A COMPREHENSIVE DRIVER BEHAVIOR MODEL FOR THE EVALUATION OF INTELLIGENT INTERSECTIONS

T. W. (Nina) Schaap¹*, Bart van Arem²
1, 2. Applications of Integrated Driver Assistance, Centre for Transport Studies, University of Twente.
*P. O. Box 217, 7500 AE Enschede, the Netherlands. +31 53 489 4361, T.w.schaap@utwente.nl

ABSTRACT

Many traffic problems occur on urban intersections. Advanced Driver Assistance Systems aim to solve these problems. However, their effects cannot be deduced directly from observing normal driving behavior, because adding a system alters the driving task. A model must be used to represent both normal intersection driving and interaction with ADAS. By using the structure of the driving task, it becomes possible to extend driver models beyond single subtasks. Five modeling tools have been reviewed; none fully fit all reviewing criteria. Nevertheless, we select a promising research approach based on a combination of tools, specifically using a Multi-Agent Systems framework. (precies 100 woorden)

KEYWORDS

Driving behavior modeling, intersection, ADAS

INTRODUCTION

With ever growing levels of traffic, many problems have also grown. For instance, traffic accidents for 2004 in the Netherlands are estimated to have cost the Dutch society over € 7.6 billion [1]. Congestion, pollution and driver fatigue are just some of the other challenges faced by transport engineers. Although much of the research on solving these problems so far has been focused on the primary road network, urban areas should not be forgotten. This is especially true for urban intersections, where the problems identified earlier become very clear. Not only do 38.5% of all traffic accidents leading to injuries occur on urban intersections [2], but these intersections are also the bottlenecks of the urban road network, when focusing on capacity and traffic flow. Therefore, addressing traffic problems should focus strongly on urban intersections.

Both in research and in industry, there are many ideas on how to solve these complex problems. One of the options is to use in-car information and support systems, in certain cases combined with infrastructure-based systems, to support the driver in his driving task. These Advanced Driver Assistance Systems (ADAS) are believed by many to be the
necessary next step to safer and more efficient traffic and transport (e.g., [3, 4, 5]). With the support of these ADAS, drivers are supposed to handle conflict situations better and feel more comfortable when driving. However, one difficulty with these estimations is that the effects of ADAS can only be seen after they have been implemented. On the one hand, many believe that traffic accidents will become less common and less severe with the use of ADAS: some estimate that the number of collisions will decrease by as much as 69% when using an intersection collision warning system [6]. On the other hand, some researchers dispute the extent of such positive effects, especially when ADAS are first implemented. For example, Janssen et al. [7] predict that the introduction of automated support systems will lead to counterproductive adaptations to the support system, such as more risk-taking behavior and decreased alertness in drivers, and to increased accident severity, before it could lead to the positive effects predicted by others. These predictions are supported by results from a driving simulator study with Intelligent Speed Adaptation (ISA), conducted by Comte [8]. She found that drivers showed riskier behavior when the ISA system was operational.

The fact that the effects of ADAS are not completely known is a serious drawback for their deployment. Therefore, we have to investigate carefully whether the concepts that have been developed will work, before we can fully commit to introducing them on the market. To do so, there are three steps that need to be taken. First, we need a decent description of normal driving behavior, which includes at least a partial explanation of the main internal processes (decision making, attention, perception) that are crucial in the task of driving. This description could then be put into a behavior simulation model. Second, we have to determine how adding a new system to the car alters the whole driving system, and thus the driving task. And third, we have to incorporate the adaptation to this altered driving task into our simulation model. We can then draw conclusions on the effects of the particular system on traffic safety, traffic efficiency and other transport factors.

As this paper is focused on the modeling of behavioral adaptation to intelligent intersections, the first step is therefore to describe the task of driving on urban intersections.

**MODELING INTERSECTION DRIVING**

As will become apparent in the following sections, intersection driving is a very complex task. A valuable tool when describing and explaining such a complex task is a behavior simulation model, a computer-based representation of task performance.

To model intersection driving, we first need an accurate description of driving behavior. There has been a lot of research into this topic. Driving behavior has been described by several normative and motivational models, as well as models that describe the risk factors in driving styles and personality. A good overview of driver models can be found in [9]. Furthermore, [15] is an extensive task analysis of driving, describing all the actions that are involved in driving a vehicle. But however valuable all these representations are, they cannot serve as a complete model for the purpose at hand, or even as a guideline for developing such a model. We need to describe and explain in detail both normal driving behavior *and* the new behavior that would be induced by adding an in-car information or support system, and thus altering the system. Furthermore, not only a small subtask of driving, but the whole structure of the task should be described in a comprehensive driver model. Only in that way can we determine the effects of ADAS on traffic safety, traffic efficiency and the environment. First, let us look more closely at the task of driving and the way it is performed.
Driving task hierarchy

In [16], driving is described as a hierarchical task with three layers: strategic, tactical and operational. At the strategic (navigation) level, route choices are made and the journey is planned. This is where the driver sets his/her goals. The tactical (maneuvering) level is the level at which the driver tries to get to these goals through maneuvering the vehicle. Here, interaction with other road users and the road layout takes place. An example of an action on this level is taking a right turn. On the operational (control) level, the driver controls the vehicle. This includes steering and handling the clutch and car controls.

These levels of the driving task always interact. In normal driving, this interaction takes place in a top-down manner. Before starting his trip, the driver decides he wants to go somewhere and thus defines his goals for the trip and the route to take. This trip planning is a strategic level task. From this route and travel goals, decisions about desired speed, which way to turn and how to behave in relation to other road users can be inferred. These are all decisions about tactical level tasks. Obviously, the tasks on the tactical level influence operational tasks: turning left in a sharp bend entails turning the steering wheel far to the left, and slowing down. In this way, strategic (higher level) tasks influence tactical (middle level) tasks, which in turn influence operational (lower level) tasks. This is why we call this top-down interaction.

Bottom-up interaction is also possible. Whereas top-down interaction happens continuously in normal driving, bottom-up influence takes place when the driving situation differs from the expectations of the driver [16]. This can occur at all the levels of the driving tasks. For instance, route planning (strategic task) can be changed by the fact that a street is blocked and the desired turn can therefore not be made (tactical task). Also, correcting the vehicle’s movements on a slippery road (operational task) can influence tactical level tasks, such as keeping the proper distance to a car in front or going the correct way on an intersection.

Rasmussen’s [17] theory on performance control states that a task can be performed at three levels of control: the knowledge-based, rule-based and skill-based level. On the knowledge-based level, performing the task requires a lot of effort and attention. All steps have to be defined through feedback (closed-loop control) and reasoning. On the rule-based level, actions are performed in a more automated way. Once a rule is chosen and initiated, the related sequence of steps is performed without reasoning about it. This happens when the task becomes more familiar. Finally, when a (sub)task becomes very familiar, it is carried out completely automatically. One is then performing on the skill-based level. These performance levels are very much linked to Michon’s [16] task hierarchy of driving. The more often a certain task is performed, and the simpler it is, the less mental effort it takes to perform the task – the task will be performed more automatically. Lower level task hierarchy tasks such as steering or braking, are therefore often handled in a rule-based or skill-based way, at least for experienced drivers. Novice or inexperienced drivers may still need to think about every step, and may therefore perform more tasks on a knowledge-based level.

Finally, three stages of information processing can be distinguished for the driving task[18]. These are selection, processing and action. The level of automation changes the importance and type of information processing, but the three stages occur at all the hierarchical levels of the driving task.

Together, these three types of defining the driving task constitute a 3-dimensional matrix in which all driving tasks can be organized. This matrix is depicted in Figure 1.
This three-dimensional structure of the driving task shows the complexity of intersection driving: all task levels, performance levels and information processing stages come together in this task. Route choice, interaction with the environment and handling the vehicle are all necessary at the same time in this situation, with some requiring more mental effort than others. As has been described before, all levels in this matrix also interact. Therefore, describing and explaining this task is a difficult but important goal in driving behavior research. Without taking into account this interaction, all models will stay on the level of single subtasks. The described structure of the driving task should therefore be used as a guideline for any comprehensive model of driving behavior that intends to model driving as a whole.

Simulation models for intersection driving

In this paper, we present an overview of some of the current simulation models for driving on urban intersections. A review of these tools will show the opportunities for modeling the task of driving and its structure, instead of modeling single subtasks.

The five models that we review here are selected based on the following properties: they are widely used, they represent more than one level of the driving task, or their application area is very flexible. We selected models that, in our judgment, together cover the wide range of intersection driving models. The list of reviewed models can be found in Table 1. Unfortunately, no information was available about some commercially used models, such as certain driving simulator software models.

Cognitive architecture - Cognitive models describe the cognitive processes that lead to the eventual driving behavior. Sometimes, cognitive architectures also take into account the physical characteristics of human operators. An example is ACT-R, which can represent perceptual, cognitive and motor actions [19]. The ACT-R driver model [20] uses production rules, factual information and a simulated world as input, and produces behavior as output.

Optimal Control Model (OCM) - This model represents human-machine interaction behavior of the human operator, with feedback and open-loop control cycli [21]. It is a stochastic model, proposing the action with the highest probability.
Multi-agent system (MAS) - The represented world is divided into objects (such as cars, drivers, trees, roads etc), represented by agents which are either static or acting. Some agents can work together: for instance, parts of a vehicle can be represented as individual agents with predefined behaviors, together forming a car. Together, the agents represent the driving environment and the driver. In MARS [22], the driving task is represented in four layers: control, maneuvering, strategic and navigation layers. These have their own actions and goals, but they can also interact. The control layer controls the vehicle-unit.

Hidden Markov Model (HMM) - In a HMM, a prediction of driving behavior is made by a chain of model states. The first learning phase consists of learning a large number of input-output relations: environmental factors and outcome behavior. The Markov chains take certain values, representing the internal state of the actor. After this learning phase, the model can give the probabilities of different driving behavior and actions, based on the input given to it. A Hidden Markov Model is a black box, giving minimal information about the internal processes constituting the final behavior. A HMM driver model is described in [23].

Microscopic traffic simulation model - A microscopic traffic simulation model represents the performances of an entire network, showing driver-vehicle units as particles on the road network. Their behavior is set by behavioral rules, defining for instance car-following and gap-acceptance behavior. The microscopic traffic simulation model MIXIC [24] contains a detailed model of driver behavior. It can be used independently to model driving behavior.

MODEL REVIEW

Reviewing criteria

The ultimate purpose of our research is to develop a simulation model of intersection driving behavior, which can be used to evaluate in-car systems and their consequences on traffic flow efficiency, traffic safety and the environment. The model could also be implemented in simulator software or in ADAS. Therefore, it needs to meet a number of constraints. To fully represent driving behavior on intersections, all three levels of the driving task [16] should be incorporated into the model, as well as the interaction between these levels. For the model to function as part of a microscopic traffic simulation model, the calculation speed should be fast and the model should run in real-time. The model’s application area should be urban intersections. Its predictions should include behavioral adaptation to ADAS, and explain where this adaptation arises. The complete set of constraints and other model reviewing topics is as follows:

1. What is the calculation speed of the modeling tool?
2. To what extent are the inherent limitations of human operators, such as errors, lapses and physical limitations, taken into account in the model?
3. Which actions and tasks of driving on an intersection are represented in the model?
4. To what extent are workload and attention represented in the model?
5. To what extent can the model explain how behavior and behavioral adaptation occurs?
6. Which levels of the task are represented (Strategic (S), Tactical (T), Operational (O))?
7. To what extent is the interaction between the three levels of the driving task represented?
8. To what extent and for which situations has the model been validated?
9. Which part of the road network is represented?
10. Does the model account for slow traffic (such as bicycles, pedestrians, etc)?
11. Can the model interact with ADAS?
12. Can the model be applied to a different traffic situation than it is designed for?
13. How much effort is needed to create a valid intersection driving model?¹
14. Is the model stochastic?

**Review of modeling tools**

In this section the optimal combination of modeling tools will be selected to create a comprehensive model of intersection driving.

<table>
<thead>
<tr>
<th>Model</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACT-R</td>
<td>Visualization max real-time. Calculation faster</td>
<td>+</td>
<td>Longitudinal, lane keeping, curve negotiation, lane changing, driver distraction</td>
<td>+</td>
<td>+</td>
<td>S, T, O</td>
<td>+</td>
</tr>
<tr>
<td>OCM</td>
<td>Real-time</td>
<td>+</td>
<td>Longitudinal, lane change, free driving</td>
<td>+</td>
<td>+</td>
<td>O</td>
<td>-</td>
</tr>
<tr>
<td>MARS</td>
<td>Visualization max real-time. Calculation faster</td>
<td>- (optional)</td>
<td>Longitudinal, interaction with other road users</td>
<td>- (optional)</td>
<td>+</td>
<td>S, T, O</td>
<td>+</td>
</tr>
<tr>
<td>HMM</td>
<td>Real-time, UTV</td>
<td>Longitudinal</td>
<td>-</td>
<td>-</td>
<td>T</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>MIXIC</td>
<td>Real-time</td>
<td>+</td>
<td>Longitudinal, lane change, free driving</td>
<td>-</td>
<td>+</td>
<td>T, O</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACT-R</td>
<td>+</td>
<td>Highway</td>
<td>- (optional)</td>
<td>- (optional)</td>
<td>++</td>
<td>--</td>
<td>+</td>
</tr>
<tr>
<td>OCM</td>
<td>+</td>
<td>Highway</td>
<td>-</td>
<td>- (optional)</td>
<td>+</td>
<td>--</td>
<td>+</td>
</tr>
<tr>
<td>MARS</td>
<td>-</td>
<td>Intersection, highway</td>
<td>-</td>
<td>- (optional)</td>
<td>++</td>
<td>-</td>
<td>-(optional)</td>
</tr>
<tr>
<td>HMM</td>
<td>+</td>
<td>Intersection, UTV</td>
<td>- (optional)</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>MIXIC</td>
<td>+</td>
<td>Highway</td>
<td>-</td>
<td>Yes, ACC</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The ACT-R model meets most of the criteria. The driver model [20] only represents driving behavior on highways, but all types of human behavior can be modeled with this architecture. One important drawback is that the visual module may not (yet) be able to handle all the relevant visual information properly. Because the model goes very deep into the cognitive

¹ The architecture of a model can provide options for developing certain types of model, but creating a valid model might take substantially different amounts of work for different types of models. This depends on the amount and contents of the assumptions that have been made and the level of implementation.
processes, all aspects should be modeled very precisely. Therefore, a limited visual model is not a good base for interaction modeling.

OCM is fast and models driving on highways validly, but it does not represent intersection driving. Its flexibility at this point is not high enough, due to a number of assumptions regarding highway driving. Driving is implemented as a stationary process, which is not applicable for intersection driving. Interpersonal differences are not accounted for.

MARS at this point it only has a minimal intersection driving model: only longitudinal control is modeled, with a predefined path and no strategic level tasks. However, its high flexibility and “white box” approach allow for new models to be implemented. The different levels of the driving task are modeled independently, and can also interact with each other. It is possible to use sub-models to describe behavioral or physical aspects of different agents.

HMM aims to classify aspects of behavior, and can predict the probabilities of these aspects after the learning phase. This model is mostly used for classification and recognition of tactical-level actions and driver motivation. Unfortunately, its internal state is unobservable, making the HMM a black box on some important aspects of driving behavior. This makes it very difficult to predict behavior with different parameters.

MIXIC’s driver model has been validated for motorway driving. Its application to urban intersections has not been implemented to an adequate level. It cannot account for intrapersonal differences, which are very important in driving.

**CONCLUSION**

Our review shows that currently, there is no known model that can fully represent driving behavior with ADAS on intersections in real-time. Some simulations do not run in real time, while others cannot represent driving behavior on all levels of the task, or do not include the limitations of human operators. The approach that we have chosen for our research is therefore based on a combination of different models and in particular making use of the MARS architecture. By adding sub-models of different types to this framework, we believe representing intersection driving behavior in a valid way is possible.

**OUTLOOK**

We have selected the optimal combination of modeling tools to model the overall driving task on urban intersections. The next step is to actually model intersection driving. Our model will focus specifically on the interaction between the driving tasks. The majority of driving behavior models so far has had a certain subtask of driving as focus. These subtask models can now serve as input for our driver model, which will model the overall driving task.

**ACKNOWLEDGEMENTS**

This research has been conducted within the research centre Applications of Integrated Driver Assistance (AIDA) from the University of Twente and TNO the Netherlands, and as part of the Intelligent Vehicles project of the Dutch TRANSUMO program.
REFERENCES


