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Validating the Interval Valued Neutrosophic Soft Set Traffic Signal Control Model Using Delay Simulation

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Abstract. Currently most signalized intersections in almost all developing countries use fixed time traffic controllers or pre-timed traffic lights. But as a real life situation, in addition to uncertainty and impreciseness there is also indeterminacy in traffic signal control constraints due to various factors like unawareness of the problem, inaccurate and imperfect data and poor forecasting in addition to uncertainty in the constraints. To overcome these interval valued neutrosophic soft set traffic signal control model at four way isolated signalized intersections has been developed. The main aim of this research is to validate the IVNSS traffic signal control model and compare it with fixed time traffic signal control model using MATLAB simulation tool. Vehicle delay at the junction is used as a measure of effectiveness. The simulation is conducted for seven consecutive days from Monday up to Sunday for eight hours to reflect the different traffic flow conditions. The simulated delay model results are analysed under 5 different scenarios. And results showed that in case of heavy traffic conditions vehicle delay under IVNSS traffic signal control model is minimized by 36 percent and under light traffic conditions the average vehicle delay is minimized by 73 percent when compared to fixed time traffic signal control model.

Keywords: Signal control- Delay- Simulation

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1. INTRODUCTION

One of the major problems of both developed and developing countries is traffic congestion in urban road transportation systems. Urban traffic congestions lead to a lot of time consumption and exhaust emissions. So alleviating congestion will have a good impact on both economy and environment. The signal control at urban intersections is an effective and most important way to reduce the traffic jams and congestions. Traffic signals are signalized devices positioned at road intersections, pedestrian crossings and other such locations to control competing flow of traffic [1]. The purpose of traffic light signal control is to make the current intersection system more effective and efficient in improving traffic safety and minimizing congestion, maximizing the capacity of flow and minimizing the delay without building new roadways which is often impossible due to scarce or non-availability of land resource. The conflicts arising from movements of traffic in different directions are addressed by time sharing principle. The advantages of traffic signal include an orderly movement of traffic, an increased capacity of the intersection and require only simple geometric design. However the disadvantages of the signalized intersection are large stopped delays [2]. Traffic signal control is a measure that is commonly used at road intersections to minimize vehicular delays. In early days as well as at present, traffic is controlled by hand signs by traffic police officers or by signals and markings called the traditional traffic control systems. Researches have established that unless otherwise implemented properly the traditional traffic control system can contribute more to the congestion at intersections [3]. Currently most signalized intersections in almost all developing countries use fixed time traffic controllers or pre-timed traffic lights.The traffic lights change phase at a constant cycle time in fixed time traffic light controller, without taking into account the peak period or highly varying traffic intensity with respect to time. Pre-timed traffic light also causes traffic congestion as it is incapable of detecting traffic intensity at the junction and to allow the vehicles waiting in the lanes to cross the junction as per the urgency necessitated by the traffic conditions prevailing at that time. The present day traffic signal controller models suffer from indeterminacy due to various factors like unawareness of the problem, inaccurate and imperfect data and poor forecasting in addition to uncertainty in the constraints. To overcome these Endalkachew et al.[4] developed an interval valued neutrosophic soft set traffic signal control model for four way isolated signalized intersections. The main aim of this research is to validate the IVNSS traffic signal control model and compare it with fixed time traffic signal control model using simulation study. A MATLAB simulation model for the proposed IVNSS traffic control system is developed and the efficiency of the model is tested subject to random variation, the basic methods of generating random variables and simulating probabilistic systems are presented. The MATLAB simulation tool is utilized to compare the developed IVNSS traffic signal control model with fixed time control model for an isolated four way intersection at St. Stifanos traffic junction, Addis Ababa, Ethiopia using Webster delay model.

2. REVIEW OF LITERATURE

Literally simulation is an imitation of certain real events or a system. This technique involves building a mathematical model that sufficiently represents a given system and using a computer to imitate (simulate) the operations of the system. Basically, it is used to analyse the behaviour of the system or to estimate its performance under various circumstances in order to find ways to improve the functioning of the system. There are several criteria named MOEs (Measures of Effectiveness); delay, level of service (LoS), average queue length, max queue length, number of stops and vehicle through put that can be used to compare the proposed IVNSS traffic signal control model with the widely used pre-timed control. But in this research we use vehicle delay at the junction as a measure of effectiveness. Vehicle delay is the most important parameter used by transportation professionals in evaluating the performance of a signalized intersection. However delay is a parameter that is not easily determined due to the non-deterministic nature of the arrival and departure processes at the intersection [10]. But lot of research has been done in this field to define delay by a number of simulated delay models. Broumi Said et al.[23] reviewed some available mathematical techniques for traffic flow using rough set, fuzzy rough set, and its extension with the neutrosophic set to solve the traffic problem and found that the rough set theory can be useful for dealing the uncertain, incomplete, and indeterminate data set. Hence, the hybridization of the neutrosophic set and rough can be considered one of the efficient tools for intelligent traffic control and its approximation via automatic red, green and yellow lights. Recommended that the proposed study will be helpful for several researchers working on traffic flow, traffic accident diagnosis, and its hybridization as future research. Arshad Jamal et al. [11] developed meta-heuristic-based methods for intelligent traffic control at isolated signalized intersections, in the city of Dhahran, Saudi Arabia to optimize delay. Genetic algorithm (GA) and differential evolution (DE) were employed to enhance the intersection's level of service (LOS) by optimizing the signal timings plan. The study results indicated that both GA and DE produced a systematic signal timings plan and significantly reduced travel time delay ranging from 15 to 35 percent compared to existing conditions. Although DE converges much faster to the objective function, GA outperforms DE in terms of solution quality i.e., minimum vehicle delay. To validate the performance of proposed methods, cycle length-delay curves from GA and DE were compared with optimization outputs from TRANSYT 7F, a state-of-the-art traffic signal simulation. Nilesh Bhosale et al. [12] compared analysis of the previously developed methodology and results of delay caused due to pre-timed two way signal coordination with least time pollution and environmental pollutions. They developed suitable methodology and simulation techniques for coordination to reduce the time pollution as well as improve the traffic efficiency and concluded that coordination of signal plays a vital role to abate congestion, reduces travel time as well as waiting time at signalized intersections. The phase difference plan method is best suited for signal coordination as these results in minimal delay in overall average travel time. Zhenyu Mei et al.[13] presented the findings of a simulation study evaluating the potential benefits of implementing transit signal priority (TSP) combined with arterial signal coordination for an isolated intersection. Simulation analysis reveals the effect of TSP strategies with flow variation on the optimal cycle, and also identifies a reasonable method for selecting the gap time and initial green time of the priority phase. The volume influences both the gap time and initial green time of the TSP phase. Moreover, the efficiency of red truncation is slightly better than that of the green time extension strategy. Theresa Thuniga et al.[17] provided an open-source implementation of a decentralized, adaptive signal control algorithm in the agent-based transport simulation MATSim, which is applicable for large-scale real-world scenarios. The algorithm is extended in this paper to cope with realistic situations like different lanes per signal, small periods of overload, phase combination of non-conflicting traffic, and minimum green times. Impacts and limitations of the adaptive signal control are analysed for a real-world scenario and compared to a fixed-time and traffic-actuated signal control. Another finding is that the adaptive signal control behaves like a fixed-time control in overload situations and, therefore, ensures system with stability. Nada B et al.[14] presented a new method of developing an optimal real-time traffic signal controller using the fuzzy logic method (FLM), taking into consideration all various incoming traffic flows. The developed FLM was designed for an isolated intersection with four legs, split phasing, and three different movements (through, right, and left). Calibration and validation tests were conducted to ensure accuracy and efficiency of the developed model. Results show that using the developed FLM for controlling traffic signals with optimized conditions is promising as it provides optimal solution for all different traffic flow combinations, during all model development stages, including the simulation, calibration and the validation process. Ardavan Shojaeyan [15] carried out the design of efficient phase optimization technique using developed phase plan. CG Road was identified as a troubled corridor during reconnaissance survey and as such, selected for study. Data on geometric features were collected by Field survey using Odometer as well as with Google Earth Software. Peak and off peak hour traffic volume data were collected using ultra high resolution full HD camera. Furthermore signal cycle timing, space mean speed, discharge head way were simultaneously collected by trained enumerator's at all three intersections. Data extraction was carried out on projector screen using updated VLC media player. The geometric and traffic data collected were analyzed with Microsoft Excel. Three different Phase Optimization Technique(POT) is tested on real traffic signal data of corridor in forward and backward direction using Time Space Diagram. With change of phase plan and phase sequence POT 1 is successful in minimizing combined delay of corridor up to 28.05 percent to 76.04 percent for all 4 forward movements for analyzed two cycles. Further improvement in POT 2 is achieved by introducing 10 second offset at intersection B which reduces combined delay up to 32.52 percent to 98.6 percent in all 4 forward movements. Tracking average travel time, demand supply and prevailing signal cycle time POT 3 is applied with equal signal cycle length of 104 second at all 3 intersections. D.Nagarajan [16] analysed traffic flow control under neutrosophic environment using MATLAB. Triangular and Trapezoidal Fuzzy numbers were used. Traffic flow management has been analyzed with respect to various ranges of indeterminacy under neutrosophic environment using MATLAB program. They also compared the traffic control management for crisp sets, fuzzy and neutrosophic sets. Chandan. Ka [18] proposed a connected vehicle signal control (CVSC) strategy for an isolated intersection, which utilizes detailed information, including speeds and positions of GPS equipped vehicles on each approach at every second. The proposed strategy first aims at dispersing any queue that is built up during the red interval, and then starts minimizing the difference between cumulative arrival flow and cumulative departure flow on all approaches of the intersection. Various traffic scenarios with 100 percent GPS market penetration rate were tested in the VISSIM 8 microscopic simulation tool. Results have established that the proposed CVSC strategy showed outstanding performance in reducing travel time delays and average number of stops per vehicle when compared to the EPICS adaptive control. D.Nagarajan, et al.

[19] studied a triangular interval type-2 Schweizer and Sklar weighted arithmetic (TIT2SSWA) operator and a triangular interval type-2 Schweizer and Sklar weighted geometric (TIT2SSWG) operator based on Schweizer and Sklar triangular norms. Moreover, they proposed an improved score function for interval neutrosophic numbers (INNs) to control traffic flow that has been analyzed by identifying the junction where the traffic intensity is more. D. Nagarajan et al. [20] analysed traffic flow management with respect to various ranges of indeterminacy under neutrosophic environment using Gauss Jordan method with the support of MATLAB program. As seen from the above, traffic signal control models have been developed by a number of researchers under neutrosophic environment but no one has studied its efficiency and compared it with other existing models.

3. PRELIMINARY CONCEPTS

In this section we present the necessary preliminary ideas and some basic results needed for the present research work. We start from the definition of a neutrosophic set.

3.1. *Single valued neutrosophic set [21]*

Let X be the universal set.A neutrosophic set A in X is characterized by a truth membership function μ_A, an indeterminacy membership function υ_A and a falsity membership function ω_A,where $\mu_A, \upsilon_A, \omega_A : X \to [0,1]$ are functions and $\forall x \in X$,$x \equiv x(\mu_x, \upsilon_x, \omega_x) \in A$ is a single valued neutrosophic element of A.

A single valued neutrosophic set A(SVNS in short) over a finite universe $X = \{x_1, x_2, ..., x_n\}$ can be represented as $A = \sum_{i=1}^{n} < \mu_A(x_i), \upsilon_A(x_i), \omega_A(x_i) > /x_i$.

The three membership functions form the fundamental concepts of neutrosophic set and they are independently and explicitly quantified subject to the following conditions.

$$0 \le \mu_A(x), \upsilon_A(x), \omega_A(x) \le 1 \text{ and}$$
$$0 \le \mu_A(x) + \upsilon_A(x) + \omega_A(x) \le 3 \ \forall x \in X.$$

3.2. *Union and Intersection of SVNS* [21]

Let A and B be two SVNS defined on a common universe X .Then the union of A and B ,written as $A \cup B = C$ is defined by

$$\mu_C(x) = max(\mu_A(x), \mu_B(x))$$
$$\upsilon_C(x) = max(\upsilon_A(x), \upsilon_B(x))\text{and}$$
$$\omega_C(x) = min(\omega_A(x), \omega_B(x))\forall x \in X.$$

The intersection of A and B ,denoted by $A \cap B = C$ is defined by

$$\mu_C(x) = min(\mu_A(x), \mu_B(x)),$$
$$\upsilon_C(x) = min(\upsilon_A(x), \upsilon_B(x)) \text{ and}$$
$$\omega_C(x) = max(\omega_A(x), \omega_B(x))\forall x \in X.$$

3.3. *Interval Valued Neutrosophic Set* [22]

For an arbitrary sub interval set A of $[0,1]$ we define $\underline{A}$ = inf of A and $\overline{A}$ = sup of A.
Let X be the universal set.An interval valued neutrosophic set A in X is characterized by a truth membership function μ_A , an indeterminacy membership function υ_A and a falsity membership function ω_A for each element $x \in X$ where

$$\mu_A(x) = [\underline{\mu}_A(x), \overline{\mu}_A(x)],\ \upsilon_A(x) = [\underline{\upsilon}_A(x), \overline{\upsilon}_A(x)],\ \omega_A(x) = [\underline{\omega}_A(x), \overline{\omega}_A(x)] \text{ are closed sub-intervals of } [0,1].$$

Thus $A = < \mu_A(x), \upsilon_A(x), \omega_A(x) > /x; x \in X$.

3.4. *Union and Intersection of IVNS* [22]

let A and B be two IVNS defined over a common universe X.The union of A and B denoted by$A\tilde{\cup}B$ is defined as

$$\begin{gathered} A\tilde{\cup}B = \{< [max(\underline{\mu}_A(x), \underline{\mu}_B(x)), max(\overline{\mu}_A(x), \overline{\mu}_B(x))], \\ [max(\underline{\upsilon}_A(x), \underline{\upsilon}_B(x)), max(\overline{\upsilon}_A(x), \overline{\upsilon}_B(x))], \\ [min(\underline{\omega}_A(x), \underline{\omega}_B(x), min(\overline{\omega}_A(x), \overline{\omega}_B(x))] > /x; \forall x \in X\} \end{gathered}$$

Similarly the intersection of A and B denoted by $A\tilde{\cap}B$ is defined by

$$\begin{gathered} A\tilde{\cap}B = \{< [min(\underline{\mu}_A(x), \underline{\mu}_B(x)), min(\overline{\mu}_A(x), \overline{\mu}_B(x))], \\ [min(\underline{\upsilon}_A(x), \underline{\upsilon}_B(x)), min(\overline{\upsilon}_A(x), \overline{\upsilon}_B(x))], \\ [max(\underline{\omega}_A(x), \underline{\omega}_B(x), max(\overline{\omega}_A(x), \overline{\omega}_B(x))] > /x; \forall x \in X\} \end{gathered}$$

Traffic flow is usually interrupted by traffic signals and stop signs. These controls have different impacts on overall flow. The operational state of traffic at an interrupted traffic-flow facility is defined by the following measures [5].Classified vehicle count or traffic volume, directional movement of vehicles, queues (saturation flow rate), signal timing and phasing data and delay.

3.5. *Traffic flow at signal junction*

3.5.1. *Traffic Volume Count*

Volume is the total number of vehicles that pass over a given point or section of a lane or road way during a given time interval; it can be expressed in terms of annual, daily, hourly, or sub hourly periods. Traffic volume count for Directional movement of each vehicle (Through, Right turn and Left turn movements) is conducted to determine the number, movements and classifications of roadway movements at a given location. These data can help identify critical flow time periods. The length of the sampling period depends on the type of count being taken and the intended use of the data recorded. For example, an intersection count may be conducted during the peak flow period. Manual count with 15-minute intervals could be used to obtain the traffic volume data.

Basically, the traffic volume and saturation flow data are collected through traffic sensors installed at the junction or video graphic record or through manual count.

3.5.2. *Capacity*

Capacity is an adjustment of the saturation flow rate that takes the real signal timing into account, since most signals are not allowed to permit continuous movement of one phase for an hour. If the approach has 30 minutes of green per hour, it can be deduce that the actual capacity of the approach is about half of the saturation flow rate. The capacity, therefore, is the maximum hourly flow of vehicles that can be discharged through the intersection from the lane group in question under the prevailing traffic, roadway, and signalization conditions. The formula for calculating capacity (c) is given below.

$c = (g/C) \times s$

where:

c=capacity(vehicle per hour)

g = Effective green time for the phase in question (seconds)

C = Cycle length (seconds)

s = Saturation flow rate (vehicle per hour per green)

3.6. *Delay at signalized intersection*

To give a clear description and to understand traffic flow conditions at an individual intersection the following performance measures are being applied: delay, level of service (LoS), average queue length, max queue length, number of stops and vehicle throughput. The reasons for determining these parameters are as follows. Delay and LoS play a primary role in determining individual intersection performance. LoS can be used to understand the quality of traffic conditions on a particular intersection and delay exposes the difference between free-flow and congested traffic conditions. Frequent stops due to congestion are a typical characteristic of urban traffic. One of the reasons for this is the presence of signalized intersections. Therefore, the information of queue length and number of stops must be included as performance measure also. The vehicle throughput can provide useful information about the maximum number of vehicles which can be discharged during the time. In addition, for an in-depth analysis of the arterial section in the analyzed urban traffic network, travel time; delay and number of stops are also useful.

Vehicle delay is the most important parameter used by transportation professionals in evaluating the performance of a signalized intersection. This is perhaps because it directly relates to the time loss that a vehicle experiences while crossing an intersection .However delay is a parameter that is not easily determined due to the non deterministic nature of the arrival and departure processes at the intersection. But lot of research has been done in this field to define delay by a number of analytical delay models. But the most popular and commonly used delay model is the Webster delay model.

3.7. *Delay Components*

In analytic models for predicting delay, there are three distinct components of delay, namely, uniform delay, random delay, and overflow delay.

3.7.1. *Uniform delay*

Uniform delay is the delay based on an assumption of uniform arrivals and stable flow with no individual cycle failures. No signal cycle fails here, i.e., no vehicles are forced to wait for more than one green phase to be discharged. This type of delay is known as Uniform delay where uniform vehicle arrival is assumed.

3.7.2. *Random Delay*

Random delay is the additional delay, above and beyond uniform delay, because flow is randomly distributed rather than uniform at isolated intersections. This case represents a situation in which the overall period of analysis is stable (i.e., total demand does not exceed total capacity). Individual cycle failures within the period, however, have occurred. For these periods, there is a second component of delay in addition to uniform delay.This type of delay is referred to as Random delay.

3.7.3. *Overflow Delay*

Overflow delay is the additional delay that occurs when the capacity of an individual phase or series of phases is less than the demand or arrival flow rate. Actual vehicle arrivals vary in a random manner [72] and this randomness causes overflows in some signal cycles. If this persists for a long time period then the over-saturated conditions lead to continuous overflow delay. The effect of the overflow depends on the degree of saturation over a given time period. This is the case at which demand exceeds capacity (v/c $>$ 1.0).This type of delay is referred to as Overflow delay

3.8. *Webster's Delay Models*

3.8.1. *Uniform Delay Model*

Model is explained based on the assumptions of stable flow and a simple uniform arrival function. Thus, Webster's model [70] for uniform delay (UD) is given as

$$UD = \frac{C(1-\frac{g}{C})^2}{2(1-\frac{v}{s})}$$

Another form of the equation uses the capacity, c, rather than the saturation flow rate, s.
$s = \frac{c}{\frac{g}{C}}$ so, the relation for uniform delay changes to,

$$UD = \frac{C(1-\frac{g}{C})^2}{2(1-\frac{g}{C}\frac{v}{c})}$$

$$UD = \frac{C(1-\frac{g}{C})^2}{2(1-\frac{g}{C}X)}$$

where, UD is the uniform delay (sec/vehicle) C is the cycle length (sec), c is the capacity, v is the vehicle arrival rate (vehicle per hour), s is the saturation flow rate or departing rate of vehicles (vehicle per hour green), X is the v/c ratio or degree of saturation (ratio of the demand flow rate to saturation flow rate), and g/C is the effective green ratio for the approach.

3.8.2. *Random Delay Model*

The uniform delay model assumes that arrivals are uniform and that no signal phases fail (i.e., that arrival flow is less than capacity during every signal cycle of the analysis period). At isolated intersections, vehicle arrivals are more likely to be random. A number of stochastic models have been developed for this case, including those by Newell, Miller and Webster. These models generally assume that arrivals are Poisson distributed, with an underlying average rate of v vehicles per unit time. The models account for random arrivals and the fact that some individual cycles within a demand period with v/c $<$ 1.0 could fail due to this randomness. This additional delay is often referred to as Random delay. The most frequently used model for random delay is Webster's formulation:

$$RD = \frac{X^2}{2v(1-X)}$$

Where, RD is the average random delay second per vehicle, and X is the degree of saturation (v/c ratio).

Webster found that the above delay formula overestimate delay and hence he proposed that total delay is the sum of uniform delay and random delay multiplied by a constant for agreement with field observed values. Accordingly, the total delay is given as:

D=0.9(UD+RD)

3.8.3. *Overflow delay model*

Model is explained based on the assumption that arrival function is uniform. In this model a new term called over saturation is used to describe the extended time periods during which arrival vehicles exceeds the capacity of the intersection approach to the discharged vehicles. In such cases queue grows and there will be overflow delay in addition to the uniform delay. This is the case where v/c $>$1.0.

During the period of over-saturation delay consists of both uniform delay and overflow delay. As the maximum value of X is 1.0 for uniform delay, it can be simplified as [72],

$$UD = \frac{C(1-\frac{g}{C})^2}{2(1-\frac{g}{C}X)} = \frac{C}{2}(1-\frac{g}{C})$$

Average delay is obtained by dividing the aggregate delay by the number of vehicles discharged within the time T which is cT. T is the analysis period in seconds.

$$OD = \frac{T}{2}(\frac{v}{c}-1)$$

4. DELAY SIMULATION

4.1. *Data Requirement for the Simulation Model*

Even though there are many intersections facing with traffic congestion in Addis Ababa, due to time and budget constraints and accessibility of relevant traffic data, it is difficult to cover all such intersections in the city. So that St.Stifanos traffic junction is selected for this study.This intersection is located in front of St. Stifanos church in Kirkos sub-city at Meskel intersection and considered as the most congested traffic junction by the road users. St.Stifanos traffic junction is one of the largest intersections in Addis Ababa with its heavy traffic congestion especially in the morning, mid-day and evening peak hours due to poor signal controlling system. The geometry of the intersection is presented in Figure 1 below and the aerial shoot of Meskel square intersection is shown in Figure 2.

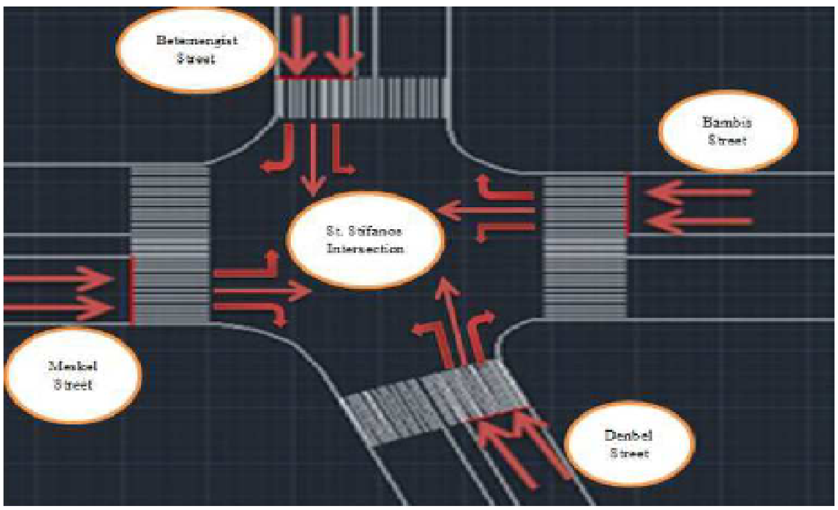

FIGURE 1. Geometric representation of the study area

4.2. *Steps for simulation*

Step 1: Obtain the input parameters (average arrival rate and average saturation flow rate (queue) for each approach per day. And use this data to simulate the vehicle arrivals and saturation flow rates using Poisson distribution.

Step 2: As categorizing arrival rates and saturation flow rates (queues) in to different interval valued neutrosophic soft sets follow uniform distribution, simulate the corresponding interval valued neutrosophic soft sets using uniform distribution using the flow rates and saturation flow rates (queues) obtained in step one. The interval valued neutrosophic data are simulated for 5 different scenarios and the average value of all the simulated values is taken as input parameter for determining the green time and cycle length for each approach. The proposed random number generation plan is simulated by using the MATLAB simulation tool. This gives the IVNSS 'A' for vehicle arrivals and IVNSS 'B' for saturation flow rate (queue).

FIGURE 2. Aerial shoot of Meskel square intersection

Step 3: Combine the two interval valued neutrosophic soft sets A and B to get a resultant interval valued neutrosophic soft set say 'C'.

Step 4: By defining an AVG-threshold value, reduce the parameters.

Step 5:

- Determine the row index for each signal group
- Row index represents the weight of the signal group.
- The first row index represents the weight of the signal group SG1.
- The second row index represents the weight of the signal group SG2.
- The third row index represents the weight of the signal group SG3 and
- The fourth row index represents the weight of the signal group SG4,
- Row index assigns value 1 if the row satisfies the given threshold value and 0 otherwise.

Step 6: Obtain the total weight values which is the sum of the weights of the signal groups with respect to the parameter e_ij which is the choice value for the signal groups.

Step 7: Select (choose) the indices (corresponding signal group) with maximum weight.

Step 8: Determine the total cycle time and the green time using the weight value obtained in Step 6.

Step 9: A MATLAB simulation is carried out for the proposed IVNSS traffic signal system to validate the model and test the efficiency of the model with respect to vehicle delay in which the variables involved are subject to random variation, we present the basic methods of generating random variables and simulating probabilistic systems.

4.3. *Assumptions*

The simulation is based on the following assumptions:

• The input parameters used for the simulation (average arrival rates and average saturation flow rates are based on the data obtained from [8].

• Maximum green time is 95 seconds and minimum green time is 27 seconds at St.Stifanos isolated traffic junction.

• The traffic movement is right, left and through.

• The yellow (amber) signal for all phases at each intersection is included in green signal and its duration is 3 seconds.

• No right turn on red and

• No pedestrian demand

• The intersection has four phases.

4.4. *Delay Simulation Analysis*

The IVNSS traffic signal control model validation is carried out comparing the results with fixed time traffic signal using Webster delay formulas. Generally for the simulation purpose the average traffic volume count (arrival rate) and average saturation flow rate (queue) are obtained by generating randomly using Poisson distribution. But in this research, the average traffic volume count (arrival rate) and average saturation flow rate (queue) are obtained directly from [8] which are used as input parameters for the simulation and the data was obtained from St. Stifanos intersection with Bambis in the East, Betemengist in the North, Dembel in the South and Meskel Square in the West as shown in Figure 1. According to the data obtained from [8], the traffic volume count was made for 8 hours per day for one week starting from the morning 7:30 AM to the evening 7:30 PM at 15 minutes interval as shown in appendix (A). This is done 3 hours in the morning (7:30-10:30) AM, 2 hours in the midday (12:00- 2:00) PM and 3 hours in the evening (4:30-7:30) PM. The traffic flow count is categorized in to two groups, the first count was made from Monday to Friday at which there is a heavy traffic flow condition and there is traffic saturations and the second count was made on Saturday and Sunday at which there is light traffic conditions or no traffic saturations. The average traffic flow rate, saturation flow rate (queue) and average vehicle delay for fixed time signal control per day for each approach for a week is shown in the table 1 and table 2 below [8].

TABLE 1. The average vehicle delay under fixed time per day for all intersection legs.(Monday-Friday)

Approach Leg	PH	Volume	FR	G/C	GT	CT	SFR	Capacity	V/c	Delay
Bambis	Morning	115	460	0.28	75	271	1377	381	1.2	188
Bambis	Mid-Day	85	340	0.26	55	214	1023	263	1.3	214
Bambis	Evening	114	456	0.29	76	263	1371	396	1.15	172
Dembel	Morning	173	692	0.36	108	301	2080	746	0.93	176.8
Dembel	Mid-Day	131	524	0.35	87	251	1577	546.6	0.96	148.8
Dembel	Evening	171	684	0.36	108	297	2058	748.4	0.91	173.7
Betemengist	Morning	88	352	0.2	55	265	1051	218.1	1.6	376
Betemengist	Mid-Day	66	264	0.16	38	231	794	130.6	2.01	552
Betemengist	Evening	85	340	0.2	52	257	1015	205.4	1.66	400
Meskel Sq.	Morning	111	444	0.27	72	262	1328	365	1.22	195
Meskel Sq	Mid-Day	82	328	0.23	51	219	981	228.5	1.44	278
Meskel Sq	Evening	121	484	0.29	81	277	1456	425.8	1.14	161

TABLE 2. The average vehicle delay under fixed time control per day for all intersection legs. (Saturday and Sunday)

Approach Leg	PH	Volume	FR	GT	CT	g/C	SFR	Capacity	V/c	Delay
Bambis	Morning	56	224	35	166	0.21	669	141	1.6	336
Bambis	Mid-Day	41	164	28	144	0.19	490	95.3	1.7	373
Bambis	Evening	52	208	34	160	0.21	621	132	1.6	333
Dembel	Morning	59	236	38	161	0.24	705	166.4	1.4	241
Dembel	Mid-Day	45	185	31	140	0.22	536	118.7	1.6	325
Dembel	Evening	60	240	39	159	0.25	715	175.4	1.4	240
Betemengist	Morning	33	132	23	157	0.15	395	57.9	2.3	652
Betemengist	Mid-Day	27	108	19	153	0.12	325	40.4	2.7	832
Betemengist	Evening	31	124	22	158	0.14	377	52.5	2.4	698
Meskel Sq.	Morning	53	212	34	164	0.2	631	130.8	1.6	336
Meskel Sq	Mid-Day	34	136	24	145	0.17	411	68	2	510
Meskel Sq	Evening	48	152	33	159	0.2	582	120.8	1.25	177

The St. Stifanos traffic signal junction is classified into four different signal groups in order to fit the developed IVNSS traffic signal control design based on the average traffic flow data obtained from St.Stifanos junction for different peak hour flow rates and peak hour saturation flow rates (queue). An IVNSS traffic signal control model is developed and simulated to estimate the signal phase, cycle length

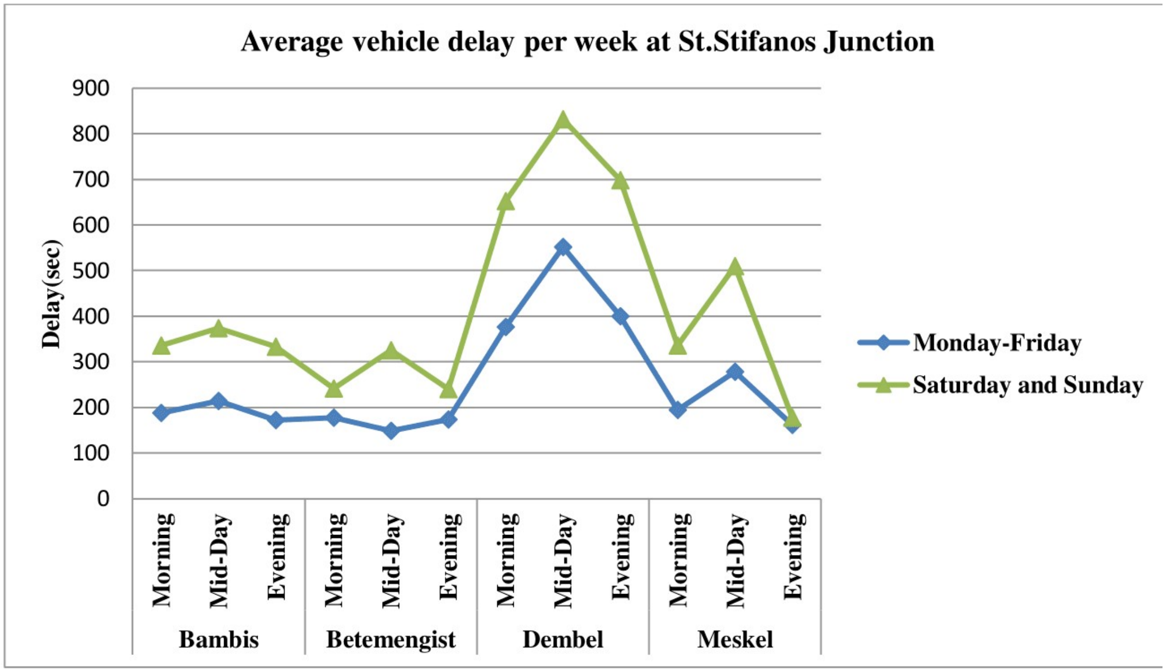

Figure 3. Weekly vehicle delay time at St. Stifanos intersection per approach under FTC

and the green time duration of the isolated intersection making use of the arrival rate and saturation flow rate (queue) at the downstreams of the intersection. The model developed is made to run for 5 different simulation scenarios, the average interval valued neutrosophic data (matrix) is extracted. The arrival rates and saturation flow rates (queue) are first simulated into interval valued neutrosophic data. The outputs of these simulation runs are then used to extract two outputs; namely, the effective green time of each signal group and the optimal cycle length. The values of cycle length and green time for different scenarios are tabulated in tables 3, 4, 5 and 6 below considering the different traffic flow conditions.

The average effective green times of each signal group and the average cycle length for the different scenarios are then used to estimate the average vehicle delay of each approach and the average vehicle delay at the junction. The results are shown in tables 7 and 8.

Table 3. Different cycle time scenarios at St.Stifanos intersection (Monday-Friday)

Phases/SG	PH	Scenario1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Average
1{maximum (EL1, WL1)}	Morning	217.4	378.3	231	231	308.7	273.3
1{maximum (EL1, WL1)}	Mid-Day	261.2	219.7	276.3	265	139	232.2
1{maximum (EL1, WL1)}	Evening	149.4	238.6	231	452	208.3	255.9
2{maximum (EL2, WL2)}	Morning	217.4	378.3	231	231	308.7	273.3
2{maximum (EL2, WL2)}	Mid-Day	261.2	219.7	276.3	265	139	232.2
2{maximum (EL2, WL2)}	Evening	149.4	238.6	231	452	208.3	255.9
3{maximum (NL1, SL1)}	Morning	217.4	378.3	231	231	308.7	273.3
3{maximum (NL1, SL1)}	Mid-Day	261.2	219.7	276.3	265	139	232.2
3{maximum (NL1, SL1)}	Evening	149.4	238.6	231	452	208.3	255.9
4{maximum (NL2, SL2)}	Morning	217.4	378.3	231	231	308.7	273.3
4{maximum (NL2, SL2)}	Mid-Day	261.2	219.7	276.3	265	139	232.2
4{maximum (NL2, SL1)}	Evening	149.4	238.6	231	452	208.3	255.9

Table 4. Different cycle time scenarios at St.Stifanos intersection (Saturday and Sunday)

Phases/SG	PH	Scenario1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Average
1	Morning	355.7	231	435	256.5	202.7	296.2
1	Mid-Day	185.7	269.9	339.8	486	187.7	293.8
1	Evening	181.1	684.3	185.7	179	333	312.6
2	Morning	355.7	231	435	256.5	202.7	296.2
2	Mid-Day	185.7	269.9	339.8	486	187.7	293.8
2	Evening	181.1	684.3	185.7	179	333	312.6
3	Morning	355.7	231	435	256.5	202.7	296.2
3	Mid-Day	185.7	269.9	339.8	486	187.7	293.8
3	Evening	181.1	684.3	185.7	179	333	312.6
4	Morning	355.7	231	435	256.5	202.7	296.2
4	Mid-Day	185.7	269.9	339.8	486	187.7	293.8
4	Evening	181.1	684.3	185.7	179	333	312.6

Table 5. Different green time scenarios at St.Stifanos intersection (Monday-Friday)

Phases/SG	PH	Scenario1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Average
1	Morning	21	122.7	81.5	44.7	74.8	68.9
1	Mid-Day	50.8	67	67.2	54.4	19.1	51.7
1	Evening	90	29.8	39.8	87.5	23.1	54
2	Morning	91.2	71.6	74.7	29.8	102.9	74
2	Mid-Day	36.3	55	97.1	88.3	28.8	61.1
2	Evening	30	44.7	39.8	145.8	63.7	64.8
3	Morning	63	122.7	6.8	96.9	37.4	65.4
3	Mid-Day	72.6	85.4	29.9	27.2	4.8	44
3	Evening	15	96.9	103.6	102.1	92.6	82
4	Morning	42.1	61.4	67.9	59.6	93.5	65
4	Mid-Day	101.6	12	82.2	95.1	86.3	75.4
4	Evening	15	67.1	47.8	116.6	28.9	55

Table 6. Different green time scenarios at St.Stifanos intersection (Saturday and Sunday)

Phases/SG	PH	Scenario1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Average
1	Morning	122	74.5	105	33	47.7	76.4
1	Mid-Day	92.8	108	121.4	132.5	31.3	97.2
1	Evening	90.6	203.5	83.2	26.9	70.6	95
2	Morning	112	67	135	66.2	17.9	111.8
2	Mid-Day	23.2	63	72.8	88.4	37.5	57
2	Evening	23.8	166.5	44.8	58.2	80.7	74.8
3	Morning	61	7.5	75	58	477	135.7
3	Mid-Day	34.8	54	85	147.3	25	131.9
3	Evening	19	166.5	6.4	9	121	64.4
4	Morning	61	82	120	99.3	89.4	90.3
4	Mid-Day	34.8	45	60.7	117.8	93.9	70.4
4	Evening	47.7	148	51.2	85	60.5	78.5

Table 7. The average signal timings and delay results for IVNSS traffic signal control model (Monday-Friday)

Phase/SG	PH	Volume	Flow rate	SFR	Capacity	V/c	CT	GT	G/C	Delay
1	Morning	112	448	2080	524	0.85	273.3	68.9	0.25	146.8
1	Mid-Day	85	340	1577	351	0.97	232.2	51.7	0.22	126.6
1	Evening	111	444	2058	434.3	1.00	255.9	54	0.21	140.3
2	Morning	61	244	2080	563.2	0.43	273.3	74	0.27	129.1
2	Mid-Day	46	184	1577	415	0.44	232.2	61.1	0.26	110.1
2	Evening	60	240	2058	521	0.46	255.9	64.8	0.25	122
3	Morning	109	436	1377	329.5	1.3	273.3	65.4	0.24	239
3	Mid-Day	81	324	1023	194	1.67	232.2	44	0.19	396
3	Evening	108	432	1456	466.6	0.93	255.9	82	0.32	146.9
4	Morning	17	68	1377	327.5	0.21	273.3	65	0.24	122
4	Mid-Day	12	48	1023	332	0.14	232.2	75.4	0.32	98
4	Evening	18	72	1456	313	0.23	255.9	55	0.22	115.5

5. Results and Discussion

From tables 1 and 7, one can see that from Monday-Friday, the average vehicle delay at the junction in the morning under fixed traffic control is ((188+177+276+195))/4= 209 whereas the average vehicle delay at the junction in the morning under IVNSS model is (147+129+239+122)/4=159.

From tables 1 and 7, one can see that from Monday-Friday, the average vehicle delay at the junction in the mid -day under fixed traffic control is ((214+149+552+278))/4= 298 whereas the average vehicle delay at the junction in the mid-day under IVNSS model is (127+110.1+396.4+98)/4=183.

From tables 1 and 7, one can see that from Monday-Friday, the average vehicle delay at the junction in the evening under fixed traffic control is ((172+174+400+161))/4= 227 whereas the average vehicle delay at the junction in the evening IVNSS model is (140.3+122+146.9+115.5)/4=131.

From tables 2 and 8, one can see that in Saturday and Sunday, the average vehicle delay at the junction

Table 8. The average signal timings and delay results for IVNSS traffic signal control model (Saturday and Sunday)

Phase/SG	PH	Volume	Flow rate	SFR	Capacity	V/c	Cycle time	Green time	G/C	Delay
1	Morning	38	152	705	181.8	0.84	296.2	76.4	0.26	158.6
1	Mid-Day	29	116	536	177	0.65	293.8	97.2	0.33	150.3
1	Evening	39	156	715	217.3	0.72	312.6	95	0.3	163.3
2	Morning	21	84	705	266	0.32	296.2	111.8	0.38	129.8
2	Mid-Day	16	64	536	104	0.62	293.8	57	0.19	144.5
2	Evening	21	84	715	171	0.49	312.6	74.8	0.24	150.3
3	Morning	53	212	669	306.5	0.69	296.2	135.7	0.46	154.2
3	Mid-Day	39	156	4907	220	0.70	293.8	131.9	0.45	154.9
3	Evening	49	196	621	128	1.53	312.6	64.4	0.2	364
4	Morning	8	32	669	204	0.16	296.2	90.3	0.3	127
4	Mid-Day	5	20	490	117.5	0.17	293.8	70.4	0.24	130
4	Evening	7	28	621	156	0.18	312.6	78.5	0.25	138

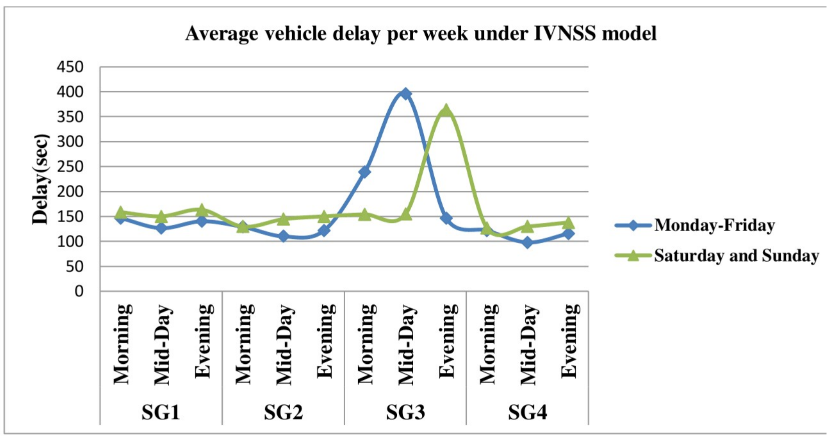

Figure 4. Weekly vehicle delay time at St. Stifanos intersection per approach under IVNSS model

in the morning under fixed traffic control is ((336+241+652+336))/4= 391 whereas the average vehicle delay at the junction in the morning under IVNSS model is (158.6+129.8+154.2+127)/4=142.
From tables 2 and 8, one can see that that in Saturday and Sunday, the average vehicle delay at the junction in the mid -day under fixed traffic control is ((373+325+832+510))/4= 510 whereas the average vehicle delay at the junction in the mid-day under IVNSS model is ((150.3+144.5+154.9+130))/4= 145.
From tables 2 and 8, one can see that that in Saturday and Sunday, the average vehicle delay at the junction in the evening under fixed traffic control is ((333+240+698+177))/4= 362 whereas the average vehicle delay at the junction in the evening under IVNSS model is (163.3+150.3+364+138)/4=204.
Comparison of the summarized average vehicle delay estimations for different flow rates and saturation flow rates is given in Table 9. As can be seen from the above discussion, from Monday-Friday the average vehicle delay at St.Estifanos traffic intersection per day is 244.6 sec/vehicle under FTC and 157.6 sec/vehicle under IVNSS traffic control model where as in Saturday and Sunday the average

TABLE 9. Summery of the average vehicle delay at St.Estifanos traffic junction per day.

Junction	Day	PH	Delay(FTC)	Delay(IVNSS)
St.Estifanos	Monday-Friday	Morning	209	159
St.Estifanos	Monday-Friday	Mid-day	298	183
St.Estifanos	Monday-Friday	Evening	227	131
St.Estifanos	Saturday and Sunday	Morning	391	142
St.Estifanos	Saturday and Sunday	Mid-day	510	145
St.Estifanos	Saturday and Sunday	Evening	362	204

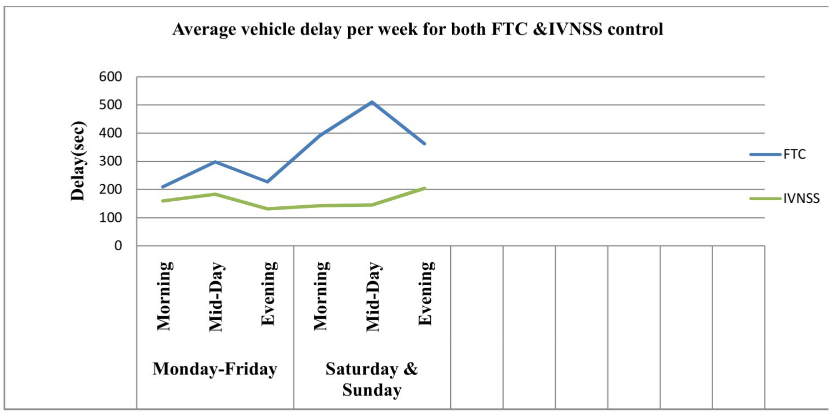

FIGURE 5. Weekly vehicle delay time at St. Stifanos intersection per approach under both FTC and IVNSS model

vehicle delay at St.Estifanos traffic intersection is 421 sec/vehicle under FTC and 163.6 sec/vehicle under IVNSS traffic signal control model. From Monday up to Friday under IVNSS traffic signal control model the average vehicle delay at the junction is reduced by 36 percent and on Saturday and Sunday the average vehicle delay is reduced by 73 percent under IVNSS control model.

6. CONCLUSION

A comparative study of the IVNSS traffic signal control with the existing fixed time traffic control shows that IVNSS traffic signal control model gives better performance in terms of delay both from Monday up to Friday at which heavy traffic (traffic saturation) is experienced and in Saturday and Sunday (holidays).in which it is expected that there is no heavy traffic conditions. Thus IVNSS model performs better than FTC, especially for both high and low traffic volumes and for both unsaturated and saturated traffic conditions. Under fixed time signal control even if the flow of traffic on Saturday and Sunday is low ,the average delay per vehicle is very high this is due to the geometric design of the junction because left-turning movements at signalized intersections are not only difficult to accommodate but also often cause accidents. Such problems can be reduced by adopting an exclusive left-turn signal phase [9].

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