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Research Article

Effects of on-Board Unit on Driving Behavior in Connected Vehicle Traffic Flow

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Connected vehicle technology has potentials to increase traffic safety, reduce traffic pollution, and ease traffic congestion. In the connected vehicle environment, the information interaction among people, cars, roads, and the environment is significantly enhanced, and driver behavior will change accordingly due to increased external stimulation. This paper designed a Vehicle-to-Vehicle (V2V) on-board unit (OBU) based on driving demand. In addition, a simulation platform for the interconnection and communication between the OBU and simulator was built. Thirty-one test drivers were investigated to drive an instrumented vehicle in four scenarios, with and without the OBU under two different traffic states. Collected trajectory data of the subject vehicle and the vehicle in front, as well as sociodemographic characteristics of the test drivers were used to evaluate the potential impact of such OBUs on driving behavior and traffic safety. Car-following behavior is an essential component of microsimulation models. This paper also investigated the impacts of the V2V OBU on car-following behaviors. Considering the car-following related indicators, the k-Means algorithm was used to categorize different car-following modes. The results show that the OBU has a positive impact on drivers in terms of speed, front distance, and the time to stable regime. Furthermore, drivers' opinions show that the system is acceptable and useful in general.

1. Introduction

Freeway is an important channel among cities. It is one of the main ways of transportation in medium and long distance, which has the characteristics of high speed and high efficiency. It can not only provide high-quality travel service level for travelers, but also promote the optimization of industries along the road and the role of regional economic development; highway network and infrastructure are increasingly being perfect, and transportation demand has also increased significantly, especially for travelling around large metropolitan areas in holidays when traffic congestion and security issues are prominent. As an important method to effectively alleviate traffic congestion, reduce traffic pollution, and improve traffic safety, ITS technology has attracted much attention [1–3]. Connected vehicle technology is an important part of ITS. In the environment of connected vehicle, vehicles on road networks based on vehicle-based self-organizing networks which is named VANET can achieve Vehicle-to-Vehicle communication (V2V) and Vehicle-to-Infrastructure communication (V2I), so that traffic information can be shared [4, 5].

In traditional traffic environment, the driver makes the decision-making action of the vehicle operation through his own perception of the external environment stimulation. The vehicle operation is extremely easy to be influenced by drivers' driving experience and personality, which leads to random traffic flow. Compared with traditional traffic environment, in the connected vehicle environment, drivers can obtain accurate and detailed information of the surrounding vehicles at every moment, which greatly reduces the dependence on drivers' individual perception. However, at the same time, the diversity and extensiveness of the information acquired and presented by connected vehicle on-board unit (OBU) bring certain information load challenges to drivers' decision-making, and the characteristics of the driving behavior, especially the car-following behavior, will change to a certain degree.

In the architecture of connected vehicle technology, the OBU is a key part of its application in actual transportation services. It has a huge market and is highly valued by automobile manufacturers. The OnStar system used by GM provides safety information services such as rescue and remote fault diagnosis for vehicles through global positioning system (GPS) and wireless communication. G-BOOK adopted by Toyota Corporation of Japan uses wireless network systems such as Vehicles Information Communication System (VICS) to establish communication links between vehicle and service center, which can provide rescue, navigation, entertainment, and other 11 services for vehicles [6]. Ford and Microsoft jointly developed the SYNC system for navigation and data transmission and voice calls of other services through the user's mobile phone terminal. The LTE-V in-vehicle system launched by Datang Telecom Group can not only meet the needs of telematics applications and improve communication reliability by reducing delays, but also meet the needs of road safety and traffic efficiency. From the development status of the OBU, it can be seen that the vehicle manufacturers mainly pay attention to the communication technology of the vehicle equipment, as well as the safety warning, navigation, entertainment, and other services provided based on this. However, studies on the impact of the OBU on driving behaviors are limited.

With the development of ITS technology, the connected vehicle technology has been applied to increase driver awareness and thus improve driving behaviors [7]. Previous researches are shown where the in-vehicle information service can improve driving safety by informing the front sign information and route planning information in advance through pictures and voice prompts [8, 9]. Varhelyi et al. collected 24 drivers' information to assess the impact of safety warning information (speed limit warning, curve section warning, frontal collision accident information warning, blind spot warning) on drivers in the actual traffic environment [10]. Liu Y C et al. researched the response time of drivers of different ages to hazard warnings under different traffic conditions with different modal information (visual, auditory) of on-board information services [11].

As an important part of microdriving behavior research, the characteristics of car-following behavior are the basis of microtraffic flow modeling and have been widely used in traffic capacity analysis, microtraffic simulation, traffic safety evaluation, and other fields. Therefore, the traffic flow model has been intensively researched for nearly 60 years, attracting experts in the fields of traffic engineering, systems engineering, vehicle engineering, and so on. Combined with operational research theory, the car-following model was firstly proposed by Reuschel [12] and Pipes [13]. The development of the car-following theory has achieved many important results. The stimulus response model and physiological-psychological model was established based on drivers' perception and response characteristics. Safety spacing model was proposed based on vehicle performance and drivers' characteristics. Artificial intelligence model using artificial intelligence algorithm was proposed to describe the complex mental and physiological behavior of drivers. Considering the relative speed, the optimal velocity model was proposed. Considering the acceleration trend in the free flow and the deceleration trend of the leading vehicle colliding, the intelligent driving model was proposed. In addition, the cellular automata model that adopted the discrete state-space model to reveal the evolution of the traffic flow was proposed [14].

The evaluation of V2V OBU, in terms of their functionality, and contribution to traffic and safety conditions, once they are deployed, is a complex task. Detailed observations of vehicle and driver behavior are needed. As the development of connected vehicle technology is in the initial stage, the road facilities are still not perfect. It is difficult to obtain the vehicle operation data under the actual connected vehicle environment. Moreover, collecting such data from a real world environment might put the test driver and the surrounding vehicles in risky situations. At present, the driving behavior data of the connected vehicle environment are studied mainly by the following methods.

(1) US NGSIM dataset, which has many types, high acquisition frequency, and huge data volume, is used as the data basis to verify the primary connected vehicle driving behavior model.

(2) Computer simulation software, such as MATLAB, obtains the connected vehicle environment data and performs sensitivity analysis on model research.

(3) Driving simulation builds the connected vehicle simulation environment and then collects driving behaviors of the recruiting drivers in the simulator.

Detailed observations of vehicle and driver behavior are needed. Therefore, in this paper, the OBU for the connected vehicle environment has been designed. At the same time, a V2V connected vehicle environment for intervehicle information interaction was built by means of the driving simulator. Drivers were recruited to collect driving behaviors under different environments. Driving simulation technology is considered to be a safety and economic research tool, and it is easy to control research variables. Different simulation environments can be designed to analyze the influence of different factors on drivers' behaviors. Driving simulation technology is not an emerging technical tool, and it has been applied in some related researches. Yun M et al. used the driving simulator to analyze the impact of vehicle navigation information on the behavior of lane-changing under different traffic flow conditions in the merging area [15]. Haneen Farah used the driving simulator of the VTI (Swedish National Road and Transport Research Institute) to simulate the coordination of infrastructure and vehicles environment (I-V) and used the OBU to provide information of road networks, weather, and accidents ahead. The trajectory data of the vehicle were analyzed, and it was found that drivers had less difference in behaviors during acceleration and deceleration under the cooperation of the roadside system [16]. In addition, Shechtman et al. discovered the validity of the driving simulation research method by investigating the types and number of errors made by the driver in the driving simulator [17].

The objective of this paper is to analyze the impact of the V2V OBU on drivers' behaviors under different traffic flow conditions. The main content of the research is of twofold: (1) to establish an interoperability platform for the driving simulator and the V2V OBU, the human machine interface (HMI) of OBU was designed to collect driving behavior data as in-vehicle V2V information service and (2) to explore the impact of the V2V OBU on drivers' car-following behaviors by using data from the driving simulator, the impact of certain demographic characteristics as explanatory variables is expected to shed light on the question whether the use of such OBU contributes to the traffic conditions and traffic safety.

2. Methodology

2.1. Framework of V2V Simulation Platform. The OBU is an important platform for the interaction among driver, vehicle, and the surrounding traffic environment in the connected vehicle environment. However, the existing OBUs in the market mainly provide drivers with driving safety assistance, route planning, audio entertainment, etc., but little information about the location, speed, and road information of the surrounding vehicles, which have a great influence on the driver's driving behavior. In this paper, the OBU in vehicle was to provide position and speed of surrounding vehicles. A simulation platform was established to simulate the connected vehicle environment.

2.1.1. The Architecture Design of OBU. The OBU should include the following modules:

(1) The data collection unit: the OBU can collect the distance data between test vehicle and others within 250 m range of the test vehicle, and the speed of the test vehicle generated by the driving simulator.

(2) Vehicle state judgment and display unit: by judging the distance and the speed, it can select different modes (security mode, prompt mode, and alert mode).

(3) Voice unit in warning mode.

(4) The clock unit.

The C/S architecture, i.e., server/client architecture, was adopted by the OBU architecture. Firstly, Wi-Fi hotspots were established through the laptop, and then the OBU and the server (python) can establish the connection. In an intranet environment, the simulator data will be transmitted to the server through the UDP protocol. Finally, the server transferred data to the client through TCP/IP protocol (Cordova mobile framework) and saved them into the SQL. The OBU architecture design flow is shown in Figure 1. Figure 2 shows the connected vehicle simulation platform that can realize the interconnection between the simulator and the OBU.

2.1.2. Human Machine Interface Design of the OBU. When conducting the experiment under connected vehicle environment, the OBU should be on, as shown in Figure 3. In the driving process, the OBU triggers different information display modes according to the driving state. The driving modes include security mode, prompt mode, and alert mode. The content of car display mainly includes speed, distance, time, warning diagram, and voice reminder in dangerous driving mode. Figure 4 shows the interaction interface of the OBU under different application modes. The function of the OBU mainly includes the display of speed, distance, time, warning diagram, and voice reminders with alert mode.

Under connected vehicle environment, alert modes are triggered when the test car is in a dangerous situation: (1) overspeed driving; (2) the distance between the test car and the front car being less than the safety distance. The OBU displays in these dangerous situations are shown in Figures 4(a) and 4(b), respectively. The safety spacing calculation model is shown in the following [18, 19]:

$$S = (V_1 - V_2) \times \frac{T}{3.6} + \frac{(V_1 - V_2)^2}{254(i + \psi)} + s_0 \tag{1}$$

where S is for minimum safety distance to the front car when car following the front driver; s_0 is for minimum distance to the front car when standstill; V_1 is for the speed of the experimental driving car; V_2 is for the speed of the front car; T is for the reaction time of the front driver, T=2.0s; i is for the slope of the road; i=0; ψ is for the coefficient of friction of the road, ψ=0.4.

When the distance between the test car and the front car is less than 250 m, the driving simulator starts to record the speed and position information of the front vehicle. When the distance is between the minimum safety spacing distance and 250 m, the arrow in front of the vehicle of the interface becomes yellow flash, indicating that the driver needs to pay attention to the front car, as shown in Figure 4(c). Other situations are safety operation mode, and the interface is shown in Figure 4(d).

2.2. Driving Simulation Experiment

2.2.1. Participants. According to Central Limit Theorem, if sum of random variables is normally distributed, a large sample size obtained from those variables also fits normal distribution. Besides, the sample size not less than 30 is a rule-of-thumb [20] and is commonly used in driving simulator experiment. For example, Saffarian et al. used 27 test drivers to study the car-following behavior under fog condition [21]. A study focusing on the overall impact of the in-vehicle intersection crossing information display system on rural intersection crossing performance and age-related effects was performed with 32 participants (16 older drivers and 16 younger drivers) [22]. A study evaluating the effects of Cruise Control and Adaptive Cruise Control on driving behavior was performed with 31 participants [23]. Accordingly, 31 participants' data were analyzed in this study, based on the distribution of age and driving experience of licensed drivers in China [24]. Table 1 summarizes the sociodemographic characteristics of all drivers. All of them owned Chinese Class C driver's licenses with an age range of 23–55 years (mean=35.0, SD=15.0) and had 1–30 years of

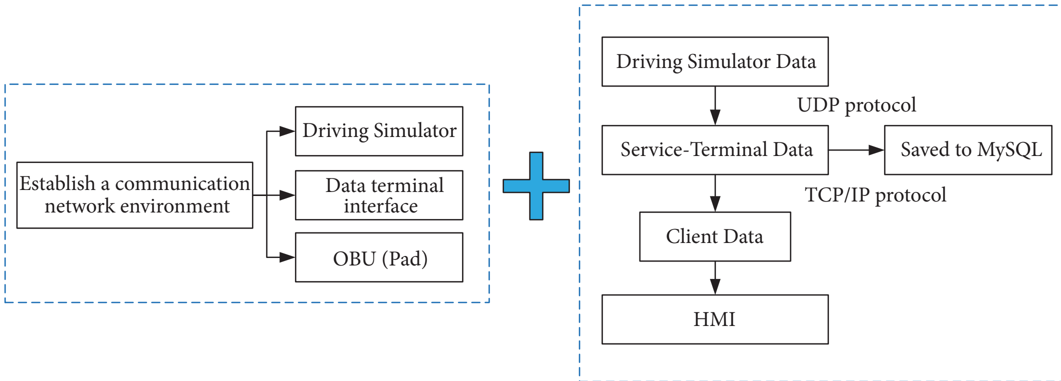


Figure 1: Architecture design diagram of the OBU.

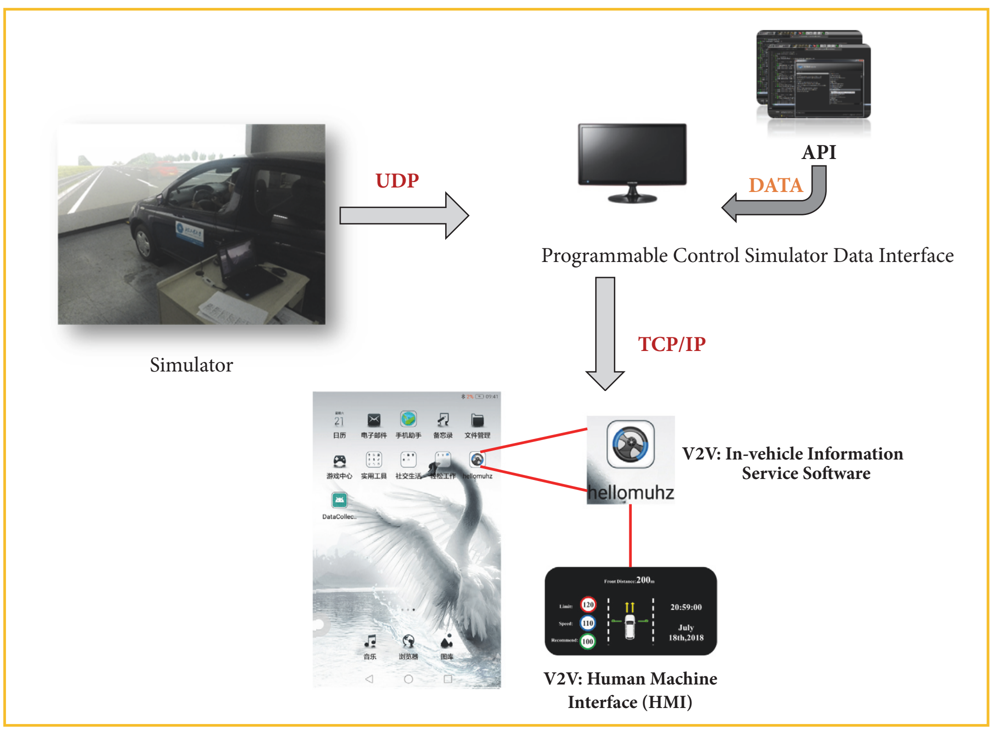


Figure 2: Simulation platform of connected vehicle environment.

driving experience (mean=9.0, SD=9.6). Among them, 20 drivers with professional driving skills came from a driving service company, and they usually drive 800 to 1500 km/week (median=1260). Others were recruited at Beijing University of Technology who lack driving experience (driving age<10 years, average driving age is 5), and they drive 80 to 150 km/week (median=110). All the drivers agreed and signed an informed consent before participating in the study, and they were paid RMB 800 after completing the experiment.

2.2.2. Scenario Design. The experiment selects Xingyan freeway in Beijing as the experiment roadway. The roadway in the simulated scenario is a four-lane freeway with two lanes in each direction, and the width of each lane is 3.75m. The experimental section length is 3Km, and the road speed limit is 120 km/h. The overview of the experimental simulation scenario is shown in Figure 5. This study used a fixed-base driving simulator in the Key Laboratory of Traffic Engineering at Beijing University of Technology. The hardware of this simulator consists of a renovated real car, computers, and video and audio equipment. The road scenarios are projected onto three big screens providing a total of 130 degrees of the

Table 1: Distribution of drivers' demographic characteristics.

Gender	**Yong ≤45 years old**	**Old other**
Male	17	5
Female	7	2

Figure 3: Driving experiment of vehicle connected environment.

driver's visual field. There were two side mirrors and one rear view mirror to show the traffic behind the simulated vehicle. This simulator records both the actions of drivers and the vehicle operation. Both parameters are recorded and saved 20 times per second. The data of drivers' actions collected by this simulator mainly includes drivers' braking and accelerating, while the data of vehicle operations recorded includes the travel distance as well as front distance, speed, acceleration, and deceleration.

2.2.3. Experimental Process. All drivers were required to perform a test drive for about 10 minutes, in order to be familiar with the operation of the driving simulator and the V2V on-board unit. Then, they participated in the formal driving experiment of 4 different scenarios in which two traffic flow conditions with and without the OBU are randomly combined to eliminate familiarity. The average driving time for each scenario is about 7~10 minutes. Each driver was arranged to take a 30-minute break among each experiment.

In order to ensure the efficiency of the experiment process and the validity of the experimental data, a set of control methods of the experiment process was designed, including the methods before, during and after the experiment. The controls in advance include the acquisition of basic information of drivers before experiments and the training before driving. The controls during the experiment include formal experiments and the monitoring of the experimental process. The controls after the experiment include the drivers' feedback and suggestions on the driving experience. Figure 6 shows the experimental process.

Before the experiment, (1) drivers need to fill in the basic information questionnaire: gender, driving experience, driver's fatigue degree, and so on and (2) the training for drivers: an introduction of experimental road, the use instruction of the OBU with 3 modes, and so on.

During the experiment, (1) before entering the formal experimental road, drivers first conduct an experiment of 1 km pretest road, so that they can adapt to the driving scenario. (2) The driver completes the scheduled experiment in accordance with the experimental sequence.

After the experiment, drivers need to fill in the questionnaire according to the driving experience after completing the experiment. The questionnaire includes the rationality evaluation of the display content of the OBU, the verification of the display content identification, and the influence evaluation of the OBU on drivers.

31 drivers were in good condition before and after experiments. Drivers could use the OBU smoothly and understand the display content well. The results of the after-driving evaluation showed that 3 people thought that the on-board equipment caused certain interference to them, but it was acceptable. Others thought that it can help them make better decisions.

3. Data Analysis

3.1. General Traffic Conditions. In order to evaluate the impact of the OBU on driving behavior under different traffic conditions, four scenarios were designed in the experiment.

Scenario A: the OBU is on and the traffic is in free flow.

Scenario B: the OBU is off and the traffic is in free flow.

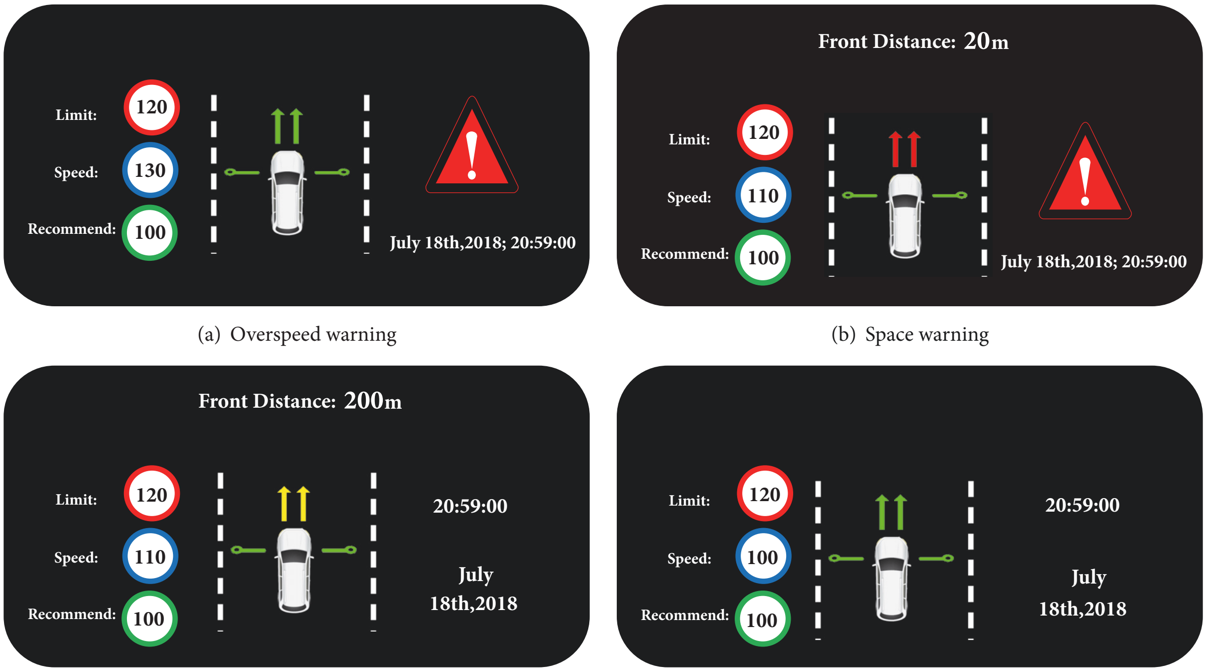
Scenario C: the OBU is on and the traffic is in synchronized flow.

Scenario D: the OBU is off and the traffic is in synchronized flow.

Under the *condition of free flow*, the flow rate is set to *800pcu/h/ln*. In addition, the flow rate is set to *2000pcu/h/ln* under the condition of *synchronized flow*. Scenario A and Scenario B were designed to explore the impacts of the OBU on driving behavior under free flow. Scenario C and Scenario D were designed to explore the impacts of the OBU on driving behavior under synchronized flow. Scenario A and Scenario C were designed to explore the impacts of the OBU on driving behavior under different traffic conditions. Scenario B and Scenario D were designed as the control group.

This paper selects the average speed, acceleration noise, average following distance, average number of lane-changes, and the probability of driver overtaking as the macrolevel evaluation indexes of the impact of the OBU on driving behavior [25]. Table 2 shows the distribution of drivers' operating data in different scenarios, and SD represents the standard deviation of the data. Due to the small traffic density and the large spacing, the phenomenon of following behavior is rare under the condition of free flow. This paper mainly studies the impact of the OBU on drivers' car-following behavior under the condition of synchronous flow.

Under synchronous flow, with more vehicles and frequent prompts of on-board information, drivers will be more cautious and keep a large safety distance from the front car. However, because of the clear information of speed and the distance of the front car, proper speeds will be recommended to drivers, and they will respond more efficiently. Therefore, the average car-following distance of drivers with the OBU on is smaller than the condition that the OBU is off. However,



(a) Overspeed warning

(b) Space warning

(c) Alert prompt

(d) Safety

Figure 4: V2V software interaction interface.

the average speed of drivers with the OBU is bigger than the condition without the OBU.

In free flow condition, through the speed with the OBU on is lower than that which is off, the phenomenon of overspeed has been reduced and the driving safety has been greatly improved. Some drivers' speeds are higher than the limit speed because drivers who exceed 10 percent of the speed limit are only warned and have no fines or other penalties in China.

3.1.1. Speed Profiles. Speed profiles were created for each driver. Figure 7 illustrates an example of the results for driver 14-17. Figure 8 presents the average speed profiles for all drivers of 2 km vary in space under four scenarios. From the results, it was found that the average speed of vehicles increased by 10.02% when the OBU is under the synchronous flow. In the free flow, the average speed reduced by 6.03% in the case of the OBU is on, but the phenomenon of the overspeed is significantly reduced, and 16.13% of drivers had this behavior when the OBU is off. However, due to information services such as warnings, the standard deviation of the driver's acceleration and speed is relatively higher.

3.1.2. Acceleration Noise. As can be seen from the acceleration curve from Figure 9, it is difficult to draw relevant conclusions from the acceleration data, so further analysis of the acceleration data is needed. In 1959, Herman proposed the concept of acceleration noise to describe the complex relationship among people, vehicle, and road in a complex traffic environment [26]. In 1962, Jones and Potts defined acceleration noise from a statistical perspective and gave the following calculation method [27].

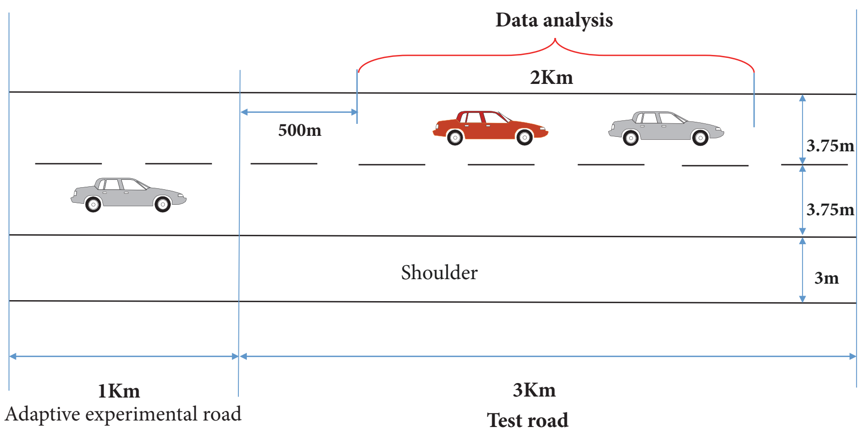
$$\mathrm{ACN} = \sqrt{\frac{1}{T}\int_0^T \left[a(t) - a_{av}\right]^2 d_t} \tag{2}$$

where ACN is the acceleration noise, T is the total time, $a(t)$ is the acceleration at time t, and a_{av} is the average acceleration of T. The results are as Table 2.

3.1.3. Significance Testing. SPSS was used to test the statistical characteristics of data; the results indicate that the obtained data obey normal distribution. F-test was used to test the significance of these indicators in different scenarios of drivers. The results showed that there was a significant difference in speed between different scenarios, and there was a significant difference in the distance between the OBU on and the OBU off condition under synchronized flow. Nevertheless, there was no significant difference in acceleration. This indicates that the car-following distance can be used as an evaluation index of the impact of the OBU on driving behavior. In addition, speed can be used as a comparison of the OBU performance under different traffic flow conditions. Table 3 describes the paired comparison results of different indicators of driving behaviors under different traffic flow and OBU conditions.

3.1.4. Average Driving Speeds by Gender. Figure 10 summarizes the results of the average driving speeds of all drivers with different genders in the four scenarios. The average driving speed of drivers when driving with the OBU was

(a) Road location



(b) Design of experiment road

(c) Virtual scenarios

Figure 5: Overall view of simulation scenario.

significantly higher than the average driving speed when driving without the OBU. The results also indicate that female drivers improved their driving speeds less than male drivers did when the OBU was on. This may be because female drivers are overloaded with information and have a longer reaction time. It is interesting to notice that male drivers' speeds were lower when the OBU was on in synchronized flow. The above results show that the operational efficiency

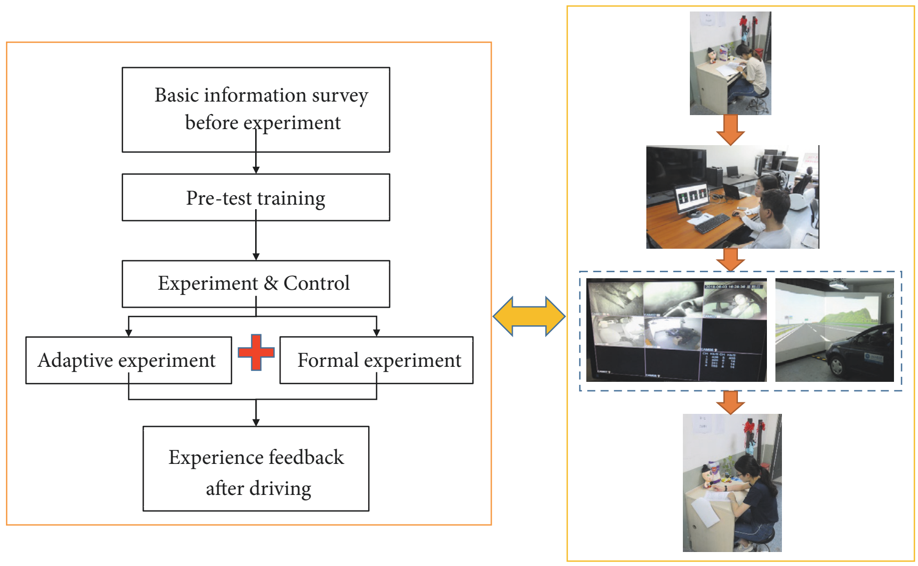
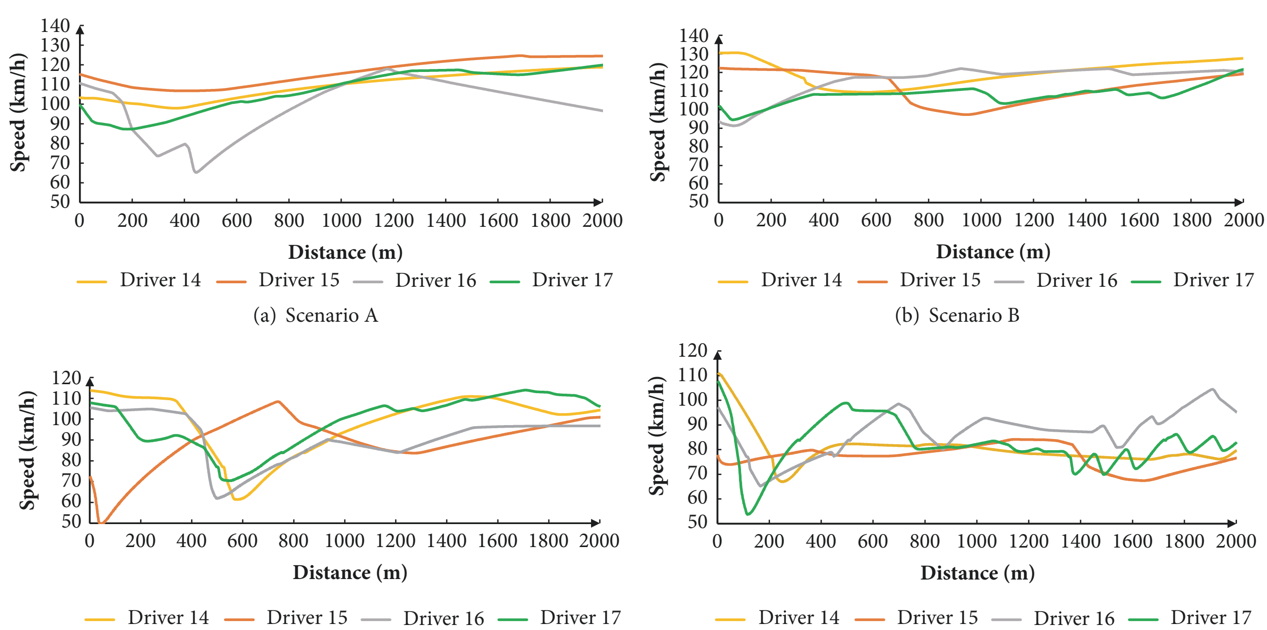


Figure 6: Experimental process.



(a) Scenario A (b) Scenario B (c) Scenario C (d) Scenario D

Figure 7: Impact of the OBU and traffic condition on speed profile of drivers 14-17.

Table 2: Distribution of vehicle and drivers' operating data.

Scenarios	Speed (km/h)		Acceleration (m/s^2)	Car-following distance (CD) (m)	Average number of lane-changes (AL)	Overspeed ratio of drivers
	mean	SD	SD	mean	mean	
A	106.65	7.28	0.27	-	0.19	0
B	113.05	4.01	0.16	-	1.86	16.13%
C	90.18	13.78	0.62	80.56	1.31	0
D	81.80	7.98	0.53	72.32	1.17	0

Table 3: Significance testing of driving behaviors in different scenarios.

Sample1-Sample2	Speed		ACN		CD		AL	
	F-Value	Sig.	F-Value	Sig.	F-Value	Sig.	F-Value	Sig.
Scenario A- Scenario B	8.824	.004	3.093	.084	-	-	46.460	.000
Scenario C- Scenario D	44.615	.000	1.373	.246	39.352	.000	0.055	.816
Scenario A- Scenario C	81.763	.000	1.898	.173	-	-	19.240	.000
Scenario B- Scenario D	366.786	.000	42.121	.000	-	-	5.901	.018

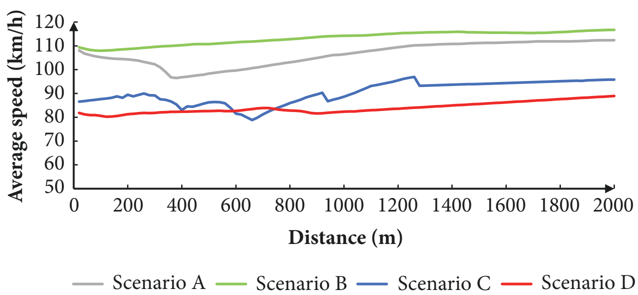


Figure 8: Distribution of average speed under different scenarios.

and safety of male drivers have been improved with the initial OBU, which indicate that male drivers are more suitable to use it.

The impact of the OBU on driving behaviors is consistent with the research results of Fuller [28], which proves the relative validity of the research data results in this paper

3.2. Car-Following Behavior. Car-following behavior refers to a traffic flow status that the rear car is affected by the driving status of the front car of the same lane. Car-following model is one of the main research contents of microcosmic driving behavior models; the car-following behavior data is the basis of the research of microcosmic driving behavior. Due to the difficulty of data acquisition, previous researches are limited. As a result, the trajectory data is difficult to be obtained and there are few studies about the influence of the front car movement on the rear car. In this paper, simulation platform of connected vehicle environment was established. During the driving experiment, driver behaviors data needed in the analysis of Data-driven car-following behavior, like acceleration, distance to the front car, and speed under different scenarios are collected with sampling frequency of 20 Hz. High precision and huge amount of data provide a good data foundation for a more refined study of the car-following behavior from a data-driven perspective. Because the simulator collects front distance (FD) from 250 m to assess the impact of the OBU on driver's entire process from the discovery of the front car to the stability of the car-following state, the driving behavior data within 250 m of FD of each driver was extracted. In addition, the data within 150 m of FD is as the car-following behavior data for analysis [29].

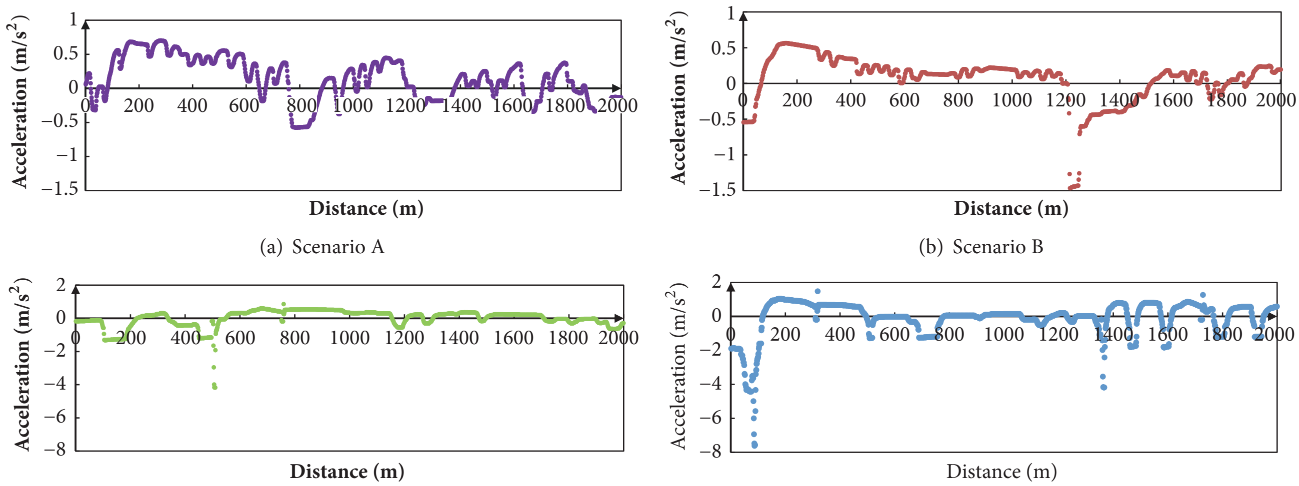
In nature driving conditions, car-following situations are complex due to the different speed and acceleration of the front car. However, from the statistical data analysis, we can get three simplified categories of car-following situations, as shown in Figure 11. The three car-following situation are named phase 1: discovery regime (DR), phase 2: intimate regime (IR), and phase 2: stability regime (SR). Phase 1 refers to the driving behavior within the distance between the rear car and the front car from 250 m to 150 m. Phase 2 refers to driving behavior within the distance between the rear car and the front car from 150 m to phase 3. Phase 3 refers to the stable distance between the rear car and the front car in a certain range; that is, the car-following behavior is in a stable state.

The k-means algorithm was proposed by MacQueen J. B., a clustering analysis method that divides data objects into different class clusters based on the distance between data and central points [30]. The principle of k-means clustering algorithm is that, according to the number of clusters initially set and the initial data set, the clustering criterion function converges by iterating and moving the clustering center points, so that the initial data is divided into k-class data clusters. K-means clustering analysis method has the characteristics of fast and simple algorithm, and the time complexity of data tends to be linear. It possesses a high processing efficiency for large data sets. Car-following behavior is related to following distance, front car speed, rear car speed, speed difference between rear car and front car, and acceleration of rear car [14].

In this paper, in order to evaluate the impact of the OBU on car-following behavior, the driving behavior data within 250 m of FD were classified. The first type is the DR behavior data of FD between 250 m and 150 m. The k-means method was used for driving behavior data of FD within 150 m, and relevant indicators that affect the car-following behaviors are taken as variables. For each driver, the car-following behavior patterns are divided into two categories: the IR behavior data and the SR behavior data. Finally, three types of FD change modes profiles were created for each driver in both conditions (with the OBU and without the OBU). Figure 11 illustrates an example of the results of driver 28.

Table 4 summarizes and compares the average driving behavior of these two conditions: the average duration of the time of phase 1 (DR) and phase 2 (IR), the FD interval of the phase 2, and the mean FD of phase 3 (SR) of all drivers with and without the OBU.

The results indicate that it takes less time for the driver to steadily follow the front car from it appears at about 250 m when the OBU is on. This is because drivers can more clearly be aware of the front car, react quickly, and make the next steps. There is no difference of the range of FD of phase 2 between the conditions: with and without the OBU. However,



(a) Scenario A (b) Scenario B

(c) Scenario C (d) Scenario D

Figure 9: Impact of the OBU and traffic condition on acceleration profile of driver 26.

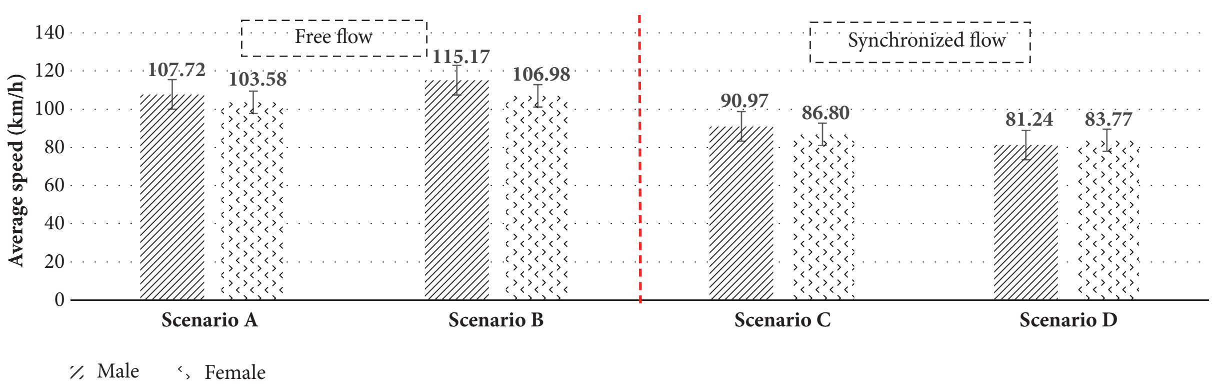


Figure 10: Impact of the gender on average speed of each scenario.

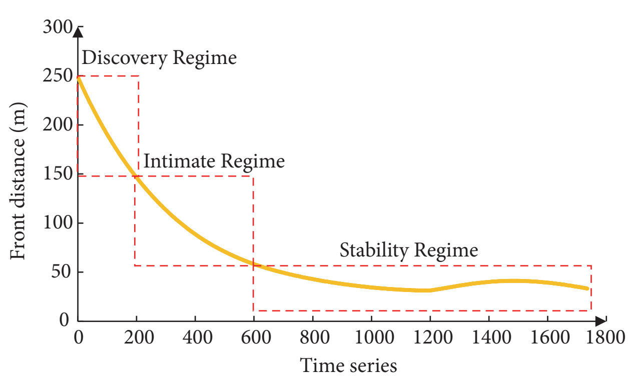


Figure 11: Compartmentalization of car-following regime of driver 28.

the average FD is higher and the standard deviation of FD is lower in phase 3 when the OBU is on. These results support the conclusion reflected by Figure 8. In summary, the V2V OBU improves the reaction of drivers and has a positive effect on safety, which was expressed by their less standard deviation of FD of phase 3 and less duration of the time from phase 1 to phase 2.

4. Conclusion and Future Work

The main aim of this study is to evaluate the impacts of the V2V system on drivers' driving behavior under different traffic conditions. An interoperability platform for driving simulator and the OBU was built to simulate the connected vehicle environment. Trajectory data of test car and surrounding vehicles were collected. The comparison study was conducted for four scenarios under different traffic conditions (free flow and synchronized flow) with and without the V2V system.

The indicators used for the analysis included driving speeds, acceleration noise, average number of lane-changes, and car-following distance. Average driving speeds of drivers when driving with the OBU were significantly higher compared to the case without the OBU under synchronized flow. Although average driving speeds of drivers when driving with the OBU were significantly lower compared to the case without the OBU under free flow, the speeding

Table 4: Distribution of vehicle and drivers operating data.

Car-following regime	With the OBU	Without the OBU
Duration of the time of phase 1 (s)	7.40	9.00
Duration of the time of phase 2 (s)	11.5	13.5
The range of FD of phase 2 (m)	150-78.58	150-77.82
Average FD of phase 3 (m)	66.43	52.45
The standard deviation of FD of phase 3	11.97	16.77

behavior was decreased, which means a positive impact on traffic safety. No statistically significant differences were found between scenario C and scenario D with respect to drivers' acceleration noise and average number of lane-changes. The results of the car-following analysis further support the above conclusion under synchronized flow. Moreover, results also show that the V2V system had a more positive impact on male drivers' driving behavior than female.

Overall, better driving performance could be achieved by providing the OBU. Because the V2V communications are supported by the OBU, more accurate information could be obtained to drivers. Moreover, the V2V system challenges the traditional role of drivers in operating vehicles. Thus, driver acceptance is essential for the application of new connected vehicle technologies into the transportation system. Future research could model the driver acceptance of the OBU. In addition, to achieve the integrity of the experimental data, driving simulator and field tests are needed to be coordinated. Finally, only ANOVA test were conducted to identify the impact of the OBU. It could make the conclusion more strengthened if the MANOVA and the random effects models could be estimated by collecting more data.

Data Availability

The data used to support the findings of this study are included within the article. Readers can access the data supporting the conclusions of the study by means of the driving simulator experiment. In this study, we designed a simulation platform of Connected Vehicle environment and readers can get more detailed information from our article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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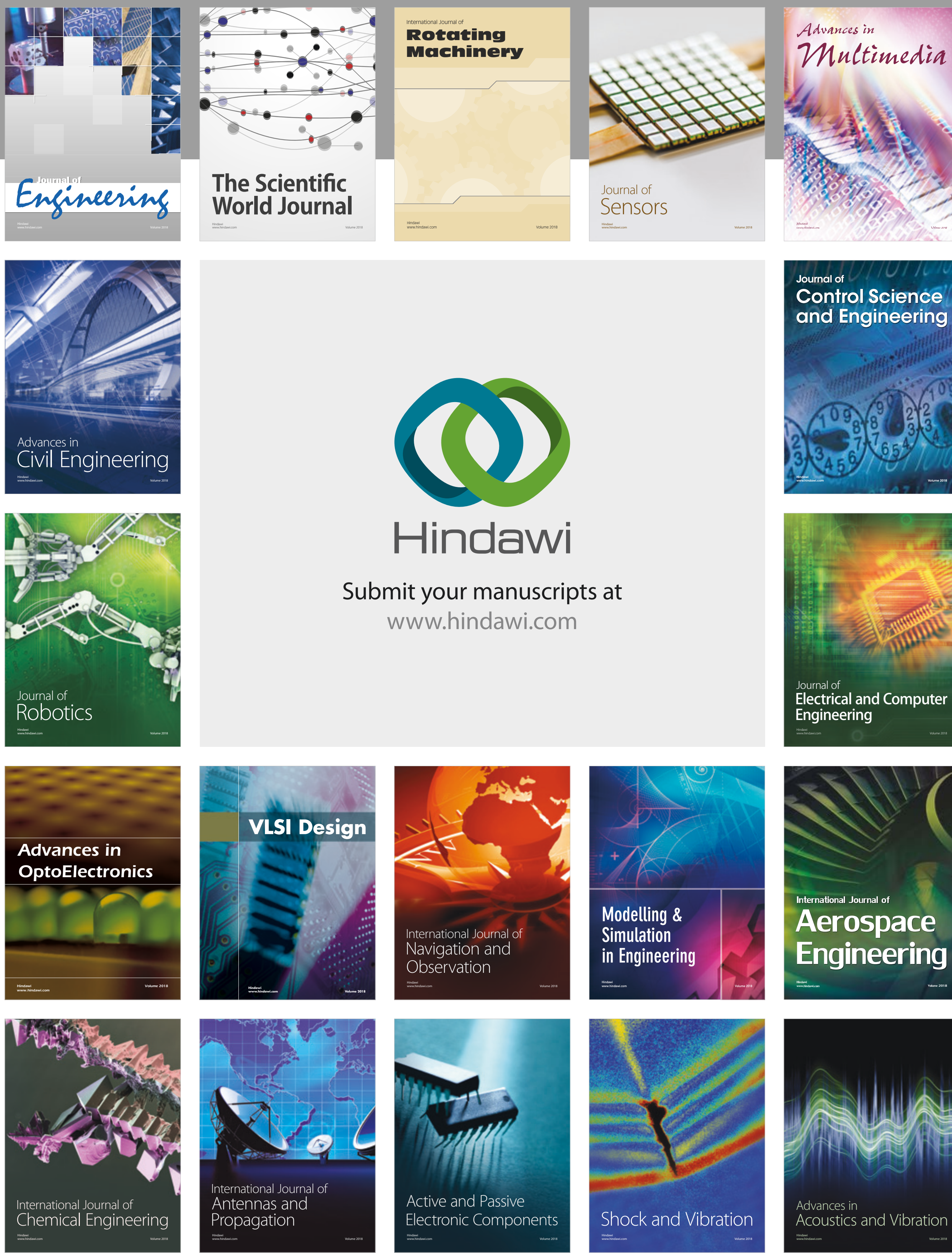
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