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Driver Behavior at Signalized Intersection Literature Review

Li Idi'il Fitri[1], Harmein Nasution[2], and Nurulhuda Listiani[3]

[1,2,3] Department of Industrial Engineering, Faculty of Engineering, Universitas Sumatera Utara, Jl. Dr. Mansur No.9, Padang Bulan, Medan, Sumatera Utara, 20155, Indonesia

Abstract. Traffic accidents are one of the highest causes of death in the world, with human behavior being the most dominant factor. Therefore, it is necessary to understand driver behavior as a traffic accident mitigation strategy. This paper aims to understand the behavior of drivers at signaled intersections and to overcome the deviant behavior. The behavior of the driver at the intersection is to stop or cross the intersection. Crossing at an intersection at a red light is deviant behavior. This deviation can occur as violation due to driver aggression or error due to a dilemma when the light is yellow. The influencing factors are personal, speed, acceleration, distance, the presence of other vehicles, and others. The main countermeasure for deviant behavior at intersections is law enforcement, such as the installation of red-light cameras. In addition, the behavior of drivers at intersections can be used as a reference in the design of safer intersections.

Keyword: Driver Behaviour, Signalized Intersection, Traffic Accident

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1. Introduction

Traffic accidents are one of the leading causes of death in the world [1]. In addition, traffic accidents also cause state financial losses of up to 2.9-3.1% of GDP [1]. Previous studies have reported that driver behavior is a major factor in traffic accidents [2]. Understanding driver behavior can be the first step in mitigating traffic accidents. Therefore, this study aims to understand driver behavior in depth, both from the causal factors and the development of the mitigation strategies that have been studied.

The intersection is the most complex location for driving. There are four critical situations when driving at an intersection, namely turn right, turn left, go straight, and stop safely [3]. Intersections are critical locations due to movement conflicts with other vehicles and interactions with roads and their furniture. To drive properly, the driver is expected to understand the information and take appropriate action. The driving task becomes complex as the driver has to act on the situation in a short amount of time. The higher the state demands, the higher the probability of an error causing a collision.

*Corresponding author at: [Universitas Sumatera Utara, Jl. Dr. T. Mansur No.9, Medan, 20155, Indonesia]
E-mail address: [li.idiil.fitri@gmail.com]

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Driver behavior is an action taken by the driver to get to the destination safely by considering limitations, constraints, needs, and motivations [4]. Meanwhile, the driver's performance is the best action that the driver can take on the existing situation. Decisions made by drivers are hierarchical in three levels, namely [4]: (1) Strategic level, in the form of general decisions to achieve goals such as how to get to the destination, when to go, which route to take, and so on; (2) Navigation level, in the form of maneuver decisions when driving such as avoiding obstacles, lane selection, driving at a yellow light, and others; (3) The level of control, in the form of decisions on short stimuli such as speeding up, slowing down, braking, and others.

Michon in Shinar et al [4] states that driver behavior does not occur in a vacuum, but has "environmental input". In driving a vehicle, the driver makes his driving intention and chooses a set of operating behaviors that best suit the driving conditions at the time [5]. It is widely accepted that driver behavior varies between drivers according to age [6], gender [6], ethnicity [5], driving experience, emotions [7], and so on. Even for the same driver, driving behavior can change from situation to situation as an adjustment to the driving environment [4]. Understanding driver behavior is crucial in designing signalized intersections to prevent operational and safety problems[6].

2. Method

There are three stages carried out in this study, namely: 1) Search and selection of articles that match the criteria, 2) Classification of research coverage articles. 3) Thematic analysis of selected articles.

This study intends to carry out an in-depth understanding of the behavior of drivers at signalized intersections. Thus, an extensive search was conducted on the Science Direct, Taylor & Francis, Emerald, JMIR, and Wiley Online Library databases. Searches are performed using keywords such as "*driver behavior*"; "*stop or go behavior";* "*drivers decision making*"; and "*signalized intersection"*. The criteria in the search were articles discussing driver behavior originating from journals rated Q1 according to Scimago, and published in the period 2012 to 2022. Thus, 15 journals that matched the need for review were found.

The classification of articles is grouped based on (1) behavior at intersections, (2) factors that influence driver behavior at signalized intersections; (3) methods of analyzing driver behavior at signalized intersections, and (4) countermeasures solutions.

3. Results and Analysis

3.1. Driver Behavior at Crossroads

Drivers behave differently at intersections. When driving a vehicle, the driver makes his driving intention and chooses a set of operating behaviors that best suit the driving conditions at the time [5]. Driver behavior is a complex thing that can arise intentionally or not.

When a driver accidentally behaves in a deviant manner at a signalized intersection, this is an error. This can happen because the demand for a signalized intersection environment is too heavy from the driver's ability [4]. While a driver who intentionally behaves in a deviant manner at a signalized intersection, this is included as a violation. This can happen due to personal and uncomfortable environmental factors [7]. Table 1 contains a list of selected studies that discuss driver behavior, both errors and violations.

Table 1 Selected article and its behavior studies.

No	Writer	Year	Behavior Studied
1	Piyanat Jantosut	2021	Violation & Error
2	Prasanta K Sahu	2021	Crossing in dilemma zone
3	Rahman	2021	Crossing in dilemma zone
4	Singh	2021	Crossing in dilemma zone
5	Ajinkya Ingale	2020	Violation & Error
6	Yang & Huemer	2022	Violation
7	Papaioannou	2021	Crossing in dilemma zone
8	Pathivada	2019	Crossing in dilemma zone
9	Shen X	2018	Violation
10	Jahangiri	2016	Violation & Error
11	Elhenawy	2015	Crossing in dilemma zone
12	Moynur Rahman	2021	Crossing in dilemma zone
13	Szajowski	2020	Violation & Error
14	Jou	2013	Crossing in dilemma zone
15	Fu & Liu	2020	Violation

The main concern at signalized intersections is the driver's decision to stop or keep driving when the traffic light is yellow[8]. This is called the dilemma zone. A collision conflict arises when the driver's decision is not right. It is classified as an error. Some research study about dilemma zone [9]–[11]. Elhanawy [12] classify driver behavior when facing a dilemma zone using a truck simulator.

Pathivada [10] conducted a study on the behavior of drivers trapped in a dilemma zone. The advantage of this study is that it was conducted in a mixed traffic environment. Szajowski [13] conducted a study on driver behavior in the dilemma zone with cooperative and defective types. His research links driver behavior to Game Theory.

Papaioannou [9] also investigated driver behavior in the dilemma zone. This is seen using UAV technology. The advantage of this research is to add aggressive variables in examining driver behavior. This can be seen from how the driver accelerates and decelerates.

In addition, the driver may also behave in a deviant manner on purpose. Yang & Huemer's study[14] conducted an analysis of risky traffic violation behavior of motorcycle drivers at signalized intersections in Taiwan such as running red lights, driving in the wrong lane, and stopping at zebra crossings. The advantage of this research is that driver behavior is observed in various types of environments, namely urban, industrial, and residential.

Several studies have focused on violations of running red lights [7], [11]. Research conducted by Jantosut in 2021 discusses the behavior of motorbike drivers crossing signalized intersections [7]. He classifies crossing behavior into four behaviors, namely (1) obeying law, where the driver has the opportunity to violate a red light but stops at the intersection; (2) risk taking, where the driver runs through a red light at high speed; (3) traffic following, where the driver passes a red light at low speed; (4) opportunistic, where the driver stops at a red light but looks for opportunities to pass before the green light. The strength of this research is that it classifies various characteristics of crossing behavior when the light is red and finds out the causal factors of each characteristic.

Meanwhile there are studies that cover both errors and violations. Sahu [15] examined driver behavior at signalized intersections using a questionnaire. He classifies driver behavior into errors and violations. Violation behavior is like running a red light, while error behavior is like confusion at traffic light transitions. The advantage of this study is the focus on driver behavior at four-signaled intersections.

The research above shows that most of the direct studies were carried out at four-armed intersections, while the types of signalized intersections varied widely in various countries. So by analyzing the behavior of drivers from various types of intersections will deepen the study of driver behavior.

3.2. Factor affecting

Driver behavior is formed by the input from the environment. Environmental factors are not only visible such as roads, traffic, weather, lighting, but also invisible environmental factors such as traffic regulations, norms, and culture [4]. Driver behavior can be seen from several mutually supportive perspectives, namely the attention and information process model, the planned behavior model; or a combination of them [4]. Table 2 shows driver behavior factors.

Table 2 Driver Behavior Factors

No	Factor	Violation	Error
1	Distance to intersection		[16]–[20]
2	Time to intersection		[10], [17]–[20]
3	Vehicle Trajectory		[9], [18]–[21]
4	Cycle Time	[3]	[12], [18]–[20]
5	Other Vehicle	[15]	[3], [22]
6	Motivation	[15]	
7	Infrastructure	[3], [7], [15]	[3], [15], [21], [23]
8	Traffic Volume	[7][14]	[22], [24]
9	Vehicle Type	[7][15]	[13]
10	Speed	[7][14]	[12]

Some of the variables that are often considered in the literature for the identification of driver behavior at intersections are time to intersection, distance to intersection, vehicle trajectory, presence of other vehicles, yellow cycle time, and vehicle type.

Many things affect it, namely the phase of traffic lights, the presence of vehicles in front, visibility, and awareness and knowledge of traffic signs. In addition, inconsistent geometry layout, weak

lane discipline, inappropriate driving behavior and location, and knowledge that does not match the driver's expectations, lead to accidents[3]. So, by analyzing driver behavior can improve driving safety. Studies show that drivers with long red lights become impatient and try to cross intersections[5], [6].

Papaioannou P et al [9] investigated the main factors that influence the behavior of stopping or crossing an intersection at a red light, namely the distance to the stop line, speed, and acceleration, as well as two additional factors, namely the aggressiveness of the driver and the relative position when the light is yellow.

Jantosut et al [7] found traffic violations by motorbike drivers to be more common in driving environments with short cross distances, high traffic volumes, and at night. Likewise, a study by Fu & Liu [21] found that incomplete infrastructure also plays a role in the courage of drivers to violate traffic. A study by Sasaki et al. [23] find that most traffic violations occur on wider, straighter and segregated roads, where infrastructure increases overconfidence.

Pathivada et al [10] identified factors that influence driver decision making in heterogeneous traffic conditions. This study found that the factors that influence driver behavior at intersections are the distance from the stop limit, vehicle speed, and the type of intersection. Vehicle type which is a characteristic of heterogeneous traffic was found to have a significant influence on driver decisions when traffic lights change.

Jantosut [7] found factors related to unique violation characteristics. *Opportunistic* drivers usually turn right, use manual-engine vehicles, not wear helmets, drives at night. Opportunistic drivers, *traffic following*, and *risk taking* usually commit violations at intersections with close distances. In addition, there are factors such as road conditions, driver aggression, distraction, and the presence of the police.

The *Theory of Planned Behavior* model by Ajzan states that behavior arises because of a person's intentions that arise due to accepted attitudes, norms, and behavioral controls. Xiaoyan Shen [11] analyzed the effect of passing a red light based on the *Theory of Planned Behavior* by adding *conformity tendency* and traffic environment variables. The results of this study indicate that TPB, *conformity tendency* and traffic environment affect the behavior of drivers passing red lights.

The types of engines used in motorized vehicles vary. Some use mechanical machines, some use manual machines. This has not yet received the attention of driver behavior researchers. While it has been found that the type of vehicle affects the driver's behavior at a signalized intersection. So, it can be material for further research.

3.3. Analysis Method

Jantosut [7] observed the behavior of drivers at intersections using CCTV. The factors studied were then examined for the probability of their relationship with the driver's violation behavior

using Multinomial Logistic Regression Analysis. Papaioannou P et al in 2017 use UAV (*unmanned aerial vehicle*) technology so that the data is more accurate [9]. Latent Class Analysis is used to classify drivers based on their aggressive level.

Machine learning models have been proven to be accurate models for predicting driver behavior at intersections. Methods such as Neural-Network and Random Forest are frequently used models. *Machine learning* methods can process many variants of data. Data collection can be done by video recording, radar, sensors, EEG signals. Biswas & Ghosh [25] proposed the Weighted Average Hybrid Model (WAHM), which is a combination of ANN and *fuzzy logistic model.* This model has a high level of accuracy.

Random forest and AdaBoost have been used with some red-light behavior predictions. Jahangiri et al [26] used 800 trees with 6 factors considered out of each tree Jahangiri et al[26] used only 50 trees in a study of aggressive drivers with red light traffic events. Elhenawy [12] and Jahangiri et al [26] in comparison with other models, random forest has a lower performance in predicting behavior to stop or run a red light because it cannot capture the nuances of the driver's decision. Other *machine learning* models such as SVM and discriminant analysis can be demonstrated that discriminant analysis has a score of up to 90%.

Research by Rahman [24] predicts driver behavior under various dilemma zone conditions using *artificial intelligence.* The dilemma zone will be longer in vehicles with higher speeds. In addition, the length and location of the dilemma zone will differ at different times. The time-based dilemma zone protection strategy will be effective in reducing the possibility of red light violations and accidents. The drawback of this study is that it does not discuss the effect of vehicle type on the dilemma zone.

Logistics probabilistic have also shown advantages over deterministic methods and incorporate DARE into formulas. The use of point detectors [16] and loop detectors[17], shows their usefulness for predicting the behavior of drivers stopping or crossing red lights which only require basic technology such as video cameras. Chen et al [18] used the Bayesian Network on 17-day historical data to build predictions. The BN model considers all features compared to Random Forest, non-linear SVM, and logistic regression.

The driver behavior analysis method can also be carried out using GPS with the help of an eye camera or face camera to see the movement of the driver's eyes and facial expressions. Eye movements can show situational awareness of the driver in behavior. Facial expressions can show the driver's emotions in behaving at signalized intersections. However, this is still not widely used by researchers in analyzing driver behavior. This can be used as material for further research.

3.4. Countermeasures Solution

By looking at the influencing factors, law enforcement is a priority solution that needs to be done[7]. Red light cameras can help prevent drivers from violating red lights. In addition, traffic

management that minimizes the appearance of conflicts between drivers needs to be considered. The less likely conflict in the right-hand direction will help reduce the gains received from initiating misbehavior. The probability of a driver running a red light based on the classification of the driver's aggressive level can be used as a consideration in the design of signalized intersections and signal timing Papaioannou P et al [9] . Salvolainen [19] found drivers were more likely to stop when warning lights and law enforcement cameras were present.

Kwon et al [20] investigated the control of red traffic lights based on the driving characteristics of detected red light violators. Driving characters were classified using *Dynamic Time Wrapping* (DTW) and *Hierarchical Clustering Analysis* (HCA). The system for *online* detection of red light violations and class classification of red light violations uses *the Multi-Channel Deep Convolutional Neural Network* (MC-DCNN). A multi-level regression model is used to estimate the additional time required for a more accurate red light signal so that the safety and efficiency of the intersection is increased.

4. Conclusion and Recommendation/Policy Implication

Driving at intersections is the most complex driving task so it has a higher risk of traffic accidents. Driver behavior at intersections is stopping or crossing. Crossing red light is a deviant behavior. It can be a violation or error. Violation means that driver crossing the red light intentionally. Error means that driver run the red light unintentionally. But both can cause side and rear collisions. Violations can occur due to aggression from the driver, while error occur due to a dilemma when at a yellow light. The main factors that influence it are the presence of other vehicles, speed, acceleration, time to intersection, distance to intersection, aggressive attitude, and many other factors. There are many methods that have been used to analyze and predict behavior such as regression analysis, probabilistic logistics, to machine learning. The most important prevention of trespassing behavior is law enforcement such as red-light cameras. In addition, driver behavior can be used as a reference in the design of safer intersections.

Future research should consider examining various traffic conditions. Many countries, especially developing countries, have a mixed traffic system where vehicles are not only cars, but also motorbikes and others. In addition, so far there has been no research on driver behavior observed at intersections with more than four arms.

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