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Situated and sequential planning and prediction of human driving behavior as decision making support system

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Abstract

The realization of safe networked traffic is getting more and more important. The planning and prediction of possible driving behaviors and the detection of missing actions in advance contribute to avoid critical situations. A decision making system enables the support the human operator (driver) and to supervise the human-machine interaction by proposing possible actions predicted by the system, by warning him or her by detecting critical situations, and to take over the driving functionality if necessary.

The contribution of the work is the development of a monitoring decision making system allowing the planning and prediction of possible driving behaviors, detection of missing actions, and to support the human operator to reach desired situations. A Situation Operator Modeling method is used as event-discrete approach to describe changes from the real world as well as driving behaviors as a graph-based model considering the changes in the environment. The behaviors of traffic-vehicles **are** calculated based on predicted trajectories using a Long Short-Term Memory (LSTM) Encoder Decoder algorithm. The approach is applied to an 'overtaking maneuver on a highway'. Decision options can be continually generated depending on the changes in the environment, can be suggested to the driver, and can support him or her to lead desired situations.

1 Introduction

Due to the importance of connected and safe traffic the development of intelligent concepts is of increasing interest. A decision making support systems which allows the prediction of possible actions in the future, the detection of missing actions leading to critical situations in advance, for supervision of the driver-vehicle interaction, and to support the driver by proposing admissible actions can contribute to increase the reliability of the human decision making processes. Ulbrich and Maurer propose a framework for tactile lane behavior modeling allowing to plan a sequence of actions in mixed-integer state spaces [13]. Policy tree of (predicted) state beliefs and actions is developed to describe the action sequences. In [5] a model based on Monte-Carlo Tree Search algorithm which predicts the behaviors of the human drivers as state spaces is proposed. In [12] the authors use a Hidden Markov Model to predict driver's intention applied to maneuvers such as stop/non-stop, change lane left/right, and turn left/right. The human reliability analysis applied to driving tasks (stopping at red signals and controlling speed on approach to buffer stops) is investigated in [6] using a combined method consisting of operational data and big data.

A Situation Operator Modeling (SOM) approach is proposed in [10] allowing the mapping of change within the environment and the illustration of that within the human-machine interaction. The SOM-approach is combined with Higher Petri-Nets in [11] to develop an automated supervision method of the driver-vehicle-interaction. A SOM-based assistant maneuver control allowing the detection of goal conflicts and human errors is developed in [4] and applied to a lane-changing maneuver. The SOM-approach is combined with a cognitive reliability and error analysis (CREAM)-based method denoted as HPRS (Human Performance Reliability Score) to realize an assistance approach applied to the driver-vehicle-interaction [7].

This contribution focuses on the demonstration of an automated assistance system allowing the decision support proposed in [1] by planning and predicting possible driving behaviors as graph-based action sequences applied to the automotive domain. The approach is based on the Situation-Operator model building methodology, here especially changes of the environment of a dynamic environment are considered. Actions that do not make sense or do not lead to the goal can be detected in advance. The human operator can be warned to avoid critical situations. In addition, the monitoring system suggests possible alternative actions to achieve the given goal, can intervene, and take over the driving functionality if necessary. In [7] the application of the SOM approach to the overtaking maneuver on a highway and the calculation of an action space are discussed.

In this paper, the development of a situated and continuously decision support assistance system is proposed and validated to the overtaking maneuver.

The paper is organized as follows: The SOM-approach is explained and applied to a overtaking maneuver on a highway in Section 2. Decision making with respect to possible actions depending on changes in the environment and the computation of discrete-event situations resulting from actions is explained in Section 3. Situated behavior planning and prediction applied to an overtaking maneuver on a highway is discussed in Section 4.

2 Definition and application of the Situation Operator Modeling to overtaking maneuver on a highway

The Situation Operator Modeling is proposed in [10]. The approach allows the mapping of changes from the real world and the related illustration of the human-machine-interaction. Scenes are modeled as situations and actions as operators. A graph-based action sequences consisting of operators (white circles) and situations (gray ellipses) is shown in Figure 1. The cognitive functions planning and acting allow the execution of a sequence from the initial situation S_i to a desired final situation S_d (cf. Figure 1). An operator connects two successive situations and effects the inner structure of the following situation.

Characteristics and operators are obtained from the analysis and consideration of real driving behavior. Characteristics building the inner structure of a situation are listed in Table 1. The characteristics C_8, C_9, and C_{10} are obtained from prefilter by compressing and fusing data from the environment and sensors.

The operators which describe the human driving behavior are listed in Table 2. The knowledge about the correctness of human behaviors and therefore the logic of sequencing sentences and

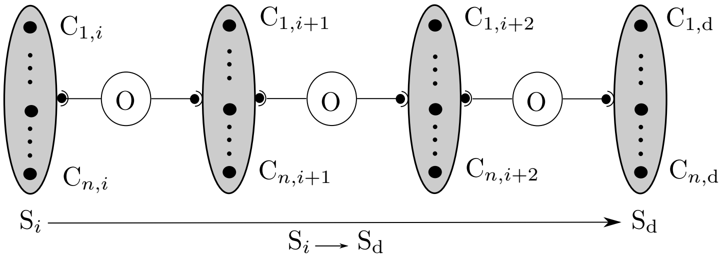

Figure 1: Action sequence from the initial situation S_i to a final desired situation S_{i+1} ([10])

Table 1: List of characteristics

Characteristic	Unit
C_1 : Longitudinal speed	[km/h]
C_2 : Lateral speed	[km/h]
C_3 : Longitudinal acceleration	[m^2/s]
C_4 : Lateral acceleration	[m^2/s]
C_5 : Yaw angle	[°]
C_6 : Steering wheel angle	[°]
C_7 : Lane number	[-]
C_8 : TTC to front vehicle in the right the lane	[s]
C_9 : TTC to front vehicle in the left the lane	[s]
C_{10}: TTC to rear vehicle in the left the lane	[s]

operators is predefined by experts. The operators O_1 and O_2 are described by the variation of the longitudinal speed, the variable input of the steering operators O_4 and O_5 is the steering angle.

Table 2: List of characteristics

Operator	Description
O_1	Acceleration
O_2	Deceleration
O_3	Keeping the actual speed
O_4	Steering to the left
O_5	Steering to the right

3 Event-discrete generation of possible actions and situations

The artificial generation of situations necessary for planning is explained as a consequence by conceivable actions mapped by describing operators. Different action sequences can be suggested to the driver as decision options, which are tested for logical coherence. The decision options also refer to the individual experiences of the operator. Central here, however, is the behavior of the other traffic vehicles which has to be integrated based on the results of a specific trajectory prediction. The generation of possible situations has to be adapted to the environmental conditions and the predicted behaviors of other traffic vehicles.

3.1 Conditions and assumptions

The evaluation of driving behavior requires the consideration of assumptions and logical relationships, as well as the dependence of the environment. The time to collision (TTC) is an important criteria and is defined as the *'time required for two vehicles to collide if they continue at their present speed and on the same path'* [8]. The time to collision consists of the time to collision of breaking and the reaction time of 1.5 s. The critical TTC of breaking is 2.5 s according to ([8]). This results a TTC-criterion of 4 s. The TTC is considered for every vehicle in vicinity. The relationships used are explained as follows:
$\mathrm{TTC}_{\mathrm{RF}}$: is the time to collision to front vehicle in the right lane. In regard to the methodology in Section 3.3 the warning value (floor value of the tolerance interval) is -4 s, the conflict value (upper value of a tolerance interval) is -2.5 s.
$\mathrm{TTC}_{\mathrm{LF}}$: describes the time to collision to front vehicle in the left lane . The warning value (upper value of a tolerance interval) is 4 s, the conflict value (floor value of a tolerance interval) is 2.5 s.
$\mathrm{TTC}_{\mathrm{LR}}$: refers to the time to collision to rear vehicle in the left lane. The warning value (floor value of the tolerance interval) is -4 s, the conflict value (upper value of a tolerance interval) is -2.5 s.
Expected driving area: The area consists of infrastructure data leading to the end desired situation.
Critical speed v_{cr}: The maximal critical speed is 130 km/h.

3.2 Trajectory prediction

Decision making and planning of the own possible driving behavior as described in [2] and [3] depends on the behaviors of other vehicles in the vicinity, which, however, can also only be predicted to a limited extent. Each trajectory prediction makes a statement about the predicted position, speed, and orientation. Using predictions and knowing the own intentions, a distance can be determined, e.g. guarantee of a minimum distance between the Ego-vehicle and traffic vehicles, this also makes a prediction to the TTC. The predicted positions and speeds of the traffic-vehicles are called by the checking of assumptions and performance conditions (cf. Figure 2) to calculate the predicted TTC between the ego-vehicle and the traffic vehicles. The trajectory prediction used in this thesis is based on the on the method of [3]. A long short term memory (LSTM) encoder-decoder is used. The inputs are the position of the vehicle as well as the positions of the vehicles in the environment around the vehicle under consideration, the outputs are related to the probability of the future positions of the vehicle to be predicted. Conventional social pooling layers (CPS) developed by [3] are integrated for trajectory prediction. The CPS method allows learning the spatial dependencies as well as the past movements around the vehicle to be predicted and therefore to be encoded. Encoded vehicle motions around the predicted vehicle are stored as a social tensor that describes and predicts a spatial grid around the predicted vehicle [3]. The trajectory encoding results from the encoded motion of the predicted vehicle and the encoding of the pooling layer of the social tensor, the decoder provides the probability about the predicted positions in the future [3]. In this work, the trajectory of a traffic vehicle with the highest probability is considered as the predicted trajectory.

3.3 Event-discret calculation depending to environment conditions

An operator effects the inner structure of a situation so that the values of the characteristics change or also the structure of the situation itself. The developed 'decision support control loop' method as described in [1] allows to calculate the following situation, to check assumptions and performance conditions, and to check reachability of goals leading to the final desired situation (cf. Figure 2). The main components of the loop are the model-based operation, checking of assumptions, and the warning module, and the checking of goal reachability. For the specific application the model-based operation module consists of a considered operator from Table 2 and in combination with the model as kinematic motion model (bicycle model). The functionality of the operator is described by the variation of a state variable as input. The characteristics of the initial situation S_i are given as inputs in the model and its values are effected by the considered operator. The outputs of the model are the new calculated values of the characteristics because the execution of the operator.

In the module 'checking assumption', the new state resulting by the applied operator is compared with conditions depending on the environment (infrastructure, traffic vessels in the driving area). If the assumptions are not fulfilled, the operator is not admissible and the calculated situation will be not considered.

In contrast to the checking assumption module, issuing warnings does not mean that rules are directly not fulfilled and that operators are directly leading to conflicts. In the 'warning module', conditions are analyzed with regard to the actual state, which may lead to a conflict in the future, for example, a warning value is determined with regard to the underlying conditions. The warning value can thus be interpreted as the upper limit value of a tolerance interval. When a corresponding situation (warning) is detected for the first time, the associated maximum time until the limit value is reached, i.e. the next situation S_{i+1} can be calculated without exceeding the permissible time. Only or then the next decision options can be generated. If the warning exists from the previous situation, the conditions and assumptions are evaluated, not admissible situations resulting by falling the lower limit of tolerance interval are excluded, and admissible states are checked for the goals reachability.

Goals leading to the final desired situation are predefined. A goal can be an area, a position, an orientation. If no warnings are detected, the calculated situation is checked for reachability of the next predefined goal. If the next goal is reached, the next situation S_{i+1} and new decision options are generated. If the goal is not reached, the characteristics must be calculated for the next time t_{k+1}.

4 Situated behavior planning & prediction and supervisory control

In this Section the event-discrete behavior planning and prediction based on proposed supervisory control method in Section 3.3 and the Figure 2 is introduced. The planning and prediction strategy is applied to the 'overtaking maneuver on a highway' shown in Figure 4.

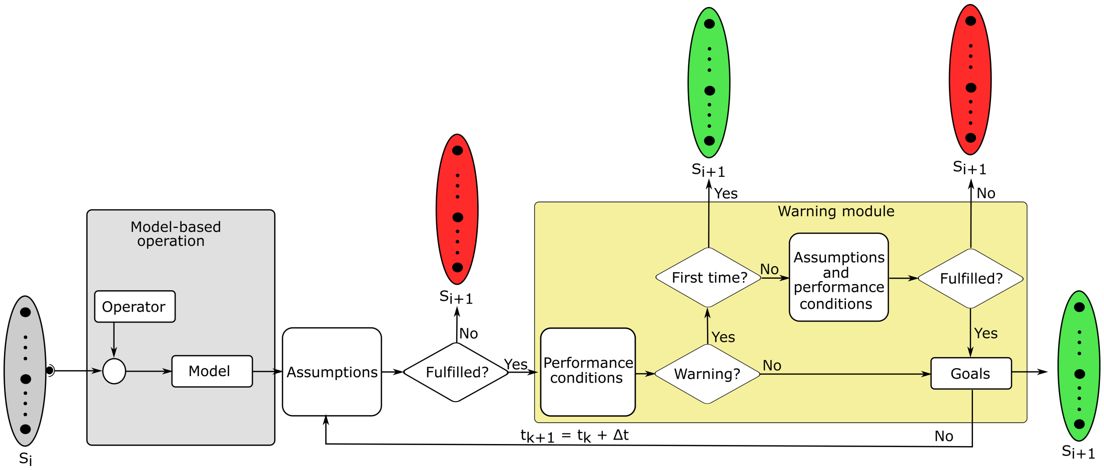

Figure 2: Event-discret calculation of situations depending to the environment [1]

4.1 Planning and prediction of decision options

The planning and prediction of decision options as described in [1] consists of three main steps shown in Figure 3 and are explained as follows:
In step 1 all predefined operators are considered. The effect of every action to the following situation are analyzed in following steps.
Step 2 refers to the event-discret calculation, the decision making considering the assumptions depending on the environment changes and the reachability of predefined goals leading to the final desired situation (cf. Section 3.3 and Figure 2). Every predefined operator must be checked with respect of the requirements related to the assumptions and performance conditions and on the reachability of with respect to the next predefined goals. In Figure 3 possible decision options are marked (green) as examples, (red) ellipses refer to generated next situations resulting by erroneous actions which are neglected in the next steps.
In step 3 the selection of a decision option from the list of possible action is realized: In this step only the set of possible actions obtained from the analysis in step 2 is considered. Only one decision option from the set can be selected. Here, the following prioritization applies: In this work, situations that can be reached when a following and given goal becomes attainable, are preferred to those that are only reached by triggering warning (cf. Section 3.3). Situations that can be reached without warnings are preferred to others that can be reached with warnings. If there is no warning and no conflicts, processes with shorter operation time are preferred.
The situation resulting from the decision option in the step 3 is now the current situation. Starting from the new situation the steps 1 to 3 will be repeated for every new obtained or triggered situation. This repetitive process is executed until the final desired situation is reached. The main idea of the developed method is to situatively and continuously support the human operator to reach the final desired situation (cf. Figure 3).

4.2 Application to an 'Overtaking maneuver on a Highway'

In this Section, the planning and prediction of decision options and possible driving behaviors is applied to the 'overtaking maneuver on a highway' shown in Figure 4.

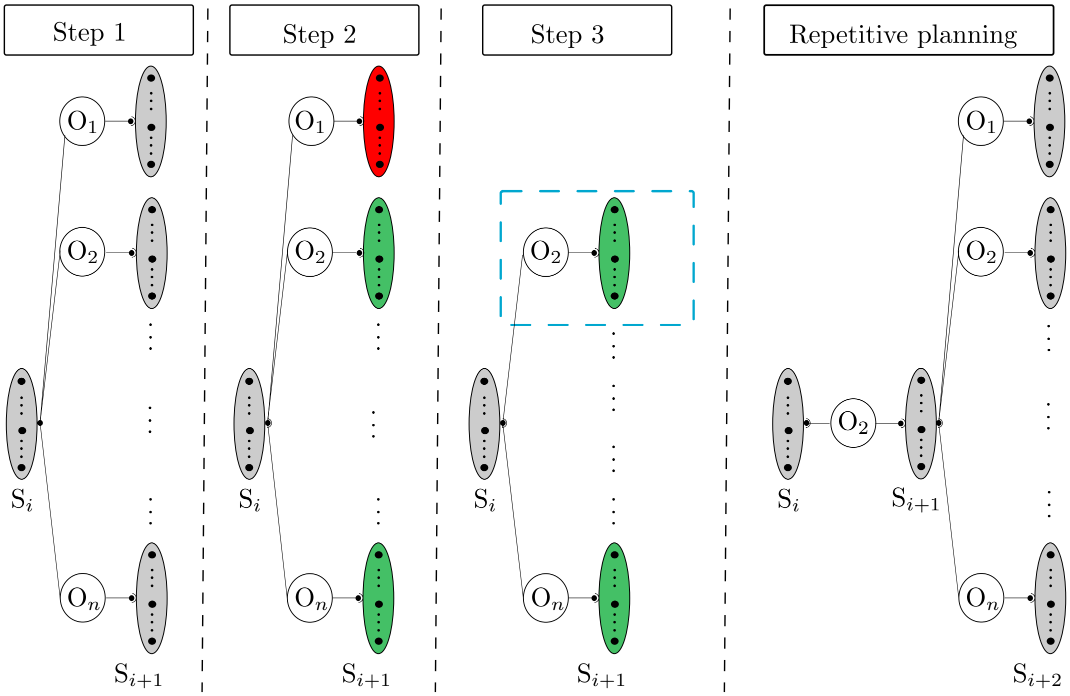

Figure 3: Process of the planning and prediction of decision options [1]

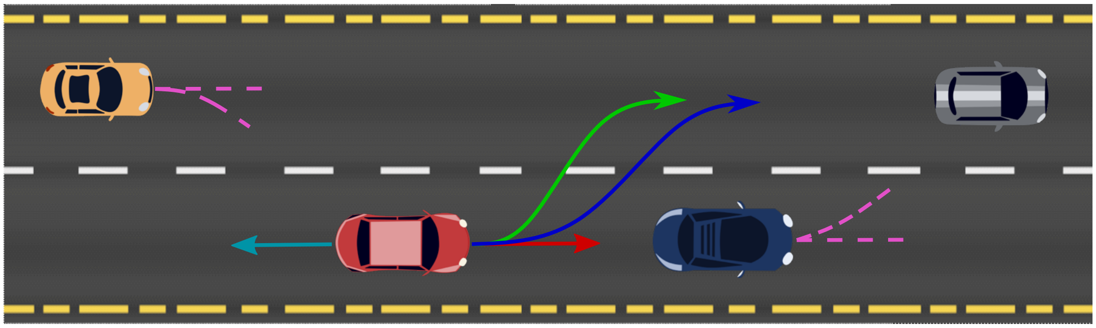

Figure 4: Overtaking maneuver on a highway, Ego-Vehicle (red)

4.2.1 Assumptions & performance conditions

The maximal critical speed v_{cr} is 130 km/h. If v_{cr} is reached, the maximal time of the operation is reached and new decision options must be generated. The expected driving area consists of infrastructure data leading to the final desired situation. If an operator leads to leave this area, the operator is classified as not admissible. According to the methodology explained in Sections 3 and 3.1 tolerance intervals related to warnings are defined and a distinction between warning values and conflict values exists. For $\mathrm{TTC}_{\mathrm{RF}}$ (time to collision to the front vehicle in the right lane) the warning value is -4 s and the conflict value is -2.5 s. If $\mathrm{TTC}_{\mathrm{RF}} \geq$ -4 s, a warning in interaction with the traffic vehicle is detected for the first time and new decision options must be generated to avoid critical situation in the future. If the new chosen action leads to the condition $\mathrm{TTC}_{\mathrm{RF}} \geq$ -2.5 s, a conflict is detected and the operator is not admissible. Conditions of $\mathrm{TTC}_{\mathrm{RF}}$ are only relevant, if the Ego-vehicle is in the right lane. If the Ego-vehicle is in the left lane and $\mathrm{TTC}_{\mathrm{LF}} \leq 4$ s and/or $\mathrm{TTC}_{\mathrm{LR}} \geq$ -4 s, warnings are generated. If $\mathrm{TTC}_{\mathrm{LF}} \leq 2.5$ s and/or $\mathrm{TTC}_{\mathrm{LR}} \geq$ -2.5 s, a conflict is reached and the considered operator is not admissible.

4.2.2 Predefined goals

Goals leading to the final desired situation must be predefined (cf. methodology in Section 3.3). The first goal consists of two conditions: a suitable distance to the vehicle in the front defined with the mathematical expression -8 s $\leq \mathrm{TTC}_{\mathrm{RF}} \leq$ -4 s, the left lane is free if $\mathrm{TTC}_{\mathrm{LF}} \geq 2.5$ s and $\mathrm{TTC}_{\mathrm{LR}} \leq$ -4 s. The second goal is to the reach the boundary line. The next goal is to reach the middle of the left lane and to drive in a straight direction. The final goal is to overtake the blue vehicle in the right lane.

4.2.3 Results of planning & prediction

The method of the situated behavior planning and prediction explained in Sections 4.1 and 3 is applied to the 'overtaking maneuver on a highway' shown in 4. Data are using in this work are drone Dataset of naturalistic vehicle trajectories on German Highways from [9]. Originally, this is video material recorded by drones, which covers the traffic flow of a 400 m long stretch of motorway. The position tolerance at less than 0.1 m. Upcoming work with real datasets will show the applicability of the approach.

The results of the planning and prediction applied to the 'overtaking maneuver on a highway are presented in Figure 5 and only possible operators are illustrated (green). The situation resulting by the selected operator is framed.

The Ego-vehicle is red (cf. Figure 4), the initial situation is S_0 and the final desired goal is to overtake the blue vehicle. The operators 'acceleration' and 'waiting' lead to the first predefined goal (suitable distance to front vehicle to overtake and the left lane is free, cf. Section 4.2.2). The operator 'deceleration' is not meaningful, the operator 'steering to right' leads to leave the expected driving area, and the operator 'steering to left' is not possible because the left lane is not free ($\mathrm{TTC}_{\mathrm{LF}} \nleq 2.5$ and/or $\mathrm{TTC}_{\mathrm{LR}} \ngeq$ -2.5 s) .The 'acceleration' maneuver takes 1,48 s and $\mathrm{TTC}_{\mathrm{RF}} = -4.81$ s by reaching the first goal, the operator 'waiting' leads to the first goal in 1.8 s and $\mathrm{TTC}_{\mathrm{RF}} = -6,72$ s. The $\mathrm{TTC}_{\mathrm{RF}}$ by the operator 'waiting' provides more safety and is selected as the next situation S_1. After waiting 1.8 s and reaching the situation S_1 only the operator 'steering to left' is possible and the left lane is free ($\mathrm{TTC}_{\mathrm{LF}} \geq 2.5$ s and $\mathrm{TTC}_{\mathrm{LR}} \leq$ -4 s). 'Steering to the left' takes 4.12 s and the goal 'reach the boundary line' is achieved (situation S_2) and new decision options must be generated. The operators 'acceleration', 'deceleration', and 'waiting' are not admissible because driving in the boundary line and so in two lanes at the same time is not allowed. 'Steering to right' means driving back to the right lane and the safety distance to the front vehicle is not suffused. After 'steering to the left' and reaching the situation S_4 the operators 'acceleration' and 'waiting' lead to the final desired goal 'overtaking the blue vehicle'. 'Acceleration' takes 2.8 s and 'waiting' 2.92 s, so the operator leads as quickly as possible to final desired situation S_5 and is selected.

The final desired situation and the final predefined goal can be reached by following the continually planned and predicted action behaviors. The resulting sequence is: waiting, steering to the left, steering to the right, and acceleration. The changes in the environment are considered for the calculation of the sequential behavior planning. The generation of the results is realized by a developed algorithm in C++ and the trajectory prediction with python tools are included in this algorithm.

5 Conclusion and future work

In this work, an event-discrete behavior planning and prediction is demonstrated to an 'overtaking maneuver on a highway'. The approach is based on a Situation-Operator modeling allowing the mapping of changes within the environment and the illustration of human-machine interaction. Possible driving actions of the driver are modeled as operators, scenes from the real world are described as situation vectors. Performance conditions depending on the changes in the environment and predefined goals leading to desired situations are defined. The event-discrete planning and prediction of possible driving behaviors allows the determination of possible decision options in advance and the detection of missing actions considering the performance conditions and the goals. The human operator can be supported by the decision making, the driving functionality can by taken over if necessary and sequential planned actions can be automatically executed. The methodology enables an automated supervisory control depending on the changes in the environment and the human operator can be supported by the decision making in real time.
In future work, action-space based planning and prediction will be developed and applied so that possible action-sequences can be predicted in advance. The results will be validated in real time systems.

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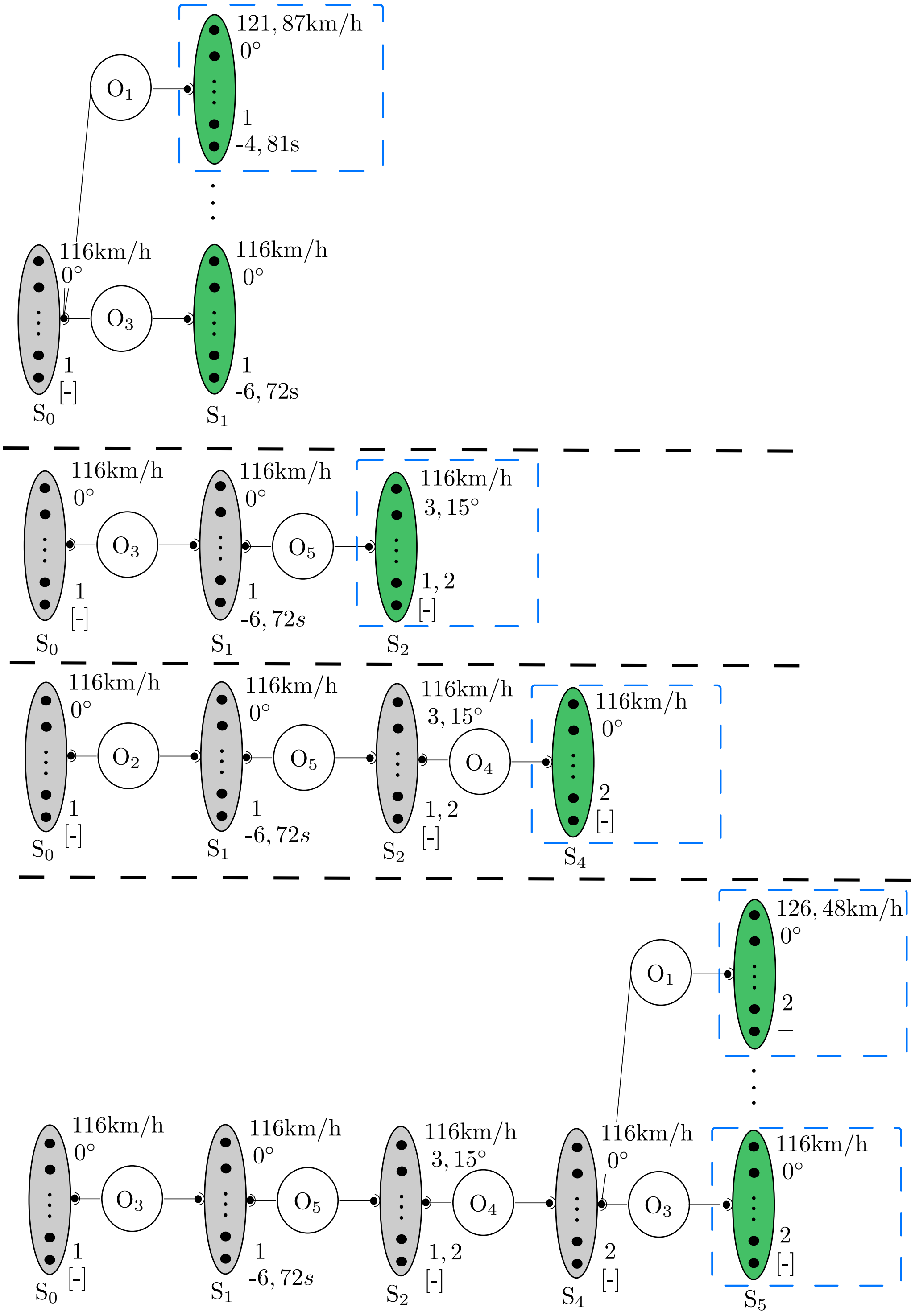

Figure 5: SOM-based representation of the application of planning and prediction method to the 'overtaking maneuver on a highway'

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