# Driving Secondary Task Load Quantification Based on the AHP Algorithm Under the Voice Interaction Scenario

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**Abstract.** With the rapid development of voice technology, Voice recognition technology has been bought into a large number of vehicle information systems, and different information from HMI displays during voice interaction will affect the driving status of drivers. In order to improve the interaction between the driver and the HMI (Human machine interaction) display to reduce driving distraction and to optimize the HMI information display, this study compared the difficulty of using the three common voice interaction interfaces based on voice interaction background and quantified the secondary task load generated by the voice interaction interface on the driver during driving. In this study, the indicators of head movement and the operation parameters of the vehicle during voice interaction are proposed to quantify the driving task load based on the hierarchical analysis method. To achieve the goal, 10 drivers are selected for driving simulation tests by using the UC-win/road driving simulator and head data acquisition software. During the test, every tester performs three-voice interaction tasks: map navigation, phone calls, and switching music. The results show that the proportion of driving load generated by the map navigation phone calling and switching music are 0.4898, 0.1992, and 0.311. Therefore, the HMI information display interface of map navigation and music switching needs to be simplified designed to reduce the presentation of redundant information. The study will provide a scientific basis for the voice interaction function of the HMI system and the information display design of the HMI interface.

**Keywords:** HMI character display · Voice interaction · Secondary task load · Hierarchical analysis · Interface information

## 1 Introduction

More frequent interactions between driver and vehicle-board information systems led to a high rate of traffic safety accidents 50% of Highway Administration NHTSA 2013 accidents are caused by the use of vehicle-board information systems when driving a vehicle [1]. Due to the high driving workload brought by the on-board voice task, the driver's attention to the main task is sometimes missing during the task time, and


Y. Bie et al. (Eds.): KES-STS 2022, SIST 304, pp. 11–21, 2022.
https://doi.org/10.1007/978-981-19-2813-0_2

cannot control the driving state of the vehicle in time [2]. Therefore, in the design and development of on-board information system, it is very necessary to determine the impact on driving safety when using common functions.

Actual road test: The driver performs a voice interaction task test on the actual road [3]. The biggest advantage of collecting the driver eye movement index and vehicle running state parameters from the voice interaction task during driving is the test results are real, but the cost and risk are high, and the reproducibility is poor, so the method can only conduct some simple test, in the more complex voice interaction task driving research, this method is generally not used [4].

Simple laboratory test: This kind of test refers to the simple laboratory configuration test without the simulation method [5], for example, using a computer to test traffic events on the computer screen. This has the advantages of simple cost and easy operation, but there is a large gap between the test and real driving, and the driving environment low the accuracy is low [6].

Simulation environment test: This kind of test uses a driving simulator with scenarios to simulate the real driving status. This method is adopted by most current studies, with the advantages of strong safety test design and easy test. Although the method is not as accurate as of the actual road test results, with the development of simulation technology, the driving simulator can give people the feeling of a real car [7]. And this kind of test can also reflect the actual driving status well, and it is easier to obtain all kinds of driver behavior and vehicle operation status parameters.

Considering the advantages and disadvantages of the above research methods, we choose the simulation environment test for the study.

Task 1: Control the on-board navigation device during driving. The Security Council of Canada, which in ref [8] is noted that in the process of destination information, the input information is less effective than the display of the information using sound control technology, the input or output information are transmitted through language, which can minimize the occupation of driver visual resources and reduce the impact on the driver's attention.

Task 2: Phone calling during driving: The task is mainly about the following conditions:1, telephone use type (contact and non-contact) 2, control method (sound control and touch control) 3, send receive messages and phone calling (different time length and different difficulty). Some previous research found that, in the above conditions during driving will damage impact the driver's reaction time and speed control, etc. Toernros et al. showed that phones are divided into handheld, and non-handheld phones, both non-handheld and handheld phones, which will have an impact on driving performance [9], The study of control mode by Ishida et al. showed that sound control mode can effectively reduce the impact of sub-task on driving performance [10]. Lesch et al. studied the use of the phone during driving, where the researchers asked the simple driver questions to answer the question accuracy as the evaluation criterion [11]. Horberry et al. found that the drivers need to think seriously or recall to record the content of the phone and send text messages, which will directly pose a threat to driving safety [12]. This study analyzed the effect of voice dialing on drivers.

Task 3: Listening to music during driving. The influence of such tasks on driving performance varies with the volume of music rhythm, and Schoemig derived from simulation trials of famous music students [13]. Different rhythms of music by taking up the driver attention space and increase the risk of traffic accidents, and the driver simulated driving speed, and speed estimates cause continuous impact within a certain range the faster the driver heart rate, the shorter the time the simulation driving time, the driver is prone to ignore the red light turn a blind eye to the zebra crossing driving error [14]. Oviedo's study showed that the higher the music decibel, the greater the stimulation to the driver, the greater the impact on driving performance [15]. The Mark study found that if the music rhythm is chosen properly and the volume is controlled at around decibels, it will help drivers relieve fatigue and shorten the response time in an emergency [16].

## 2 Voice-Based Interactive Driving Simulation Test

### 2.1 Design of Test

Driving simulation test | Map navigation interface

Call the phone interface | Music switch interface

**Fig. 1.** Driving simulation test and voice interaction interface information display

The test is based on UC-win/road software and a driving simulator. The selected simulator scene is urban road, speed limit:70 km/h. The front car in the simulator is set driven freely. The following rear car in the simulator is controlled by the driver(tester) with the steering wheel and brake pedal. In the premise of ensuring driving safety, the diver can drive freely. The HMI monitor is simulated with a tablet computer. For the position of the HMI in the car, we assume the center of the steering wheel as the coordinate origin, and use a laser rangefinder of mm level to measure the relative position of the HMI monitor, and fix the HMI monitor to the corresponding position of the simulator according to the actual measurement. At the beginning of the test, the driver needs to wear the sensor device which is used to record head movement indicator, and then begins the driving simulation. During the driving simulation, the tester sends voice commands to the HMI display at any time to act as the sequence of 1, to search for the near gas station according to map navigation. 2, Phone calling; 3, Switching music. The tester must ensure safe driving when searching for the targets in a quiet test environment without any other interruption. And after the test, the tester must complete the preservation of the driving simulator and head movement data after the test. Ten drivers (mean = 24.5, standard deviation = 4.2) with driving experience are selected to conduct the driving simulation test (Fig. 1).

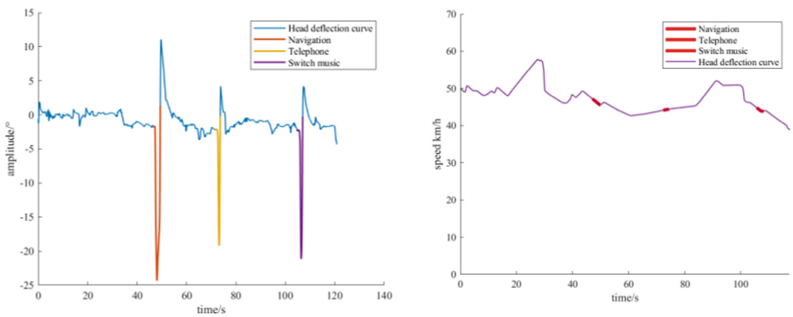
## 2.2 Test Index Collection

The relationship between head motion and the HMI display position is mainly reflected in the following two aspects, the first is the head motion time to search for the HMI task during driving, and the second is the amplitude of head motion. Head movement time determines whether the driver can drive safely, and the range of head movement determines the comfort of the driver's head.

The data of the driving simulator mainly reflects the driving performance of the driver. The head movement in the driving process affects the speed, the distance between the front and the rear, the time when the driver steps on the brake pedal, and the lateral control of the vehicle. And the simulator collects the data according to the above indicators: 1, the speed difference between the front and rear cars at the start and end of the head movement, 2, the distance between the front and rear cars at the start and end of the head movement, 3, the average value of the throttle opening and closing degree and 4, the lateral deviation of the vehicle during the head movement.

## 2.3 Test Data Processing

The obtained driving simulator data and head data were processed, and the results are shown in Fig. 2 and Fig. 3.




Head data processing Simulator data processing

**Fig. 2.** Head data matching and vehicle speed data matching

According to the head motion curve and driving simulator speed curve, the map navigation task of the driver has the largest amplitude and unstable speed control, the telephone task has the smallest amplitude and good vehicle control, the operation parameters of the music switching task are between the above two. The metrics extracted under the three Secondary tasks are shown in Tables 2, 3 and 4. Tables 2, 3 and 4 is to extract the driver's head deflection index and driving performance information (Table 1).

**Table 1.** Indicator encoding

| Name of index | Code | Name of index | Code |
|---|---|---|---|
| Head movement time | HMT/s | Start distance | SD/m |
| Head dynamic amplitude | HDA/° | End distance | ED/m |
| Speed difference at the beginning | SDB/km·h$^{-1}$ | Map navigation | MN |
| Speed difference at end | SDE/km·h$^{-1}$ | Make a call | MC |
| Average opening and closing degree of accelerator pedal | AOCD/$\omega$ | Music switching | MS |
| Standard deviation of vehicle yaw | SDVY/° | | |

**Table 2.** Map navigation data extraction

| Tester\Indicator | HMT | HDA | SDB | SDE | AOCD | SDVY | SD | SE |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.76 | 25.62 | 2.85 | 5.89 | 0.01 | 0.00 | 48.11 | 89.02 |
| 2 | 2.66 | 24.92 | 8.02 | 1.99 | 0.33 | 0.00 | 49.82 | 42.62 |
| 3 | 2.74 | 17.90 | 1.23 | 0.66 | 0.19 | 0.01 | 49.81 | 52.71 |
| 4 | 2.94 | 20.70 | 7.80 | 4.79 | 0.15 | 0.00 | 54.51 | 52.14 |
| 5 | 3.08 | 21.70 | 3.16 | 3.28 | 0.03 | 0.00 | 47.20 | 43.39 |
| 6 | 3.68 | 23.49 | 4.38 | 1.69 | 0.05 | 0.01 | 39.24 | 39.29 |
| 7 | 4.16 | 22.08 | 0.40 | 4.18 | 0.02 | 0.01 | 25.81 | 37.69 |
| 8 | 3.52 | 21.47 | 2.22 | 3.66 | 0.00 | 0.01 | 48.70 | 19.55 |
| 9 | 3.26 | 21.91 | 3.36 | 4.26 | 0.04 | 0.01 | 39.98 | 47.02 |
| 10 | 3.30 | 19.65 | 0.74 | 5.83 | 0.12 | 0.00 | 22.70 | 32.40 |

**Table 3.** Dial data extraction

| Tester\Indicator | HMT | HDA | SDB | SDE | AOCD | SDVY | SD | SE |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.02 | 18.95 | 5.25 | 4.46 | 0.12 | 0.01 | 111.35 | 50.98 |
| 2 | 2.76 | 18.30 | 1.37 | 4.82 | 0.17 | 0.00 | 55.82 | 54.94 |
| 3 | 1.56 | 20.58 | 0.98 | 0.24 | 0.20 | 0.00 | 34.59 | 50.37 |

(*continued*)

**Table 3.** (*continued*)

| Tester\Indicator | HMT | HDA | SDB | SDE | AOCD | SDVY | SD | SE |
|---|---|---|---|---|---|---|---|---|
| 4 | 1.92 | 16.11 | 2.72 | 7.18 | 0.08 | 0.01 | 61.32 | 60.84 |
| 5 | 1.74 | 20.56 | 5.01 | 4.48 | 0.09 | 0.00 | 38.86 | 50.58 |
| 6 | 1.48 | 21.09 | 0.62 | 5.60 | 0.12 | 0.00 | 30.23 | 44.42 |
| 7 | 1.86 | 20.63 | 1.33 | 2.71 | 0.04 | 0.00 | 46.31 | 27.75 |
| 8 | 2.72 | 11.24 | 0.18 | 4.25 | 0.02 | 0.00 | 44.38 | 51.84 |
| 9 | 1.72 | 18.53 | 1.83 | 4.82 | 0.21 | 0.01 | 31.48 | 43.91 |
| 10 | 2.40 | 20.16 | 2.15 | 0.50 | 0.21 | 0.01 | 21.58 | 22.54 |

**Table 4.** Switch for music data extraction

| Tester\Indicator | HMT | HDA | SDB | SDE | AOCD | SDVY | SD | SE |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.26 | 20.88 | 5.60 | 6.06 | 0.06 | 0.00 | 92.34 | 115.25 |
| 2 | 1.90 | 20.56 | 1.36 | 0.98 | 0.14 | 0.00 | 43.78 | 56.42 |
| 3 | 2.06 | 17.14 | 0.33 | 2.31 | 0.05 | 0.00 | 52.63 | 35.52 |
| 4 | 2.18 | 17.19 | 5.94 | 3.38 | 0.21 | 0.01 | 55.00 | 59.55 |
| 5 | 2.00 | 18.08 | 3.36 | 4.13 | 0.14 | 0.00 | 41.70 | 41.46 |
| 6 | 3.02 | 15.50 | 2.26 | 1.02 | 0.10 | 0.00 | 38.46 | 31.08 |
| 7 | 2.32 | 17.71 | 5.14 | 1.89 | 0.07 | 0.00 | 40.18 | 47.52 |
| 8 | 2.84 | 18.89 | 1.90 | 0.73 | 0.15 | 0.00 | 17.47 | 44.21 |
| 9 | 2.26 | 22.71 | 5.92 | 2.30 | 0.11 | 0.00 | 44.45 | 32.87 |
| 10 | 2.46 | 20.30 | 5.02 | 2.18 | 0.17 | 0.00 | 36.24 | 20.07 |

## 3 Model Construction

Analytic Hierarchy Process is the decision-making method that decomposes the elements related to decision-making into goals, guidelines, plans, etc., for qualitative and quantitative analysis. The proposed method has the advantages of systematization, flexibility, and simplicity. In this study, the degree of HMI display is evaluated by the head deflection index and driving performance index. The hierarchical analysis method meets the specific requirements of this study.

The process of creating a model via hierarchical analysis is as follows:

Step 1: Define the problem, determine the target;
Step 2: From the highest layer (target layer), through the middle layer (standard layer) to the lowest layer (scheme layer) to form a hierarchical structure model;
Step 3: Compare the scores to determine the score of the lower level to the upper level. Each standard layer does not necessarily have the same proportion with another. Each

of them has a certain proportion in the minds of decision makers. The scales 1–9 and their meanings are defined as Table 5: the judgment matrix.
Step 4: The hierarchical synthesis calculation;
Step 5: The consistency test.

**Table 5.** Judges the matrix scale definition

| Scale | Meanings |
|---|---|
| 1 | Compared with the two indicators, they have the same importance |
| 3 | The former of the two indicators is slightly more important than the latter |
| 5 | The former is obviously more important than the latter |
| 7 | The former is strongly more important than the latter |
| 9 | The former is extremely more important than the latter |
| 2, 4, 6, 8 | The median of the above-mentioned adjacent judgment |
| Count backward | If the importance ratio of the index $i$ to index $j$ is $a_{ij}$ then the importance ratio of the index $j$ to the index $i$ is $1/a_{ij}$ |

## 3.1 Build a Hierarchical Analysis Matrix

In order to analyze the difficulty of the interface of HMI display, the driver's workload is taken as the target layer. We selected eight standard layer indicators: head movement time, the head deflections, the speed difference of voice interaction, the standard deviation of the deviation, the mean of the vehicle accelerator pedal, the distance difference of voice interaction. Scheme layer selection: map navigation, making phone calls, and switching over music. According to the results of the test, the scale of each index is determined, and the scale matrix of the criterion layer and the significance layer is constructed (Fig. 3).

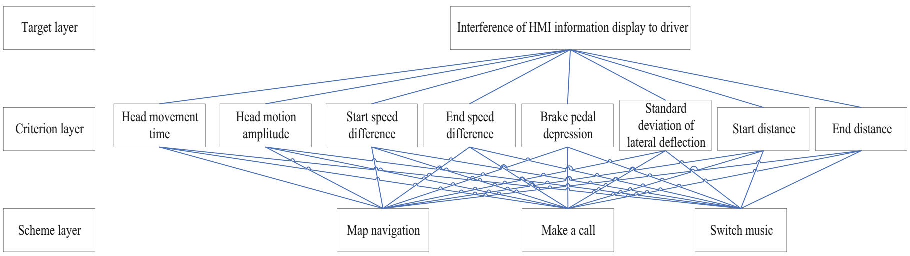



**Fig. 3.** Schematic diagram of the hierarchical analysis method structure

### 3.2 Calculate the Consistency Index CI

$$CI = \frac{\lambda_{max}}{n - 1} \quad (1)$$

where $CI$ is the consistency index, $\lambda_{max}$ is the maximum eigenvalue of the judgment matrix, and $n$ is the number of indicators at the level.

### 3.3 Find the Consistency Indicator RI

**Table 6.** Mean random consistency indicators

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.24 | 1.36 | 1.41 | 1.46 |

where the RI in the table is the mean random consistency index (Table 6).

### 3.4 Calculate the Consistency Ratio, CR

$$CR = \frac{CI}{RI} \quad (2)$$

where $CR$ is the consistency ratio, and when CR is less-than 0. 1, a one-time test is considered passed. Otherwise, some appropriate corrections should be made.

The second layer $CI$ calculation and one-time test result is $\lambda_{\max} = 8.5841$, $CI = 0.0834$, $CR = 0.0592$, $CR < 0.10$. The third layer of index CI calculation and one-time test results are as shown in Table 10. All the metrics shown in Table 7 passed the consistency test. Table 8 scaling matrix was determined based on the Table 2, 3 and 4 driver performance data and Table 5. The third layer scaling matrix is obtained based on the mean value comparison of different voice interaction tasks. The main principle of comparison is: When the scale value is large, then the influence on the driver's driving workload is large. The third layer of scaling matrix was obtained based on the principles of the interface impact on drivers and Table 5, as shown in Table 9.

**Table 7.** Calculation and one-time test of the third layer of consistency index *CI*

| Standard layer index | $\lambda_{\max}$ | CI | CR | Pass? |
|---|---|---|---|---|
| HMT | 3.0468 | 0.0234 | 0.0450 | Yes |
| HDA | 3.0536 | 0.0268 | 0.0516 | Yes |
| SDB | 3.0536 | 0.0268 | 0.0516 | Yes |
| SDE | 3.0536 | 0.0268 | 0.0516 | Yes |

(*continued*)

**Table 7.** (*continued*)

| Standard layer index | $\lambda_{max}$ | CI | CR | Pass? |
|---|---|---|---|---|
| AOCD | 3.0055 | 0.0028 | 0.0053 | Yes |
| SDVY | 3.0536 | 0.0268 | 0.0516 | Yes |
| SD | 3.0536 | 0.0268 | 0.0516 | Yes |
| ED | 3.0536 | 0.0268 | 0.0516 | Yes |

**Table 8.** The second layer of the scaling matrix

| | HMT | HDA | SDB | SDE | AOCD | SDVY | SD | ED |
|---|---|---|---|---|---|---|---|---|
| HMT | 1.0 | 2.0 | 2.0 | 3.0 | 0.2 | 0.2 | 2.0 | 2.0 |
| HDA | 0.5 | 1.0 | 4.0 | 4.0 | 0.2 | 0.2 | 2.0 | 2.0 |
| SDB | 0.5 | 0.3 | 1.0 | 1.0 | 0.3 | 0.2 | 1.0 | 1.0 |
| SDE | 0.3 | 0.3 | 1.0 | 1.0 | 0.3 | 0.2 | 1.0 | 1.0 |
| AOCD | 5.0 | 5.0 | 4.0 | 4.0 | 1.0 | 0.3 | 5.0 | 5.0 |
| SDVY | 5.0 | 5.0 | 5.0 | 5.0 | 4.0 | 1.0 | 5.0 | 5.0 |
| SD | 0.5 | 0.5 | 1.0 | 1.0 | 0.2 | 0.2 | 1.0 | 1.0 |
| ED | 0.5 | 0.5 | 1.0 | 1.0 | 0.2 | 0.2 | 1.0 | 1.0 |

**Table 9.** The third layer of the scaling matrix(part)

| Metric 1 | | | | Metric 2 | | | |
|---|---|---|---|---|---|---|---|
| HMT | MN | MC | MS | HDA | MN | MC | MS |
| MN | 1 | 3 | 3 | MN | 1 | 2 | 2 |
| MC | 0.33 | 1 | 0.5 | MC | 0.5 | 1 | 0.5 |
| MS | 0.33 | 2 | 1 | MS | 0.5 | 2 | 1 |

## 3.5 Weight Calculation

$$W_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}, i = 1, 2, \ldots, n \tag{3}$$

where $W_i$ is the weight value, $n$ is the number of metrics in the corresponding scaling matrix, and $a_{ij}$ is the scaling value of column $j$, row $i$ of the scaling matrix. Combining the scaling matrix Tables 8 and 9 and formula 3, the calculated degree of influence to different interfaces on the driver, as shown in Table 10.

According to the results of the hierarchical analysis method, the HMI interface of map navigation is the most difficult, with the largest Secondary task load to the driver. The

HMI information of the music playback interface is the least difficult, and the secondary task load to the driver is small. It shows that in the case of HMI voice interface design, the navigation interface design information is too much, and the driver's workload will increase when the driver acts voice interaction and observes the interaction effect. When optimizing the design, the unnecessary information display should be reduced to reduce the load of the driver voice interaction.

**Table 10.** Weight calculation of index level analysis

| Weight | HMT | HDA | SDB | SDE | AOCD | SDVY | SD | SE | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.101 | 0.107 | 0.049 | 0.047 | 0.243 | 0.354 | 0.050 | 0.050 | Weight |
| MN | 0.590 | 0.491 | 0.312 | 0.198 | 0.539 | 0.491 | 0.491 | 0.491 | 0.490 |
| MC | 0.159 | 0.198 | 0.198 | 0.491 | 0.163 | 0.198 | 0.198 | 0.198 | 0.199 |
| MS | 0.252 | 0.312 | 0.491 | 0.312 | 0.297 | 0.312 | 0.312 | 0.312 | 0.311 |

## 4 Conclusions

We analyze the relationship between the head data of the testers and the operating parameter data of the simulated vehicle. The hierarchical analysis method is also used to quantify the driving load from the map navigation, phone call, and music switching interface of the voice interaction, and the scale judgment matrix is constructed according to the influence relationship between the head movement and the driving simulator. Finally, the Secondary task load results are calculated at different interfaces with the arithmetic average weight calculation method, and this makes us achieve the value of Secondary task load degree quantification. The calculation results show that among the three voice interaction interfaces, the map navigation interface is 0.4898, the caller is 0.1992, and switching music is 0.311. This indicates that the map navigation interface should be appropriately simplified to reduce the impact on the driver.

In later studies, other forms of voice interaction tasks or other forms of driving Secondary tasks can be analyzed, And further study can comprehensively improve the voice interaction system and reduce the workload generated by the voice interaction interface on drivers.

**Acknowledgements.** This study was supported by the National Key R&D Program of China under Grant (No. 2018YFB1600501), National Natural Science Foundation of China under Grant (No. 71971097), and Youth Program of National Natural Science Foundation of China (No. 52002143).

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