ORIGINAL ARTICLE

COMPUTATIONAL MODEL OF SITUATION AWARENESS FOR ACTION PERFORMED IN DRIVING

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ABSTRACT

Driving is defined as a process of moving from one destination to another with the main aim to get to the destination safely. This study proposes a computational situation awareness model to assist drivers in effective performance of action based on his decision. The model incorporates cognitive factors that will influence action performance (yes/no) of the driver. To illustrate the proposed model, simulation scenarios based on overtaking maneuvers has been conducted. The experimental results show that the external factors attention and expectation have contributed to the effect on the safe and risky driving behavior and by suggestion on the driver's action to perform the overtaken maneuvers based on his decision. Moreover, this model has been verified using an automated verification tool by checking its traces with the existing results from the literature.

Keywords: Computational Models, Situation Awareness Model, Performance of Action, Driving

INTRODUCTION

Driving is simply defined as a process of moving from one destination to another with the main aim to get to the destination safely. The idea of situation awareness has been recognized as a significant contributor to the quality of decision-making in computational modeling[1] and in complex, dynamic changing environments[2-3]. Decision making is an essential cognitive process of human behaviour whereby an ideal alternative is chosen among options established on certain standards[4-6]. Each decision-making process yields a final choice that may or may not prompt performance of action.

Based on the review of previous studies, it is observed that course of action and it evaluation in driving has not been considered in modeling the situation awareness (SA). To address this, this paper proposes a generic computational model which integrates related factors based on cognitive and psychology theories to describe basic decision making and it evaluation to see the possibility for its implementation which is tested in driving domain. That is, it explores the effect of attention and expectation on the safe and risky driving behavior, and its relation towards driver's confidence level to perform over-taking maneuvers and the possibility of the action implementation.

METHODS

Underlying concepts of SA

Before explaining the underlying concepts of SA, there is a need to highlight the related studies on computational model of situation awareness in dynamic environments. The studies (Rao & Georgeff[7], So & Sonenberg[8], [9]Hoogendoorn, et al., [1]Aydoğan, et al.,) designed computational models of SA that was applied on air-traffic management domain, meta-level control strategy, F-16 fighter pilot training and in airline operation control domain respectively. [10]Bosse, et al., also present a computational model of situation awareness and it is the extension of [9]Hoogendoorn et al. This model integrated qualitative time references, which offer the option to use temporal relations [11](Allen, 1981), and is a clear representation of situation awareness model[12]. The model has been tested by simulating it behavior in a simulation environment for F-16 fighter pilots.

Based on the review of the related literatures, the present study discovered some important dynamic factors from cognitive and psychological theories related to the decision confident for effective decision-making and action performed (yes/no) in dynamic environment such as driving are lacking. Based on the proposed model in Figure 2, the various elements to be observed by the driver in driving environment can explained as follows: Road (r), the road type, and it nature (dry, wet)[13] whereby the car moves on. Traffic (f), the density in terms of cars per mile or km and the congestion in the traffic[13] may be observed as the car moves on the road. Obstacles (b), the different complications that may be found along the road, such as stationary vehicles, and other objects which are classified as static and dynamic [12,14].

Car condition (c), the status of the car; for example the engine may be faulty/good[12,14].

The Visibility[13] (v), consist of the weather condition (clear/cloudy and rainy) may be observed on the road and the light condition (day/ night time) whereby the driving take place.
The various concepts that explain the relationship between the interacting factors of the model is outlined in Table 1.

Table 1 - Concepts in SA Model

Concept	Formalization	Description	Related Theory
Environment	*En*	The surrounding in which the car and the driver operate	SA[12,14]
Attention	*An*	The cognitive and behavioural process.	SA[12,14]
Expectation	*Ep*	Driver's anticipation of the driving environment	SA[12,14] & RPD[15]
Automaticity	*Am*	Ability to act/react to a situation automatically in a driving environment.	SA[12]
Observation	*Ob*	Ability to perceive elements in a driving environment.	SA[12,14] & CSA[9]
Belief Formation	*Bf*	Ability to form certainty of the observation made.	CSA[9]
Belief Activation	*Ba*	Ability to translate the certainty of the observations into activation values of beliefs.	CSA[9]
Decision	*Dc*	Cognitive process resulting in the selection of a course of action.	SA[12,14] & CSA[9]
Performance of Action	*Pa*	Implementation of the decision taken by the driver	SA[12,14] & RPD[15]

Computational model of SA

This section describes the details of the model in mathematical specifications. Computational model is a concept used in SA theory for observation, comprehension, projection and communicating the theory with the aim of checking whether the perceptions about the behaviour from theory matches the actual behaviour in real life environment[16-17]. This model is presented in Figure 1 and Figure 2 respectively. Figure 1 represents the generic structure of the model. In this figures it can be seen that the model consist of several interrelated nodes. Once the structural relationships in the model have been determined, the models can be formalized. In the formalization, all the nodes are designed in a way to have value ranging from 0 (low) to 1 (high).

The proposed model consists of several instantaneous relations and a single temporal relation, which will be explained in detailed below.

Instantaneous Relationships:

$Or(t)=a_{Or}.Ar(t)$ **(1)**
$Of(t)=a_{Of}.Af(t)$ **(2)**
$Ob(t)=a_{Ob}.Ab(t)$ **(3)**
$Oc(t)=a_{Oc}.Ac(t)$ **(4)**
$Ov(t)=a_{Ov}.Av(t)$ **(5)**

Equations (1) to (5) are the formalization for computing the driver's observation of the various elements in the driving environment with respect to parameter a ($0 \le a \le 1$) is used to denote the level of observations.

$Fr(t)=Or(t).Er(t)$ **(6)**
$Ff(t)=Of(t).Ef(t)$ **(7)**
$Fb(t)=Ob(t).Eb(t)$ **(8)**
$Fc(t)=Oc(t).Ec(t)$ **(9)**
$Fv(t)=Ov(t).Ev(t)$ **(10)**

Therefore, equations (6) to (10) represent the formalization for computing the driver's beliefs formation of those observed elements. Later, the belief activation (Bs) for safe condition is represented by logistic sigmoid function as shown in equation (11) below.

$$Bs(t)=\frac{1}{1+e^{(-\beta(P))}} \quad \textbf{(11)}$$

Where, $P = (w_1.Fr\ (t) + w_2.Ff\ (t) + w_3.Fv\ (t)).(1-w_4.(1-Fc\ (t)))(1-w_5.Fb\ (t))$

Beliefs activation for risky condition (Br) is represented by logistic sigmoid function as shown in equation (12) below.

$$Br(t)=\frac{1}{1+e^{(-\beta(1-(Q)))}} \quad \textbf{(12)}$$

Where $Q = (w_6.Fr\ (t) + w_7.Ff\ (t) + w_8.Fv\ (t))(1-w_9.(1-Fc\ (t)))(1- w_{10}.Fb\ (t))$

With β represents steepness parameter of the logistic function (steepness of the curve at that point). w_1 to w_{10} denotes weights of the observed elements from the driving environment; w_1 to w_5 are weights of the observed elements that form belief activation for safe conditions while w_6 to w_{10} are weights of the observed elements that form belief activation for risky conditions. Different weights are assigned to each of the weights w_1 to w_{10}, based on priority. Priorities were given to certain factors based on the importance that have been assigned to them. The weights are form as a result of the certainty of the driver's (agent) observation himself; although there could be situations in which an observer (agent) does not trust its observations fully (e.g. when the agent is stressed) and these weights may be assigned according to the extent to which the agent is inclined to trust those information sources[3]. Equations (1) to (12) are representing the instantaneous equations because they give the resultant process that led to the temporal equation.

Temporal Relationship:

Decision making *(Dc)* mainly contributed towards the accumulation of belief activation for safe conditions *(Bs)* and deducting the accumulation of belief activation for risky conditions *(Br)*.This is presented using the equation (13) shown below.

$$Dc\ (t+ \Delta t) = Dc\ (t) + \gamma.\ ((Bs\ (t) - Br\ (t)) - Dc\ (t)).Dc\ (t).\ (1-Dc\ (t)).\Delta t \quad \textbf{(13)}$$

The formalization computes the decision making of an automobile driver. The confidence level of the driver to decide can be classified within the range of 0 to 1 and can be explained using an overtaken scenario as shown in Table 2.

Table2 - Classification of confidence level to make decision

Confidence Level	Situation	Decision
0	dangerous	Driver should not overtake.
0.1 - 0.2	bad	Same as above
0.3 - 0.4	fairly bad	Not advisable to overtake.
0.5	average	Starting point.
0.6 - 0.7	fairly good	Advisable to overtake but with caution.
0.8 - 0.9	good	Driver can overtake.
1	very good	Driver can overtake perfectly.

Klein[15] argued that when the course of action is selected (decision), the action performed is evaluated through mental simulation to see if it will work or not yes/no. If yes the action performed is implemented, if No then otherwise. Note that the external factors are attention, expectations and automaticity of the automobile driver. They determine the outcome of the whole processes. The rate of change of temporal specification is determined by flexibility rate (γ), the regulating parameter represented as automaticity in the simulation and it represents the update speed parameter for decision. This change process is measured between t and $t + \Delta t$.

The methodology of the proposed model will be based on agent based simulation methodology framework by [18]Drogoul, Vanbergue, & Meurisse (2002). This decentralized methodology is applicable for formal representation because of complex and dynamic nature of driver behaviour. These authors discovered the relationships between computational agents, as found in multi-agent systems (MAS) or Distributed Artificial Intelligence (DAI), and the different techniques reformed under the generic name "multi-agent based simulation" (MABS). Their main target showed that MABS, despite its name, is in fact rarely based on computational agents. Therefore, the methodology of this paper can be summarized into three stages, namely: construction, simulation and evaluation. Each of these stages has different activities to achieve each stage objective.

Construction Stage

This stage consists of three components: The domain, the design and the operational.

The domain stage: This involves identification of various factors of the computational model based on cognitive and psychological theories from literatures.

The design stage: This stage is where the identified factors obtained from literatures are put together to obtain the design model otherwise known as a conceptual model. The relationship between those factors can be represented using flow arrows.

The operational stage: At this stage, the conceptual model consists of dynamic factors that interplay based on literatures. These factors can be formalized using ordinary differential equation (ODE) to form mathematical functions (equations). Those equations formed are called the computational model and the process to obtain the computational model otherwise known as operational model by translating the design model to the formal representations is called formalization.

Simulation Stage
The simulation will be implemented in a numerical simulation environment and then be verified by testing using suitable numerical analysis programming language such as MATLAB.

Evaluation Stage
The evaluation stage will be done to ensure that the model and simulations are correct and reliable. Verification is one of the evaluation methods used to ensure that the model implementation accurately represents the developer's conceptual description of the model and the solution to the model. Similarly, automated verification based on several properties utilizing the Temporal Trace Language (TTL) modal logic to check either the outputs are following the current cases in the literature is use in this paper. This language allows formal specification and analysis of dynamic properties; it is either a qualitative or a quantitative representation.

RESULTS

This section illustrates the mechanism of the proposed model whereby three scenarios are simulated showing the effect of attention and expectations of an automobile driver on the safe and risky driving conditions behavior; and on his confidence level to make effective decision to perform an overtaken maneuvers based on factors to be observed and the possibility of implementing the action performed as shown in Table 4. All the simulations conditions are based on the input values of the five input factors (*road, traffic, obstacles, car condition* and *visibility*). In this simulation we used the following settings: time steps with t_{max} = 500 which is segmented into four frames; f1, the 1^{st} time frame $(0 \le t < 125)$; f2 the 2^{nd} time frame $(0 \le t < 250)$; f3 the 3^{rd} time frame $(0 \le t < 375)$; and t4, the 4^{th} time frame $(0 \le t < 500)$ respectively and $\Delta t = 0.3$, $\gamma = 0.5$, $\alpha = 1$, $\beta = 1$.
These settings were obtained from a number of experiments to determine the most suitable parameter values for the model. From Table 3, e.g., 1 means good and 0 means bad for all the factors except obstacle. The simulation results for these three scenarios are shown in Figure 3, Figure 4 and Figure 5. The simulation results for the three scenarios shows the level of safe and risky driving conditions of an automobile driver, his confidence level to decide to perform the overtaken manoeuvre at each time frame and the action performed implementation based on the decision taken.

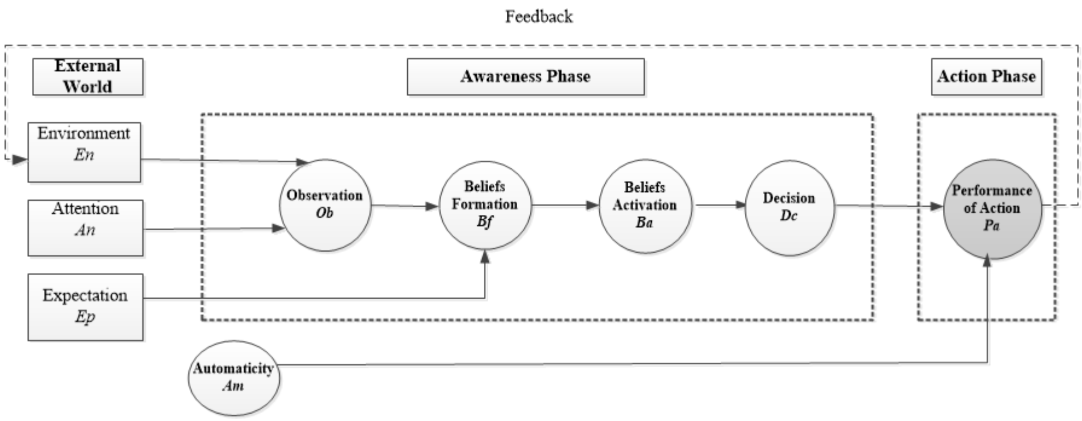

Figure 1: Generic Model of Situation Awareness

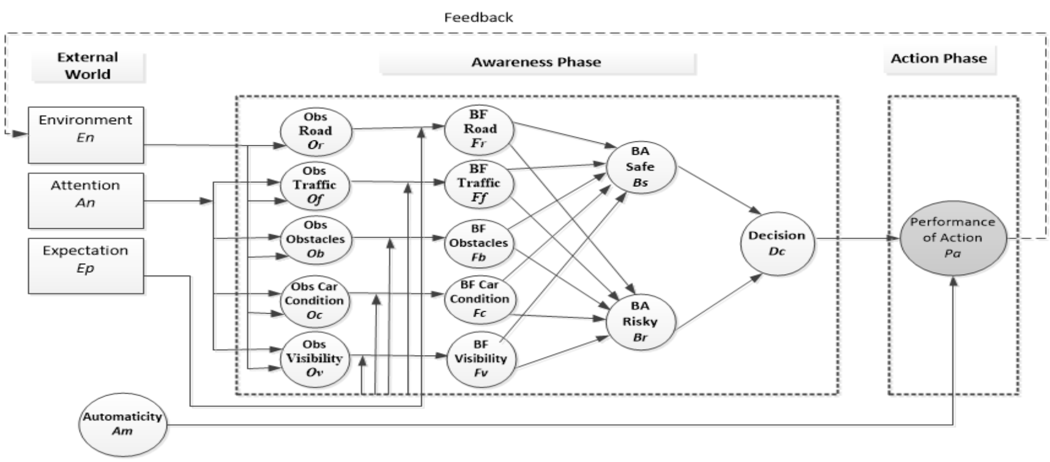

Figure 2: Model of Situation Awareness in Driving Domain.

Table 3 - The SA Model Conditions

Scenarios	Factors	Time Frame Steps			
#1		f1	f2	f3	f4
	Road	0	0	1	0
	Traffic	0	1	0	0
	Obstacles	1	0	0	1
	Car condition	1	1	1	0
	Visibility	0	1	1	0
#2					
	Road	1	0	1	0
	Traffic	0	0	1	1
	Obstacles	1	0	0	1
	Car condition	0	1	0	0
	Visibility	0	1	0	0
#3					
	Road	0	0	0	0
	Traffic	0	0	0	1
	Obstacles	1	0	0	0
	Car condition	0	1	1	1
	Visibility	1	1	0	1

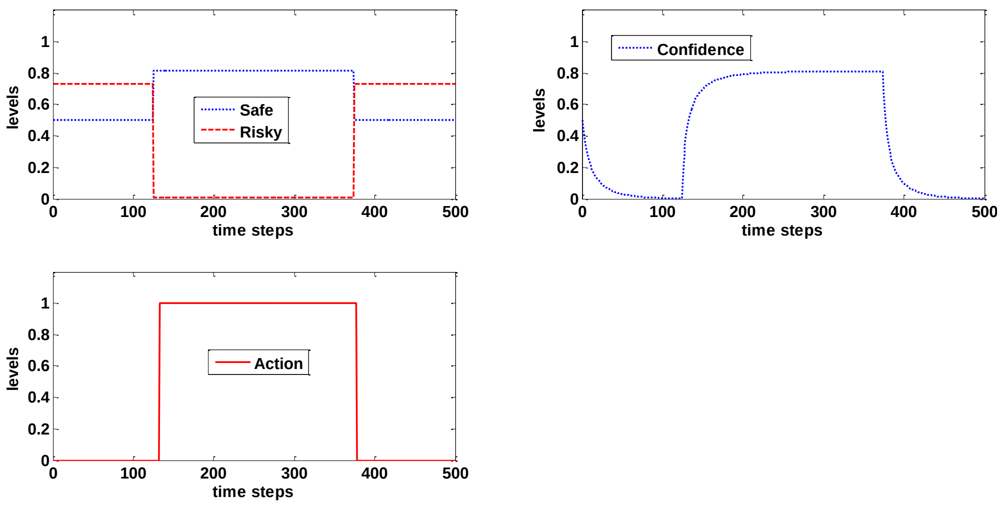

Figure 3: Simulation Conditions Result (for scenario #1)

Scenario #2: High Risk

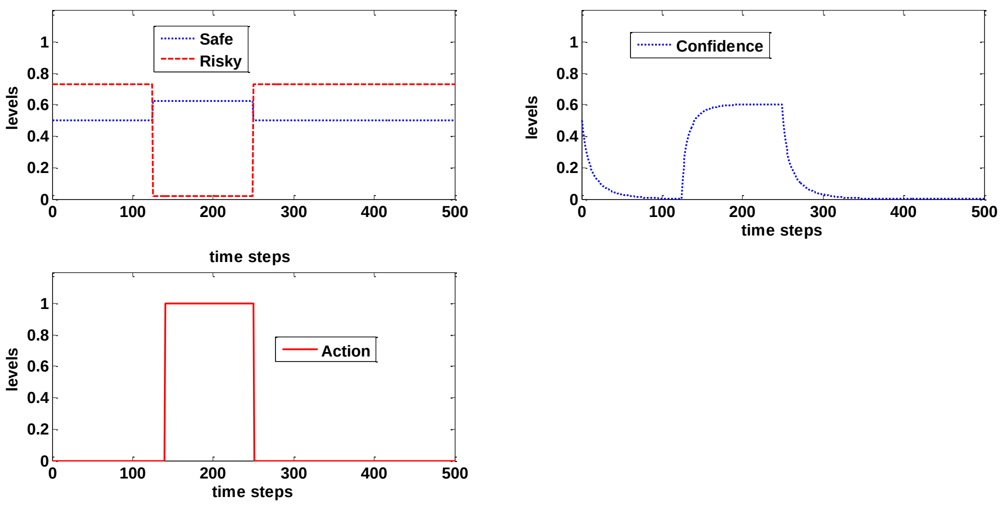

Figure 4: Simulation Conditions Result (for scenario #2).

Scenario #3: Moderate Risk

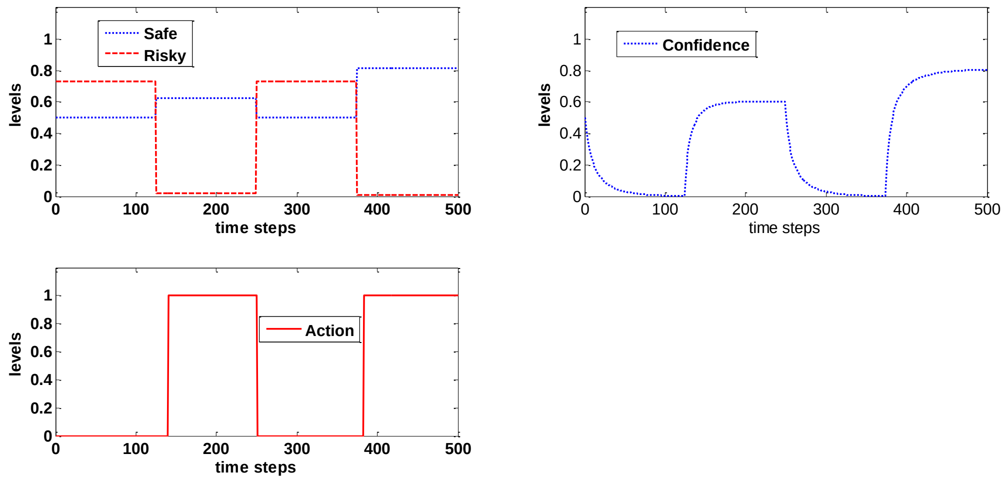

Figure 5: Simulation Conditions Result (for scenario #3)

DISCUSSION

Scenario #1: Low Risk
At the first time frame, the level of risky increased while the level of safe decreased and the driver had low confidence level to decide, based on that, his action performed is No (0). In the 2nd and 3rd, the risky level decreased to the based-line (0) while the safe level increased and the driver's confidence level increased, based on that, his action performed is yes (1) for both time frames. At the 4th, the level of risky increased and the level of safe decreased and the driver's confidence level declined to the base line hence, his action performed is No (0) as shown in figure 3.

Scenario #2: High Risk
At the first time frame, the level of risky increased while the level of safe decreased and the driver had low confidence level to decide and based on that his action performed is No (0). In the 2nd, the risky level decreased to the based-line (0) while the safe level increased and the driver's confidence level increased, based on that his action performed is yes (1). In the 3rd and 4th, the level of risky increased while the level of safe decreased and the driver's confidence level to decide declined to the base line hence, his action performed is No (0) for both time frames as can be seen in figure 4.

Scenario #3: Moderate Risk
The level of risky increased while the level of safe decreased and the driver had low confidence level to decide and based on that his action performed is No (0) for the first time frame. In the 2nd, the risky level decreased to the based-line (0) while the safe level increased and the driver's confidence level increased, based on that his action performed is Yes (1). In the 3rd, the risky level increased while the safe level decreased. The driver's confidence level to decide at that point declined to the base line hence, his action performed is No (0). At the 4th time frame, the level of safe increased while the level of risky decreased to the base line and the driver's confidence level inclined hence, his action performed is Yes (1) as shown if figure 5.

EVALUATION

In order to verify whether the model indeed generates results that adherence to related situational awareness literatures, a set of properties have been identified from related literatures. Therefore, these properties will answer whether the model produces results that are coherent with the literature. A typical example of a property that can be explored and checked whether there is no unexpected conditions occur (e.g. boundary testing; *Belief formation* < 0 or *Decision* > 1) In addition, by executing a large number of simulations and verifying these properties against the resulting traces, we can easily identify potential logical errors.

To allow the verification process to take place, these properties have been specified in a language called Temporal Trace Language (TTL). TTL is built on atoms referring to states of the world, time points, and traces[19]. This relationship can be presented as a *state* $(\gamma, t, output(R))|=p$, means that state property *p* is true at the output of role *R* in the state of trace γ, at time point *t*. For this purpose, special software has been developed for TTL, featuring both a property editor and a checking tool that enables formal verification of such properties against a set of simulated traces. Number of simulations including the ones described in previous sub-section have been used as basis for the verification and were confirmed.

VP1: Monotonous Decrease of Confident Level during Risky Conditions

∀γ:TRACE, t1, t2:TIME, V1,V2,V3,V4, d:REAL, X:AGENT
[state(γ, t1) |= belief_risky(X, V1) & state(γ, t2) |= belief_risky(X, V2) & state(γ, t2) |= confident(X, V3) & t1 < t2 + d & V2 > V1] ⇒V3≤ 0.2.

VP2: Variable v1 Above v2

For all time points *t* between *tb* and *te* in trace γ if at *t* the value of *v1* is *x1*, and the value of *v2* is *x2* then minimum *x*1 ≥ *x*1.

VP5≡ ∀γ: TRACE, ∀t, tb, te:TIME, v1,v2:VAR, x1,x2:REAL [state(γ,t)|= has_value(v1,x1) & state(γ,t)|= has_value(v2,x2) & tb ≤ t ≤ te ⇒ x1 ≥ x2

Property P2 is used to verify whether a variable value stay above another variable value during a specified interval. For example, during the formation of confidence, the belief about risky should never exceed belief about safety.

VP3: Bad Car Condition Decreases Confident Level

∀γ:TRACE,t1,t2:TIME,R1,R2,R3,R4,d:REAL, X:AGENT

[state(γ,t1) |= car_condition(X, R1) & state(γ, t2) |= confident(X,R2) & state(γ,t2)|= car_condition(X, R3) & state(γ,t2)|= confident(X, R4) &

t1 < t2 + d & R1 > 0 & R1 > R3] ⇒R2 > R4

VP4: Variable v Between Boundaries

For all time points *t* between *tb* and *te* in trace γ if at *t* the value of *v* is *x*, then minimum value <*x* < maximum value.

VP2≡ ∀γ: TRACE, ∀t, tb, te:TIME, v:VAR, max, min:REAL [state(γ,t)|= has_value(v,x) &

tb ≤t ≤ te ⇒min < x < max

This formal specification can be used to check whether a variable stays between certain observed boundaries. For example, attention and belief activation should never become lower than 0 or higher than 1.

CONCLUSION

This paper proposed a computational model of situation awareness that help drivers in making effective performance of action based on his decision. The model is later formalized and simulated based on scenarios. The contributions of this paper are as follows. Apart from the computational model for SA that incorporates cognitive factors. Scenarios to evaluate the applicability of the model in real life domains have been conducted. It has shown for the given scenarios that the external factors attention and expectation have significant effect on the safe and risky driving behavior and by insinuation on the driver's confidence level to make decision and the possibility of implementing the action performed (yes/no). Lastly, the verification of the model has also been achieved. Our next step is to incorporate training for cognitive factors that will evaluate the performance of action of the experienced driver into the model.

ABBREVIATIONS

SA-Situation Awareness, RPD-Recognition Prime Decision, CSA-Cognitive Situation Awareness.

COMPETING INTERESTS

There is no conflict of interest.

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