Proceedings of the 10th World Congress on Electrical Engineering and Computer Systems and Sciences (EECSS'24)
Barcelona, Spain - August 19 - 21, 2024
Paper No. MHCI 109
DOI: 10.11159/mhci24.109

Effective Guidance Information as a Means to Reduce the Cognitive Cost of Secondary Tasks While Driving

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Abstract - BeaCON is a novel driving simulator and analytics framework which provides a unified view of both the user behaviour process and user cognitive process for the analysis of cognitive load while driving. This unified view along with the data mining framework enables BeaCON to identify the root cause of the cognitive load while driving. Identification of the root cause can be used to create more effective guidance information for the driver. BeaCON enables the measurement of total cognitive load for the whole route as well as for individual point locations. In this work, we use BeaCON to analyze the effects of secondary tasks while driving and the identification of the root cause. The identified root cause is used to design more effective guidance information for the driver, which reduces the total cognitive cost associated with the journey.

***Keywords*:** BeaCON, Navigation System, Cognitive Load, Human-Machine Systems

1. Introduction

A car navigation system provides guidance information for the user by means of audio and visual inputs [1]. The interaction with infotainment systems and other secondary tasks induces a workload on the driver [2]. The interaction with the Navigation System (NS) also can be considered a secondary task that provides a distraction from the primary task of safe driving [2]. NS aims to provide guidance information with minimal disruption to drivers, as outlined in [3]. The primary task of NS is to guide the driver rather than the vehicle to reach the destination [4]. Secondary tasks like talking on the phone and talking to fellow passengers while driving create driving distractions [2]. Varying levels of driving automation influence the level of distraction created by secondary tasks [5]. Driver distraction creates increased cognitive load as well as may lead to deviating from the minimum required attention for safe driving. Secondary tasks also increase the accident risk. Deep thinking is also included for analysis along with some of the categories of secondary tasks listed in [2]. The secondary tasks included for analysis are given below.

- Deep thinking
- Listening to music
- Drinking coffee
- Talking with fellow passengers
- Talking on the phone in hands-free mode

BeaCON driving simulator and data analytics enable, for the first time, analysis and research experiments towards "Giving the driver adequate navigation information with minimal interruption" [6]. An overview of BeaCON framework is shown in Figure 1. The main novelty of BeaCON is the creation and integration of cognitive models into the framework [4] and the fusion of user behavioural data (i.e., brake, accelerator, steering angle) along with user cognitive data (i.e. processing visual input of the next manoeuver) to identify the root cause of high cognitive load scenarios while driving [4]. ACT-R [7] based cognitive models for navigation are integrated into BeaCON to analyze user thought processes while driving. The

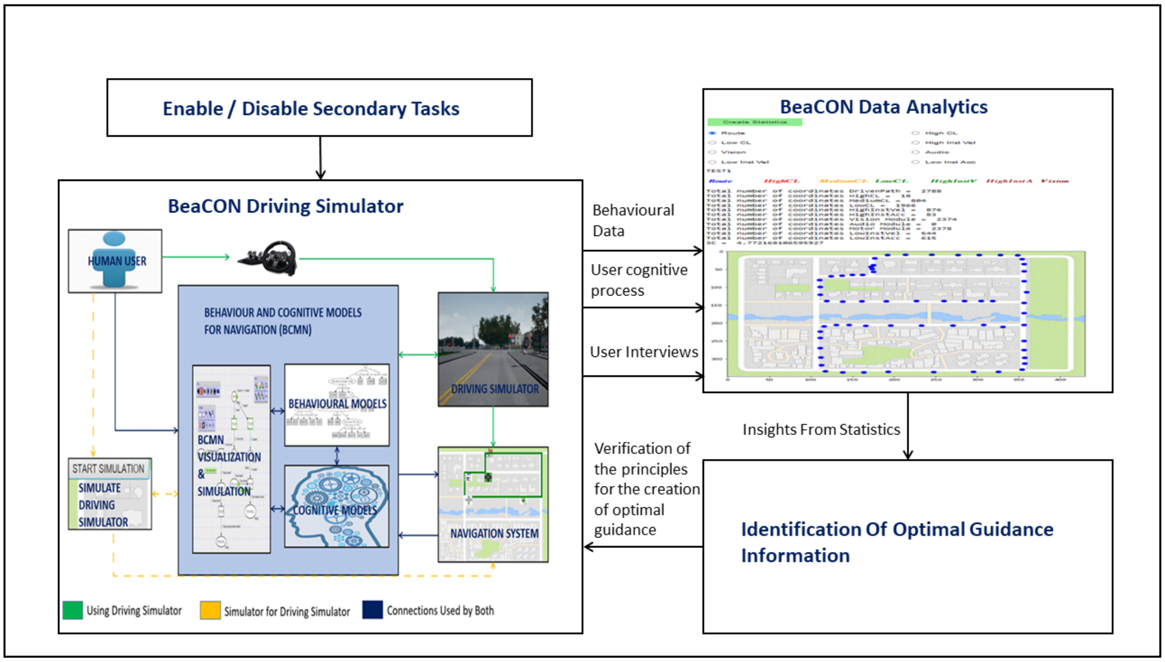

Fig. 1: Overview of the BeaCON framework for testing the effects of secondary tasks.

fused data is the input for the data mining part of BeaCON which creates insights for designing more efficient guidance information.

BeaCON introduces a new concept named 3C (Cognitive Cost Calculation) which enables the measurement of the cumulative cognitive load of the user for the whole route [4]. The cumulative value, 3C is calculated from the cognitive load from individual point locations on the route where a non-optimal cognitive load is observed. The steering entropy algorithm with many custom enhancements is used to calculate the cognitive load at individual point locations. 3C optimization, using effective guidance information and a reference value of 3C, is achieved via experiments where the reference 3C is the lowest 3C observed in ideal driving conditions (i.e., Optimal weather conditions, less traffic, etc.).

2. Related Work

A cognitive model for the driving task as well as the variation of the response time for the lateral position control of the vehicle, when the user is doing the secondary tasks of dialling is provided in [8]. However, the analysis in [8] is limited to one secondary task as well as the creation of guidance information to reduce the lateral position deviation of the vehicle is not in scope. [10] presents the importance of human behaviour analysis while designing intelligent navigation systems, but [10] does not provide any study on the importance of secondary task analysis while designing intelligent navigation systems. [6] create a research framework for the analysis for generating optimal guidance information. However, [6] does not provide any study to identify the effects of secondary tasks on driving. [11] conducts an in-depth examination of driving attention, encompassing the subprocesses of monitoring, control, and decision-making and [12] centres its attention on enhancing situation awareness within driving contexts, but both [11] and [12] do not integrate the effects of secondary tasks. [13] offers a cognitive model for navigation but does not explore research about the reduction or representation of cognitive load for secondary tasks. Although the human cognitive state is taken into account for navigation systems in [14], this work does not consider the importance of secondary tasks and the effect of the secondary tasks on the driver's cognitive state.

3. Conducting Experiments to Identify the Role of Secondary Tasks

The steps are illustrated in Figure 2. The main parts of BeaCON framework involved are

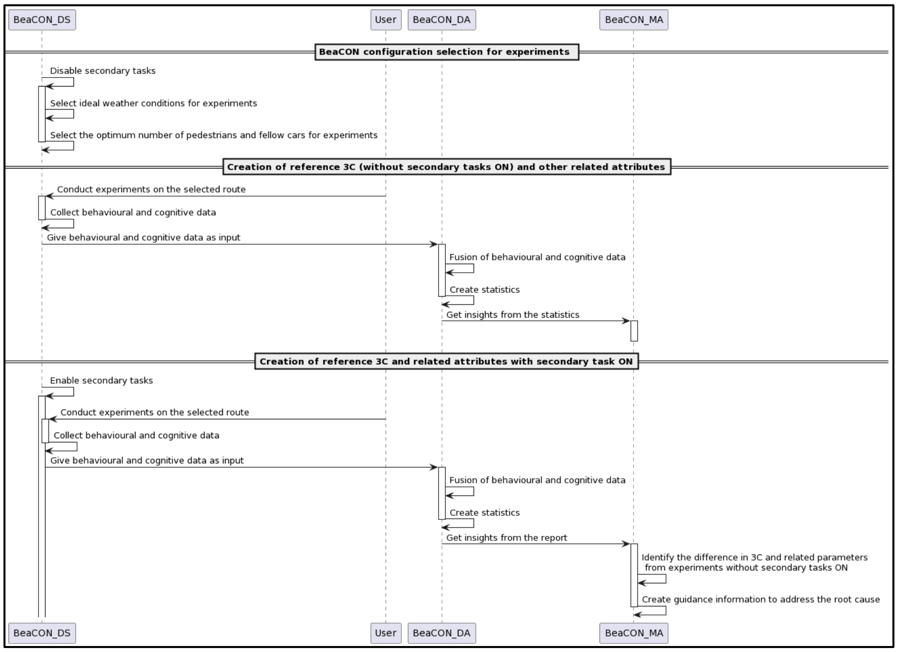

Fig. 2: Conducting experiments with BeaCON to identify the effects of secondary tasks while driving.

- BeaCON_DS (BeaCON Driving Simulator)
- BeaCON_DA (BeaCON Data Analytics)
- BeaCON_MA (BeaCON Manual Analysis by a data scientist)
- User who drives on the selected route

The data mining framework of BeaCON provides an intuitive GUI (Graphical User Interface), as shown in Figure 3, which enables selecting the parameters of interest and creating statistics for analysis. Three main categories of attributes can be analyzed in the data analytics part of BeaCON

- Cognitive Load (CL) parameters (High CL, Low CL, etc.)
- Behavioural parameters (High Instantaneous velocity, High acceleration, etc.)
- Information from the cognitive models (User processing audio input, user processing vision of next manoeuver, etc.)

Identified 3C is also displayed along with other attributes (i.e., Cognitive Load points).

4. Experimental Results

The test route used for experiments is shown in Figure 4. In order to create the reference test data, which is without the secondary tasks activated, the user drives on the selected test track without secondary tasks multiple times and the most optimal driving behaviour is chosen. To simulate deep thinking while driving, the user is given the task of counting in reverse order from a big number. In one of the experiments with counting, the user is provided a goal of reaching a target number at the time of finishing the test route. The results are shown in Table 1. During the experiment with drinking coffee while

Fig. 3: Intuitive GUI from BeaCON for data analytics.

driving, the user was holding the coffee in one hand on multiple occasions while driving. This created significant interruptions for driving many times. During the experiment with using hands-free mobile phones, user received phone calls three times while driving. The main interruption point is during the initial phase where the user takes the phone call.

Table 1: 3C and other parameters from user experiments with and without secondary tasks.

Experiment	3C Value	High CL Points	Medium CL Points	High InstVel Points	High InstAcc Points	Number of Straight Roads With High CL	Number of Junctions and Manuevers With HighCL	High InstVel With HighCL Points	High InstAcc With HighCL Points
Reference experiment with no secondary tasks	2.5	12	488	876	83	0	4	4	0
Counting in reverse order	4.3	23	638	684	47	3	5	5	2

Counting in reverse order with a counting target to be achieved	5.05	17	927	1310	160	3	3	6	1
Music played in the background	3.6	15	617	684	83	1	6	2	0
Drinking coffee	6.2	23	973	855	83	3	4	7	0
Talking with fellow passengers	3.7	6	729	684	47	0	5	3	0
Talking in the phone in handsfree mode	7.6	46	1035	876	83	5	4	6	0

5. Insights for Designing Effective Guidance Information

Secondary tasks of deep thinking while driving, simulated by the counting in reverse order experiments show a significant increase in the total cognitive cost (3C) for the whole route. The number of high cognitive load points is also significantly higher compared to the reference experiment data while most of the high cognitive points are outside manoeuvers and junctions (i.e. straight road driving, addressing pedestrians, keeping the car on the proper side of the road, etc.). High cognitive load points are observed during high velocity and high acceleration scenarios which is also a major deviation from safe driving patterns. Therefore, the guidance information designed to reduce the cognitive cost shall bring back the user's attention to the road not only for complex entities like junctions, etc. but also for other driving scenarios for example, lane keeping on a straight road. One of the methods to address this might be tracking driving behaviour and giving real-time feedback on driving so that the driver is more aware of the deviation from safe driving patterns. This might address the distributed medium CL points also. High-speed warnings also address the high CL observed during high instantaneous and high acceleration scenarios.

Secondary tasks of listening to music and talking to fellow passengers did not increase the total cognitive cost significantly. However, the number of high CL points observed for junctions and manoeuvers is high. This shall be addressed by more assertive guidance information for the user for junctions and manoeuvers. Secondary tasks of attending phones with multiple connect and disconnect steps show the highest deviation from the reference cognitive load. The number of high CL points is significantly higher even though the high CL scenarios in junctions and manoeuvers are not higher compared to other test scenarios. During the experiment, each time the user presses the accept button, after seeing the caller information shows significant interruption for the user. This is one of the reasons for the very high number of high CL scenarios. Methods that allow the user to take a call with less cognitive resource consumption (i.e., only based on voice commands) shall reduce the cognitive load to a great extent.

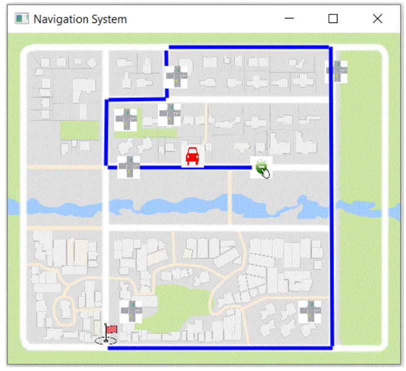

Fig. 4: Test route with manoeuvers and junctions selected for the experiment.

Providing real-time feedback about the deviations from safe driving patterns shall reduce the distributed medium cognitive load scenarios. During the experiment with secondary tasks as the user drinking coffee, each time when the takes the coffee in hand shows significant interruption for the user. This is one of the reasons for the very high number high CL scenarios. Handling the steering with one hand, while the user is holding coffee in the other hand induced more cognitive load for the tasks which otherwise the user does with ease. This created the highest number of medium-cognitiveload points while driving. Real-time feedback about the deviation from safe driving patterns shall help here as well. Secondary tasks of talking with fellow passengers have not shown a significant increase in the total cognitive cost. The increased cognitive cost from the reference driving is distributed throughout the whole route.

6. Designing of the Guidance Information

The identified insights are used to design the following properties of the guidance information. The following steps are involved during the identification of the optimum guidance information.

- Analysis of the root cause of the high cognitive cost.
- Analysis of what guidance information shall be provided.
- Analysis of how to provide guidance information.
- Analysis of when to provide the guidance information.

As per [2] drivers are engaged in activities other than driving for 50% of the driving time. Many of the activities where the driver focuses while driving are related to secondary activities [2]. To analyze the root cause of the cognitive load, concepts and experiments provided by ACT-R cognitive architecture are used [7]. ACT-R provides a cognitive architecture by providing specifications for the structure of the brain at an abstraction level sufficient to describe how the mind achieves its functionality. ACT-R provides eight modules as a part of the cognitive architecture, two perceptual modules which are visual and aural. Two response modules which are manual and vocal. The other four modules are for central processing behaviour for example, the imaginal module holds the mental representation of the problem [7]. The ACT_R cognitive modules can function in parallel. Reference experiments conducted in [8] uses an ACT-R based cognitive model as per the concepts and cognitive modules provided by [7].

In the ACT-R based driving model provided by [8], there are two main tasks involved: controlling and monitoring. Controlling mainly involves correcting the lateral position of the vehicle and minoring involves the creation of situation awareness. Ideally, the task switch interval between the two is 500 milliseconds, even though some situations devote more attention to control (e.g. lane change) and some situations devote more attention to monitoring (e.g. driving a straight road on a highway). As per the model if there is a delay of more than 500 milliseconds to come back to control tasks, there is a significant impact to safe driving. While controlling, the visual, procedural and manual modules defined by ACT-R are being used. During monitoring, visual, procedural and declarative modules are being used.

As per the experiments shown in [8], with a secondary task of dialling a phone number, the observations are that the lateral deviation of the vehicle is high, and the reason is the minor increase in the delay to return to the control task. When the delay to return to the control tasks increases, this in turn increases the lateral deviation and speed deviation. The same results are very much applicable to the root cause of the cognitive load observed during the secondary tasks while conducting experiments with BeaCON since BeaCON uses advanced steering entropy for the calculation of the cognitive load. The steering entropy uses the deviation between the predicted steering angle as well as the actual steering angle to identify the cognitive load of the driver [9]. BeaCON provides significant advancement to the basic steering entropy algorithm to calculate the accurate cognitive load and 3C values. The guidance information is designed in such a way that this will avoid or decrease the delay in returning to the control task. The designed guidance information strategy is listed in Table 2.

Table 2: Design of guidance information strategy to reduce cognitive load associated with secondary tasks

SN	Secondary Activity	Identified Guidance information strategy	Justification
1	Counting in reverse order	- Repeated guidance information for junctions as well as for manoeuvers. - Warning messages for complex junctions and manoeuvers. - Warning messages about dynamic events, for example, presence of pedestrians. - Warning messages to the user if there is an observation of repeated lateral deviation. - Warning messages to the user if there is an observation of repeated speed deviation.	This task is analogous to deep thinking by the driver while driving. High cognitive load is observed for straight roads, junctions and manoeuvers as well as there are points with high instantaneous velocity as well as with high instantaneous acceleration.
2	Counting in reverse order with a counting target to be achieved	- Repeated guidance information for junctions as well as for manoeuvers. - Warning messages for complex junctions and manoeuvers. - Warning messages about dynamic events, for example, the presence of pedestrians. - Warning messages to the user if there is an observation of repeated lateral deviation, till the lateral deviation error gets corrected. - Warning messages to the user if there is an observation of repeated speed deviation, till the speed deviation error gets corrected.	This is like the above situation except that the user stress is increased because of a counting target to be achieved. The warning messages for lateral and speed deviation can be provided in repeated intervals till normal driving patterns are observed.
3	Music played in the background	- Repeated guidance information for junctions as well as for manoeuvres. - Warning messages for complex junctions and manoeuvres.	High cognitive load is observed for junctions and manoeuvers compared to other situations like straight roads.
4	Drinking coffee	- Repeated guidance information for junctions as well as for manoeuvers. - Warning messages for complex junctions and manoeuvers. - Warning messages about dynamic events, for example, the presence of pedestrians. - Warning messages to the user if there is an observation of repeated lateral deviation, till the lateral deviation error gets corrected. - Warning messages to the user if there is an observation of repeated speed deviation, till the speed deviation error gets corrected.	The cognitive load pattern observed is similar to counting in reverse order with a target value to be achieved, but the 3C value is much higher. The high cognitive load value observation with a high instantaneous value is also high. So, one of the primary targets of guidance information is to reduce speed deviations.

5	Talking with fellow passengers	- Repeated guidance information for junctions as well as for manoeuvers. - Warning messages for complex junctions and manoeuvers.	High cognitive load is observed for junctions and manoeuvers compared to other situations like straight roads.
6	Talking in the phone in handsfree mode	- Repeated guidance information for junctions as well as for manoeuvers. - Warning messages for complex junctions and manoeuvres. - Warning messages about dynamic events, for example, the presence of pedestrians. - Warning messages to the user if there is an observation of repeated lateral deviation, till the lateral deviation error gets corrected. - Warning messages to the user if there is an observation of repeated speed deviation, till the speed deviation error gets corrected.	High cognitive load is observed for straight roads, junctions and manoeuvres as there are points with high instantaneous velocity as well as with high instantaneous acceleration.

7. Conclusion

The effects of many secondary tasks on the total cognitive cost are demonstrated. The design of guidance information to reduce the 3C value associated with each scenario is explained. The design of the guidance information strategy is justified by using the concepts from ACT_R cognitive model. Currently, experiments are not conducted with a very long route as well as many other categories of secondary tasks listed in [2] are not included in the experiments. Tests can be conducted with more challenging routes to identify the effects of cognitive load more accurately as well as drivers with different experience levels can be used to accommodate the effects of driver experience also on the test results.

Acknowledgements

We thank the members of the Cooperative Media Lab of the University Bamberg. We also thank the reviewers for their valuable comments. We also thank the colleagues from HERE Technologies, Frankfurt, Germany.

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