
Development of a Steering Entropy Method for Evaluating Driver Workload

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ABSTRACT

The authors have developed a steering entropy method to easily and accurately quantify the workload imposed on drivers who are engaged in activities apart from the normal driving operations of longitudinal and lateral control. A driver's steering behavior tends to become more discontinuous while performing an activity in addition to driving. To quantify these discontinuities, steering entropy values are obtained from a time-series history of steering angle data. A special-purpose driving simulator and a test procedure have been developed that allow workload evaluations to be conducted efficiently. The simulator and test procedure were used to evaluate the additional workload incurred by 14 different types of activities. The steering entropy results were compared with a dual task method as well as a subjective evaluation method. These results showed a high degree of correlation between the three approaches, which confirmed the validity of the steering entropy method as a means to quantify workload. Measurements were then made of progressively more difficult tasks. It was found that the steering entropy values increased in direct proportion to the degree of (subjective) task difficulty, which corroborated the high measurement accuracy of this method.

INTRODUCTION

Accompanying the penetration of car navigation systems, cellular phones and now on-board Intelligent Transportation System (ITS) devices, society has begun to question whether it is safe to operate the controls of such equipment or to talk on the telephone while driving. In commercializing ITS equipment, development engineers must accurately identify how large a workload the operation of such devices imposes on drivers, and factor that information into the development of equipment that requires minimal involvement from the driver.

There is a need to be able to ascertain accurately and easily the workload imposed on drivers by the operation

of such equipment. Accuracy is, of course, a necessity. Simple and easy-to-use evaluation tools are required because of the rapid pace of technological innovation in on-board ITS devices and the tendency for new products to be developed at short intervals. Assuming that the driver's workload would be measured every time a new device is developed, the measurement procedure must be simple and easy to apply. Against this backdrop, the steering entropy method is proposed as a procedure that enables the driver's workload to be measured accurately and easily.

LIMITATIONS OF CONVENTIONAL METHODS

The objective of this research was to establish a method that would make it possible to quantify accurately and easily the additional workload imposed on drivers by any activity other than the action of driving. Activities other than driving here refer to, for example, talking on a cellular phone, thinking, dozing, checking instrument panel meters and gauges or information presented on a dashboard display, and operating the control switches of a navigation system, air conditioning system, cellular phone or some other device.

Before explaining the steering entropy method, some well-known workload quantification methods will first be examined to see how well they accomplish the objective of this research. The methods considered here are the dual task method, the measurement of a physiological signal and the subjective evaluation method [1. de Waard 96; 2. Salvendy 97].

DUAL TASK METHOD – With the dual task method, a subject is asked to perform two tasks simultaneously, the task of interest and a task to be measured. The extent to which the latter task is accomplished is used as the measurement index. A typical procedure is to illuminate a light at random intervals while the subject is performing the measured task. The subject is instructed to push a switch as soon as he notices the illuminated light. The

time from the illumination of the light until the subject pushes the switch is measured. This measured reaction time is used as an index of the workload. The lighter the task is, the shorter the reaction time becomes and vice versa.

What are the limitations of the dual task method with respect to the criteria of accuracy and ease-of-use? First of all, the method lacks fine sensitivity because the measured task itself imposes a workload. By way of example, this is analogous to the fact that it is difficult to measure an extremely small current with an amp-meter because the amp-meter itself consumes electricity in the process of measuring the current. Another problem with the dual task method is that the measured data are subject to variation because of the instantaneous manner in which the workload is measured at the sampling point. As shown in Figure 1, even though the load is the same, the difference in measurement timing results in the large measured value at the left or in the small measured value at the right. Consequently, in order to improve accuracy, it would be necessary to increase and randomize the measurement frequency, which artificially increases workload even more. One could also increase trial durations or the number of trials or the number of test subjects but this results in more expensive and time consuming evaluation procedures.

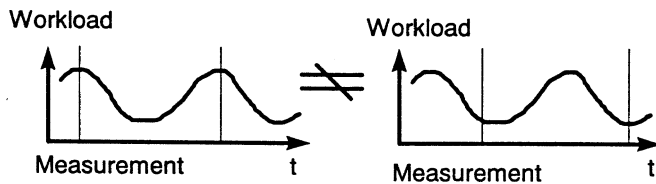


Figure 1. Limitation of the Dual Task Method

MEASUREMENT OF PHYSIOLOGICAL SIGNAL – The measurement of a physiological signal involves measuring the change in some physiological phenomenon. The change induced by the imposition of a task on a subject is detected and used to quantify the workload. Typical physiological phenomena that are measured are eye movement, pulse rate, and brain waves, among others.

What are the limitations of this approach with regard to accuracy and ease-of-use? One problem is that special equipment is needed for measuring physiological phenomena, such as an eye camera, an electrocardiograph or an instrument for measuring brain waves. Analyzing the data thus acquired also takes considerable time and effort. A further limitation is that it is difficult to make accurate judgments because the causal relationship between the task and the physiological change is usually not clear.

SUBJECTIVE EVALUATION METHOD – With the subjective evaluation method, test subjects are asked to evaluate the degree of difficulty of a task by ranking it on a multi-point scale. If their assessments were completely unbiased, this method might be the best approach with respect to ease of use and accuracy. However, if the subjects have a preconceived notion that a task is difficult,

they will rank it on the difficult side. Conversely, if they have the preconception that a task should be easy, they will assign a score on the easy side. Since such preconceptions depend entirely upon the subjective judgment of the test subjects, it is impossible to eliminate their influence. Therefore, the measurement system itself would always contain the possibility that accuracy might be compromised.

PRINCIPLE OF STEERING ENTROPY

With the steering entropy method, the workload is calculated directly from the driver's steering behavior. It measures the effect of additional activities on a driver's behavior by quantifying their effect on the steering profile in terms of its predictability. It differs fundamentally from the above-mentioned indirect procedures in that the driver's normal behavior is not affected and that the driver need not be aware of the fact that he/she is being monitored. In our approach the experienced workload is directly linked to the driver's smoothness of control. In that respect, it operates on a different dimension than the indirect measures of workload. It directly quantifies how driving behavior is affected rather than how other aspects of the driver's behavior or how physiological or mental state are affected. As will be exemplified below, steering predictability decreases as drivers interject more error corrective maneuvers. The frequency and magnitude of these steering corrections increases as more attention lapses of varying duration are expended in order to perform an activity. During these attention lapses, driving performance gradually deteriorates which drivers subsequently respond to by interjecting corrective maneuvers.

The following is an explanation of the principle of steering entropy. While operating a vehicle, drivers are constantly estimating the situation ahead and unconsciously apply smooth steering control. Smooth can be understood here to mean turning the steering wheel a little at a time or in small increments. For instance, consider a situation where a vehicle that is traveling straight ahead enters a curve. Before starting to corner, the driver already begins to turn the steering wheel a little at a time so as to obtain the optimum steering angle relative to the road's curvature at the moment the vehicle enters the curve. When driving on a continuous straight stretch of road, the driver also turns the steering wheel in small increments so as to keep the vehicle traveling straight ahead. In this way, the driver corrects slight lateral deviations of the vehicle caused by ruts in the road or imbalances between the right and left wheels.

Consider a situation in which the driver performs some activity apart from driving. During that interval, the activity distracts the driver's attention and/or eyes from the driving task. As a result, the driver is unable to monitor the environment effectively and the vehicle deviates to some degree from the intended path. Upon completion of the activity, the driver's attention and/or eyes again return to the driving task. At that point, realizing that the vehicle has deviated from the intended path, the driver executes

a corrective steering maneuver more quickly than usual because the perceived deviation is unexpected or greater than those experienced during fully attentive driving. In general, under a no-workload condition, the driver steers smoothly because of the anticipatory nature of preview control. However, when some activity is performed which imposes a workload on the driver, the smoothness of his steering behavior is lost to a certain extent. In the steering entropy method, we define "extent" more rigorously. Its magnitude can be regarded as a result of two factors. One is the time expended on the activity and the other is the degree of attention devoted to it.

Figure 2 shows time-series histories of steering angle data that were recorded when a test subject drove on the same course. The upper graph is the history without any additional workload and the lower graph is the history when a workload incurring mental arithmetic was imposed on the subject. Compared with the upper graph, the lower graph shows irregular, discontinuous steering behavior that lacks smoothness. In other words, it indicates a lower level of order, i.e., a state of higher entropy, than the upper graph.

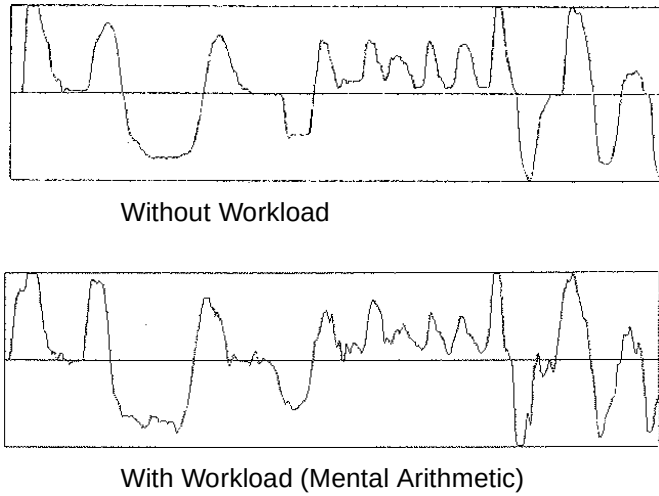


Figure 2. Comparison of Time-Series Histories of Steering Angle Data With and Without an Activity Apart from Driving

THEORY OF STEERING ENTROPY

This section explains the procedure for calculating steering entropy (H_p). First, the test subject is asked to drive a certain course under a no-workload (zero-activity) condition and steering angle data are recorded. In actual driving tests described below, the steering angle θ was sampled at 50ms intervals and the average of three measured values was computed to reduce measurement noise. As a result, the average steering angle was obtained for every 150ms. This sampling interval is a

good approximation of a human operator's manual tracking delay time and corresponds to the lowest sampling frequency that can justifiably be used to represent a human operator's control response in a wide range of manual tracking tasks [3.Sheridan & Ferrell 81]. The exact sampling frequency is not critical except that very high sampling frequencies result in prediction errors that are too noisy resulting in a loss of sensitivity in estimating workload.

Using steering angles of the previous three time steps ($\theta(n-3)$, $\theta(n-2)$ and $\theta(n-1)$), we perform a second-order Taylor expansion on time $n-1$ to obtain the predicted steering angle $\theta p(n)$ at time n (i.e., the steering angle likely to be obtained if steering is executed very smoothly)

$$\theta p(n) = \theta(n-1) + (\theta(n-1) - \theta(n-2)) + 1/2 ((\theta(n-1) - \theta(n-2)) - (\theta(n-2) - \theta(n-3)))$$

The prediction error $e(n)$ is defined as the difference between $\theta(n)$ and $\theta p(n)$ (Figure 3)

$$e(n) = \theta(n) - \theta p(n)$$

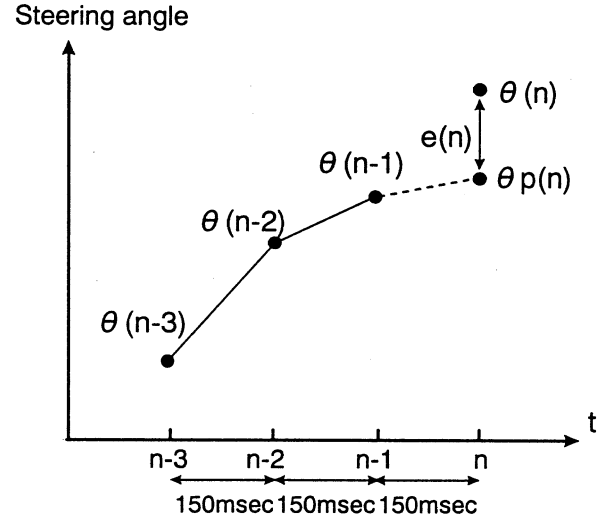


Figure 3. Principle (1)

In our real time implementation, $e(n)$ estimates are calculated and recorded at 150ms intervals while the test subject is driving the course for several minutes under the no-workload condition. The 90 percentile value α of the frequency distribution of the recorded prediction errors is then computed (Figure 4). The shape of the prediction error distribution becomes narrower (smaller α) as the driver's steering behavior becomes smoother. The value of α indicates the fundamental steering behavior of an individual. It is used as the reference standard when measurements are made of the workload incurred by different activities.

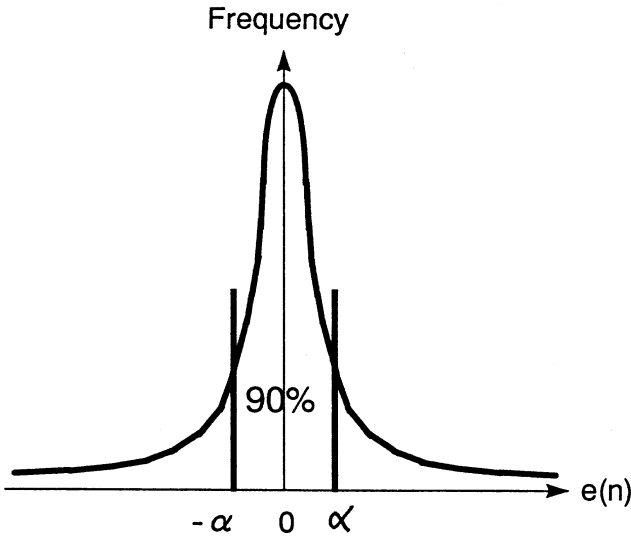


Figure 4. Principle (2)

The frequency distribution is then divided into nine bins based on this α (Figure 5). The proportion, $p_1, p_2, \dots, p_9$ of prediction errors falling into each bin is computed and the steering entropy value H_p is calculated as [4.Khinchin 57]

$$H_p = -\sum_{i=1}^9 p_i \log_9(p_i) \quad (i = 1-9)$$

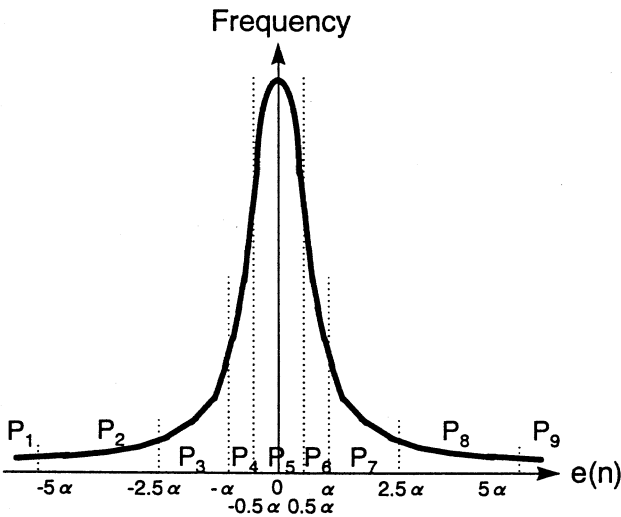


Figure 5. Principle (3)

A log base of 9 assures entropy values between zero and one when subjects perform different activities while driving the same course. Calculation of these entropy values is discussed next.

For a particular activity, the test subject drives the exact same course but is now instructed to perform the given activity as frequently as comfortably possible. Using the above bin definitions, obtained under the no-workload condition, prediction error frequencies p_i for each bin are computed and H_p is calculated. This results in one H_p estimate per trial during which a particular activity is performed.

When a workload is imposed, steering behavior lacks smoothness to a degree depending on how demanding the task is. As shown in Figure 6, this results in a broader frequency distribution and consequently a higher H_p value.

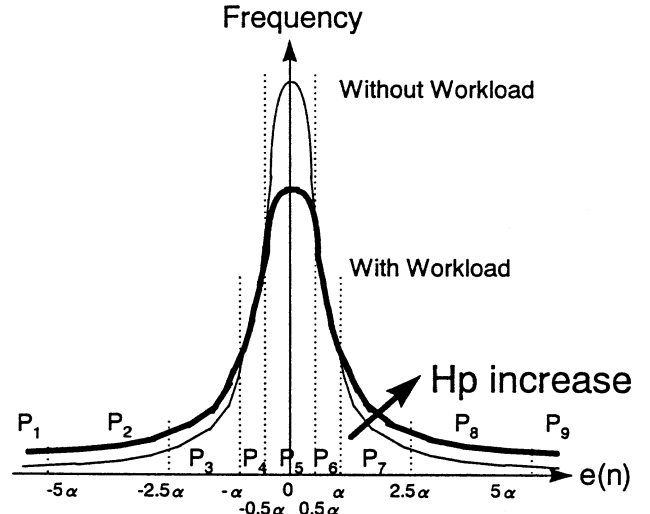


Figure 6. Principle (4)

SPECIAL-PURPOSE SIMULATOR

When determining the steering entropy value for each action, the driving task per se must be identical—including the driving course, vehicle speed, obstacle avoidance maneuvers and other factors—for every measurement made. If measurements are not made under identical conditions, factors other than the workload can cause the calculated H_p values to vary, resulting in a deterioration of measurement accuracy.

Since the calculation of steering entropy requires only steering angle data, workload measurements could be made either with an actual vehicle or with a laboratory simulator. A special-purpose simulator has been developed because it was thought that a simulator would be better with respect to achieving identical driving conditions for every measurement, an essential condition for accuracy. However, because the simulator differs slightly from actual driving, measurements were also made using an actual vehicle and the results were compared with the data obtained with the simulator in order to validate the latter. The workload measurements were conducted on a test course that made it relatively easy to obtain identical driving conditions for every measurement. The test results obtained with an actual vehicle will be described below.

The simulator used in these tests is shown in Figure 7. It consisted of such vehicle components as a steering wheel, driver's seat, instrument panel, and accelerator and brake pedal. A 17" color monitor was positioned on top of the instrument panel to display a preceding vehicle traveling at variable speeds on the road ahead of the driver. A test subject sat in the driver's seat and was instructed to follow the preceding vehicle at the same

speed. While watching the monitor, the person operated the steering wheel, brake pedal and accelerator in the same manner as when driving an ordinary vehicle (feel and dynamic response closely matched reality). Test subjects were required to follow the preceding vehicle in order to assure similar driving actions for every individual. The winding course consisted of gradual curves that involved continuous steering. One trial lasted approximately three minutes.



Figure 7. Special-Purpose Simulator

TEST PROCEDURE

Practice driving sessions were conducted any number of times at the beginning until test subjects were familiar with the simulator. A general criterion for concluding the practice sessions was when α fell below a certain value. The reason for conducting the practice sessions was to avoid any deterioration of accuracy that might otherwise have occurred due to a mix-up of factors if workload measurements had been made without any prior familiarization. For instance, a decrease in H_p due to a subject's level of skill with the simulator might have masked an increase in H_p due to the imposed workload, which would have caused measurement accuracy to decline.

After confirming that the test subjects were proficient at operating the simulator, data acquisition began. First, each subject was asked to drive under a no-workload condition to compute their α value as well as H_p as a baseline for load free driving. This personal α value is used to define the bins used to compute H_p in that sub-

ject's subsequent trials. They then performed separate trials for each of 14 workload imposing activities.

EXPERIMENT—VARIOUS WORKLOAD IMPOSING ACTIVITIES

The value of H_p was found for each of the following 14 activities. The test subjects were asked to perform the activities in a series of consecutive driving simulator trials each of which lasted approximately three minutes. There were four test subjects who are indicated in the tables by their initials (TN, NH, SN and ON).

1. Listening to traffic information:
A prerecorded radio announcement of traffic information will be played. Listen for the traffic congestion mentioned at the specified location.
2. Conversation—repeating spoken words:
Listen and repeat exactly what the test engineer says.
3. Conversation—giving a yes/no answer:
Give a yes or no answer to the question. For example, "Do you like restaurant A?"
4. Conversation—selecting among three choices:
Select one of the three choices given in the question. For example, "Which restaurant do you like—A, B or C?"
5. Mental arithmetic:
Count down as fast as possible starting from a number around 950 by subtracting 7 each time.
6. Checking a navigation map display:
Check the map position and the name of the location shown on the navigation system screen.
7. Selecting a name from a list:
Look at the list of four names displayed on the navigation system screen and choose the name you like.
8. Operating hardware switch controls:
Change the air conditioner mode as instructed by pushing the switch next to the screen. Repeat the operation.
9. Operating touch panel controls:
Change the air conditioner mode as instructed by pushing the touch panel screen. Repeat the operation.
10. Map scrolling:
Scroll the map displays according to the route indicated in the map displayed on the screen.
11. Changing the map scale:
Change the map scale so that the specified location is displayed on the screen.
12. Taking out coins:
Take out the specified amount of money from the various coins in the console box.
13. Making a cellular phone call:
Pick up the cellular phone in one hand and dial the specified number.

14. Answering a cellular phone call:

When you hear the cellular phone ring, take it out of the box on the passenger's seat. (The box contains other small items such as a TV remote control, wooden bar, etc. that might be mistaken for the cellular phone.)

The Hp values calculated for each activity for each of the subjects are given in Table 1 along with the average values across the four participants. The results are also shown in Figure 8.

The activities can be broadly grouped as follows: (A) typical conversations (1)-(4), (B) thinking (5), (C) diversion of the eyes only (6)-(7), and (D) diversion of the eyes accompanied by the operation of equipment controls (8)-(14). The results indicate that the workload increased in the order of (A), (B), (C) and (D). It is observed from these results that talking on a cellular phone, which has become an issue of concern recently, imposes a relatively small workload on the driver, provided it is a typical conversation, compared with the tasks in categories (C) and (D) that are commonly performed while driving.

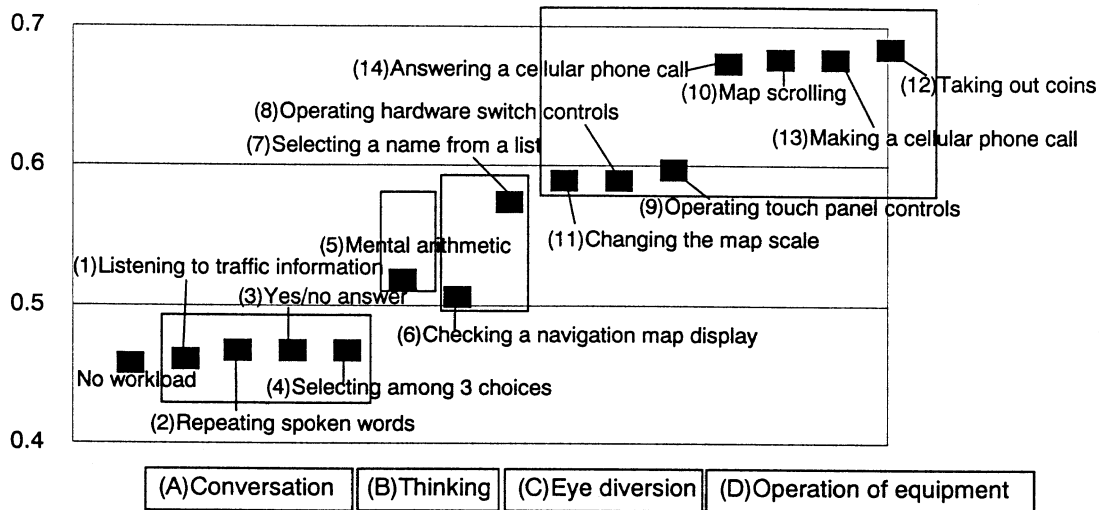


Figure 8. Measured Hp Results for Each Activity

Table 1. Measured Hp Results for Each Activity

	TN	NH	SN	ON	Ave.
No workload	0.454	0.493	0.462	0.475	0.471
(1) Listening to traffic information	0.437	0.459	0.477	0.476	0.462
(2) Conversation—repeating spoken words	0.455	0.468	0.460	0.489	0.468
(3) Conversation—giving a yes/no answer	0.467	0.492	0.458	0.458	0.469
(4) Conversation—selecting among three choices	0.472	0.455	0.459	0.490	0.469
(5) Mental arithmetic	0.538	0.511	0.524	0.505	0.520
(6) Checking a navigation map display	0.553	0.463	0.483	0.533	0.508
(7) Selecting a name from a list	0.637	0.481	0.544	0.637	0.575
(8) Operating hardware switch controls	0.661	0.590	0.565	0.546	0.591
(9) Operating touch panel controls	0.689	0.622	0.533	0.551	0.599
(10) Map scrolling	0.741	0.686	0.571	0.718	0.679
(11) Changing the map scale	0.679	0.612	0.508	0.564	0.591
(12) Taking out coins	0.623	0.677	0.801	0.639	0.685
(13) Making a cellular phone call	0.613	0.668	0.800	0.633	0.679
(14) Answering a cellular phone call	0.809	0.640	0.662	0.588	0.675

It should be noted, however, that the values presented here were obtained when each activity was performed continuously during approximately a three-minute interval. During the actual operation of a vehicle, drivers ordinarily cannot continuously perform the operations in categories (C) and (D) in particular. Strictly speaking, the data given here represent a momentary workload level at the time the test subjects were performing each particular activity.

COMPARISON WITH DUAL TASK METHOD

Workload imposed by each of these 14 activities was also measured with a dual task method in order to compare the results with the steering entropy method. As shown in Figure 9, three LED indicators were attached to the top of the instrument panel of the simulator. Any one of the LED indicators was illuminated at arbitrary intervals between 10 and 30 seconds. The test subjects drove the same course and followed the preceding vehicle just as they did in the previous experiment. They were instructed to push a switch with their right thumb the moment they noticed that an LED indicator was illuminated. The switch was located on the steering wheel in a position where it was almost touching the right thumb. Pushing the switch turned off the illuminated LED indicator. The reaction time between the illumination of an LED indicator and pressing the switch was measured and recorded.



Figure 9. Test Setup with LED Indicators

Measurements were made for the same 14 activities and with the same four test subjects as in the experiment for measuring the steering entropy values. Approximately ten reaction times were measured per activity per subject per trial. These values were then averaged to obtain the average reaction time for each activity. It was assumed that reaction time increases in proportion to incurred workload.

The graph in Figure 10 compares the average reaction time across the four test subjects for each activity against corresponding Hp values. These data are also listed in Table 2. The correlation coefficient between the average reaction times measured with the dual task method and the average steering entropy Hp shows a high value of 0.827, which is thought to verify the validity of the steering entropy method.

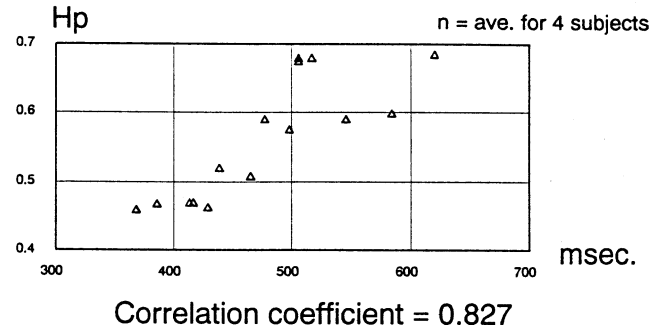


Figure 10. Comparison with Dual Task Method

COMPARISON WITH SUBJECTIVE EVALUATION METHOD

At the time the above-mentioned Hp values were obtained, each test subject was also asked to rate the degree of difficulty experienced in performing the task upon completion of each trial. Evaluations were made on the basis of a five-point scale, with "1" being easy and "5" being the most difficult.

The graph in Figure 11 compares the four subjects' average rating of their experienced workload and their average Hp values. The corresponding data are presented in Table 2. The correlation coefficient between the subjective evaluation scores and the steering entropy Hp shows an exceptionally high value of 0.947. This indicates that the steering entropy values corresponded remarkably well with the subjects' perception of the imposed workload.

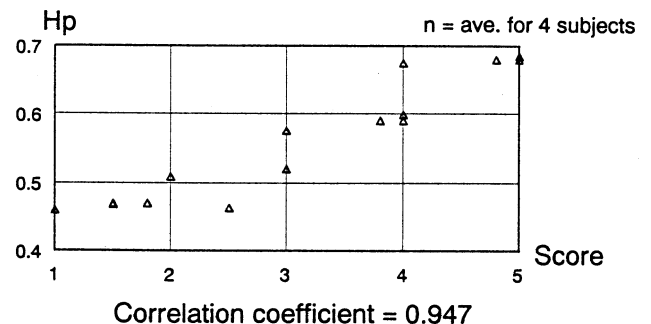


Figure 11. Comparison with Subjective Evaluation Method

Table 2. Comparison of the Results Obtained with the Three Methods

	Reaction time with dual task method (msec)	Subjective evaluation method	Steering entropy Hp
No workload	361	1.0	0.471
(1) Listening to traffic information	429	2.5	0.462
(2) Conversation—repeating spoken words	386	1.5	0.468
(3) Conversation—giving a yes/no answer	417	1.5	0.469
(4) Conversation—selecting among three choices	413	1.8	0.469
(5) Mental arithmetic	439	3.0	0.520
(6) Checking a navigation map display	465	2.0	0.508
(7) Selecting a name from a list	498	3.0	0.575
(8) Operating hardware switch controls	477	3.8	0.591
(9) Operating touch panel controls	583	4.0	0.599
(10) Map scrolling	517	5.0	0.679
(11) Changing the map scale	545	4.0	0.591
(12) Taking out coins	620	5.0	0.685
(13) Making a cellular phone call	506	4.8	0.679
(14) Answering a cellular phone call	506	4.0	0.675

PROGRESSIVE INCREASE IN TASK DIFFICULTY

EYE DIVERSION TASK – An experiment was then conducted to determine whether the steering entropy Hp would steadily increase in proportion to a progressive increase in the degree of task difficulty. In this experiment, an LED indicator was installed between the instruments in front of the test subjects. As shown in Figure 12, the LED indicator was illuminated for N seconds in a ten-second interval. The length of N was progressively increased from one second to two, three, four or more seconds. The subjects were instructed to focus on the LED while it was illuminated and could not watch the monitor to follow the preceding vehicle. It was assumed that the workload increased progressively in proportion to the increase in N.

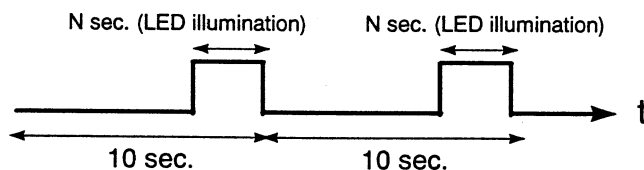


Figure 12. Eye Diversion Interval

The results obtained for the four test subjects are presented in Table 3 and Figure 13. It is clear that Hp increased steadily with increasing N, i.e., task difficulty. These results are thought to substantiate the high mea-

surement accuracy and high sensitivity across a wide range of workloads of the steering entropy method.

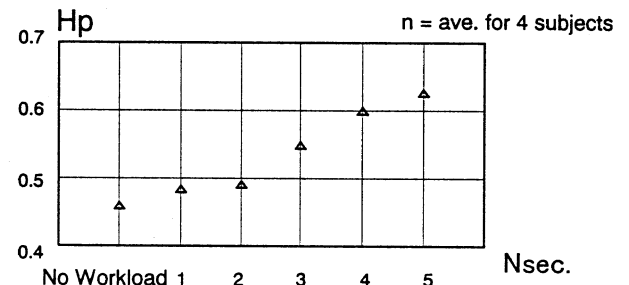


Figure 13. Measured Hp Results for Eye Diversion Task

MENTAL ARITHMETIC TASK – A similar verification experiment was then conducted in which the workload was increased by asking the subjects to do progressively more difficult mental arithmetic problems. In this experiment, a test engineer sitting nearby read two single-digit numbers that were generated at random by a personal computer every N seconds. The subjects were instructed to add the numbers mentally and give the answer orally. The workload was progressively increased as N was shortened.

The results obtained for the four subjects are given in Table 4 and Figure 14. These results also indicate that Hp steadily increased as N was reduced, i.e., the workload was increased, which is thought to substantiate further the high measurement accuracy of the steering entropy method.

Table 3. Measured Hp Results for Eye Diversion Task

	TN	NH	SN	ON	Ave.
No workload	0.469	0.471	0.442	0.456	0.460
1 sec.	0.466	0.481	0.486	0.501	0.484
2 sec.	0.483	0.490	0.495	0.496	0.491
3 sec.	0.610	0.501	0.491	0.596	0.550
4 sec.	0.616	0.595	0.524	0.663	0.600
5 sec.	0.609	0.649	0.546	0.699	0.626

Table 4. Measured Hp Results for Mental Arithmetic Task

	TN	NH	SN	ON	Ave.
No workload	0.469	0.471	0.442	0.456	0.460
3 sec.	0.491	0.468	0.473	0.456	0.472
2 sec.	0.547	0.500	0.510	0.456	0.506
1.5 sec	0.527	0.534	0.567	0.503	0.533

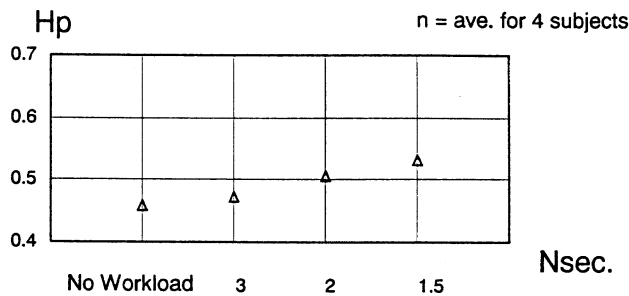


Figure 14. Measured Hp Results for Mental Arithmetic Task

VEHICLE TESTS

As the final experiment, the steering entropy Hp was measured in driving tests conducted with an actual vehicle. The vehicle used was a 1996 Nissan Cima sedan. Tests were conducted on a 2-km course, consisting of straight-aways and semicircular curves, around the perimeter of the Nissan Oppama Proving Grounds.

The only preparation needed for this experiment was to record the output of a steering wheel angle sensor (in 0.5 deg. graduations) in a personal computer as the subjects drove the test vehicle around the course. One advantage of the steering entropy method is that calculations can be performed so long as the steering angle is known and no other measuring equipment is needed.

The vehicle was driven at a steady speed of approximately 60 km/h and Hp values were calculated for every lap. No workload was imposed on the subjects during the first lap and their Hp were calculated under the zero-activity condition. The subjects were then required to perform one activity per lap. The activities consisted of men-

tal arithmetic (noted earlier as number (5)), map scrolling (10) and making a cellular phone call (13). The results obtained for the two subjects (NH and SN) who participated in these tests are given in Table 5 and Figure 15.

The correlation coefficient between the Hp values obtained in the simulator tests and those obtained in the vehicle tests was a high 0.820, and the same tendencies were seen for each activity in both sets of tests. This suggests that the steering entropy method facilitates workload measurements with both an actual vehicle and a simulator. One especially interesting result is that the Hp values measured in the vehicle tests for map scrolling and making a cellular phone call, representing workloads with a high degree of difficulty, were lower than those measured with the simulator. This difference is thought to be attributed to a heightened awareness of risk in case of the real vehicle tests which caused them act less excessively in trying to perform the activity. In the simulator tests, on the other hand, the subjects had a stronger desire of trying to perform the activities even if it meant overtaxing themselves.

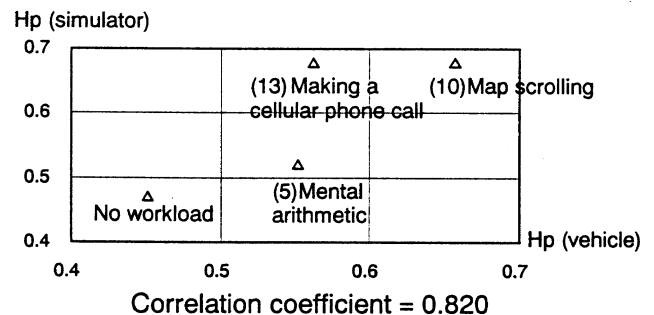


Figure 15. Comparison of Hp Results Measured in Vehicle and Simulator Tests

Table 5. Comparison of Hp Values Obtained in Vehicle and Simulator Tests

	NH (Hp in vehicle tests)	SN (Hp in vehicle tests)	Ave. Hp in vehicle tests	Ave. Hp for 4 subjects in simulator tests
No workload	0.424	0.478	0.451	0.471
(5) Mental arithmetic	0.495	0.608	0.552	0.520
(10) Map scrolling	0.720	0.594	0.657	0.679
(13) Making a cellular phone call	0.539	0.585	0.562	0.679

There are still various aspects about workload measurements in actual vehicles that require further work. One point is the fact that it requires a special environment, such as a proving ground course, where there is little influence from other drivers. Another aspect is the inconvenience involved, including the time and effort needed to obtain the measurements and the travel to the test course. There is also the question of safety. On the positive side, however, there is the fact that measurements made with actual vehicles represent true values.

It is thought that there is ample value in pursuing further research on this method in the future. It also contains latent possibilities for extension to the development of on-board safety systems, such as a system for detecting the driver's degree of concentration on driving operations and various warning systems. This is another factor that makes this field an extremely interesting subject for research.

SUMMARY

In this paper we described the theoretical basis of the steering entropy method, the special-purpose simulator, and a measurement procedure to facilitate easy and efficient evaluations of driver workload. The validity and measurement accuracy of the proposed steering entropy method was demonstrated through: (i) comparisons with conventional workload assessment methods on a large number of activities, (ii) tests in which the task difficulty was progressively increased, and (iii) a comparison between driving simulator and actual vehicle tests.

CONCLUSION

As mentioned at the outset, the original objective of this work was to establish a method that would make it possible to quantify accurately and easily the workload imposed on drivers by any activity other than the action of driving itself. The experimental results presented here show that the steering entropy method facilitates such

accurate measurements. The fact that only a time-series history of steering angle data needs to be measured makes this method definitely convenient. At the present time, this method is thought to be the most consistent with the objective of this research.

There is concern that the installation of more information devices in vehicles in the coming years will increase drivers' workload and become the cause of more traffic accidents. The authors hope that widespread use of the steering entropy method in countries around the world will result in the accumulation of technical information concerning this technique. Moreover, it is hoped that this method will enable engineers to ascertain workload easily and accurately, thereby accelerating the development of ITS equipment that is user-friendly and imposes little workload on drivers.

As a final note, the concept of this steering entropy method was originated by Dr. Erwin R. Boer [5.CBR 97], one of the co-authors. The other three co-authors applied the theory of this method in conducting the experiments described here.

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