What Humans Might be Thinking While Driving: Behaviour and Cognitive Models for Navigation

Arun Balakrishna[1] and Tom Gross[2]

1Automotive Software Development Services, HERE Technologies, Frankfurt, Germany
arun.balakrishna@here.com
2Human Computer Interaction Group, University of Bamberg, Bamberg, Germany
tom.gross@uni-bamberg.de

Abstract. In an optimally integrated HMS (Human Machine Systems) human and machine understand each other to provide an optimum integration. This is one of the core principles which is applicable for the research frameworks in vehicle navigation domain for effectively conducting research for creating optimal guidance information for the human driver. Creation and integration of human cognitive models for navigation is necessary to follow this principle effectively. BeaCON: Behaviour-and Context-Based Optimal Navigation is an existing research framework in the car navigation domain, for conducting analysis for the research problem "*Giving the driver adequate navigation information with minimal interruption*". Currently BeaCON does not use the human cognitive models for navigation for the creation of guidance information and because of that the integration with the human driver is not achieved to an optimum level. In this paper, we present enhancement of BeaCON by integrating behaviour and cognitive models of navigation. Understanding the human thoughts while driving enables BeaCON to have a granular analysis of user cognitive state while creating guidance information, which results further cognitive load reduction for navigation tasks by creating more effective guidance information.

Keywords*:* BeaCON, Navigation System, HMS, Entity of Interest, Cognitive Load, Cognitive Architecture, Machine Learning

1 Introduction

A car Navigation System (NS) shows the user the current location on the map and gives both audio and visual information for providing guidance for travelling from one location to another [4]. "*Giving the driver adequate navigation information with minimal interruption*" in car navigation domain is one of the identified research gaps in HMS [3]. This research problem can be divided into following three sub problems as described in [1]

1. Given a set of route and map information, what is an optimal guidance information for the user?

2. How to find optimal guidance information for the user, provided set of inputs to create the same is given?
3. How to find when, how and what guidance information must be given to the user?

Optimal guidance information eliminates the driver distraction created by NS [5]. To conduct effective research in the above-mentioned problems an understanding of the driver cognitive state for different contexts is necessary. Cognitive models enable the understandability of the user thoughts while driving and enable the extraction of the current and target cognitive state of the user. Identification of past, current and target cognitive state of the user while driving helps to deduce the root causes for the increased cognitive load as well as the creation of the guidance information which addresses the root cause in a more effective way. BeaCON is an existing research framework which enables the analysis of the research problem "*Giving the driver adequate navigation information with minimal interruption*" in car navigation domain [1]. One of the main principles in BeaCON is to understand the human user while creating guidance information which enables creation of optimal guidance information. Currently BeaCON does not use the human cognitive models for navigation for creating guidance information. Lack of cognitive models for navigation as well as its integration with behaviour models limit the effectiveness of the created guidance information. The work presented here addresses this gap by creating and integrating the cognitive models for navigation with the enhanced behavioural models, which can be together visualized as Behaviour and Cognitive Models for Navigation (BCMN) enhancement for BeaCON. Cognitive models in BCMN are created using ACT-R (Adaptive Control of Thought Rational) which is a well-known cognitive architecture for understanding and modelling human cognition process [6]. Currently BeaCON holds the static and dynamic behaviour models created using machine learning algorithms [2]. WEKA machine learning suite [8] is used for the creation of static and dynamic behaviour models. Static behaviour models are created based on statistical survey which includes questions in the following areas as described in [2]

- Driver distraction by the NS
- Extent to which NS understands the user intentions
- Optimal integration between the user and NS

Dynamic behaviour models recreated every time when a new user behaviour is observed [2]. Dynamic behaviour models are created based on the user context and the measured user cognitive load for the context.

Currently BeaCON creates the guidance information for a context, based on the created static and dynamic behaviour models as well the current and upcoming user contexts [1]. This paper also presents the improvements observed in the created guidance information because of creation and integration of BCMN, as well as the visualization and simulation support implemented for the created cognitive models in BCMN.

2 Related Work

The work conducted here already considers the research findings in the domain of optimum integration between human and navigation system as well as takes the research further. Balakrishna & Gross [1] provides a novel research framework which enables efficient analysis for creating optimal guidance information. But [1] does not contain the human cognitive models of navigation integrated for improving the efficiency of created guidance information. The analysis about the influence of navigation system behaviour on human behaviour [9] proves that an understanding of granular human behaviour is necessary for designing intelligent navigation system. Enhancement of BeaCON with BCMN enables granular understanding of human cognition while driving where the human cognitive state is created based on current and future navigation contexts. Yoshida, Ohwada et al. [10] also considers the cognitive state for improving the in-vehicle systems. But [10] is not using cognitive models which incorporates the contribution of real-world map entities (Manoeuvres, Roundabout etc.) while driving. The framework introduced for automated driving system testable cases and scenarios [11] provides bench marking strategies where some of them are applicable for human based driving also. The major focus of [11] is the automated driving scenarios, and because of that [11] does not provide human cognition models as a part of the framework. Haring, Ragni et al. [12] creates a cognitive model for human attention during driving, which divides the driving attention process to three sub process which are control, monitoring and decision-making process. The models created in [12] are not integrated to a research framework for enabling further research in the field of optimal guidance information as well as does not consider majority of the driving contexts. Krems & Baumann [13] propose a theory for creation and prediction of mental representation of objects and situation awareness for the driving contexts. But [13] is not concentrating to a granular level on the vehicle navigation tasks, as well as lacks proper experimental foundation. A cognitive model for car drivers which incorporates result from cognitive psychology and human machine interaction is presented in [14]. But [14] is neither considering many of the navigation related contexts which must be modelled very granularly nor conducting research on cognitive load measurement and reduction mechanisms.

3 Behaviour and Cognitive Models for Navigation (BCMN)

BCMN enables granular understanding of human cognitive state during navigation. The other components of BeaCON use these cognitive models while creating optimal guidance information. Detailed description of BCMN is given in the following sub sections.

3.1 Architecture of Cognitive Model for Navigation in BCMN

ACT-R [7] based cognitive model is created for the navigation process which is implemented using the LISP programming language. Currently declarative, goal and procedural modules provided by ACT-R are used. Some of the major ACT-R features from [7] are given below.

- ACT-R based cognitive architecture is a specification of the structure of the brain at a level of abstraction necessary enough to describe the function of the mind. Different ACT-R modules are associated with corresponding brain regions.
- The declarative module holds and retrieves critical information from the memory and the goal module keeps track of current user intentions.
- Communication among these modules is achieved by using the procedural modules.
- In ACT-R, chunks represent the knowledge a user already has, while solving a problem.
- Chunks also can be visualized as small unit which contains small amount of information.
- Sub symbolic level activation of the chunks and utility-based rule selection of the production rule shall be used for enabling learning for the created cognitive model.

A brief description about the ACT-R based architecture of cognitive model for navigation is given in the following sub sections. The declarative module in the cognitive model for navigation contains mainly the following chunk types.

Chunk Types

- ***State***

A chunk type named state which contains a state name and a description is given below

```
(chunk-type state stateName stateDescription)
```

The chunk type *state* is used for representing the existing knowledge of a user about different cognitive states for navigation i.e., “announcement-active”, “understanding-announcement”. An example of state chunk created is given below

```
(state-1 ISA state stateName "state-1" stateDescription
"announcement-active")
```

- ***Transition***

A chunk type named transition which contains current state, trigger, and next state is given below

```
(chunk-type transition currentState trigger nextState)
```

The chunk type transition represents the existing knowledge of the user about the state transition based on a trigger. An example of transition chunk is given below.

```
(transition-1 ISA transition currentState "state-1" trig-
ger "trigger-1" nextState "state-2")
```

- ***Navigation***

The chunk type named navigation represents the existing knowledge of the user about the navigation state as well as transition based on the trigger. An example of navigation chunk is given below.

```
(chunk-type navigation navigationStart navigationEnd nav-
igationCurrent navigationTrigger)
```

An example of navigation chunk is given below.

```
(navigation-input ISA navigation navigationStart "state-1"
navigationEnd "state-16" navigationTrigger "trigger-2")
```

Navigation chunk type is also used to set the contents of the goal buffer which currently act as one of the interfaces to the cognitive model. The cognitive state of the user can be used by the navigation system for deciding the next guidance information as well to decide when to present the next guidance information.

Production Rules

ACT-R production rules contains the condition and the corresponding action [7]. Conditions specifies the patterns in the buffer associated with different modules which must be matched for the production to fire [7]. An example of a production which handles different navigation triggers (i.e., Audio announcement) are given below.

```
(p navigation
   =goal>
    ISA        navigation
    navigationCurrent   =var1
    navigationTrigger   =var3
  - navigationEnd       =var1
  =retrieval>
    ISA         transition
    currentState    =var1
    nextState      =var2
 ==>
   =goal>
     ISA         navigation
     navigationCurrent   =var2
  +retrieval>
```

```
     ISA          transition
     currentState  =var2
    trigger       =var3
     !output!       (=var2)
     !output!       (=var3)
)
```

In the production above, based on the navigation trigger the user knowledge about the next transition is retrieved as well as the navigation state is set accordingly. The cognitive state holds the current state of the user with the navigation task.

3.2 BCMN Integration with Other Components of BeaCON

The big picture level block diagram of BCMN, integrated into other components of BeaCON is shown in Figure 1. The purpose of BeaCON is to conduct experiments using Human-in-the-loop systems, collect behavioural data and based on that find user cognitive load points and optimize the machine learning behavioural models, which are the models used by the system to understand the user [1]. Figure 1 also shows the interconnection between different components of the BCMN enhanced BeaCON framework. The BCMN enhanced BeaCON framework consists of 5 main components as described in Table 1

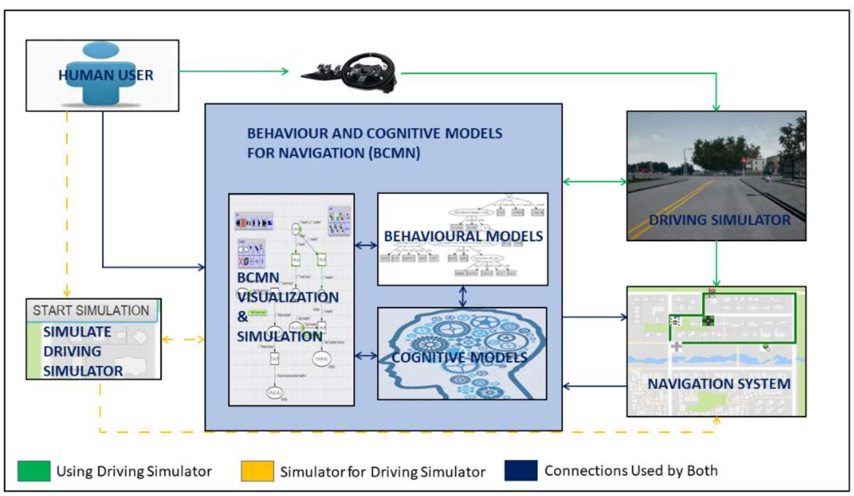

Fig. 1. BCMN integration with other components of BeaCON

Table 1. Components of BCMN enhanced BeaCON

SN.	Component	Description
1	Behaviour and Cognitive Models for Navigation (BCMN)	Purpose of BCMN is to identify the cognitive load and the root cause by using the following subcomponents. • Static behaviour models • Dynamic behaviour models • Human cognitive models for navigation
2	Navigation System (NS)	The navigation system tracks the car position in the route and highlights the path to be taken by the human user. Navigation system also presents the guidance information to the user as per the input from BCMN as well as based on the current driver context [1]. The inputs from NS are used by BCMN for getting the driving context information.
3	Driving Simulator (DS)	CARLA driving simulator based custom implementation is used in BeaCON [14]. CARLA simulator is primarily designed for developing and testing autonomous driving agents, because of that extensive enhancements for existing interfaces are done to support the human driver interface using Logitech G920 driving hardware [1]. The inputs from DS are used by BCMN for getting the driver context information.
4	Simulator for Driving Simulator (SDS)	SDS enables faster research and development for BCMN enhanced BeaCON features [1]. Using SDS, the developers can add and test new features without invoking the DS component.
5	Human User (HU)	BCMN enhanced BeaCON is a human oriented research framework for the effective analysis of the research problem "*Giving the driver adequate navigation information with minimal interruption*".

BeaCON supports different driving simulation environments corresponding to low, medium, and high cognitive load inducing situations [1] while conducting the experiments.

3.3 Communication Between BCMN and the Navigation System Application

The integration of the cognitive model for navigation with the navigation system application is given in Figure 2. The steps shown in Figure 2 is repeated for every EOI [2] during the navigation process. The navigation system gets the following inputs for creating the next guidance information.

- Current cognitive state of the user from BCMN.
- Cognitive load for the next EOI as per the previous learning.
- Characteristics of the next EOI for which the user might need guidance information.

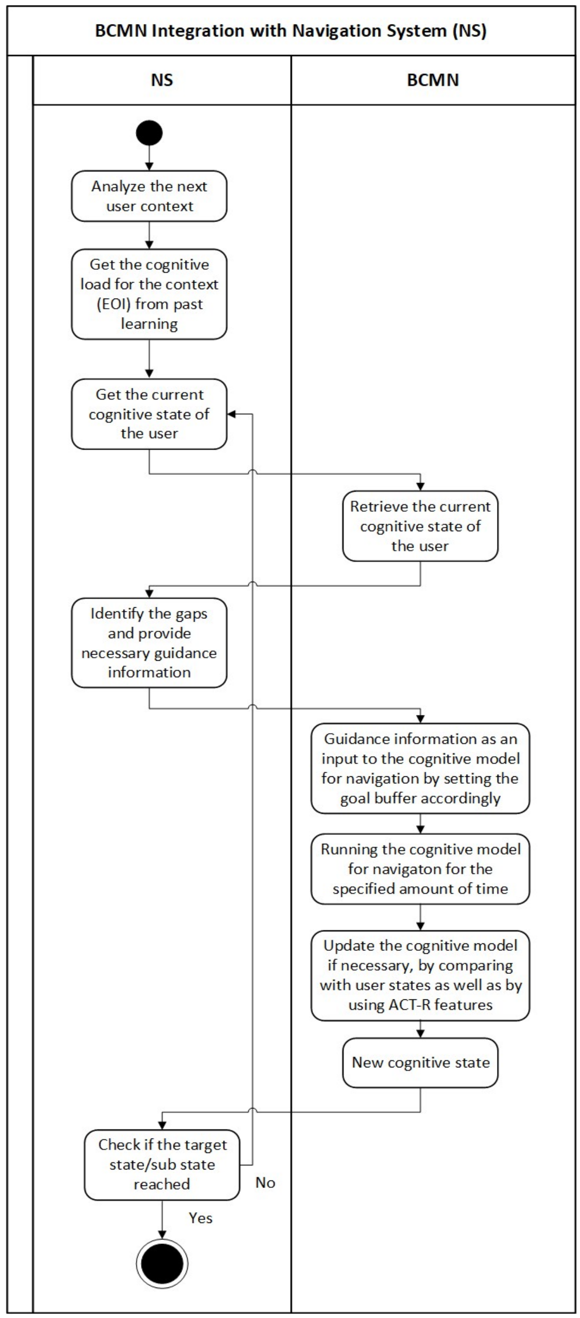

Fig. 2. Communication between BCMN and NS for each EOI

4 Conducting Human-in-the-loop Experiments with BCMN Enhancement

The algorithm for conducting Human-in-the-loop experiments are given below, the steps for conducting experiments using the research framework is shown in Figure 3.

//Input: Candidate drives between two selected points on the map
//Output: Optimized guidance information is generated using the driver context, behaviour models and human cognitive models
Step 1: Two points in the map are selected for conducting human experiments for evaluation of optimum guidance information generation.
Step 2: Candidate drives between the selected points.
Step 3: Generate and present guidance information for every user context (EOI) [2], based on current behaviour models, user contexts and cognitive state.
Step 4: Collect the behavioural data for updating the behaviour models as per latest behaviour observed for the EOI.
Step 5: Once user reached the destination, stop collecting behavioural data.
Step 6: Give the behavioural data input to the bench marking tool.
Step 7: Bench marking tool creates necessary logs for driving behaviour.
Step 8: Measure cognitive load at different contexts of driving (EOI) and create report.
Step 9: Replay the driving behaviour to re-verify the findings from the report.
Step 10: Driver cognition state for EOIs from the cognitive models shall be reverified and shall be enhanced when necessary.
Step 11: Cognitive load values at different points are used to recreate the dynamic behavioural models.

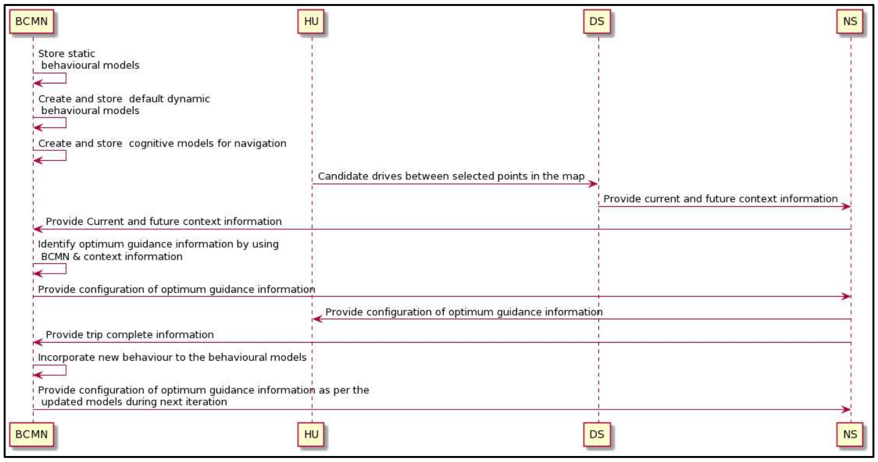

Fig. 3. Conducting human-in-the-loop experiments with BCMN enhancement

5 Visualization and Simulation for Cognitive Models for Navigation

Visualization of the created cognitive models in BCMN are very much necessary while conducting research as well as review of the cognitive process associated with navigation tasks. Visualization enables review and discussion of cognitive models in BCMN, with users who are not involved or familiarized with computer programming. But ACT-R based implementation of cognitive models uses LISP programming language and there is no visualization and simulation support are available out of the box which can be used by BCMN. Because of that, separate tools are developed for visualization and simulation of the created BCMN models, which are not directly a part of the BeaCON framework. The created tools cannot simulate all the ACT-R based functionalities, but it is extensively useful while visualizing and analyzing part of the cognitive models (i.e., Cognitive state during high speed and bad weather input). The cognitive models for navigation can be visualized and simulated by using the colored Petri net models created using the Petri net formalism, using the Graphical User Interface (GUI) provided by CPN Tools [17], since the design of the created cognitive models is aligned with Petri net based principles. An example of visualization of cognitive model (Part of the main model), which is responsible for creation of guidance information during bad weather and high-speed condition is given in Figure 4.

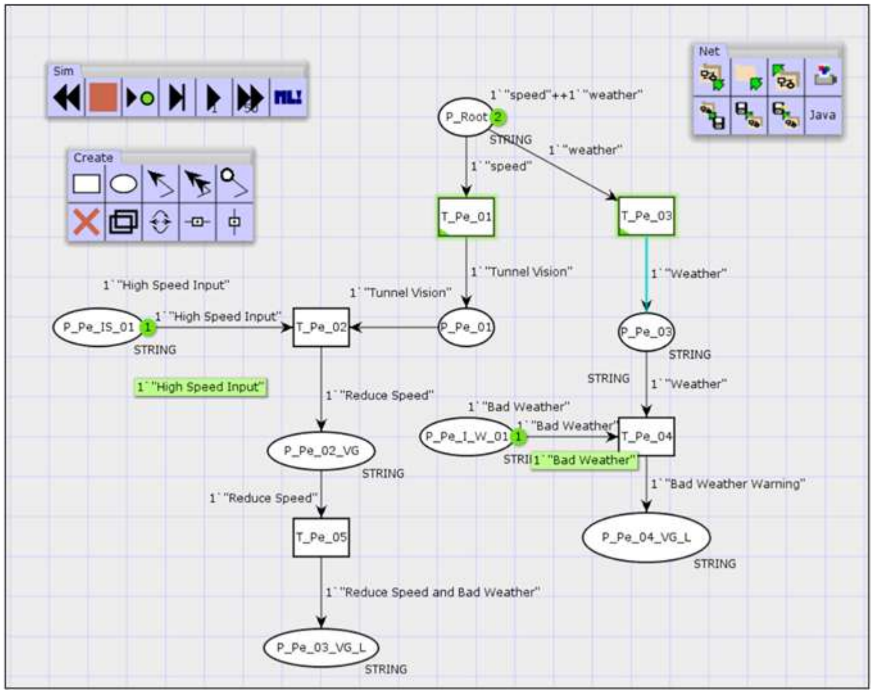

Fig. 4. Visualization and simulation of cognitive model for "*bad weather and high-speed condition*" using CPN tools

One of the drawbacks of GUI based modelling of cognition above is that the modelling is static, which means all the inputs to be visualized and simulated must be decided during the creation of the models. To solve this, a dynamic simulation facility is also created using a JAVA based custom tool. The GUI shown above in CPN Tools creates a Petri Net Mark-up Language (PNML) file which can be given as an input to this custom JAVA based library for parsing and simulating the NS behaviour along with cognitive model behaviour. A subset of Petri net based formalism called BCMNML (BCMN Mark-up Language) is defined which has to be followed while creating the cognitive models in the GUI for enabling subsequent use of JAVA based library for dynamic simulation. The JAVA based library provides more simulation facilities as well as provides API for giving simulation input dynamically, which is not supported in the static GUI based simulation. On the other hand, the GUI based static simulation increases the understandability of the cognitive models which can be used in the initial phases of development, review, discussion, and enhancement. JAVA based library also provides extensive logging facility which can be used to understand the cognitive model's behaviour for different input and different contexts. For example, the logs created for "Reduce Speed" voice guidance during the simulation of the BCMN cognitive model shown in Figure 3 is given below.

```
TRANSITION: Calling Arc T_Pe_02-P_Pe_02_VG from Transi-
tion T_Pe_02
ARC: Arc input T_Pe_02-P_Pe_02_VG input data [Reduce
Speed]
ARC: Arc expression checking T_Pe_02-P_Pe_02_VG Expres-
sion [Reduce Speed] And input [Reduce Speed]
ARC: Triggering arc expression for name T_Pe_02-
P_Pe_02_VG with expression [Reduce Speed]
ARC: Enabling T_Pe_02-P_Pe_02_VG
ARC: Setting triggered true for T_Pe_02-P_Pe_02_VG
PLACE: Setting token for P_Pe_02_VG with token [Reduce
Speed]
PLACE: Voice guidance P_Pe_02_VG with token [Reduce
Speed]
```

Once the cognitive models are created and reviewed using the visualization and simulation facilities above, mapping to the LISP programming language-based implementation in BeaCON is done manually because of the complexity involved for the mapping.

6 Experimental Results

Experiments conducted by making the users drive between two predefined points in BCMN enhanced BeaCON. Steering entropy [16] method with custom changes is used for cognitive load measurement as described in [1]. The cognitive state for navigation for the user, for different driving contexts are collected and verified with the state of cognitive models in BCMN. The transition of different cognitive model states in BCMN are also reviewed with the user cognitive states. The replay of the driving behaviour with the candidates indicate that the deducted reason for cognitive load is the root cause, as well as it is correctly modelled in BCMN. BCMN state transitions for a user driving a test route is given in Figure 5. Figure 6 indicates the BCMN state transition while driving through a familiar junction. The spikes shown in Figure 5 and Figure 6 indicate the high cognitive load points, where the root cause is identified as unfamiliar junctions on the test path as well as late guidance information. A custom-made location mapping tool, which is already a part of BeaCON [1] is used to map the cognitive load points to the location on the map.
The description about different cognitive states shown in Fig 5 is given below.

- **State 1:** Announcement is active
- **State 2:** Understanding the announcement
- **State 3:** Announcement listening is completed
- **State 16:** Waiting for next guidance information

The description about different cognitive states shown in Fig 6 is given below

- **State 7:** Identifying familiarity of the upcoming junction
- **State 11:** Recollecting the distance to the junction
- **State 12:** Junction is visible

- **State 13:** Preparing to take the junction
- **State 14:** Navigating the vehicle through the junction
- **State 15:** Navigating through the junction is completed

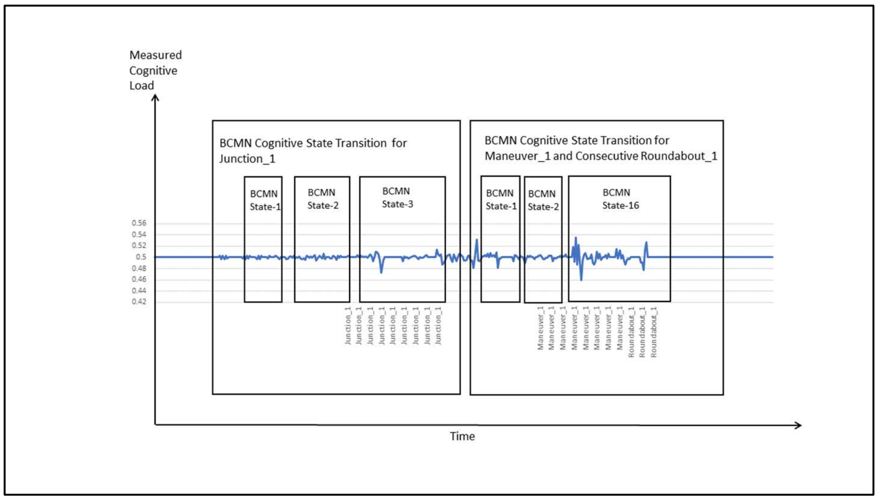

Fig. 5. BCMN state transitions while driving a test route with different EOIs

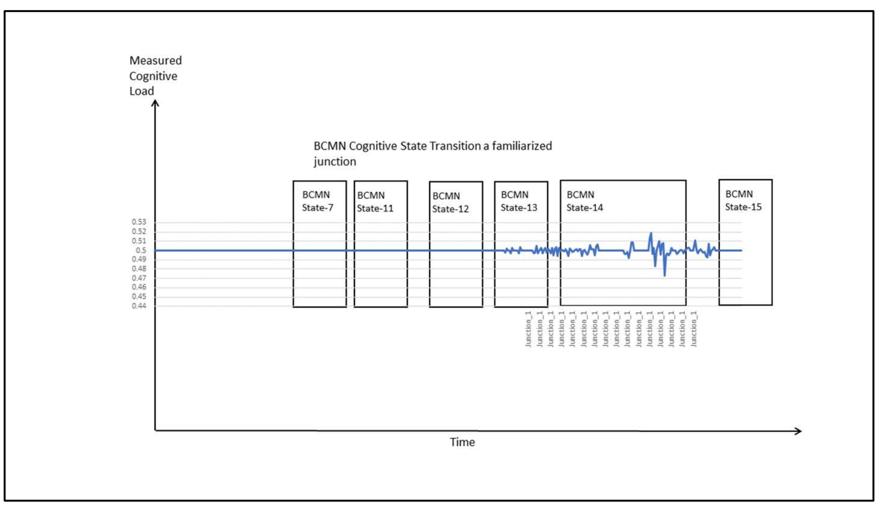

Fig. 6. BCMN state transitions while driving a test route with a familiar junction

Some of the facts deduced through the experiments conducted with BCMN enhanced BeaCON are given below.

- The cognitive load associated with a specific cognitive state also depends on the previous cognitive states in most of the scenarios.
- Cognitive load associated with cognitive state depends highly on the familiarity of the route.
- The time at which the guidance information is provided has an influence on the cognitive load associated with different cognitive states.
- Speed of driving in the test route has an impact on the cognitive load at different cognitive states. Even for familiar route, high speed indicated high cognitive load at different cognitive states.
- Cognitive load associated with the already crossed EOI has an impact on the cognitive load associated with the upcoming EOIs.

7 Conclusion and Future Work

The BCMN enhanced BeaCON for the analysis of the research problem "*Giving the driver adequate navigation information with minimal interruption*" is presented. The value addition by BCMN for the BeaCON framework for analyzing the research problem is presented as well as its importance is justified. Comparison with the state of the art is done as well as uniqueness of BCMN for analyzing human cognition state for navigation tasks is presented. The experimental results confirm that the integration of BCMN for BeaCON contributes significantly to the cognitive load detection and reduction. The visualization of cognitive models using the custom tools developed is presented, which increases the efficiency of research for BCMN enhanced BeaCON. Using the advanced ACT-R facilities, the created cognitive models in BCMN can be enhanced further, which can be considered for the roadmap of BCMN. Sub symbolic level activation of the chunks and utility-based rule selection shall be used for enhancing the cognitive model in BCMN. More experiments can be conducted with BCMN enhanced BeaCON for deducting more user behaviour data which can be used for reducing the cognitive load associated with different EOIs. Experiments can be conducted with different categories of user (i.e., Candidates with different level of driving experience) to identity the scenarios where the cognitive model in BCMN deviates from the cognitive state of the user and to correct the gaps identified in the cognitive model in BCMN.

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