Review of Objective and Subjective Methods for Rear-End Collision Risk Assessment

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Abstract

Rear-end collisions are the most common toll road accident in several countries, such as Japan, China, the United States, and Indonesia. The risk factors associated with this type of collision are investigated using objective and subjective methods. Therefore, this study aims to review the methods used to investigates rear-end collision risk assessment on toll roads. This research is a literature review research with 1057 articles collected from search engines, such as Science Direct, PubMed, Taylor & Francis Online, IEEE, SAGE, and Plos One. The data collected were processed in three stages to determine the characteristics, thereby leading to the final use of 12 articles with eight on objective methods and four on both objective and subjective methods (mixed). The results showed that the objective and subjective methods have advantages and disadvantages without limitations. Future research is recommended to measure the risk factors of rear-end collision using multiple objective and subjective methods.

Keywords
Rear-end Collision, Risk Assessment, Objective method, Subjective method

1. Introduction
Rear-end collisions occur in many countries such as Japan, China, the United States, and Indonesia. According to Chen et al. (2019), Mizuno et al. (2020) and Didin & Iridiastadi (2020), 30% of rear-end collisions in the United States cause injury and property damage. Crash injuries are the 8th leading cause of death, with approximately 1.35 million deaths yearly (Sexton et al. 2018). These collisions occur at specific locations on highways or freeways due to high speeds (Ahmed et al. 2021; Stephens et al. 2017). A rear-end collision occurs when the front of a vehicle crashes into the back of another (Baldock et al. 2005; Khadim et al. 2020).

Qin et al. (2019) and Shao et al. (2020) stated that this type of accident comprises one or more vehicles such as trucks, buses, and other passenger transport vehicles. The direct impact of a rear-end collision consists of varying degrees of injuries sustained by the drivers and passengers, which also causes damage to the vehicle and infrastructure. Meanwhile, the indirect impact of rear-end collisions lead to post-accident trauma, economic and other social losses felt by the families of perpetrators and victims (Pipkorn and Piccinini 2020; Shao et al. 2020).

Xi et al. (2019) and Willadsen et al. (2016) defined risk factors as the conditions associated with the probability of rear-end collision. According to Didin and Iridiastadi (2020), they are conditions associated with rear-end collisions based on the driver, vehicle, and environmental factors. The driver factors include gender, behaviour, experience, and ability (Chen et al. 2020; Khadim et al. 2020; Shao et al. 2020). Meanwhile, the vehicle factors due to the risk of rear-end collisions are the type of transmission and vehicle production year (Chen et al. 2020; Shao et al. 2020). Finally, the environmental factors include road characteristics, driving time, weather, traffic, and lighting conditions (Chen et al. 2019; Chen et al. 2020; Figueira and Larocca 2020; Shangguan, Fu, and Liu 2020; Zhang et al. 2019). Various causes influence each factor, which varies according to the associate country due to different traffic conditions, driver behaviour, and the environment (Mizuno et al. 2020; Stephens et al. 2017).

The objective and subjective methods are the standard techniques used to measure the risk of rear-end collision. The objective method is unbiased, value-free, reliable, and actual, quantitatively collected from empirical observations and measurements (Resnik 2001; Asenahabi 2019). According to Wang et al. (2016) and Wu & Wang (2021), the objective method is determined using crash data, simulator and naturalistic driving studies. Meanwhile, the subjective method values individuality, culture, and social justice with data qualitatively collected through observation, questionnaires and personal interviews (Karlsson & Engelbrektsson 2010; Mashko 2017; Asenahabi 2019). The subjective methods include a questionnaire on driver behaviour and attitude (Wang et al. 2020; Wu and Wang 2021), while the mixed method comprises the objective and subjective methods. Presently, there is no ideal process suitable for risk assessment, and every method has its limitations. However, rear-end collision risk assessments are used for further research because many risk factors still need to be found. A study related to the research method is needed to explain the advantages and disadvantages of the methods and provide some implications for subsequent studies.

Furthermore, reviews of preliminary studies focused on the objective, subjective, and mixed methods. This study aimed to review the method used to determine the rear-end collision risk assessment on the toll road. Therefore, the results from this study are helpful for practitioners and authors to design research methodology on the transportation sector based on their conditions and goals.

2. Literature Review

Preliminary studies used objective, subjective and mixed methods to assess the risk associated with rear-end collision. The objective methods used in various laboratory driving simulators are simple, medium and advanced driving simulators. The simple driving simulator used three wide screens, namely Logitech G25, G27, and G29, for the steering wheel and gaming chair (Chen et al. 2020). The medium driving simulator used full three-side widescreen from the projector with the actual car used to make the driver's natural car environment. This type of simulator is available in Beijing Jiaotong University Driving Simulator (Li et al. 2016). Finally, the advanced driving simulator used one big screen 250^{o} to the horizontal, FoV real car at an 8 degree of freedom motion system and five projectors available in Tongji University Driving Simulator (Wang et al. 2016).

Meanwhile, another objective method is the naturalistic driving study comprising various types of apparatus. The naturalistic driving study in some rear-ends collisions research was conducted with some apparatus such as dashboard camera, lidar, Global Positioning System (GPS), Data Acquisition System collect, including rate sensor, accelerometer, an illuminance sensor, passive alcohol sensor, audio and vehicle network data installed in the driver's car (Wang et al. 2020). Preliminary studies carried out by Jo Oh & Kim (2019), Pipkorn & Piccinini (2020), and Shao et al. (2020) applied the naturalistic driving study in cars and trucks. Other research that provided objective methods were observation using road cameras, connected vehicle technologies, crash data history, and vehicle trajectory dataset for developed model (Champahom et al. 2020; Fu et al. 2020; Jang et al. 2020; Jo et al. 2019; Li et al. 2020).

However, the subjective method for rear-end collision risk assessment was carried out using some interviews and questionnaires. According to Krasniuk et al. (2021), the Driving Behavior Questionnaire (DBQ) is the most common reference for the subjective method. Besides that, Driver Attitude Questionnaires (DAQ) provide a subjective method from individual, driving, practical, and video information (Wang et al. 2020). Other preliminary studies used more than one method of measure risk. For example, the driving study used DBQ and naturalistic driving study methods (Wang et al. 2020).

This research provided a literature review on the advantages and disadvantages of using objective and subjective methods to assess the risks associated with rear-end collisions. Didin and Iridiastadi (2020) investigated the risk factors for musculoskeletal symptoms of construction workers (Kusmasari et al. 2018) using cognitive ergonomic measurement tools (Fista et al. 2019) and investigation factors that influence risk at rail level crossings (Read et al. 2021).

3. Methods

3.1 Literature search and data management

The literature review used seven electronic search databases from 2020 to 2021 with the same keyword and advance search feature. The electronic search databases applied in this study include Science Direct, PubMed, Taylor & Francis Online, IEEE (Institute of Electrical and Electronics Engineers), SAGE, and Plos One. The keyword used is "rear-ended collision risk assessment", which was processed using the Mendeley software and Microsoft Excel. The article was written in English with a highly qualified journal based on Scimago Journal Rank. This literature review procedure was carried out based on several literature review references and a systematic rule of review from the University of Edinburgh (Fista et al. 2019; Kusmasari et al. 2018; Piper 2013; Didin and Iridiastadi 2020; Talib et al. 2019)

3.2 Included and excluded Criteria

This literature review focused on rear-end collision risk assessment article. The criteria of the selected article are as follows:

1. Connected to the rear-end collision risk assessment
2. Year of publication 2020-2021
3. Using one of the methods to examine the rear-end collision risk, such as objective and subjective methods.

3.3 Screening process

The screening process on this literature review used the advanced feature to search for articles using some keywords. The second step is to check the articles individually to ensure there are no duplicates. The third step is the screening process using the articles' abstracts to determine the background of the study, leading problems, method, and conclusion. After examining the abstracts, some potential articles in the criteria were used to determine the objective and subjective methods for rear-end collision and risk assessment. Several selected articles comprising the dependent variable, object, country, the advantages and disadvantages of the research methods were summarized in the table with the rear-end collision risk factor.

4. Results and Discussion

The literature review on the objective and subjective methods from 2020-2021 generated 1057 articles based on six online search publishers, as shown in Figure 1. The result found that articles from Science Direct, PubMed, Taylor & Francis, IEEE, SAGE and Plos One online database are 497, 291, 5, 134 and 120 articles, respectively. The total number of articles used to check the title and abstract related to objective and subjective rear-end collision risk assessment methods was 1053. Furthermore, 22 articles were reviewed during this process, and 10 failed to confirm the criteria. The final data collected from this literature review consists of 12 research objectives and subjective methods.

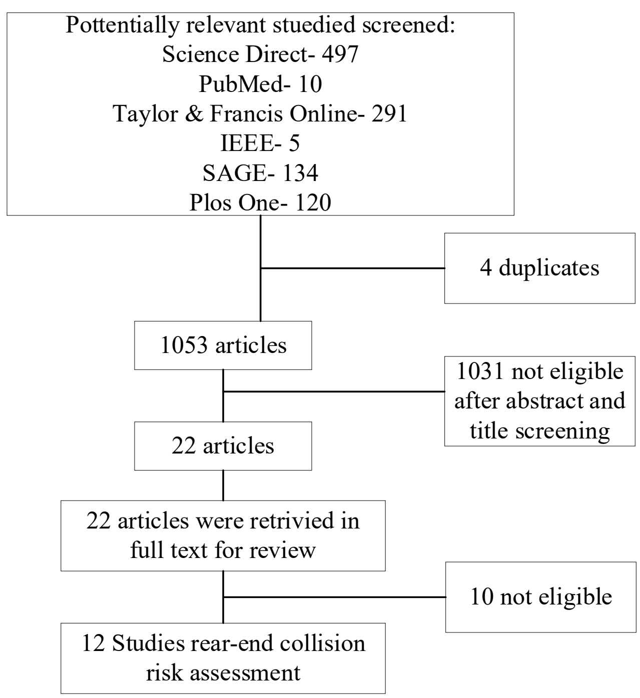

Figure 1. Stage of literature review of methods for rear-end collision risk assessment

4.1 Objective Methods

The literature review in Table 1 showed that approximately 8 and 4 articles used objective and mixed methods (objective and subjective), respectively. The objective methods consist driving simulator, naturalistic driving study, fatigue stress measurement system connected to the vehicle, and crash data. The previous study used some apparatus for the driving simulator. For example, the Beijing Jiaotong University (BJTU) multi-user driving simulators comprises a driver seat, an automatic gearbox, gas and brake pedals, screens to project the front view, and software that provides a virtual road environment (Huang et al. 2020). Another simple driving simulator comprising 3 LED screens, 42 inches with 150^o field view, power steering, gear selector, pedal, sound speaker, and the digital speedometer was used to carry out preliminary studies in India (Mahajan and Velaga 2021). In Iran, research carried out a medium driving simulator with a real passenger car in the laboratory, a three-screen projector, steering wheel, and real-time applications (Mozaffari and Nahvi, 2020). Another previous research in China used an advanced driving simulator with the sensor used to simulate vehicle engines, tires, and wind. The unique features used hydraulic cylinders to allow 6 degrees of freedom (6-DOF), three screens projecting virtual environment at an angle of 48^o wide and 46^o high with a projector resolution of 1280 x 768 pixels 60Hz frame rate (Yang et al. 2021). Some of the advantages associated with the driving simulator are safety and cost efficiency during the experiment. Moreover, the disadvantages are simulator sickness, driving environment fidelity, and experimental conditions capable of modifying drivers behaviours (Mahajan and Velaga 2021; Yang et al. 2021).

Previous research used the naturalistic driving study to measured rear-end collision risk assessment. The research carried out in China used data acquisition units connected to Video Event Recorder (VER) and installed on vehicles integrated with sensors such as cameras, a 3-axis accelerometer, and GPS (Pipkorn and Piccinini 2020). There are several advantages associated with the naturalistic driving study, such as providing extensive information concerning what happened before or near-crashes, better understanding the causative chain of crash events, and having high fidelity. However, the disadvantages are a high risk during data collection, low control, and high cost (Wu and Wang 2021).

Epidemiological studies and modelling used to measure rear-end collision risk assessment used the crash database analysis with confirmation from police accident reports. The advantages of these methods are comprehensive information on circumstances and scenarios that lead to rear-end collisions related to infrastructure, vehicles, and the environment. The disadvantage was limited pre-crash information related to driver behaviours (Ahmed et al. 2021; Champahom et al. 2020).

4.2 Subjective Methods

The literature review results in Table 1 show four articles using subjective and objective methods (mix methods). However, previous studies used visual cognitive, which failed to produce a significantly different result from DBQ. Subjective methods reached differentiated characteristics such as the driver's driving style, skill, and experience. Besides DBQ, a driving style questionnaire was used to explore driving behaviour through risk and an attitude questionnaire to reflect the identification level. Another tool used to indicate loss of alertness among drivers in the subjective method is the Karolinska Sleepiness Scale: alertness rating (KKS) (Mahajan and Velaga 2021). A previous study in Japan used Visual Analogue Scale (VAS) to measured feelings of fatigue (Mizuno et al. 2020). This subjective method provides the finding research with the other objective method such as driving simulator (Krasniuk et al. 2021; Wang et al. 2020).

Table 1. Literature Review Result

Reference	Risk Factor	Methods		Dependent Variables	Object and Country	Advantages	Disadvantages
		Objective	**Subjective**				
(Huang et al. 2020)	Environment and Vehicle	Driving simulator		Driver's behavioural patterns in a vehicle fleet and the patterns of rear-end collisions	Student driver, China	• Simulator completed with software for virtual road/traffic environment design and simulation. • Ten simple driving simulators were used simultaneously, which were connected by one server. • The size of the simple driving simulator was compact and used multiple simulators in one room.	• The multi-user driving simulator system is different from a real vehicle fleet. • The driving simulator needs to validate the field data.
(Pipkorn and Piccinini 2020)	Driver and Vehicle	Naturalistic Driving Study		Driver's response	Commercial vehicle, China	• Naturalistic Driving Studies used quantitative analysis to determine the rear-end and near-crashes.	• Analyses performed on data obtained to a large extent from manual video coding are prone to human error. • Low video resolution tends to affect data precision.
(Li et al. 2020)	Vehicle	Modelling		Transition condition of rear-end collisions	Driver in highway, China	• Modelling used vehicle trajectory data set, especially with Time to Collision (TTC) index, utilized for potential risk assessment. • TTC values tell one factor, but with transition conditions, more factors and causality can show.	• Trajectory data needed threshold for TTC
(Wu et al. 2020)	Vehicle and Environment	Naturalistic Driving Study		Rear-end crash risk at freeway bottlenecks	Driver in the freeway, China	• A naturalistic driving study using connected vehicles increased travel time during data collection. • Implementing connected vehicles enhances safety during driving.	• Vehicles need to connect with the environment) using high technology and VSL (variable speed limit) Strategy.

Reference	Risk Factor	Methods		Dependent Variables	Object and Country	Advantages	Disadvantages
		Objective	Subjective				
(Champahom et al. 2020)	Environment	Modelling		The number of rear-end collisions that occur on each road.	Driver in highway, Thailand	• Recorded accident data used for the advanced statistical model play an essential role in analyzing many potentially known factors.	• Some independently analyzed factors were missing.
(Mozaffari and Nahvi 2020)	Driver and Vehicle	Driving simulator		Driver's psychological motivations	A bus driver and Passenger car driver, Iran	• The driving simulator is used for the evaluated performance of the advanced driver assistance systems. • The simulator used C++ programming language for parallel computation and a medium driving simulator with an actual vehicle environment.	• The simulator used three screens to display the program in a less natural driving environment.
(Ahmed et al. 2021)	Environment	Modelling		Rear-end crash rate	Driver in a freeway, United States of America	• Crash and traffic data from sensors were used to develop the model. • Extracted data from police reports used Traffic Engineering Accident Analysis System.	• There was difficulty extracting accurate crash data, which is essential to obtaining filter crash data associated with research purposes directly.
(Wu and Wang 2021)	Driver and Environment	Naturalistic Driving Study		Crash/Near Crash	Driver in highway, Taiwan	• The naturalistic driving studies (NDS) provided extensive information concerning activities before and after near-crashes. • NDS was used to collect time-series data, video, event, and driver attributes.	• Potential measurement error in measure perception time.

Reference	Risk Factor	Methods		Dependent Variables	Object and Country	Advantages	Disadvantages
		Objective	Subjective				
(Krasniuk et al. 2021)	Driver	Driving simulator	Questionnaire	Occurrence of simulated rear-end collisions	Multiple Sclerosis Driver, United States of America	• The research applied visual cognitive assessment because the scores insignificantly differed from DBQ and were used to conduct the driving simulator. • The driving simulator is a suitable method for multiple sclerosis drivers due to more safety.	• A driving simulator cannot solely determine someone's fitness to drive, crashes and not directly related to real-world driving. • The driving simulator is used to determine sickness and practising time for the participant.
(Mizuno et al. 2020)	Driver	Naturalistic Driving Study	Questionnaire	The extent of rear-end collision risk	The truck driver, Japan	• A naturalistic driving study using fatigue stress is used to monitor the fatigue-related sympathetic nerve for preventive action such as the driver's rear-end collisions.	• Measurement was carried out for eight months.
(Yang et al. 2021)	Driver and Vehicle	Driving Simulator	Questionnaire	Collision avoidance behaviour, braking force, steering wheel angle	Experience driver and novice driver, China	• The 6-DOF Driving simulator was part of the advanced sensor used to detect driving behaviour, such as the accelerator, brake, and steering. • The simulator has a smooth and detailed simulated environment.	• While using the driving simulator, the participant needs more time to familiarize with the tool. • The simulator is supported by hydraulic cylinders, a real cab and requires considerable space.
(Mahajan and Velaga 2021)	Driver	Driving simulator	Questionnaire	Safety Indicator	Driver in highway, India	• The driving simulator comprises LED screens, power steering, a pedal system similar to the actual car, a sound system, and a digital speedometer. • The simulator was less dangerous with fatigued and driven in a natural road environment.	• Driver fatigue during the experiment.

4.3 Methods Comparison

The authors used several considerations to design the research methodology. Criteria for the selected design were the research problem, personal experiences, and audience. Furthermore, each research has different objectives ranging from money resources, time, facilities, team capabilities, samples, connections, and urgency. The different research conditions led to the use of a variety of methods or tools with various advantages and disadvantages (Creswell 2009; Rahman 2017)

Table 2 shows the advantages and disadvantages of each method used in rear-end collision risk assessment. There are three types of objective methods, namely naturalistic driving study, driving simulator, and modelling. Meanwhile, the questionnaires were used to determine the subjective method used in the literature review. This comparison's research conditions are less expensive, consisting of a large amount of data, high fidelity, fewer respondents, partnership with the police department, fewer error analyses, controlled environment, and low risk.

The objective method has the most considerable advantages in the literature review using a driving simulator. The advantages of this method are limited duration, respondent, error analyses, controllable environment, and low risk when retrieving data. There are numerous types of driving simulators with different tools and specifications, leading to diverse prices. However, in this literature review, three studies added subjective methods with a questionnaire used to complete the research data and determine the objective method's deficiencies (Krasniuk et al. 2021; Yang et al. 2021; Mahajan and Velaga 2021). The research needs to use a naturalistic driving study or develop a model to determine crash accidents from historical data.

Meanwhile, when the purpose is to observe the driver's behaviour while driving, especially the behaviour before the incident of a rear-end collision, it is recommended to use a naturalistic driving method. There are still shortcomings, such as the possibility of error analyses when humans process data using video analysis. Meanwhile, the naturalistic driving study has a high risk when taking data directly in the field without a controlled environment (Wu et al. 2020; Wu and Wang 2021).

Table 2. Research Method Comparison

Methods		Research condition								
		Less cost	A large amount of data	Short research period	High fidelity	Less respondent	Partnership with the police department	Fewer error analyses	Controlled environment	Low risk
Objective Method	Naturalistic Driving Study	✗	✓	✗	✓	✗	✓	✗	✗	✗
	Driving Simulator	✗	✗	✓	✗	✓	✗	✓	✓	✓
	Modelling	✗	✓	✗	✗	✗	✓	✗	✓	✓
Subjective Method	Questionnaire	✓	✗	✓	✗	✗	✗	✓	✗	✓

Note: ✓:Advantages ✗:Disadvantages

5. Conclusion

In conclusion, there are advantages and disadvantages associated with the objective and subjective methods without limitations. Furthermore, it is highly recommended to use objective and mixed methods to conduct a rear-end collision risk assessment to obtain significant research findings. The results provided another perspective for future research based on their conditions and goals. Future research needs to apply both methods to assess the rear-end collision or another collision risk with a thorough understanding of existing risk factors.

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