Understanding Driver Compliance Behaviour at Signalised Intersection for Developing Conceptual Model of Driving Simulation

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Summary
A conceptual model represents an understanding of a system that is going to be developed, which in this research, a driving simulation software to study driver behavior at signalised intersections. Therefore, video observation was conducted to study driver compliance behaviour within the dilemma zone at signalised intersection, with regards to driver's distance from the stop line during yellow light interval. The video was analysed using Thematic Analysis and the data extracted from it was analysed using Chi-Square Independent Test. The Thematic Analysis revealed two major themes which were traffic situation and driver compliance behaviour. Traffic situation is defined as traffic surrounding the driver, such as no car in front and behind, car in front, and car behind. Meanwhile, the Chi-Square Test result indicates that within the dilemma zone, there was a significant relationship between driver compliance behaviour and driver's distance from the stop line during yellow light interval. The closer the drivers were to the stop line, the more likely they were going to comply. In contrast, drivers showed higher non-compliant behavior when further away from stop line. This finding could help in the development of conceptual model of driving simulation with purpose in studying driver behavior.
Keywords:
dilemma zone, signalised intersection, driver compliance behavior, thematic analysis.

1. Introduction

Yellow light interval has been associated with risky driver behaviour that could lead to crashes as a result of Dilemma Zone (DZ) incursions. The DZ is defined as a zone where a driver needs to make a quick decision either to stop or go at the stop line of the signalised intersection, during the yellow light interval [1]. In this study, quick driver decision refers to driver's compliance behaviour at the stop line during the yellow light interval within the dilemma zone, either to 'stop' (comply) or 'go' (not comply). Driver's action may affect safety at the signalised intersection. For instance, when a driver makes a conventional 'stop' decision, the vehicle may stop abruptly within a relatively short distance to the stop line during the yellow light interval, leading to a rear-end accident. Conversely, when a driver aggressively makes a 'go' decision, the vehicle may pass the intersection within a relatively long distance during the yellow light interval. Consequently, it may lead to crashes with vehicles from other directions. Noncomplying with traffic signal regulation not only is a violation of traffic law, but also a cause of near-accidents and accidents. Therefore, it is imperative to study driver compliance behaviour within the dilemma zone at signalised intersection, so that the findings could contribute to the development of conceptual model for driving simulation that can be used to study driver behaviour.

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2. Literature Review

2.1 Driver Behaviour Studies

In recent years, various studies related to driver behaviour have been explored, for instance with regards to railway crossing [2], signalised intersection study [3]–[5], and dilemma zone study [6]–[8]. Among these studies, research related to driver behaviour within the dilemma zone has been been the focus in [7], and [9]–[11]. These studies examined the driver behaviour at signalised intersections at specific locations. When a driver approaches a signalized intersection, the driver will be in a state where quick-decision making must be made. This situation involves identifying factors that influence risk-taking behaviour and error in judgment [12], which is known as dilemma zone. The driver needs to decide quickly either to proceed through the intersection or to stop during the onset of yellow light[12].

2.2 Dilemma Zone

Dilemma Zone (DZ) can be categorised into two - Type I and Type II, controlled and affected by different factors [1], [13]. DZ Type I is a condition where the driver's decision to comply or not during the yellow light interval are influenced by physical parameters, such as short duration of yellow light interval, geometric characteristics of the road and vehicle speed limit [1]. On the other hand, DZ Type II involves comply/non-comply decision making that is based on unique interpretation and prediction of driver behaviour, including driver characteristics, impairment, and distraction level [14]. Since this research aims to develop a conceptual model of driving simulation that studies driver behaviour at signalised intersection, the dilemma zone being investigated is DZ Type II. For the last few years, researchers have investigated DZ's speculative nature, which specifies the zone where more than 10% and less than 90% of drivers would choose to stop, known as the 'indecision zone' [6].

2.3 Driver Compliance Behaviour

The data obtained from an observational survey involving modelling drivers' stopping behaviour revealed driver's actual conduct, in which the number of passengers in the car significantly influences the driver's stopping behaviour [15]. Moreover, this research reported that drivers show different behaviour when alone than when they are with passenger. When they are alone, there is extended freedom in their mind to "break" the law. The study demonstrated that the tendency to make complete stop increases with the number of passengers in the car [14].

Apart from driver's own perception of its surrounding, classifying driver's behaviour at signalised intersection involves several other factors such as driver's characteristics, vehicle's approach speed, trip purpose, traffic flow situations, weather conditions, signal settings, the intersection layout, the time setting of the signal, and the distance from the stop line. Additionally, approach speeds are also a critical determinant for driver's compliance behavior during yellow light interval at a signalised intersection [16].

Weather conditions is one of the influential factors to the driver's reaction time, the choice of speed and lane while driving [17]. In the research, [17] simulated the driving environment under various type of weather, with a purpose to study the visual traits and psychomotor behaviour. They reported that among all weathers that have been tested while the driver was driving, the driver most frequently yawned during a clear and bright weather. This result is supported by other research which pointed out that people yawn not because of boredom but because of the lack of stimulation, which causes difficulties in maintaining one's focus [18]. Consequently, the decreasing level of concentration while driving can be one of the factors of car crash. Therefore, a clear weather will be one of the criteria in our study since a lot of crashes happened during clear weather.

The driver's distance from the stop line was one of the most significant factors contributing to the driver compliance behaviour during the yellow light intervals [7], [19]. Unfortunately, driver's ignorance of the traffic rules when yellow light interval starts could lead to crashes among vehicles at signalised intersections.

In Malaysia, several driver behaviour studies have highlighted that the increased number of traffic accidents every year could be attributed to driver compliance behaviour [4], [20]–[23]. The road traffic accident has been reported as one of the leading causes of death in Malaysia in 2016, with 5.36% after coronary / heart disease, stroke, influenza, and pneumonia [24]. In 2018, MIROS claimed that the highest contributor to road accidents is human behaviour (driver behaviour) which is 80.6%, while only 6.2% was due to road condition. The high number of accidents caused by driver behaviour may be due to the lack of driving experience and skills, driver compliance behaviour, and risk-taking behaviour among young drivers. Contrarily, crashes among older drivers may occur because of cognitive, visual, and mobility impairment [25].

The driver compliance behaviour may also be affected by the road's width, the volume of traffic, and the speed and spacing between vehicles, especially at signalised intersections [26]. Moreover, the findings revealed that traffic situations from other junctions also affected driver's compliance behaviour. These traffic situations include the difference in traffic volume and various cars' distance from the stop line.

In summary, previous researchers have identified various factors that affected driver compliance behaviour, including weather, traffic conditions, length of the yellow light interval, traffic volume and situations, choice of speed, driving environment, and traffic situations from other junctions of the signalised intersection. Therefore, to further understand what other factors that affect the driver behaviour, it is crucial to examine the relationship between driver's distance from stop line and compliance behaviour within the dilemma zone at signalised intersection. This could be achieved via video observation. The next section will explain the criteria of the video observation.

3. Methodology

Video observation has become one of the standard practices among researchers who study driver behaviour [1], [27]–[29]. This study implemented video recording method to observe the actual driver compliance behaviour during the yellow light interval at signalised intersection. Thus, the video recording session was designed so that drivers were unaware of the camera's presence.

3.1 Field of Video Observation

This section will explain how the video observation was designed and carried out. Two key factors in designing the field of observation were identified as (1) the location selection, and (2) the recording condition, based on [27]. The first factor, which is the location selection is essential to ensure the study's objective is achieved by confirming the choice of location matches the targeted area criteria. As this study aimed to examine the relationship between car distance and driver compliance behaviour within the dilemma zone at signalised intersection, thus the keywords used in determining the targeted area are "car distance", "driver compliance behaviour", "dilemma zone", and "signalised intersection".

The second factor, the recording conditions - refers to recording time and length, camera angles, and target area range. The camera placement was selected carefully to ensure there would be no blurry effect. The camera angle also was taken into account so that it covers the range of targeted area , hence every moment was recorded successfully. Recommendation by [7] was also followed, where the camera was positioned a bit further than the targeted area to ensure the area border was fully captured, and the targeted audience was unaware of the recording sessions.

Consequently, a three-junction intersection with two lanes was selected as the observation area. This road was chosen because it is a major road that connects two major cities (Arau and Kangar) and connects to the major highway, Changlun-Kuala Perlis Highway, thus indicating high volume of traffics. To get a clear view of 100-meter distance from a stop line, the video camera that was attached to a tripod was purposely installed 120 meters away from the stopline. Additionally, distance marker in the form of four small cones were placed at an identical distance of 25 meters each. Therefore, the first cone was positioned at 25 meter, followed by second cone at 50 meter, third cone at 75 meter and fourth cone at 100 meters from stop line. Fig. 1 illustrates the field design of video observation.

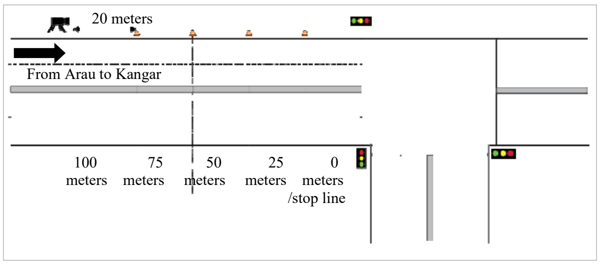

Fig. 1 The Illustration of Video Observation Field Design

The video recordings were orchestrated into four sessions, with consideration to:

a. Peak/peak-off hour (selected based on [23])
b. Random days (excluding public holiday).
c. A different crowd of traffic congestion.
d. Bright and sunny weather.

Thus, a total of eight-hour video footage was recorded.

3.2 Data Extraction

The data extraction process was carried out as soon as the data collection process ended by using a VSDC Free Video Editor software, which enables a layout of the 12x12 grid to be placed on top of the video, and synchronized with the stop line's width and distance. Small cones were set at 25 meters (Zone A), 50 meters (Zone B), 75 meters (Zone C) and 100 meters (Zone D) from the stop line, as shown in Fig. 2.

Fig. 2 The Layout Grid used in the Data Extraction Process

The data extracted from the eight hours of video footage was entered into a Microsoft Excel spreadsheet. After the data extraction process was completed, the dataset of video observation underwent the analysis process. The data was analysed using Thematic Analysis and Chi-Square Independence Test. The thematic analysis was performed to discover the major themes related to the relationship between car distance and driver compliance behaviour. The chi-square independence test was carried out to examine if the car distance from the stop line affected the driver compliance behaviour at signalised intersection.

3.3 Thematic Analysis

Thematic analysis is a form of analysis that emphasises identifying, examining and recording themes within dataset [30]. The thematic analysis is also known as a six-phase framework that helps to discover patterns from a wide range of data and categorises it into specific and related themes. The video analysis breakdown is shown in Table 1. Through the thematic analysis, several themes within the dilemma zone at signalised intersection were identified, and the relationship between these themes were examined.

Table 1: The Video Analysis Breakdown According to the Thematic Analysis Framework

Phase	Activities
Phase 1 Be familiar with the data	Video footage was viewed at least five times or more, focusing on the scene of a yellow light interval within 100-meter distance from the stop line. The eight hours of video footage was split equally into half an hour video. This process was done to simplify data management, playback and data validation. The information extracted out includes the yellow light interval's timestamp, timestamp of when drivers' entering zones (at the beginning of yellow light interval), braking timestamp, and timestamp of driver's arrival the intersection stop line. The video was examined several times on different days, to ensure the researcher could triangulate the video footage data. By watching the video footage for a number of times, the researchers were able to identify several patterns, which were recorded as initial pre-codes because these codes were not the final result. The researcher documented initial pre-codes from the video footage.
Phase 2 Generate initial codes	Various pre-codes were reorganised after each group of data. Patterns of themes were identified.
Phase 3 Search for themes	Codes were divided into themes and sub-themes. The differences between video observation data were critically reviewed, especially during the yellow light intervals. Themes and sub-themes were decided based on their relevance towards the study' objectives.
Phase 4 Review themes	Themes were reviewed once more to determine relevance to the study, which inquired the factors that contribute to the driver compliance behaviour within the dilemma zone at signalised intersection. The video footage was reviewed once more to ensure there was no data left behind during phase 1 of the analytic process.
Phase 5 Define themes	The relevant themes that have been identified, and their definition and relevance to the research questions were finalised. Significant names that represent the core of the themes were chosen.
Phase 2 Write up	The finalised themes were visualised in a diagram.

3.4 The Chi Square Test

A quantitative analysis using the Chi-Square Independence Test would be able to test if two categorical variables were related in some populations [31]. Hence, this study tested the relationship between (1) the founded themes (from the thematic analysis), and (2) the distance of driver from the stop line. The results of this test revealed the relationship between these variables. The data were analysed using SPSS software version 24. The test runs in the SPSS gave an Asymptotic Significance (2-sided), which delivers the significance of the relationship between two variables. The Asymptotic Significance is often associated as "p-value", short for probability value. If the p-value is less than 0.05, the relationship between the two variables is significant or dependent on each other [31]. A meaningful relationship means that the two variables were dependent on each other.

4. Results and Discussions

The video observation was successfully carried out during the non-peak hour (10 am to 12 pm) and peak hour (4 pm to 6 pm), totalling eight-hours of video footage. The video footage was also recorded on random weekdays and weekends, excluding a 3-day public holiday. Other types of vehicles, including a lorry, bus, truck, and motorcycles were excluded from the calculation from the eight hours of video footage.

Overall, there were a total of 4,563 cars in the eight-hours of video footage. Later, the data was re-examined and resulted in 262 cars that fit with our desired data. This calculation was achieved after excluding the cars that were not in the yellow light intervals and were located more than 100 meters away from the stop line. It was discovered that a quarter (24.4%) of the 262 cars were non-compliant drivers, which is defined as a behaviour at signalised intersection where a driver intentionally speeds off and passes the intersection stop line during the onset of the yellow light. Meanwhile, a compliant driver is defined as a behaviour at signalised intersection where a driver decelerates and stop at stop line during the yellow light interval. The result of the video observation exclusion process are summarised in Fig. 3.

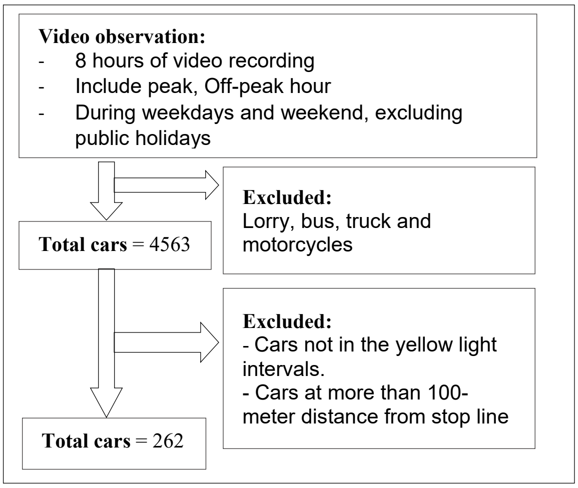

Fig. 3 Result of the exclusion process in video observation

4.1 Results from Thematic Analysis

Through this analysis, a few patterns that influenced the driver compliance behaviour within the dilemma zone at signalised intersection were identified. The analysis phase was started by getting familiar with the data in the video footage. The video was watched several times on different days to ensure the data is credible and reliable. The raw data of video footage were coded into a codebook, created using Microsoft Excel. The information was labelled with initial codes as a preparation for the analysis.

Next, similarities and differences of data was determined based on the initial codes labelled earlier. As a result, two main themes, along with their sub-themes were identified. The first theme was coded as "traffic situations experienced by the driver", while the second theme was coded as "driver compliance behaviour". Table 2 illustrates the main themes and corresponding sub-themes.

Table 2: The Established Main Themes and Sub-Themes

Themes	Subthemes
1. Traffic situations experienced by the driver	a) No presence of car behind and in front of driver (NPCBF) b) Presence of car behind the driver (PCB) c) Presence of car in front of driver (PCF)
2. Driver compliance behaviour	a) Driver comply to the traffic rules (CBY) b) Driver non-comply to the traffic rules (CBN)

The connections between themes and sub-themes are visualised in Fig. 4, with regards to distance from the stop line during the yellow light interval, the driver compliance behaviour is determined by either one of three traffic situations that the driver is experiencing – No presence of car behind and in front (NPCBF), Presence of car behind (PCB), or Presence of car in front (PCF). Under the NPCBF sub-themes, the driver's decision to comply or not with the traffic rules were not affected by the existence of car in the driving environment; however, other reasons may influence the driver's decision making such as his/her distance from the stop line, time of traffic and personal agenda [29]. Next, the PCB and PCF sub-themes displayed additional traffic situations that determine driver compliance behaviour. For PCB and PCF sub-themes, one of the causes influencing the driver compliance behaviour was the distance between the driver's car with the car behind or in front of it.

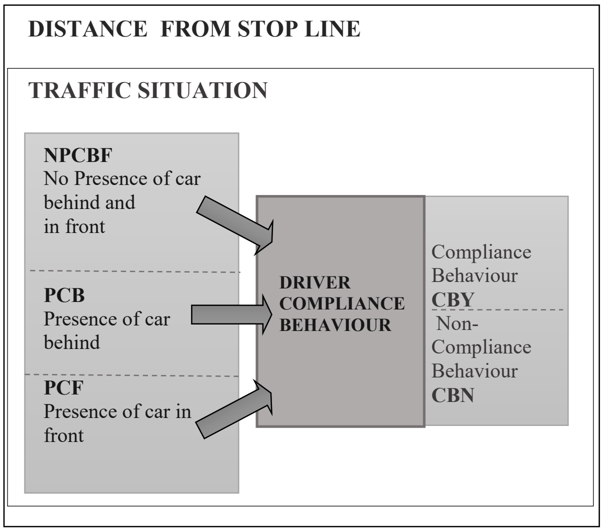

Fig. 4 Connection Between Themes (Traffic Situation and Driver Compliance Behaviour)

As a summary, the qualitative analysis has established themes within the DZ at signalised intersection. Consequently, the relationship between the two main themes must be proven statistically. Therefore, a Chi-Square Independence Test was performed to analyse the inter-dependency between the established themes and distance from the stop line. The chi-square test was applied because it is a suitable test to determine whether there is a significant association between two variables in one population. In the next section, results from the Chi-Square Independence Test are presented.

4.2 Results of Chi Square Independence Test

The results of Chi-Square Independence Test of the video observation presented the relationship between driver compliance behaviour and distance (divided into four zones) from the stop line. Table 3 summarises the data analysis for both sub-sections based on three categories of data; (1)

driver compliance behaviour, (2) distance from stop line, and (3) traffic situation.

Table 3: The Category of Analysed Data

Themes	**Subthemes**
Driver compliance behaviour	The driver's compliance (comply or non-comply) to the traffic light.
Distance	Represents the dilemma zone. It is divided into four zones; zone A (25 meters), zone B (50 meters), zone C (75 meters) and zone D (100 meters) away from stop line
Traffic situation	Represents three common traffic situations experienced by the driver -no presence of car(s) behind and in front of driver (NPCBF), presence of car behind driver (PCB), and presence of car in front of driver (PCF).

It was discovered that out of 262 cars, three-quarter (75.6%) showed compliant behaviour, and only 24.4% showed non-compliant behaviour. The distribution of driver compliance behaviour by distance from stop line (described in Zone) is illustrated in Fig 5. It can be seen that generally, both compliant and noncompliant behaviours escalated as the driver's distance from stop line increased.

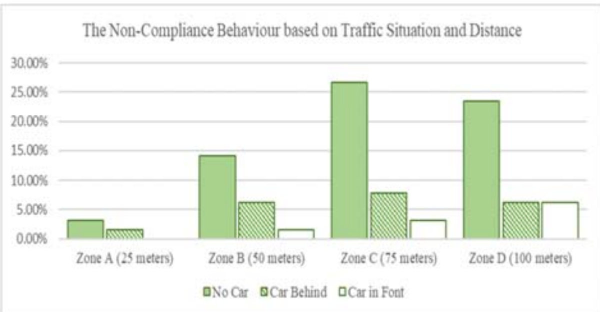

Fig. 5 The Distribution of Driver Compliance Behaviour by Distance

A chi-square test of independence was performed to examine the relationship between the driver compliance behaviour and driver's distance from the stop line. The dependency of two-variables is determined by the p-value. The dependencies between two variables are significant if the p-value is less than the significance level (0.05). According to [31], the standard level of significance used to justify a statistically significant effect is 0.05, which explains why 0.05 is used to define the significance level of this research. The result of the chi-square test showed that the relationship between driver compliance behaviour and distance is significant because p is less than 0.05 (x2=16.290, df=3, p=0.001), which is shown in Table 4.

Table 4: The Chi-Square Test of Driver Compliance Behaviour and Distance

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16.290[a]	3	.001
Likehood Ratio	15.465	3	.001
N of Valid Cases	262		

The findings indicated that drivers had higher tendency to show non-compliant behaviour if their distance were farther from the stop line. In other words, the closer the driver was to the stop line, the more likely they were going to comply during the yellow light interval. This finding corresponds to [19] where the driver's distance from stop line was one of the most significant factors that contributed to the driver compliance behaviour during the yellow light intervals. Fig. 6 illustrated that non-compliance behaviour (CBN) was highest in all zones when drivers were in traffic situation NPCBF. This means, when there was no car in front and behind, most drivers showed the non-compliance behaviour regardless of driver's distance from the stop line. This behaviour was followed by PCB and PCF traffic situation. In PCB, when there was car behind, driver had higher tendency to show CBN, and in PCF, when there was car in front, driver had lowest tendency to show CBN, probably to avoid collision.

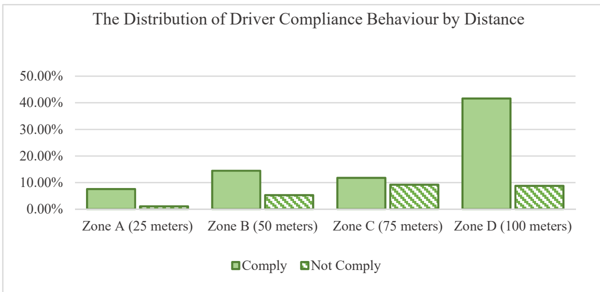

Fig. 6 The Non-Compliance Behaviour based on Traffic Situation and Distance

A chi-square test of independence was performed to study the relationship between traffic situations and distance from stop line that influenced the non-compliant behaviour. The p-value of this test is 0.890, greater than the significance level (0.05), as shown in Table 5 (x2=2.306, df=6, p=0.890). This result indicate that regardless of their distance from the stop line (either in Zone A, B, C, or D), drivers would speed-off and passed through the stop line during yellow light interval when there were no car in front and behind them.

Table 5: Chi Square test results of traffic situation and distance

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.306a	6	.890
Likehood Ratio	2.504	6	.868
N of Valid Cases	64		

4.3 Developing the Conceptual Model of Driving Simulation

A driving simulation software is one of the most important part in a driving simulator which provides dynamic virtual environment, hence should be developed with identical stimuli to the actual world, in addition to allowing the user to have a sense of actual driving environment. In order to develop a driving simulation that suitably represents the necessary elements or factors, a conceptual model (CM) must be designed first. The Robinson's CM Framework (RCMF) was followed in designing the CM in this study. The objectives of the CM were the essence of the modelling process and acted as a referral point of the developers (Robinson, 2015a). The CM consists of the abstract of the case study of the research.

The components of the CM are driver response, 3D virtual environment, driver database and visual database. Findings from the video observation contributed in designing the 'task' in 3D virtual environment (3D VE). 3D VE mimics the real-world environment, which is composed of several sub-components such as (1) traffic situation, (2) route trigger, (3) distance trigger, (4) task and (5) intersection. Task is created based on all the possible scenarios that should be experienced by the subject of experiment (driver) within the dilemma zone at signalised intersection, so that driver compliance behaviour data can be recorded during the yellow light intervals. Each scenario shall be called a task for the simulation.

It was discovered that there were three traffic situations that regularly experienced by drivers within dilemma zone at signalised intersection, which also influenced the driver compliance behaviour, according to the results of the video observation. The three situations are (1) no presence of car(s) behind and in front of the driver's car (NPCBF), (2) presence of a car behind the driver's car (PCB), and (3) presence of a car in front of the driver's car (PCF). Meanwhile, within the dilemma zone, driver distance from the stop line could be divided into four zones namely 25-meter, 50-meter, 75-meter and 100-meter. Combination of traffic situations and driver distance would contribute to the creation of tasks for the simulation. Therefore, one task consists of one 'distance trigger' and one 'traffic situation'. Hence, there are 12 tasks altogether, due to all possible matches between 'distance trigger' and 'traffic situation' (4 'distance trigger' x 3 'traffic situation'). The design of the CM components is illustrated in Fig. 7.

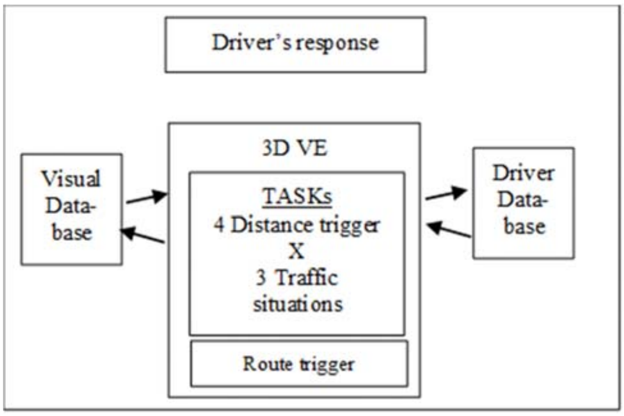

Fig. 7 Design of CM Components of the Driving Simulation

5. Conclusions

This study conducted a video observation at signalised intersections to examine driver behaviour during yellow light interval, with regards to their distance from the intersection. When drivers are in the dilemma zone, they need to make quick decision whether to stop or go, and this decision is influenced by the traffic situations that they are experiencing. The data from video observation was run using Chi-Square Test. Its result indicates that within the dilemma zone, there was a significant relationship between driver compliance behaviour and driver's distance from the stop line during yellow light interval. The closer the drivers were to the stop line, the more likely they were going to comply. In contrast, drivers showed higher non-compliant behavior when further away from stop line. Drivers had the highest tendency to show non-compliant behaviour when the traffic situation was considered safe, such as no car in front and behind them. The findings helped in determining the possible scenarios to be designed for a driving simulation that studies driver behaviour. This has been presented in the form of a conceptual model design. Further work will discuss in detail the input,output, processess and databases of the CM.

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