the green times depending on their speed, which would be different to the speed of the existing ones.

Then, we could also create more control plans to actuate during more hours of the day and more days of the week.

At the same time, if we apply this method of traffic management to adjacent intersections, we will be able to cover the control to a longer extension of the A52. Thus, the traffic congestion will be decreased in the complete network.

Last but not least, an important improvement that we could apply to our controller could be the way we will make decisions to take into account the carbon emissions at the junction and try to minimize them.

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