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Efficiency of Vehicle Actuated traffic control on isolated intersection

Dejan Ćiprovski[1, 2], Aleksej Makarov[1], Miljan Vučetić[1,3]

[1] Vlatacom Institute, Belgrade, Serbia
[2] University Metropolitan, Belgrade, Serbia
[3] University Signidunum, Belgrade, Serbia

E-mail address: dejan.ciprovski@vlatacom.com, aleksej@vlatacom.com, miljan.vucetic@vlatacom.com

Abstract— **This paper is described different strategies for traffic control and simulation, namely - Vehicle Actuated (VA) compared to Fixed Time (FT) traffic control. We are comparing and evaluating the impact of FT and adaptive traffic signal control strategies for one of the biggest and busiest intersections in Tashkent, the capital of Uzbekistan. The parameters used for comparing these strategies are the average vehicle travel times and average vehicle queue lengths. TRL TRANSYT 15 software was used to determine the fixed signal timing plan based on intersection geometry, inter-green matrix, and traffic flow. PTV VISSIM software is used for VA algorithm development and simulation to get the maximum and average vehicle travel times as well as queue lengths. It is shown that the parameter optimization can reduce the queue lengths down to 65% and the travel time down to 51%.**

Keywords - traffic control, intelligent traffic light, simulation, signal control methods

I. INTRODUCTION

Nowadays, having an effective and well-managed traffic signal control scheme is essential for reducing traffic congestion. Traffic signals operate in either fixed timed or actuated mode or some combination of the two. A sequence of intervals with fixed durations makes up pre-timed control. They repeat a preset constant cycle. Actuated signals, as opposed to fixed timed signals, can react to the presence of vehicles or individuals at the crossing. Intervals are called and extended as a result of vehicle detectors in actuated control. In response to detector actuation, the controllers can change the order and sequence of phases in addition to changing the cycle duration and green times [1].

Utilizing data and information from detectors placed at intersection approaches, vehicle-actuated control manages traffic flows at intersections. Semi-actuated and full-actuated are two categories in which this type of control might be placed. Detectors for the semi-actuated traffic signal control should be placed at the intersection approaches with low hourly traffic volumes (side approach). Therefore, green traffic light (right of way) is active for traffic flows at the main approach when there is no demand from the detectors at the side roads. When the detectors are triggered, the right of way belongs to traffic flows at side road. Detectors are placed at each of the intersection's approaches in the fully actuated traffic signal control. In this method of control, the detectors placed in each approach are used to gather data and information on traffic flows. To manage the intersection, data received and information from all detectors are used [2].

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The objective of this paper is to demonstrate and validate the introduction of the Vehicle Actuated signals to the isolated intersections in terms of vehicle travel times and queue length. The basic contributions of the paper is to reduce traffic jams and to increase intersection capacity and vehicle speeds. The overall public safety is not impaired.

The paper is organized as follows. The second section of the paper sumarizes related works around the world, third and fourth sections are devoted to traffic control modeling. The fifth section is devoted to the results of the simulation. Finally, Section VI concludes the paper.

II. RELATED WORKS

There are numerous articles and papers written related to this topic. This section will be reviewed of them. Inefficient traffic management has been a major urban problem that has resulted in large economic expenses in numerous cities across the world. According to the Institute of Economic Affairs (IEA) analysis, a 2-minute delay to every car journey costs the United Kingdom economy almost 16 billion GBP annually, almost 1% of GDP [3].

In Macedonia, signal control strategies are signal group based and they operate under isolated and coordinated FT control. The city of Skopje is an exception, where UTOPIA adaptive traffic signal control has been put into place to reduce traffic congestion. The city of Skopje also implemented isolated and coordinated FT control before the implementation of

UTOPIA. The UTOPIA is an adaptive traffic control system created to improve traffic flows and give public transportation significant priority while maintaining private traffic travel times [4].

Since the early 1980s, Chile has implemented TRANSYT as a tool for cost-benefit analyses of infrastructure projects and traffic control plans. In addition, Santiago's Area Traffic Control System has deployed signals that operate based on timing computed using TRANSYT 8S since the middle of the 1990s. The SCOOT (Split Cycle Offset Optimization Technique) software is used by some networks. The 1750 traffic lights in the capital are controlled by the Santiago Area Traffic Control System; 1410 of them operate on FT signal plans based on TRANSYT, 270 on SCOOT, and 70 isolated intersections are fully actuated (VA). Due to the network's largely consistent traffic patterns and occasional significant saturation, fixed-time plans are used (e.g., towards the city center in the morning - AM peak and from the city center in the evening - PM peak). It is well known that under such circumstances, FT plans that are activated at specified periods and last for an extended period time are sufficient [5].

The study done in the city of Jaipur (MI Road – 9 intersections), India suggests that overall, the VA controllers with the improved implementation strategy performed much better than the current FT signals. However, the cycle time length, green time, gap, and so forth need to be studied; typically, with the help of robust simulators. Further, the performance can be significantly improved, especially along the corridor, using a good progression (coordination) model [6].

III. Fixed-Time Traffic Simulation Software

For the aim of developing, analyzing, and modeling all kinds of intersections (from isolated to large signal-controlled intersections as well as priority-controlled traffic) TRL TRANSYT software can be used [5]. TRANSYT is a software suite that includes a macroscopic traffic model, a signal optimizer, and a simulation model. Using manually supplied traffic flows, the basic traffic model determines a baseline Performance Index (an economic cost based on stops and delays). The signal timings are then modified as part of an optimization process by TRANSYT with the goal of lowering the Performance Index (PI). In this paper, TRANSYT software is used to generate fixed signal plans based on intersection geometry, traffic flow and, traffic movements. Basic traffic control terminology used is as follows:

1) **Phase** is a signal that is displayed for a certain pedestrian or traffic link. One or more signal heads are fed by each phase at a junction (mostly the same approach), which operates as an electrical circuit from the controller.

2) **Stage** is a group of non-concurrent phases that operate simultaneously.

3) **Cycle time** denotes one complete set of traffic signal operations.

4) **Intergreen period** is the amount of time between the conclusion of one phase's right of way and the beginning of the next phase's right of way.

A. Intersection design

The intersection used in this paper is one of the busiest and largest intersections in Tashkent as shown in Fig.1. The intersection is four-legged with North (N), South (S), East (E) and West (W) approaches (Fig. 1).

North, East, and West approaches have 4 traffic lanes while the South approach has 3 traffic lanes. Every approach is controlled by its own Phase:

- North = Phase A;
- East = Phase B;
- South = Phase C;
- West = Phase D.

Due to underground passage pedestrian movements are not considered within this paper.

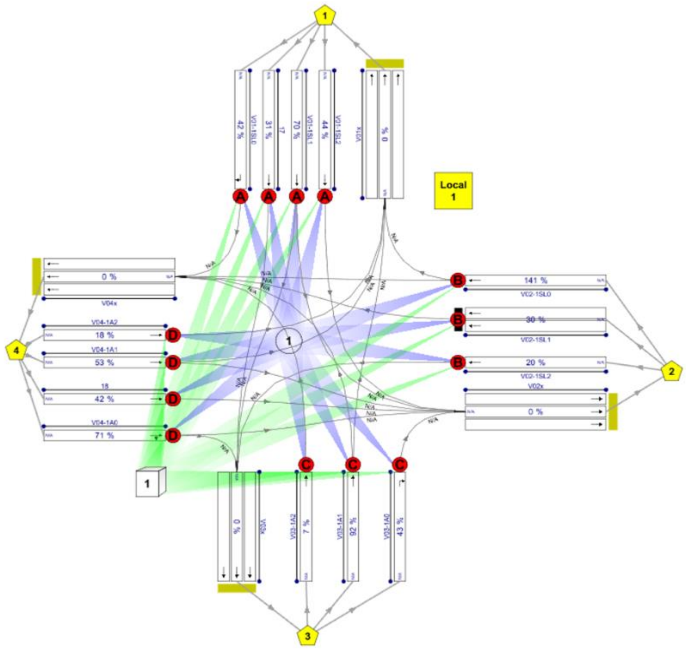

Figure 1. Intersection Network Diagram - TRANSYT

B. Intergreen matrix

To ensure basic traffic safety at the intersection, the Conflict matrix with intergreen times is introduced. Conflicts occur when two movements at a junction, such as a main road and a side road, cannot proceed safely at the same time. An example of conflict points is shown in the picture below (Fig. 2).

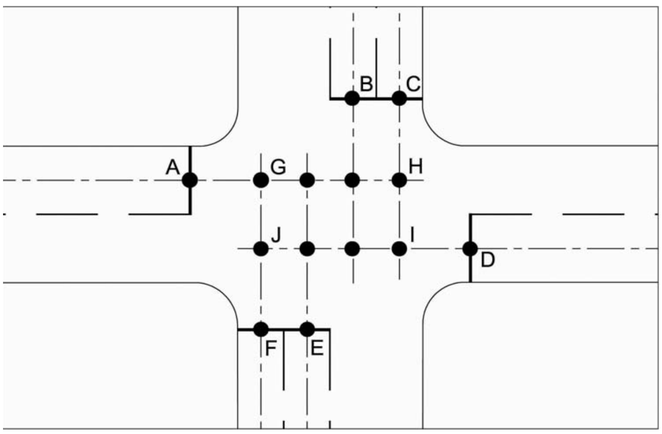

Figure 2. Conflict points (4-legged intersection)

After the Conflict matrix is established, the Intergreen periods have to be calculated. When configuring a junction, intergreen periods (Fig. 3) must be carefully measured. If they are too short, they can cause the next stage to begin before the previous one ends. Otherwise, too long intergreen intervals can cause unnecessary delays within an intersection, which can have a negative impact on the intersection capacity.

The yellow (amber) indicator and the all-red indication (if applicable) are both present during the intergreen interval of a stage. Stopping distance, intersection clearance time, and pedestrian crossing time, if there are no pedestrian signals, all apply to this stage.

Drivers are warned by the yellow signal indication that another phase will shortly be given the right-of-way. Therefore, the intergreen interval should be long enough to allow vehicles that are farther from the stop line than the stopping distance to easily brake to stop the vehicle. Vehicles that have passed the point of no return should be able to pass through the intersection safely during the intergreen interval.

This issue is called the "dilemma zone" concept. If the intergreen time is too short, only those vehicles that are close to the intersection will be able to continue through the intersection safely. In addition, only vehicles that are reasonably distant will have adequate time to react to the signal and stop. Those who are in between will be caught in the "dilemma zone," and won't have enough time to stop or safely cross the intersection.,

Intergreen Matrix | Interstage Matrix | Banned Stage Changes

\	A	B	C	D
A	-	9		9
B	5	-	3	
C		5	-	4
D	9		9	-

Figure 3. Intergreen times

C. Traffic counts – OD matrices

The following step is to calculate the Origin Destination (OD) Matrices. OD matrices enable the specification of origin and destination traffic flows, which are then automatically assigned to traffic streams within the TRANSYT network.

Traffic count is the counting of the number of vehicles passing through a road over a period of time. It is defined as the procedure to determine mainly volume of traffic moving on the roads at a particular section during a particular time. Traffic Volume Survey can be done manually or by use of automatic methods depending upon various factors like manpower available, budget, technology/instrument available, and the magnitude of traffic data required.

Because traffic composition affects the capacity of traffic signal approaches, the traffic count was performed with classification. The effect of traffic composition on capacity is typically considered using weighting factors known as "passenger car units". All vehicle types are converted into passenger car units (PCU) using constant factors. Table 1 shows the values of PCU used simulation.

TABLE I. PCU VALUES

Vehicle type	PCU
Car/Van	1.0
Bus	2.0
Truck	2.3
Bike	0.2
Motorcycles	0.4
Tractor	1.5
Cart	3

Fig. 4 represents the OD matrix with traffic counts (PCU) during the rush hour (5pm). OD matrices approaches are marked with numbers:

- North (Phase A) = 1;
- East (Phase B) = 2;
- South (Phase C) = 3;
- West (Phase D) = 4.

\	1	2	3	4	Total
1	0	850	510	340	1700
2	420	0	140	840	1400
3	600	300	0	100	1000
4	320	960	320	0	1600
Total	1340	2110	970	1280	-

Figure 4. OD matrix

D. Current fixed signal timing plan

The current cycle time for the intersection is set to 130 seconds. Phase distribution within stages is shown on the image below (Fig. 5). Intersection is operating in 2 stage mode.

Stage 1: Phases A, C = green; B, D = red;

Stage 2: Phases B, D = green; A, C = red.

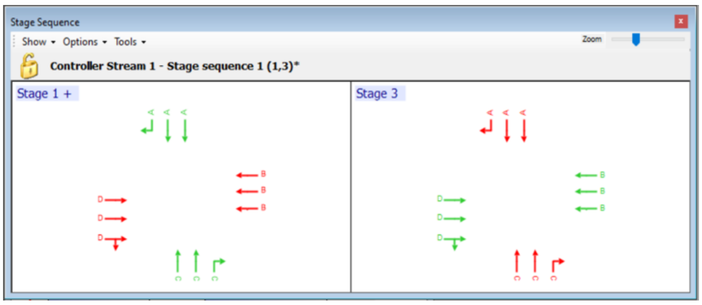

Figure 5. Stage sequence

The existing signal timing plan at the intersection is presented in Fig. 6. Because of the higher traffic flow from North approach, phase A is extended 16 seconds within Stage 1 and

Phase D is extended 12 seconds within Stage 2. That means that at the intersection are presented 2 extended stages.

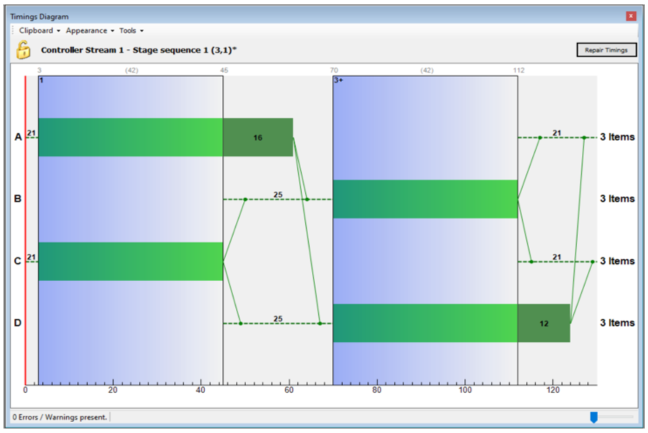

Figure 6. Current signal timing plan

Phases duration are shown in the table below (Table 2).

TABLE II. PHASES DURATION

Phase	Active	Duration
A	3 – 61	58 seconds
B	70 – 112	42 seconds
C	3 – 45	42 seconds
D	70 – 124	54 seconds

The traffic light sequence is red, red/amber (3 seconds), green, amber (3 seconds), red (Fig. 7).

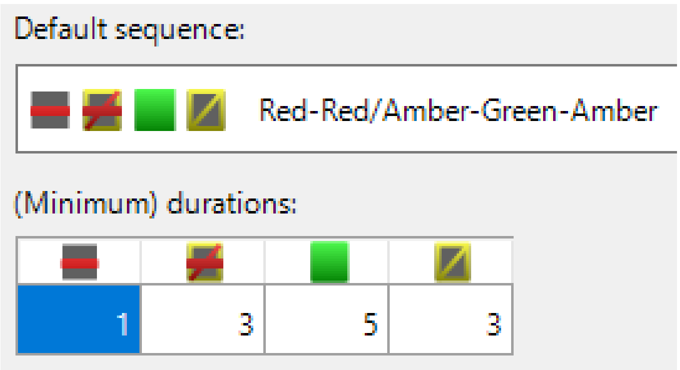

Figure 7. Traffic light sequence (PTV VISSIM)

The saturation flow rate is the maximum flow of vehicles per hour that could traverse a single approach lane of a signalized intersection if the approach were allocated green time for a full hour. Saturation flow rate is a critical value in the design and capacity analysis of signalized intersections and the determination of traffic signal phasing plans. A number of factors influence the saturation flow rate of an intersection approach lane, including the location of the intersection, the vehicle composition of the traffic stream and the presence of parking or public transport facilities near the intersection. Geometric elements that are important for saturation flow rate estimation include number of lanes, lane width, accommodation of turning movements and the gradient of the approach [7].

The degree of saturation (DoS) is an important measure of the usable green time and indicates how close the network is to reaching its maximum capacity. A DoS value greater than 100% indicates oversaturation, and a queue will grow as long as the specified flow conditions exist. Degree of Saturation (DoS) for the current signal timings plan is 96% which is close to the limit.

IV. Vehicle Actuated Simulation Software Model

PTV VISSIM [8] is simulation software widely used by traffic engineers from around the world as support in making decisions. It is a robust software that takes into account a wide range of criteria, enabling us to provide a large number of outcomes [9].

A. *VISSIM Traffic Model*

The traffic model generated within VISSIM software is shown on Fig. 8. The model is almost the same as the one created using TRANSYT software. The difference is that VISSIM model includes inductive loop detectors marked as blue rectangles. The detectors can be specified on the approaches and associated with the phases that are affected when the detectors are actuated. The type of detector used and its location on the approach links depends on the purpose of the detector. Extension and count detectors operating in presence mode and located at the stop bar are typically used to signal the controller that there is a demand for a phase to be serviced. Extension and count detectors operating in passage mode and located upstream of the stop bar are typically used for extending the green time for a phase or when implementing the volume/density functions of the controller. In our example, every traffic lane is equipped with detectors. North, East and West approaches are equipped with 3 rows of detectors while the South approach is equipped with 2 rows of detectors.

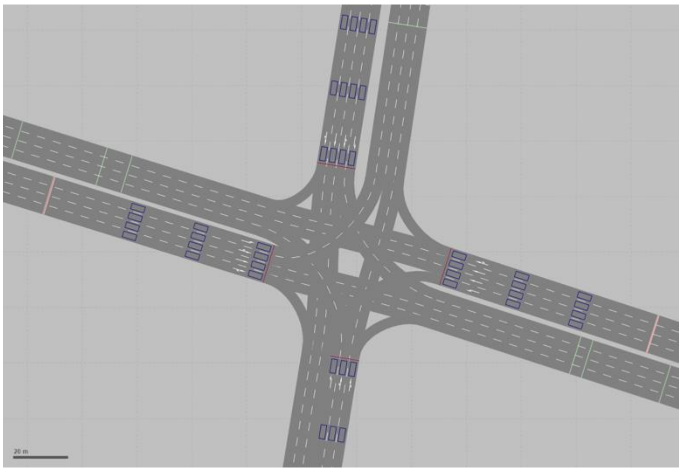

Figure 8. VISSIM traffic model

First row (near stop line) serves to detect the vehicle presence and initialize demand for the stage in which that phase is active, while second and third row are used to extend green times for that approach (phase).

B. *Vehicle Actuated Programming in VISSIM*

VisVAP (Vehicle Actuated Programming), an add-on module for the VISSIM simulation program, was used for the creation and simulation of traffic control algorithms. VisVAP enables the use of object-oriented programming. Flowcharts are used to implement the algorithm's logic for traffic control. The layout of the flowchart in Fig. 9. It shows that an ASCII database with the extension "pua" containing information on the number of phases, intergreen matrices, signal plan definitions, and so on is required. Following the creation of an algorithm in the VisVAP module, the file with extension "vap" is generated. The VISSIM simulation tool is then used to load this file. The detectors and traffic lights created in the traffic network serve as connection between the "vap" file and VISSIM [8].

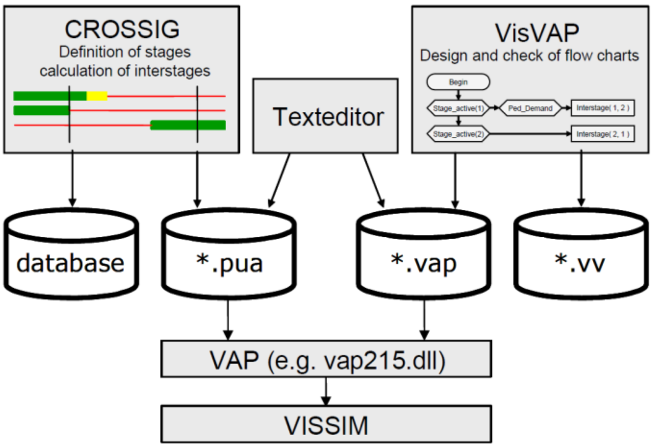

Figure 9. VisVAP flowchart [10]

Instead of the CROSSIG add-on, text editor is used to create “pua” file. Intergreen times remain the same as in TRANSYT model. Because of the complexity to create two stages with extended phases, VISSIM model introduces four stages:

Stage 1: Phases A, C = green; B, D = red;

Stage 2: Phase A = green; B, C, D = red;

Stage 3: Phases B, D = green; A, C = red;

Stage 4: Phase D = green; A, B, C = red;

C. Algorithm development

The algorithm developed for the intersection is shown in Fig. 10. As it is mentioned before, the VA signal plan consists of four stages. The Minimum green time for every phase is set to 10 seconds. In order to prevent long green times due to continuous demands, maximum stage duration is introduced for all four stages (Table 3).

The unit extension is set to 3 seconds. The unit extension has to be long enough for a subsequent vehicle traveling through busy traffic (traffic jam) with a safe headway to maintain a green signal (assuming the maximum green has not yet been reached).

TABLE III. TABLE 1 MAXIMUM STAGE DURATIONS

Parameters	Duration (s)
MAX_STG1	30
MAX_STG2	50
MAX_STG3	15
MAX_STG4	20
MAX_GAP	3

The expressions used in this paper are shown in the table below (Table 4). Expressions to initialize stages are used. To initialize stages there are appropriate expressions called “Stage_active(1, 2, 3, 4)”. To “call” the stage, there are expressions “Call_Stg(1, 2, 3, 4)” and to extend stage there are “Extend_Stg(1, 2, 3, 4)” expressions.

TABLE IV. TABLE 2 VISVAP EXPRESSIONS

Expressions	Contents
Call_Stg1	Detection (1) OR Detection (3)
Call_Stg2	((Detection(9)) AND (Occupancy(2) > 20)) OR (Occupancy(4) > 20)
Call_Stg3	Detection(2) OR Detection(4)
Call_Stg4	((Detection(11)) AND (Occupancy(1) > 6)) OR (Occupancy(3) > 6)
Extend_Stg1	Headway(7) <= MAX_GAP
Extend_Stg2	Headway(9) <= MAX_GAP
Extend_Stg3	Headway(6) <= MAX_GAP
Extend_Stg4	Headway(11) <= MAX_GAP

By default, Stage 1 (Stage_Active (1)) is active. Stage 1 remains active until the maximum Stage 1 duration is reached (MAX_STG1) if there is no demand for Stage 2 (Call_Stg2) and vehicles are detected on approach 3 (Extend_Stg1). Otherwise, after the Stage 1 minimum time is reached, the controller will change its state to Stage 2.

Stage 2 (Stage_Active (2)) remains active until the maximum Stage 2 duration is reached (MAX_STG2) if there is no demand for Stage 3 (Call_Stg3) and vehicles are detected on approach 1 (Extend_Stg2). Otherwise, after the Stage 2 minimum time is reached, the controller will change its state to Stage 3.

Stage 3 (Stage_Active (3)) remains active until the maximum Stage 3 duration is reached (MAX_STG3) if there is no demand for Stage 4 (Call_Stg4) and vehicles are detected on approach 2 (Extend_Stg3). Otherwise, after the Stage 3 minimum time is reached, the controller will change its state to Stage 4.

Stage 4 (Stage_Active (4)) remains active until the maximum Stage 4 duration is reached (MAX_STG4) if there is no demand for Stage 1 (Call_Stg1) and vehicles are detected on approach 4 (Extend_Stg4). Otherwise, after the Stage 3 minimum time is reached, the controller will change its state to Stage 1.

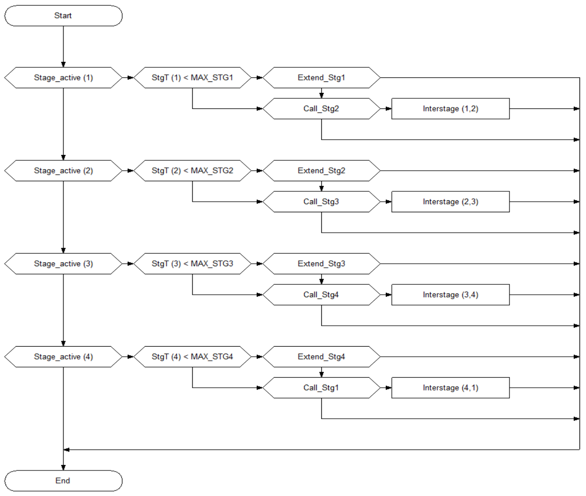

Figure 10. VISSIM algorithm

V. RESULTS AND DISCUSSION

Before the onsite installation of the detectors and VA signal control, VISSIM simulation model is used to provide results that can help us to estimate validity of the solution.

Three parameters are measured for both solutions, FT and VA signals and the results are compared. Simulation period is set by default, 1 hour (3600 seconds).

Parameters used and compared are:

1. *Average travel times* for all intersection movements (in seconds).

The distance for which the travel time is measured is 200m - 100m before stop line and 100m after the stop line; there are 4 approaches and all movements are allowed which means that vehicles from all 4 approaches can drive to every other approach (left, straight and right).

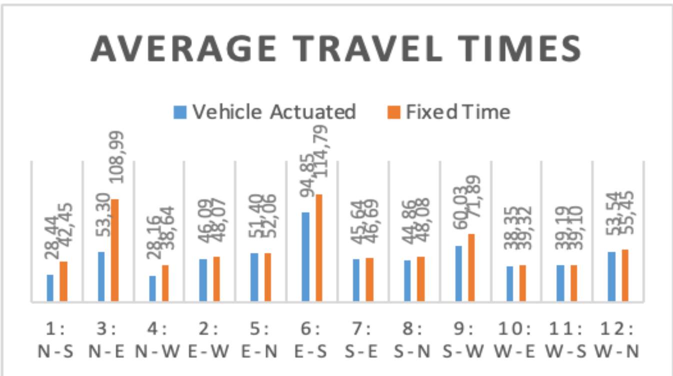

Figure 11. Average travel times

Fig. 11 shows that the average travel times for almost all traffic movements are decreased when the VA traffic control is operating. The most significant difference is shown for all three movements from North approach (N-E, N-W and N-S). Average travel time for N-S movement decreased for 33%, N-E for 51% (from 108.99 to 53.3 meters) and N-W for 27%. In total, North approach movements decreased for average 37%.

2. *Average queue length* for all intersection approaches per one hour – 3600 seconds;

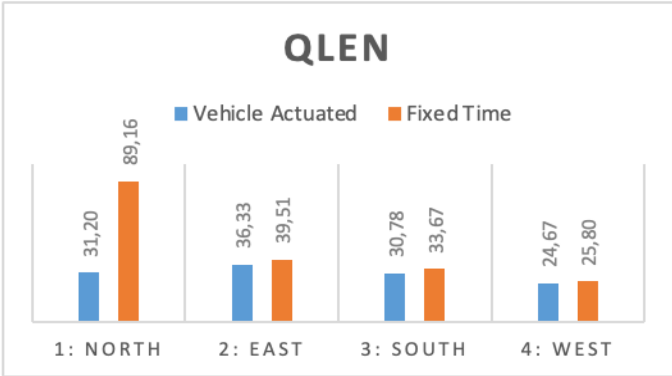

Figure 12. Average queue length

The average queue length per approach is measured. For all 4 approaches, the average queue length decreased but the most significant difference is noticed on North approach (Fig. 12). The average queue length, when the VA mode operates, decreased by 65% (from 89,16 to 31.20 meters). In total, North approach average queue length decreased for more then 21%.

3. *Maximum queue length* measured upstream by the queue counter – 3600 seconds.

The maxmimum queue length was measured for each approach. The results differed. The maximum queue length decreased only for the North approach (40%). For the East, South and West approaches, the maximum queue lengths are larger in VA than FT mode (Fig. 13). These results can be neglected because the average queue lengths as well as average travel times are significantly lower.

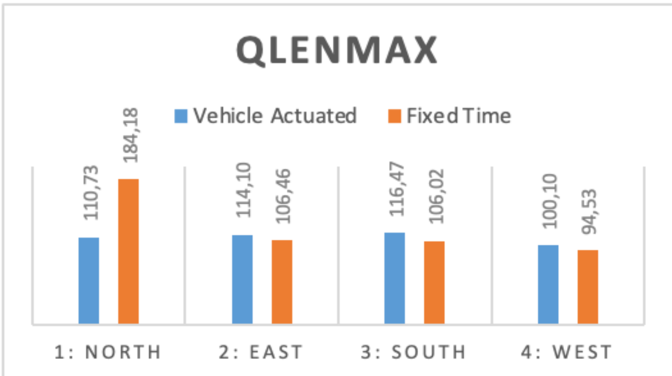

Figure 13. Maximum queue length

One of the obstacles to such systems are the costs they are associated with. According to National Cooperative Highway Research Program (NCHRC), the average installation cost per intersection is approximately $65,000 [11].

VI. CONCLUSION

This paper shows traffic control at one of the largest and busiest intersections in Tashkent, Uzbekistan. The intersection currently operates in FT mode. TRANSYT, software for macroscopic traffic modeling was used to create FT signal plans based on intersection geometry, traffic flow and traffic movements. The signal plan generated by TRANSYT was used for simulation with other software. Namely, VISSIM, software for microscopic traffic flow simulation, was used to develop the VA control algorithm and to compare the data, FT versus VA, in terms of vehicle travel times and queue lengths (both the average and maximum values).

The results of the evaluation show that the performance of the VISSIM adaptive traffic signal control decreased vehicle travel times and queue lengths, as compared to TRANSYT FT control. Average travel times for the North approach (the busiest one) movements decreased for average 37%. The average queue length for the same approach decreased for more then 21%. The maximum queue length is significantly decreased for the North approach by 40%.

The algorithm developed for this case is simple to understand - stage transition is the same as FT mode, the only difference is in the duration of the phase green times, based on traffic flows. Both the average traveling times and queue lengths can decrease when using a properly optimized VA algorithm.

Usage of properly optimized VA algorithm can reduce both average traveling times and queue lengths. However, the justification of this approach depends on the cost of the installed sensor, which should be compared to fuel economy, environmental protection and other parameters, which will be the subject of the future work.

The limitations of this paper are related to the influence to adjacent intersections. The VA cycle time is not constant due to vehicle flow, and it could affect the capacity of the adjacent intersection because they are operating in FT mode. It will be also, the subject of the future work.

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Dejan Ćiprovski graduated with the Master of Science degree in road traffic safety from the Faculty of transport and traffic engineering in Belgrade, 2012. He is currently attending PhD studies at the Metropolitan University in Belgrade, Serbia. Dejan has been working for Vlatacom Institute since 2013. He is working as a traffic engineer on the projects for Traffic Control in Luanda, Angola and Tashkent, Uzbekistan. Dejan is also involed in eID projects and border control for the Republic of Suriname.

Aleksej Makarov received in 1997 his PhD degree in telecommunications from the Swiss Institute of Technology (EPFL). From 1997 to 2003 he worked for STMicroelectronics in Switzerland and California, where he led teams developing innovative mobile phone architectures and functionalities, and represented the company in 3GPP. Aleksej has been working for Vlatacom since 2003. and led the nation-scale ID card, border control, traffic control, and other projects. In 2017-2018, he was research fellow at the University of Oxford. He wrote 9 international patents, authored or co-authored about 40 scientific publications.

D Prof. dr. Miljan Vučetić graduated with the Master of Science degree in telecommunication from the Faculty of transport and traffic engineering in 2008. He received PhD in computer science from the University of Belgrade in 2013. Dr. Vučetić worked as Data Scientist on Big Data, ETL and Data Mining projects. His main research interests include information systems, computational intelligence, machine learning, artificial intelligence in general, data mining, software engineering and knowledge discovery. He has been involved in FP7 and H2020 projects, as a reviewer for the top scientific journals and as a program committee member for prestigious international conferences. He is an author of more than 60 referenced papers and 13 technical solutions. Miljan is a member of IEEE and certified Microsoft engineer.