Calibrating driver's decision to cross or not during the yellow phase; a microsimulation study

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1. Introduction

Worldwide accident statistics across the regions indicate that the majority of all traffic accidents occur at intersections, some of which are signalized (Hakkert & Mahalel, 1978). While road safety level at signalized intersections depends on various factors, one of the main problems that arises is driver's decision whether or not to cross the intersection during the yellow signal. The dilemma zone is defined as an area near the stop line, within which drivers are too close to stop safely and at the same time too far to completely cross the intersection at a speed within the permitted limits, before the red phase begins (Gazis et al., 1960); (Papaioannou, 2007). Any decision made by drivers can lead to an accident or near-accident (Zhang et al., 2014).

Among the various sub-models used for microscopic traffic simulation, Vissim software utilizes choice models to determine driver's stop/go decision during the yellow interval. The decision parameters included in these models are set to have predefined values, proposed by the software manufacturers. However, these predefined values may, in some cases, not be able to replicate the driving conditions of the area concerned. To this end, Vissim allows users to input a range of values for different factors, including those affecting driver's stop/go behavior in the yellow interval (Dey et al., 2018).

Based on the above, the purpose of this study is to examine whether the Vissim default parameter values are capable of representing the actual field conditions in terms of driver's stop/go behavior during yellow phase at a typical signalized intersection in eastern Thessaloniki, Greece and if not, to calibrate those parameter values based on a binary choice model, developed using field data.

2. Methodology

2.1. Study Area

The research study was carried out at a signalized cross-shaped intersection, located in eastern Thessaloniki, Greece. This intersection has already examined within the broader context of dilemma zone, in a previous study (Papaioannou et al., 2021). Traffic data were collected only for one approach of the intersection and more specifically the one that connects the city of Thessaloniki with the "Makedonia" airport, one of the major trip generators in the wider area of Thessaloniki. The chosen road section was functioning in good flow conditions, with a traffic flow of 1,500 vehicles/hour and a capacity of 6,000 vehicles/hour, when field data were collected.

2.2. Data Collection

Basic field data required for building the Vissim model, such as road and intersection geometry, traffic volume and signal timing, were collected through field observation. The road section under consideration consists of three traffic lanes, 3.5 m wide each. The signalization of the intersection gives priority to the direction towards the airport and has a significantly higher traffic load than the crossing road. The cycle length of the intersection is 85 s. The green signal duration is 50 s, the red 31 s and the yellow 4 s.

Data required for modeling driver's stop/go behavior were collected through video recording captured by a UAV, which has a built-in high-resolution camera, GPS and telecommunications equipment for transmitting data to the ground station in real time. Data were gathered for 12 days during March and April 2018.

2.3. Data Analysis

For data analysis, the Tracker Video Analysis and Modeling Tool was used, which is an open-source software that provides tools for performing kinematic analysis of experimental video recordings (Douglas Brown et al., 2021). For each vehicle approaching the intersection, several data were recorded, including approaching speed, distance to stop line, acceleration/deceleration, driver's decision to stop or clear the intersection and type of vehicle. Speed, distance to stop line and acceleration/deceleration were recorded from the initiation of the yellow indication until the moment that vehicles stopped or passed the stop line.

2.4. Simulation with default values

For modeling driver's decision to stop or clear the intersection at the onset of the yellow signal, Vissim software uses a binary logistic regression model. Using the predefined values of the model parameters (approaching speed and distance to stop line), which are provided by Vissim software by default and largely represent driver's stop/go behavior on Germany, the first simulation scenario was run and the results were recorded.

2.5. Modeling driver's behavior – simulation with calibrated values

A binary logistic regression model was formulated in an IBM-SPSS environment, to provide new, calibrated parameter values based on the observed stop/go behavior. The two major factors affecting driver's stop/go decision, were found to be distance to stop line and approaching speed at the onset of the yellow signal. The new parameter values were then used for simulating road traffic in the second simulation scenario, the results of which were recorded and compared to those of the first.

3. Analysis and Results

3.1. Field Data – Sample Statistics

On average, 60 vehicles per hour were captured within a range of 140 m from the traffic light, at the time of the yellow indication. The exact number of vehicles that were observed to face the yellow signal was equal to 500, with the largest proportion of the sample consisting of cars (87.60%). Regarding driver's stop/go decision, 59% of the sample crossed the intersection during the yellow indication, while 41% decided to stop. The average approaching speed of drivers at the initiation of the yellow signal was calculated to be 20.22 m/s (S.D. = 4.36) or 72.80 km/h, slightly higher than the posted speed limit (70 km/h). Finally, the average distance to stop line was calculated to be 73.26 m (S.D. = 40.45). **Figure,** which was constructed using the field data, provides an indication of the correlation of driver's stop/go decision with approaching speed and distance to stop line.

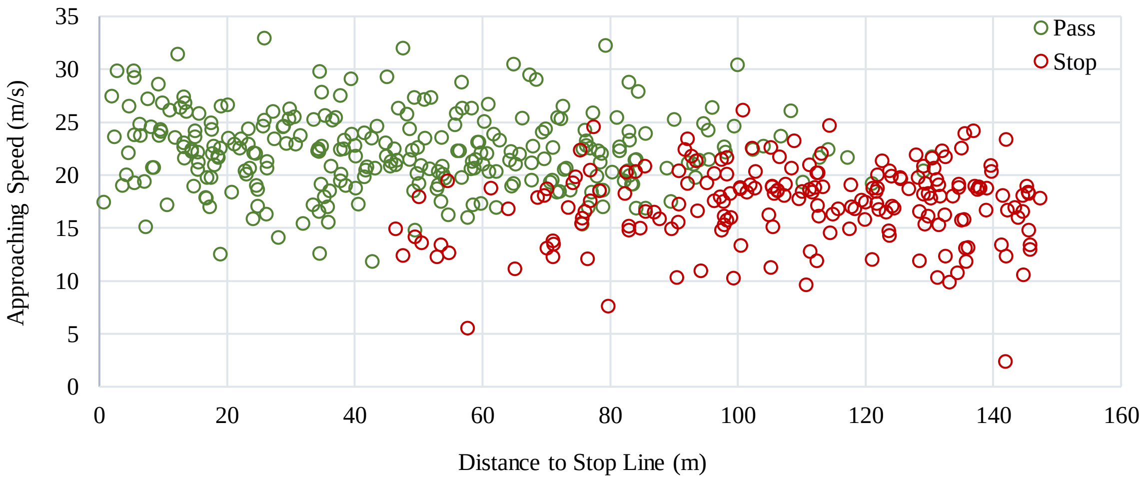

Figure 1: Correlation of driver's decision with approaching speed and distance to stop line – field data

According to **Figure 1**, the distance to stop line for which there is not an obvious stop/go decision, ranges between 60 m and 100 m. In this intermediate zone, a speed of approximately 20 m/s forms a critical speed threshold largely determining driver's decision to pass or stop. Moreover, based on **Figure1**, the critical distance to stop line regardless of vehicle speeds, is about 80 m.

3.2. Simulation Using Default Vissim Parameters

The first simulation scenario included the use of non-calibrated factors affecting driver's stop/go decision at the yellow interval, as provided by the micro-simulation software by default. After running the simulation, the results in terms of vehicles' approaching speed and distance to stop line at the initiation of the yellow signal, as well as the outcome of crossing or not the intersection, were extracted. These results were obtained for 500 vehicles, a number which equals the sample size derived from the field observations.

In terms of the total number of vehicles that crossed the intersection or stopped, the results obtained from the first simulation scenario appeared to be significantly different from those derived from ground truth data. More precisely, the first simulation scenario resulted in 36.4% of vehicles crossing the intersection during the yellow phase and 63.6% of vehicles stopping, while the corresponding percentages based on field observations, were calculated to be 59% for crossing and 41% for stopping. Similar to **Figure 1**, but being constructed using the first simulation scenario results, **Figure 2** presents the outcome of crossing or not the intersection during the yellow phase in relation to vehicles' approaching speed and distance to stop line, for a total number of 500 vehicles.

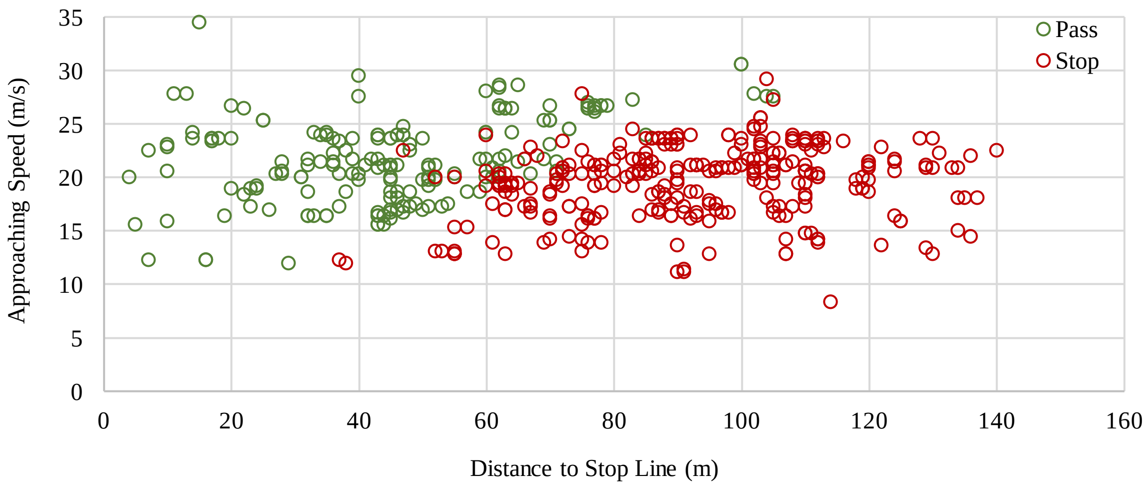

Figure 2: Correlation of driver's decision with approaching speed and distance to stop line – 1st simulation scenario results

Based on **Figures 1 and 2**, it could be concluded that when using the default Vissim parameters, the distance to stop line for which there is not an obvious stop/go decision considerably decreases, ranging between 50 m and 70 m, in comparison to 60 m and 100 m that has resulted from the field measurements. In this intermediate zone between 50 m and 70 m, an approaching speed of approximately 20 m/s seems to form a critical speed threshold that determines to a large extent the driver's stop/go decision. Moreover, a critical distance to stop line of 60 m has resulted, regardless of vehicle speed, which is significantly lower than the corresponding distance calculated using the field observations.

Based on the above, the first simulation scenario using the default Vissim parameters resulted in inconsistent results, which barely replicate the field conditions in terms of driver's stop/go behavior during the yellow interval.

3.3. Calibrating Vissim Default Parameters – Binary Logistic Regression Model Results

In order for the default values of the stop/go decision parameters to be calibrated, a binary logit choice model was developed, relying on the field data that were collected using the UAV technology and further processed using the Tracker Video Analysis and Modeling Tool. This model was developed for explaining driver's stop/go behavior as a function of distance to stop line and approaching speed at the initiation of the yellow light, since those factors are considered by Vissim software as the contributing factors for driver's stop/go decision. The goodness-of-fit statistics showed that the binary logit model developed fits quite well the observed data (Nagelkerke R Square = 0.82, Hosmer and Lemeshow Test = 0.97, Classification (overall percentage) = 91.80%).

Based on the estimated values of the parameters derived from the binary choice model, the second simulation scenario was performed. The results of the second simulation scenario, which were gathered in the same way as those of the first, indicated that when using the calibrated parameter values, the simulation can reflect to a very large extent the real driving conditions of the area concerned. This is definitely the case, since the percentage of vehicles crossing the intersection (62%) and stopping (38%) during the yellow interval, which resulted from the second simulation scenario, are quite similar to those derived from the field observations (59% and 41% respectively).

The ability of the second simulation scenario to satisfactorily replicate the observed driving conditions, can also be concluded by comparing the following**Figure 3**, which was constructed using the second simulation scenario results (calibrated parameter values), to **Figure 1**. In both Figures, the distance to stop line for which there is not an obvious stop/go decision appears to range between 60 m and 100 m, while in this intermediate zone, an approaching speed of approximately 20 m/s seems to form a critical speed threshold that largely determines the driver's stop/go decision.

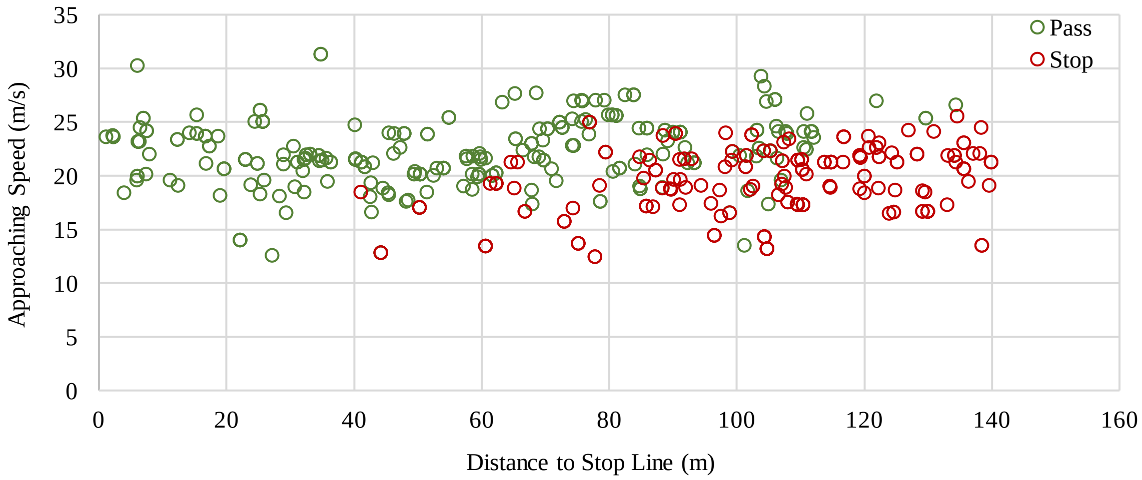

Figure 3: Correlation of driver's decision with approaching speed and distance to stop line – 2nd simulation scenario results

3.4. Comparing the two Simulation Scenarios

Table 1 presents the results of the two simulation scenarios and those derived from the field data, in terms of the percentage of vehicles that crossed or not the intersection during the yellow phase. As shown in **Table** , the use of the default Vissim parameter values in the first simulation scenario did not lead to satisfactory results, when compared to the field measurements. On the contrary, the use of the calibrated parameter values in the second simulation scenario yielded more accurate results that largely match the driving conditions captured by the field data.

Table 1: Percentage of vehicles crossing/stopping – field measurements and simulation scenarios results

Choice	Field Measurements	1st Simulation Scenario (default Vissim parameter values)	2nd Simulation Scenario (calibrated parameter values)
Cross	59%	36.4%	62%
Stop	41%	63.6%	38%

Finally, various traffic-related parameters were also calculated for the two simulation scenarios at the intersection level, including CO_2, NO_x and CO emissions, average speed, total delay, average delay of all vehicles, average delay per vehicle and average queue length. The traffic-related parameters were calculated for an 1-hour simulation time interval.

The two simulation scenarios resulted in significantly different values of the traffic-related parameters calculated. In broad terms, the use of the calibrated values of the stop/go decision parameters in the second simulation scenario has led to a smoother traffic situation, as implied by the reduction of the calculated values of those factors contributing to heavy traffic flow conditions (varying from 4% to 12%). Consequently, the use of the default, non-calibrated parameter values could also lead to an overestimation/underestimation of the traffic-related parameters that actually describe the traffic flow conditions of the area concerned.

4. Discussion & Conclusions

This research effort deals with the calibration of the Vissim default values of those driving behavior parameters that affect driver's decision to clear or not the intersection during the yellow phase. The intersection of interest is a cross-shaped, signalized intersection located in eastern Thessaloniki, Greece and the traffic data required for calibration, was collected with the use of an UAV. The main purpose of the study was to examine whether the Vissim default parameter values could be used to simulate the actual field conditions in terms of driver's stop/go behavior during the yellow interval and if not, to calibrate those values using field data.

To this end, two simulation scenarios were performed using Vissim. When compared to the field data, the results of the first simulation scenario indicated that the use of the default parameter values did not lead to an accurate representation of the observed field conditions, in terms of driver's stop/go behavior during the yellow phase. It was therefore concluded that a calibration of those parameter values was required, which was implemented by developing a binary logistic regression model based on field data. The new, calibrated parameter values were then used in the second simulation scenario, the results of which largely matched the field conditions of the area concerned.

Based on the empirical findings from the control intersection, it could be argued that Greek drivers tend to be more aggressive than German drivers. This argument is supported by the fact that when using the default Vissim parameter values (first simulation scenario), the distance to stop line for which there is not an obvious stop/go decision was calculated to range between 50 m and 70 m, compared to 60 m and 100 m based on the results of the second simulation scenario and field measurements. Moreover, the critical distance to stop line regardless of vehicle speeds is about 80 m based on field data and the results of the second simulation scenario, as against 60 m based on the first simulation scenario results. In addition, the use of the calibrated values of the stop/go decision parameters resulted to considerably different traffic flow conditions, in terms of traffic delays, queue lengths, gas pollutants, etc. It was therefore concluded that the utilization of the default parameter values could lead to an overestimation/underestimation of the traffic-related parameters that largely determine the traffic flow conditions of the area under consideration.

Next research steps, include further investigation for the adaption of the calibrated parameters to different contexts (e.g., different types of intersections within Greece and different countries). Moreover, a sensitivity analysis could be conducted, in order to examine the sensitivity of the stop/go simulation outcome in relation to variations of those parameter values. Finally, a parameterization of Vissim software would be interesting to be performed, in order for the latter to include more factors for the determination of the binary stop/go outcome, such as driver's age, gender, familiarity with the study area, yellow-light duration, etc.

References

Dey, A., Roy, S., & Uddin, M. (2018). Calibration and validation of VISSIM model of an intersection with modified driving behavior parameters. *International Journal of Advanced Research*, *6*(12), 107–112. https://doi.org/10.21474/IJAR01/8120

Douglas Brown, Wolfgang Christian, & Robert M Hanson. (2021). *Tracker Video Analysis and Modeling Tool for Physics Education*.

Gazis, D., Herman, R., & Maradudin, A. (1960). *The Problem of the Amber Signal Light in Traffic Flow Author (s): Denos Gazis , Robert Herman and Alexei Maradudin Published by : INFORMS Stable URL : http://www.jstor.org/stable/167548 Accessed : 21-07-2016 01 : 23 UTC Your use of the JSTOR archive ind*. *8*(1), 112–132.

Hakkert, A. S., & Mahalel, D. (1978). Estimating the number of accidents at intersections from a knowledge of the traffic flows on the approaches. *Accident Analysis & Prevention*, *10*(1), 69–79. https://doi.org/10.1016/0001-4575(78)90009-X

Papaioannou, P. (2007). Driver behaviour, dilemma zone and safety effects at urban signalised intersections in Greece. *Accident Analysis & Prevention*, *39*(1), 147–158. https://doi.org/10.1016/J.AAP.2006.06.014

Papaioannou, P., Papadopoulos, E., Nikolaidou, A., Politis, I., Basbas, S., & Kountouri, E. (2021). Dilemma zone: Modeling drivers' decision at signalized intersections against aggressiveness and other factors using uav technology. *Safety*, *7*(1). https://doi.org/10.3390/safety7010011

Zhang, Y., Fu, C., & Hu, L. (2014). Yellow light dilemma zone researches: a review. *Journal of Traffic and Transportation Engineering (English Edition)*, *1*(5), 338–352. https://doi.org/10.1016/S2095-7564(15)30280-4