Simulator-Based Mental Workload Assessment of the In-Vehicle Navigation System Driver Using Revision of NASA-TLX*

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항법장치 simulator기반의 RNASA-TLX를 이용한 항법장치 운전자 mental workload 평가에 관한 연구

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〈Abstract〉

In developing the HMI(Human-Machine Interface) evaluation system for the IVNS(In-Vehicle Navigation System), design guidelines and evaluation methods are the most crucial problems for its use and efficiency. As the part of this system, focused on the final product of the database, subjective mental workload assessment is seriously considered to evaluate the driver's own driving task using the IVNS. This paper suggests the methodology for the ergonomic assessment of the IVNS that corresponds to the subjective measurement of the driver's mental workload by rating his or her own driving task. For this approach, Revision of NASA-Task Load Index(RNASA-TLX) was developed which translated and revised the version of NASA-TLX that is generally accepted an efficient and powerful method for evaluating the in-vehicle information systems. To verify the RNASA-TLX, an experiment was conducted in a real road situation, because the result of the laboratory approach is uncertain and has the differences from the real road test.

1. INTRODUCTION

When an IVNS was introduced into a vehicle, the driver was faced with the 'resource competition' what Wickens(1980) first referred between the visual demands of the in-vehicle display and the external driving scene [2].

Therefore, most reported evaluations of route guidance or navigation systems have used field trial data, and the evaluation have been limited to capture the driver's eye glance, in terms of direction, frequency and duration as the ergonomic evaluation parameters [11]. These kinds of ergonomic parameters for evaluating the visual strategies are the important criteria in order to define the potential consequences of the disturbance of the driving task. However, they are not the sufficient

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criteria for assessing the usability and the support of the functions offered by the system and do not give information about the actual driver's mental workload [12]. Moreover, because human beings are usually very adaptable to the new situations, it is very difficult to analyze the IVNS ergonomic characteristics by simple stimulus-response types of approaches. However, both subjective and objective methods are complementary, rather than conflict one from another. They are also time and cost consuming. Also, because of the complexity of the application situations and the inter-individual variability of the driver, it is certainly valuable to have an evaluation process as complete as possible.

2. THEORETICAL BACKGRAOUND

2.1 Mental Workload and Other Assessment Techniques for an IVNS

Although there is no universally accepted definition of the mental workload, the basic notion is related to the difference between the amount of resources available within a person and the amount of resources demanded by the task situation. Therefore, mental workload can be changed by altering either the amount of resources available within the person or the demands made by the task on the person for the assessment [8]. Another well admitted definition considers that the mental workload is the ratio of the task demands to the average of the maximal capacity of each individual. It must be noted that the individual maximal ability is variable. Generally, as task demands increase, so does the mental workload [12]. The purposes of mental workload assessment of the IVNS are as follows [5].

① Allocating functions and tasks between the IVNS and the driver based on the predicted mental workload.

② Comparing alternative component, format or the task designs in terms of the workloads imposed (for example, the color, the modality, the typography of the display, information structure and so on).

③ Monitoring the IVNS driver to adapt the task difficulty in response to increase and decrease in mental workload.

④ Estimating the system usability and safety of the driver.

Until now, in order to measure the driver's workload of the IVNS, several approaches have been used like below.

(1) Measurements of the physiological parameters

Several measures are primarily sensitive to workload upon specific processing resources(e.g., event-related potentials), whereas others(e.g., pupil diameter and heart rate variability) seem to index overall mental workload (Karmer, Sirevaag, & Braune,1987; Roscoe,1987; Wickens, 1984). Unfortunately, physiological measurements are sensitive to artifacts such as physical, workload, noise, and emotion-induced effects(Roscoe, 1987 ; Sanders, 1987). Also, these measurements are fairly intrusive and subject to large inter-individual differences. The advantage is that they are usually applicable without interfering directly with the task [10]. However, this method is considered quite disappointing nowadays and is a heavy methodology to evaluate the driver's mental workload in a real road situation [12].

(2) Method of the dual task

The principle of this method is to evaluate the availability of the individual capacity to realize a supplementary task to the primary one. Also, this method assumes that an increase in workload on the primary task can be indicated by the level of performance on the secondary lower priority task [13]. The workload is importantly considered when the available capacity is poor. This method is typically considered a laboratory approach, taking into account the consequences in terms of interference in a real situation. Furthermore, the driving with an IVNS is already a dual task : adding a supplementary task raises questions about the driver choice in terms of priority, which task is considered the main one [12].

(3) Formalizing the driver's judgment

This method formalizes the driver's own judgment about the workload he or she experienced. Therefore, these kinds of techniques are relatively easy to implement and tend to be accepted by operators. This approach is rather 'subjective,' such as SWAT(Subjective Workload Assessment Technique), NASA-TLX, etc. Considering the characteristics of the scales, NASA-TLX seems the best predictor of subjective workload, whereas SWAT is better as a cognitive model [13]. Results using SWAT and NASA-TLX have been similar, but NASA-TLX yields more consistent scores among people doing the same task [8].

These kinds of data collection tools must be considered as an evaluation rather than a measurement. So these are global, even crude criteria, and able to detect only important phenomenon and this approach has to be conducted in addition to other objective measures such as the performance. The use of these multidimensional approaches of the mental workload allows typically relative comparison between the situation and the system [12].

2.2 NASA-TLX

The NASA-TLX, first developed by the U.S. Army, has been used on board samples of people in various situations(Hart and Staveland, 1989), and more recently, in the driving environment(Alm and Nilson, 1990; Jordan and Johnson, 1991). After comparison among various existing tools, NASA-TLX has been considered superior in terms of sensitivity and well accepted by the operator [12][13]. In these days, the interesting of this method has increased to evaluate the mental workload of various in-vehicle information systems, for example, RDS-TMC(Radio Data System-Traffic Message Channel), CMS(Changeable Message Sings), ARS(Automatic Response System), etc. [2][7][9][12][18]. Moreover, Shinji Miyake tried to measure the line workers' mental workload through this method [15].

This method assumes that the workload is influenced by various factors such as *the mental demand, the physical demand, the temporal demand, the performance, the frustration level* and *the effort*. These scales were selected from a larger set on the basis of research that showed each scale to make a relatively unique contribution to the subjective impression of workload [13]. After assessing the magnitude of each factor on six scales, the individual performs pairwise comparisons among the six scales, in order to determine the higher source of workload factor of each pair. A composite note qualifying the level of workload is developed by using both the scales rating and the relative weights computed from the comparison phase. An weighted workload is so computed for each cited scale and for a global score [9]. Table 1 shows the six scales of the NASA-TLX [13].

3. EXPERIMENT

All of cases, the IVNS must provide the driver with the simple and compatible information as much as possible for reducing workload and for acquiring road safety [5]. This experiment has been conducted to test the NASA-TLX and to verify the developed RNASA-TLX by comparing the widely used modalities, visual only vs. visual and auditory combination type. This kind of research had been widely performed at the IVNS

〈Table 1〉 Six Scales of NASA-TLX

TITLE	DESCRIPTION
Mental demand	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical demand	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal demand	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration level	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

development step. Therefore, the result is clear that the visual and auditory modality requires the lower mental workload than the visual only type modality [11][16][17].

Fourteen male graduate and undergraduate students were recruited for this experiment. The mean age was 27.7 years old(range = 22 to 32 and standard deviation = 1.3). They had no physical or experience-related problems in driving with 3.1 mean years of driving experience. Two kinds of direction instructions were presented from a Pentium 90 portable PC equipped with 90W external speaker. This simulator was the static route guidance system type with 2D sample target area digital map, but the communication constraint existed between vehicle and simulator. Therefore, the speed was limited around 40km/h for the driver's safety.

An experiment vehicle was driven around Ajou university. First, NASA-TLX evaluation session was conducted with 5 subjects. However, because of the inappropriateness and not significant of the result, RNASA-TLX was developed and the evaluation session was conducted again. For the more accurate results of two sessions, the training session was conducted about NASA-TLX, RNASA-TLX and about the driving using the simulator until they completely understood just before driving. Also, subjects were requested to remember the experimental driving situations, NASA-TLX and RNASA-TLX six factors. The tasks took about 15 minutes for each information modality. The driving routes of each experiment had not known to the subjects.

During the driving task, visual and auditory information was presented before 20m of intersection and this information was maintained until arriving his way of intersection - the subjects already knew these conditions before experiment.

In case of testing the visual and auditory modality, the auditory information presented around 0.5 second before the visual presentation. The subjects were free to see the IVNS simulator whenever they wanted. Also, they were free to operate the other in-vehicle devices - audio, wiper, air-conditioner, and so on. For more accuracy and reality of the experiment, the experimenter should prepare the efficient pre-experiment route driving to determine the sites of information presentation.

4. DEVELOPMENT OF RNASA-TLX

4.1 Demerits of NASA-TLX

The mental workload which is multi-dimensional and it depends upon the type of task. Therefore, the main difficulty for this type of investigation lies in a good understanding of the meanings of suggesting scales [5]. In executing the NASA-TLX experiment session, despite of a detailed explanation and a training session before experiment, subjects had the problems in understanding and rating the original NASA-TLX six scales. During evaluation session, most of subjects complained that the words that described the scales were so difficult to understand and rate. It is because most of scales were consisted of technical, vague, and unfamiliar words for the common driver. Actually, the six scales do not contain any word that is related to the target evaluation system, such as component name, operation-related, and information receiving organ etc. It means that the six scales should reflect the vehicle and the driving situation with driving environment when using an IVNS. Therefore, well defined and clear meanings of words were required to implement this experiment successfully.

Also, through the past and literature study, several problems were identified to implement the NASA-TLX for the mental workload evaluation in driving when using an IVNS by Annie and Anne [12].

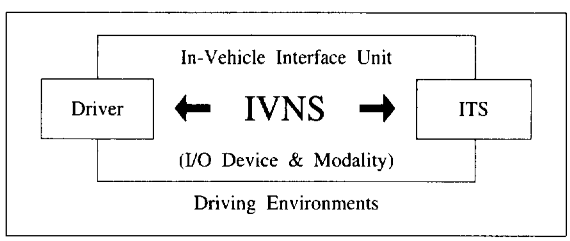
One of the scales, *the physical demand* is usually defined in the following terms : How much physical activity was required(e.g., pushing, pulling, turning, controlling, activating, etc.)? It appears that this question would not be relevant when considering the driving activity where the physical component corresponding to the control of the vehicle is quite automatic for an experienced driver, and where maneuvers are not supposed to be physically demanding during the experiment sessions.

Another one is *the mental demand* described in following terms : "How much mental and perceptual activity was required - thinking, deciding, calculating, remembering, looking, searching." This statement recovers both perceptive and cognitive aspects of the workload. It seems that the scale would be interesting in the context of the driving task to identify these various driver's activities.

Finally, the evaluation of *the performance* scale can be done by gathering objective data(vehicle trajectory, errors, speed, headway distribution, etc.). The subjective rating of a good performance by the driver can present discrepancies with the measured one, but these differences could be due to many other factors than the mental workload itself.

4.2 Development of RNASA-TLX

To correct the disadvantages of the NASA-TLX, IVNS interface model and the product analyses were conducted. Through these investigations, all components of the IVNS that could affect on the driver's mental workload were examined. Considering the human-vehicle-road system in a real driving situation, HMI model can be defined conceptually like ⟨Figure 1⟩. It deals with a four-dimensional space at the HMI point of view : driving environment, driver characteristics, IVNS(Input / Output Device & Modality), and ITS



⟨Figure 1⟩ Conceptual HMI Model of Navigation Using IVNS

(Intelligent Transportation System) [4][6].

〈Table 2〉 Six Scales of RNASA-TLX

TITLE	DESCRIPTION
Mental demand	How much mental attention was needed during driving when using an IVNS? Namely, how much mental stress was required during driving via an IVNS : to keep the lane, to avoid the collision, to observe the traffic law, and so other things which related to driving activity.
Visual demand	How much visual activity was required during driving when using an IVNS to recognize the information from an IVNS or other external information sources? For example, digital map and its information and the traffic signal, back mirror, beacon and so other external information sources.
Auditory demand	How much auditory activity was required during driving when using an IVNS to recognize or hear the information presented from an IVNS or other auditory sources?
Temporal demand	How much time pressure was required due to rate or pace at the task elements occurred during driving using an IVNS? For example, in operating or menu selecting process, and information presentation pace or speed.
Difficulty in driving	How hard you driving when using an IVNS with other in-vehicle control equipment or optional devices. For example, car-phone, stick, side break, audio and so on?
Difficulty in understanding information	How hard you understanding information presented from an IVNS? Was the information from an IVNS compatible with your association? Was the mass, density? And other information related factors are suitable for you?

In this model, an IVNS interfaces between the driver and overall ITS that is not yet completely installed. Therefore, the only in-vehicle interface unit is considered to revise the NASA-TLX. In the near future, the IVNS will function as the information provider of the traffic and the other supplementary information in a vehicle.

Supplementary function includes the road side services, the personal digital assistance function, and the entertainment function etc. All of these functions should be supplied whenever the driver needs in the various modalities.

During driving task, the driver gets about 80% of information by his or her visual activities. Moreover, when navigating an IVNS, auditory related factors are also critical factors, because many kinds of information are presented by the auditory modality surrounded with the roadside noises. Therefore, the visual and auditory related factors directly influence on the driver's behavior and road safety. Also, these days, the route for the destination is generally selected by the telephone number, the menu or the driver's voice.

The RNASA-TLX is designed seriously considering these kinds of real situations. Therefore, the main interface modalities, visual and auditory factors were definitely considered. In addition, user-friendly and user-requirement information characteristic was seriously considered because the IVNS information directly influences the driver's behavior. Namely, too much information or the complex information burdens the driver with the mental workload. As the results, RNASA-TLX six scales were designed with *the mental demand, the visual demand, the auditory demand, the temporal demand, the difficulty in driving* and *the difficulty in understanding information*. Except *the mental demand* and *the temporal demand* of the original NASA-TLX, other scales were changed to *the visual demand, the auditory demand, the difficulty in driving* and *the difficulty in understanding information*.

In addition to the changed scales, contexts of six scales were also changed more distinctly to minimize the correlation among six scales for better understanding of the subjects and clear result. In this version, six scales include the all kinds of the mental workload sources of the IVNS and take the useful aspects of the NASA-TLX. For example, *the mental demand* includes the overall mental workload of navigating with the IVNS. However, it contains *the performance* related factors of driving of the original NASA-TLX without any objective data. *The temporal demand* scale contains the all kinds of factors that have the possibility to occur the temporal demand. Also, *difficulty in driving* describes the detailed vehicle-related equipment. Moreover, other scales contain the visual, auditory, and information-related factors to cover the all kinds of mental workload sources of the IVNS.

〈Table 2〉 suggests the detailed descriptions of RNASA-TLX.

5. EXPERIMENT RESULT & ANALYSIS

RNASA-TLX questionnaires were given just after the completion of the two kinds of modality comparison experiments. In this version of RNASA-TLX, the scale proposed does not present a graduation so as to avoid over-directing the subjects. RNASA-TLX that suggested in this paper has three steps of procedures like the original NASA-TLX.

5.1 Step 1 : Rating six factors by subjects

Subjects were asked to rating the RNASA-TLX six scales. A value of 0 corresponds to low perceived workload, whereas 100 corresponds to high perceived workload in the questionnaire.

5.2 Step 2 : Assessment of the importance of six scales by pairwise comparison

They were then asked to complete the pairwise comparisons of these factors. The total number of 15 pairwise comparisons were conducted by each subject for each modality experiment. For this approach, the nine point scales was used which suggested by Saaty [14]. This nine point scales widely used in many applications allows the respondents to express their preferences among options as equally, moderately, strongly, very strongly, or extremely preferred. These preferences are translated into pairwise weights of 1, 3, 5, 7, or 9, respectively, with 2, 4, 6, and 8 as intermediate values[14][19]. Also, Saaty's rule of thumb is that the Consistency Ratio(CR) should be less than 0.10 for acceptable results. When judgments are inconsistent, the decision maker should be given the opportunity to revise the pairwise comparisons [14]. By pairwise comparison of 6 scales, subjects rated *the visual demand*(0.325228) was the highest mental workload source of the visual information type. After that *the mental demand*(0.254339), *the difficulty in driving* (0.140388), *the temporal demand*(0.111386), *the difficulty in understanding information*(0.092824) and *the auditory demands*(0.075835) were followed. However, in this experiment session, 5 subject's CR values were above 0.1, they had to conducted pairwise comparisons until the values were valid.

Then, for the visual and auditory combination type modality, the highest ranked scale was *the auditory demand*(0.262518), and *the mental demand*(0.257249), *the difficulty in understanding information*(0.175813), *the temporal demand*(0.127138), *the visual demand* (0.115998) and *the difficulty in driving* (0.061285) were followed. Also 8 respondent's CR values were above 0.1, so these respondents had conducted pairwise comparisons until the values were valid.

5.3 Step 3 : Real weight of each scales for revealed the weighted workload scores

This was computed by multiplying each rating by the weight according to a scale by the subjects.

⟨Table 3⟩ shows the average weighted workload scores and global score of RNASA-TLX. It shows that the visual and auditory combination modality required lower global weighted workload. Looking at the differences of six factors in detail, this modality required higher mental workload only at *the auditory demand.*

⟨Table 3⟩ The Weighted Workload Scores and Global Score of RNASA-TLX

RNASA-TLX Six Scales	Visual	Visual & Auditory
1. Mental demand	14.49	5.34
2. Visual demand	8.24	6.83
3. Auditory demand	3.93	12.66
4. Temporal demand	25.69	2.70
5. Difficulty in driving	5.47	4.04
6. Difficulty in under -standing information	5.60	2.40
7. Global weighted score	10.57	5.66

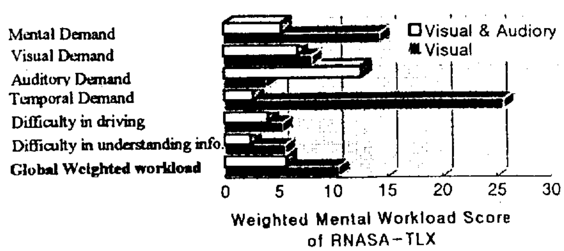
⟨Table 4⟩ The Weighted Workload Scores and Global Score of an Original NASA-TLX

NASA-TLX Six Scales	Visual	Visual & Auditory
1. Mental demand	5.29	4.87
2. Physical demand	5.61	6.69
3. Temporal demand	9.11	4.41
4. Performance	11.09	7.74
5. Effort	3.56	5.25
6. Frustration level	3.56	4.83
7. Global weighted score	6.37	5.63

The visual only type obtained the higher workload in terms of *the mental demand, the visual demand, the temporal demand, the difficulty in driving,* and *the difficulty in understanding information.*

The overall weighted mental workloads between two modalities are significant (p=0.05) by Wilcoxon signed-rank test(statistics is W=21 when the sample sizes are 14). This result shows an overall decreased weighted workload with the visual and auditory combination information multimodality.

Also, as shown in ⟨Table 4⟩, the result of the original NASA-TLX was unreasonable comparing with the previous research [11][16][17]. Except *the temporal demand* and *the performance*, other scales were not significant between two modalities(p=0.05). Figure 2 shows the result of the experiment using the RNASA-TLX through the graph.



⟨Figure 2⟩ The Result of RNASA-TLX Weighted Workload

6. CONCLUSIONS

As shown by this research, successful implementation of mental workload evaluation mainly depends upon the good understanding of the precise meaning of scales by subjects. If titles and descriptions of scales were properly revised, NASA-TLX will be more powerful and effective to reveal the main mental workload sources of various in-vehicle information systems. Therefore, RNA-SA-TLX will be available for evaluating the other in-vehicle information systems that have similar HMI patterns with IVNS for example, HUD(Head-Up Display), RDS-TMC, CMS etc.

However, despite of the convenience of analysis procedure and derivation of main mental workload sources, there exists the defect of NASA-TLX. This method could not reveal the main factors which influence on each predetermined 6 mental workload sources, for example, typography, color, information density, and so on, because this kind of study needs time and cost consuming experiments with various groups of drivers. Also, a problem of visual and auditory combination modality was revealed by experiment. When the vehicle running the near construction fields or other noisy areas, there is a possibility to confuse or to misunderstand the instructions from IVNS. For this reason, most of subjects wanted to auditory options about the characteristics of voice, age, gender and tone. Namely, if possible, IVNS should have the alternative voices to reflect the driver's own ergonomic characteristics and preferences.

With the advance of in-vehicle information systems, HMI problems of these systems are regarded as critical and important issues for the success of ITS, because it directly related to the driver and road safety. Hereby, with increasing interest of the HMI research and standard of advanced countries, IVNS HMI problems is considered as the new paradigm of interface engineering. Therefore, this research could be applied for the development of HMI guidelines and IVNS HMI standard as the basic research.

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