A brief review of the impact of distracted driving on traffic safety

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Abstract: Nowadays, with the popularity of electronic devices such as navigation systems, smartphones, and other in-vehicle systems, the number of factors triggering distracted driving is increasing, making distracted driving one of the significant causes of traffic accidents. This paper attempts to summarize the present research situation of the impact of distracted driving on traffic safety, highlights the research methods and trends, then proposes future research directions.

1. Introduction
With the rapid development of the transportation industry, the issue of road traffic safety has attracted significant attention. Road traffic is a complex system composed of people, vehicles, roads, etc. Thus, the causes of traffic accidents can be divided into three categories: human factors, vehicle factors, and road environment factors. Most of the human factors are determined by driving behavior. The driving behavior is a complex behavioral process consisting of perception (vision, reaction, and attention characteristics), judgment, and operation, which requires a high degree of concentration to maintain safe and accurate operation. In recent years, with the growing popularity of electronic devices, using mobile phones and other in-car devices while driving has been increasingly prevalent. Besides, drivers sometimes drink, eat, smoke, and chat with passengers during driving, which leads to distracted driving. Distracted driving is defined as a diversion of attention away from activities critical for safe driving toward a competing activity [1].

Driver distractions will cause trouble concentrating on the rapidly changing external environment, which can easily lead to traffic accidents. Studies showed 25-30% of all police reports in the US involve distracted driving [2], and distracted driving caused almost 80% of crashes and 65% of near-crashes [3]. Distracted driving not only affects the operation of the driver, but also affects the surrounding vehicles through the operating state of the car itself in the traffic flow, forming a wave conduction pattern, which in turn affects the entire traffic flow (Figure 1). Therefore, the impact of distracted driving on traffic safety can be divided into two parts: first, the impact on the safety of the vehicle itself, and second, the impact on the safety of traffic flow.

Aiming at the impact of distracted driving on traffic safety, this paper is structured as follows: first, the existing research methods of distracted driving are summarized. Then, from the perspective of the research methods, researches on the impact of distracted driving on the vehicle and the traffic flow are reviewed, respectively. Finally, possible future research directions are proposed.
2. Methods of study distracted driving

Many scholars have researched distracted driving and adopted many methods, which can be broadly categorized as follows:

(1) **Naturalistic driving experiment**, use cameras or motion sensors installed in the vehicle to record the driving behavior data. Although naturalistic driving experiments can record driving behaviors in the real environment, in most cases, the experiment is time-consuming and expensive.

(2) **Driving simulation experiment**, based on specific equipment (driving simulator), with the designed driving scene, allows the driver to conduct operations in a virtual environment. Driving simulation experiments are less risky, more reproducible than naturalistic driving experiments, with more indicators and more accurate data available. However, simulated driving environments are very different from real-life scenarios, and the reliability of the data has yet to be tested. Despite this, the simulated driving experiment is still the most commonly used method to study distracted driving[4].

(3) **Statistical research**, based on existing data sets (such as accident data released by NHTSA, police reports, etc.), analyze the correlation between traffic accidents and distracted driving. But this method primarily depends on the quality of the data set and the types of indicators recorded.

(4) **Observation method**, through on-site observation or video observation, counts the driver distraction under natural conditions. The observation method can obtain driver distraction type, process, duration, and the corresponding surrounding environment data in the natural state to study the formation mechanism of distracted driving.

(5) **Traffic simulation**, establish a driver model, and analyze the impact of distracted driving through traffic simulation. The main advantages of this approach are that the calculations are relatively fast, easy to set up, and repeatable. Still, the driver model requires extensive validation before use to ensure accuracy.

3. The impact of distracted driving on vehicle safety

In terms of the impact of distracted driving on vehicle safety, numerous studies have been done based on the methods described earlier, focusing on the effects of distracted behavior on the probability of accidents and driving performance. Researches are more likely to use naturalistic driving experiments and simulator experiments.

3.1. **Researches based on naturalistic driving experiment**

To understand the impact of driver behavior and performance on traffic safety, several research projects have previously conducted large-scale naturalistic driving experiments. The data collections for some of these projects are open for public use, and there have been numerous studies conducted by scholars using these datasets, as shown in the table below (Table 1).
Table 1. Some large-scale naturalistic data collection

| Data collection                  | Data scale                                               | Related papers                          |
|---------------------------------|----------------------------------------------------------|-----------------------------------------|
| SHRP2 NDS (Strategic Highway    | 3,400+ drivers and vehicles.                             | Lv et al., 2019;                        |
| Naturalistic Driving Study)     | 5,400,000+ Trip summary records.                         | Wu and Xu, 2018;                        |
|                                 | 36,000+ Crash, near-crash, and baseline driving events. | Jenkins et al., 2017                   |
|                                 | Approximately 2,000,000 vehicle miles of driving.        | Seppelt et al., 2017;                   |
|                                 | Almost 43,000 hours of data.                              | Klauer et al., 2014;                    |
|                                 | 241 primary and secondary driver participants.           | Tian et al., 2013                       |
| 100-Car Naturalistic            | 12 to 13-month data collection period for each vehicle;  | Hansen et al., 2017;                   |
| Driving Study                   | 18-month total data collection period. Five channels of   | Zheng et al., 2016;                     |
|                                 | video and many vehicle states and kinematic variables.  | Sathyanarayana and Hansen, 2012         |
|                                 |                                                          | [10–12]                                 |
| UTDrive                         | Rich multi-modal data recorded in a car environment (i.e.,| Hansen et al., 2017;                   |
|                                 | audio, video, gas/brake pedal pressures, forward distance,| Zheng et al., 2016;                    |
|                                 | GPS information, and CAN-Bus information including      | Sathyanarayana and Hansen, 2012         |
|                                 | vehicle speed, steering angle, pedal status)            | [14–16]                                 |
| SH-NDS (Shanghai Naturalistic   | Collected 60 Chinese drivers’ real-world driving data,  | Zhang et al., 2019                     |
| Driving Study                   | with a total mileage of 161,055 km.                      |                                         |
|                                 | Investigated decision-making mechanisms for essential   |                                        |
|                                 | driving behaviors based on 108,933 car-following events, |                                        |
|                                 | 17,309 lane-change events, 7,845 cut-in events, and 3,256 vehicle-pedestrian conflicts. |                                        |

For example, Klauer et al. [11] used 100-car NDS data, screen out 685 crashes and near-crashes from the data of 42 novice drivers and 109 experienced drivers, and observed video images to mark the distractions involved. It was found that for novice drivers, distracting behaviors such as making phone calls, texting, picking up something, and eating can significantly increase the probability of crash and near-crash. Zhang et al. [18] used 296 mobile phone behavior samples from the SH-NDS dataset to analyze the impact of mobile phone use while driving on driving control behavior. Results showed that cell phone use resulted in reduced control activities, more sluggish control operations, and a significant effect on longitudinal control stability.

However, large-scale naturalistic driving experiments are sometimes not sufficient for some researchers with specific research objectives, so they equip their test vehicles and design their experiments to conduct naturalistic driving studies. For example, Wang et al. [19] equipped the test vehicle with a lane marking recognition system, millimeter wave radar, video recording system, and GPS. The experiment allows the driver to mimic visual distractions by judging the speed and relative distance of the vehicle behind them through the rearview mirror while driving, thus investigating the effect of visual distraction on the driver’s lane-keeping ability. The results show that, compared with normal driving, visual distraction increased the steering wheel reversal rate and the standard deviation of the steering wheel acceleration, but reduce the driver’s lane-keeping ability.

3.2. Researches based on driving simulation experiment

Compared with naturalistic driving experiments, simulated driving experiments have more controllable factors, the degree of customization of the experiment is higher, and there are more types of indicators available. Thus the vast majority of studies of distracted driving have used this approach.

Tarabay Rana et al. [20] used a simulated driving experiment to design several secondary tasks of different difficulty levels to quantify the effect of increased workload caused by distracted driving in specific road conditions on driver performance and physiological state by detecting physiological indicators such as the cardiac and pelvic electrical activity of the driver. Drivers were found to adopt
compensation behaviors at the operational level, such as reducing speed, in order to be able to drive and perform additional tasks at the same time.

Li [21] simulated the car-following behavior on urban roads through three cognitive distraction tasks designed at different levels. It was found that as the level of cognitive distraction increased, the steering wheel rotation changed significantly, and the standard deviation of vehicle lane departure decreased, suggesting that the driver might compensate by turning the steering wheel to reduce the lane departure distance when in a cognitive distraction state.

Yan et al. [22] used a driving simulator to simulate a car-following scene, and respectively detected the driver's performance in the case of emergency braking of the vehicle in front under three states: normal driving, using a mobile phone for non-emotional dialogue, and performing mathematical operations. It was shown that hands-free calls on mobile phones impaired driving performance, and the more complex cognitive distractions performed simultaneously, the more braking reaction time increased.

3.3. Comprehensive review
Most existing studies on distracted driving have shown that distracted behavior can have a significant impact on drivers' operations. The most noticeable effect is to increase the driver's reaction time, which is positively correlated with the probability of accidents[23]. However, many studies have shown that drivers will take compensation measures (e.g., increasing headway, decreasing speed, decreasing frequency of lane changes, etc.) during distractions, which can reduce the risk of accidents to a certain extent[24, 25]. At the same time, studies based on simulators and studies based on naturalistic driving are sometimes inconsistent in the conclusions they reach, and there are current studies that attempt to explain this [26].

Moreover, the effects of different distractions and types of distractions on driving performance vary considerably, reflecting different effects on performance metrics for each vehicle. Even studies on the same kind of distractions have sometimes reached opposite conclusions[27], and further investigation is needed in the future as to why this difference occurs.

4. The impact of distracted driving on traffic flow safety
In order to study the impact of distracted driving on traffic safety, in addition to the distracted vehicle itself, it is necessary to obtain information such as the location and speed of surrounding vehicles and downstream vehicles. Therefore, it is mostly impossible to use naturalistic driving experiments and statistical research to obtain reliable data. The existing literature in this area can be broadly divided into two categories, one is based on driving simulation experiments, and the other is based on traffic simulation.

4.1. Researches based on driving simulation experiment
Xu et al. [28] designed a car-following scene with four cars based on simulated driving experiments, and analyzed the operating indicators of the third and fourth cars when the driver in the second car uses a mobile phone. The results show that distracted driving leads to longer convoys, smaller headway distances for following vehicles, and greater distances between distracted vehicles and the head vehicle than between other following vehicles.

Cooper et al. [29] designed experiments in which 36 participants performed distracted driving (phone calls) in simulated traffic flows of different levels and compared the results to those without distraction. The results showed that distracted driving reduced the number of lane changes and average speed in medium and high traffic flows. Near the tipping point of stable traffic flow, distracted driving has a more profound impact on traffic flow.

Stavrinos et al. [30] had participants performed a driving simulation experiment by setting different levels of traffic flow (free-flow, steady flow, and congested flow) under different distracting behaviors (phone calls, texting) and without distracting conditions. The results showed that texting behavior led to greater lane departures and more accidents, with most distracted participants experiencing increased
speed fluctuations, less frequent lane changes, longer time to complete the experiment, and being overtaken by more vehicles.

4.2. Researches based on traffic simulation

The idea of researches based on traffic simulation is roughly as follows: establish a driver model for a specific driving behavior (such as distracted driving), set up influence rules between vehicles, then set up the traffic flow environment, and analyze the impact of parameter changes in the model on the safety and efficiency of the traffic flow through computer simulation.

The current driver models mainly include the following categories:

(1) Cellular automata model

Zhang [31] took the "hands-free mobile phone calling" and "WeChat voice messaging" driving secondary tasks as the research objects. By establishing a cellular automata simulation model considered the characteristics of distracted driving behavior, the impact of different distracting vehicle proportions and different distracting durations on road traffic safety was studied. The results showed that, within a specific density range, as the percentage of distracting vehicles increase, road traffic flow decrease, the frequency of lane changes increase, traffic congestion increase and traffic safety decreases, which led to the conclusion that distracted driving will have a noticeable negative impact on traffic safety.

Zhang et al. [32] proposed a traffic flow simulation model based on the cellular automata model. The dynamic safety distance model was used in the vehicle speed update and lane change mechanism. Distracted driving with different degrees of distraction was modeled quantitatively. The study was carried out for both single-lane and dual-lane simulations to analyze the probability of distracted driving in relation to the traffic flow and the frequency of traffic accidents. The results showed that as the probability of vehicle distraction increases, the traffic flow through the road section would decrease, and the frequency of accidents will increase.

(2) Car-following model

Lindorfer et al. [33] used the extended intelligent driving model and the micro-traffic simulation simulator TrafficSim to analyze the impact of driver's varying reaction time, anticipatory driving and distracted driving on traffic efficiency and safety. The results showed that collisions occur when driver reaction time is longer than 1.1 s. Severe distraction also led to a high probability of rear-end collisions. The number of collisions depended largely on the driver's reaction time, anticipation ability and traffic density.

Xiao [34] used the driving simulation platform and eye-tracking equipment to obtain the driving characteristics of the driver during normal driving, talking on a phone while driving, speaking via phone software while driving, and the distribution of the driver's gaze area. A random occurrence model of distracted behavior and an improved optimized speed model were developed to analyze the effects of distracted behavior on traffic flow stability and traffic efficiency. The results showed that the driver's distracted driving speed, following distance, lane change frequency, and driving stability all changed significantly, making it more prone to traffic accidents, while the stability of the traffic flow was disturbed, reducing road capacity and traffic efficiency—the more serious the distraction, the greater the impact on driving performance and traffic safety.

Van Lint et al. [35] proposed a multi-level traffic flow modeling simulation framework, which considers human factors such as reaction time, sensitivity to stimuli, and expected speed. The framework combined with an intelligent driver model to reproduce the traffic bottlenecks and traffic jams caused by distracted driving. Further, the paper analyzed the underlying reasons why distracted driving causes these traffic phenomena.

(3) Model in simulation software
Nourzad et al. [36] used Distract-R to estimate the time distribution of distractions for different types of distractions. They utilized the COM function of the VISSIM software to change the driving behavior parameters of vehicles entering the simulation to achieve large-scale simulation of distracted driving. The results show that when the number of distracted driving vehicles increases, the average headway and speed of the traffic flow will decrease, and the speed dispersion will increase significantly. At the same time, the impact of distracted driving on the vehicle itself is more significant than the effects on surrounding vehicles. Overall, the negative impact of distracted driving on traffic flow is substantial.

4.3. Comprehensive review
Current research on the effects of distracted driving on traffic flow has focused on some microscopic metrics such as TTC (time to collision), TH (headway), SM (safety spacing), and some macroscopic metrics such as overall traffic flow speed, density, volume, number of lane changes, vehicle travel time, number of collisions, etc., rarely using a combination of metrics to assess the safety of traffic flow.

Most studies have noted that the effects of distracted driving on traffic safety are more pronounced during steady and congested flows, but this effect is concentrated on longitudinal rear vehicles and largely unaddressed in studies of impacts on horizontal parallel cars.

5. Prospects for future research directions
Current research on the impact of distracted driving on traffic safety has focused on the impact on the vehicle, with less research on the impact on traffic flow. It is, therefore, likely to be the focus of future research.

At present, researches on the impact of distracted driving on traffic safety is limited to one or a few cars in the number of distractions, or the content of distractions is limited to a specific type of distraction, with few large-scale distraction analyses conducted. For example, how does the presence of a certain percentage of distracted drivers affect traffic flow, or how does the situation change when there are both drivers on the phone and drivers texting or engaged in other secondary tasks in the traffic flow? There has been relatively little research on these topics.

Similarly, existing studies on the large-scale impact of distracted driving do not consider the interaction of distracted vehicles with other vehicles. There are two main methods available: researches based on driving simulation can more realistically reflect the impact of human factors on traffic flow, but there is a limit to the number of distracted drivers, so it is impossible to simulate distractions on a large scale; and researches based on traffic simulation, although it is possible to simulate large-scale distractions, there is still some difficulty for the model to simulate the behavior of distracted drivers in real conditions. In the future, the combination of these two methods can be considered. Through the multi-user driving simulation platform, multiple drivers can conduct experiments in the same simulation scene, and the interaction between drivers and surrounding vehicles can be studied during driving. Then, with the help of traffic simulation, the impact of drivers’ driving behavior on traffic flow and traffic safety can be revealed in more detail.

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