Multi-model based behaviour analysis for inclusive mobility

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Abstract. The paper proposes an original approach based on holistic and specific models of human or technical behaviors. Holistic models concern generic behaviors that can be achieved by different human or technical decision-makers and specific models represent individual behaviors of a given human or technical decision-maker. They are modelled with Petri nets and Faults trees. The analysis of combinations between these models generates scenarios that can affect inclusive mobility in terms of human health, system safety or fluidity of mobility. These scenarios are represented with cause trees and simulated with the MissRail® platform to validate their feasibility. They involve behaviors of road users like pedestrians, car or train drivers and of Artificial Intelligence based systems like an Adaptive Cruise Control or a Lane-Keeping Assist..

1 Introduction

Throughout the world, inclusive mobility is a global challenge to avoid any social exclusion for everyone and everywhere. A lot of researches aim at making inclusive mobility possible by considering criteria like safety, accessibility, fluidity, health, equity, or sustainability. Most of them consist in developing automated tools to assist mobility with regard to temporary or permanent human, technical or organizational factors. Off-line human reliability assessment methods can be used to identify factors that can affect human behavior and to support the design of dedicated assistance to recover or control human errors [1-9]. Other approaches use technical supports to collect on-line cognitive, physiological or physical data to assess workload, attention, vigilance or stress or to determine the impact of assistance tools on human behavior or performance [10-17]. Learning based approaches can also be useful for inclusive mobility study by considering human-machine interaction for transportation system resilience to control successfully any unprecedented or unstable situation [18-20].

The paper proposes a new framework to analyze interactions between humans or between humans and Artificial Intelligence-based systems in order to improve future inclusive mobility. It is applied to road users like pedestrians, car or train drivers and to Advanced Driver Assistance Systems (ADAS) as Cruise Control (CC), Adaptive Cruise Control (ACC) or Lane-Keeping Assist (LKA).

Section II develops inclusive mobility principles and gives examples of failed mobility to introduce the interest of the proposed method that is developed on Section III. Section IV gives examples of simulation of identified scenarios that can make obstacle to inclusive mobility.

2 Risk analysis of inclusive mobility

2.1 Inclusive mobility principles

Integrative design focuses on collective purpose and interest whereas inclusive one gives priority to individual needs and capacity [21-28]. Inclusive design considers the limitations and capabilities of a system as added value. Therefore, any failed or successful experience of an individual can be beneficial to others.

Inclusive mobility is an example of application of such a design concept. It is initially dedicated to accessibility for disabled, old, illiterate, disadvantaged, troubled or vulnerable people and to the development of assistive technology for accessibility facilitation [29-35]. It is extended for being applied to all users whatever their cognitive, physical, cultural or social levels and whatever the place of their mobility. This aims to avoid any discrimination between people. It must meet societal criteria such as well-being, health, safety, respect for the environment, economic viability, efficiency of mobility services, or fluidity of traffic.

Assistive technology developed for inclusive mobility is usually well accepted by users. However, in particular conditions, some of them can lead to possible usage risks that can affect inclusive mobility process in terms of safety or ecology criteria.

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2.2 Examples of risk of inclusive mobility achievement

Table I gives examples of risks for achieving inclusive mobility goals.

Table 1. Usage risks of assistive technology on inclusive mobility.

Assistive technology	Usage risk of assistive technology on inclusive mobility	References
CC	Increased reaction time, reduced alertness, reduced inter-distances	[36-37]
CC & ACC	Increased reaction time for emergency braking maneuver if the "+" or "-" buttons of CC or ACC are used as an accelerator or braking system	[38-39]
	Conflicting braking maneuver between human behaviors to control an aquaplaning with human behaviors to deactivate the CC or ACC	[38-39]
	Risk of conflicting braking or acceleration maneuvers between human behaviors to control an aquaplaning with behaviors of CC or ACC	[37-41]
	Conflicting braking or acceleration maneuvers between human behaviors to control consumption with behaviors of CC or ACC	[38, 39, 42]
HUD	Reduced perception ability due to focused attention on the front of the vehicle	[43-45]
LKA	Conflicting steering wheel maneuver between human behaviors to avoid an obstacle with behaviors of LKA to stay on the lane	[24, 27]

The use by drivers of a CC may lead to the increasing of reaction time, a decreasing of vigilance or a decreasing of inter-distance between cars [36-37]. Drivers have to manipulate the "+" or "-" buttons to increase or decrease the speed setpoint of an activated CC or ACC. They can also use them as an accelerator or a braking system. These modifications of buttons goal can be dangerous in case of emergency braking for instance that forces drivers to put the correct foot back on the correct brake pedal [38-39]. When CC or ACC are activated, i.e. they have in charge the car speed control by considering the setpoint given by drivers, one the procedures to deactivate them consists in activating the brake pedal. However, this deactivation maneuver is contradictory with one of the aquaplaning control strategies which requires not braking [38-39]. Behaviors of activated CC or ACC are also contradictory with those of drivers in case of aquaplaning occurrence. Indeed, CC or ACC may decide to accelerate or brake if the current car speed is lower or higher than the speed setpoint while drivers may prefer not to accelerate nor brake to avoid loss of car control. CC or ACC may generate accident in this specific aquaplaning context if there are activated and affecting inclusive mobility in terms of corporal damage and interruption of transport services or of traffic fluidity.

Similarly, both ADAS can decide to brake in a downhill road or accelerate in an uphill road depending on the gap of current speed and the speed setpoint while drivers can behave in opposite ways, i.e. they can prefer not to brake downhill and not to accelerate uphill in order to optimize fuel consumption. Consequences of contradictory behaviors of CC or ACC are possible increasing of consumption. The Head-Up Display (HUD) system is useful for displaying data in front of the driver or pilot who limits head movements for searching them. However, visual attention is focused on a reduced area and unforeseen dangerous events may not be perceived when they occur outside this reduced field of vision [43-45]. During the overtaking procedure carried out by drivers, activated LKA may automatically return the vehicle to the center of the initial lane and this may cause a collision between the vehicle and the object of overtaking [24, 27].

The design process of assistive technology for inclusive mobility needs the development of off-line assessment methods to analyze possible impact of combinations of behaviors of an individual, of several humans or of ADAS interacting with humans. The next section proposes such a method.

2.3 Multi-model based behaviour analysis method

Fig. 1 presents the several steps of the proposed method. The first step relates to the analysis of behaviors of humans or machines observed on field or based on user manuals or norms. The second step consists in modelling them by using the Petri net and Fault Tree formalism. Petri net-based models represent holistic or specific normal behaviors. Holistic models are generic models that can be applied by different human or technical decision-makers while specific ones relate to behaviors of a given decision-maker.

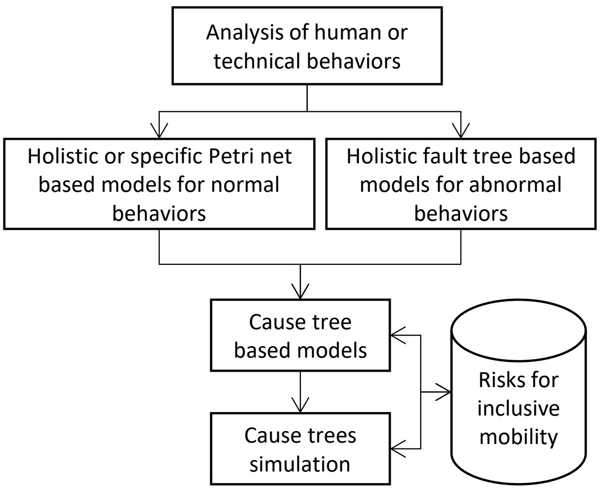

Fig. 1. Multi-model based behavior analysis method.

A Petri net, noted R_i, is an oriented graph composed by places P_{ik} and transition T_{il} between places. Places are occurrences of normal behavioral states and transitions correspond to particular conditions between states and for moving from one state to another. The set, noted R, contains all Petri nets.

Holistic Petri nets related to generic behaviors applicable to different decision-makers can be linked, i.e. an input place from a Petri net can be an output from another and an output place of a Petri net can be an input of another one.

A fault tree, noted FT_i, is a diagram that gathers all scenarios that can make the occurrence of an undesirable event possible. A set noted FT contains all fault trees.

The set of identified cause trees, noted CT, are built by studying possible interferences between Petri nets and fault trees by applying (1) and (2).

Formula (1) aims to detect possible interferences between two Petri nets, noted R_i and R_k, by comparing the labelling of their transitions. The application of this process to all pairs of Petri nets gathers pairs of transitions in CT. Formula (2) identifies other possible interferences between these pairs and the content of fault trees from FT. It builds the set S of scenarios to be simulated composed by sub-sets of triplet.

$$\{\forall R_i \in R\ \forall T_{i,m} \in R_i,\ \forall R_k \in R,\ i \neq k,\ \forall T_{k,n} \in R_k,\ (T_{i,m} = T_{k,n} \rightarrow (CT \leftarrow CT \cup (\ T_{i,m},\ T_{k,n})))\} \quad (1)$$

$$\{\forall FT_i \in FT,\ \forall E \in FT_i,\ \forall T \in CT,\ (E \cap T) \neq \{\emptyset\} \rightarrow (S \leftarrow S \cup (T \cup E)))\} \quad (2)$$

The last module of the method is the construction of scenarios from S to be simulated with the MissRail® platform. The MissRail® platform was developed at the Université Polytechnique Hauts-de-France and makes it possible to simulate several road users such as pedestrians, vehicles, trains or trams in a given infrastructure and to implement behaviors of ADAS [46]. Interdependency between holistic Petri nets are used in order to generate a logical flow of events that make genesis of the content of S possible.

3 Example of application

3.1 Holistic and specific models genesis

Petri nets R1, R2, R3 and R4 respectively model behaviors related to a decision-maker in a move, a decision-maker at a standstill, the collision avoidance control and signaling system respect in normal situations, Fig 2. They are applicable by road users like pedestrians, cyclist, car or train drivers. These models are interconnected, i.e. an input of a model can be an output of another one and vice versa. For instance, output of R1 are R3 or R4. An input of R2 is one of possible outputs from R3. These links will be used for building simulated scenarios of risks for inclusive mobility. Two Petri nets are built, Fig 3. The first one, noted R5, is the behavior of a LKA to maintain the trajectory on the initial lane. The second, noted R6, models the behavior of an ACC to control inter-distances and particularly when there is a stopped obstacle on the trajectory.

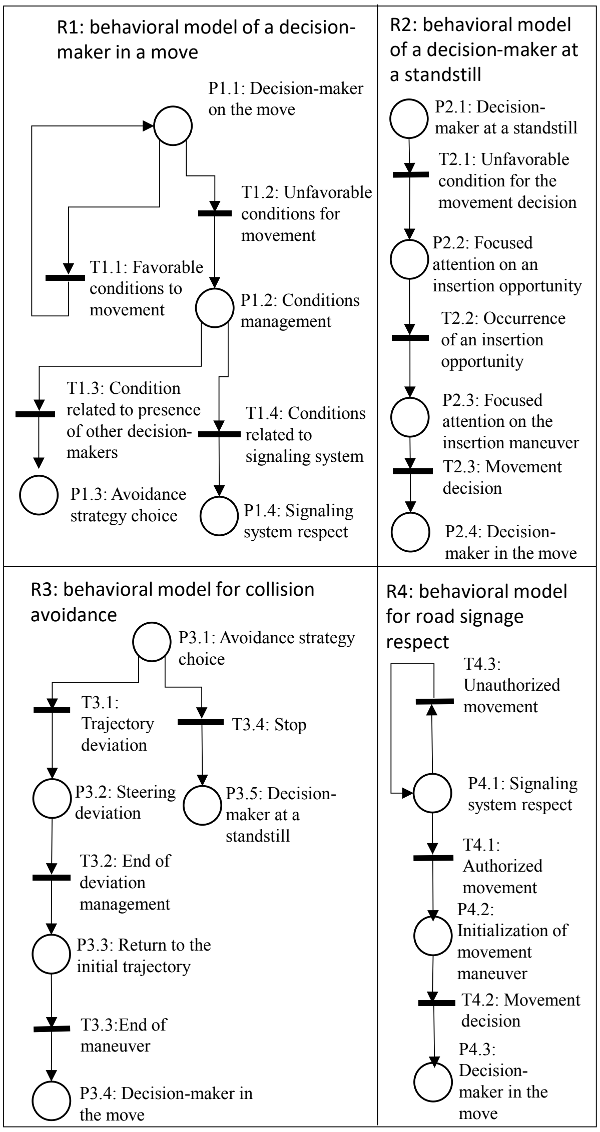

Fig. 2. Holistic Petri nets of four generic maneuvers.

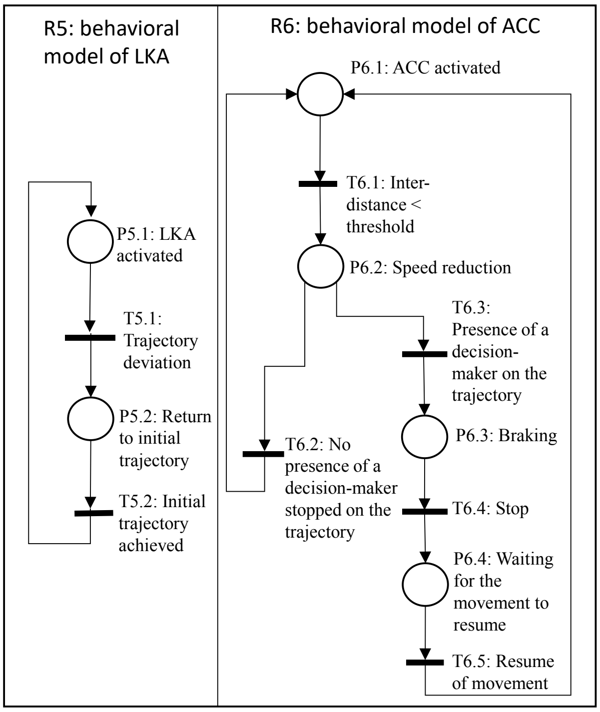

Fig. 3. Specific Petri nets for ACC and LKA.

Two holistic fault trees are identified and relate to two undesirable events can affect inclusive mobility, Fig 4. Fault tree noted FT1 impacts mobility safety and possibly human health while fault tree noted FT2 corresponds to the disruption of fluidity of traffic.

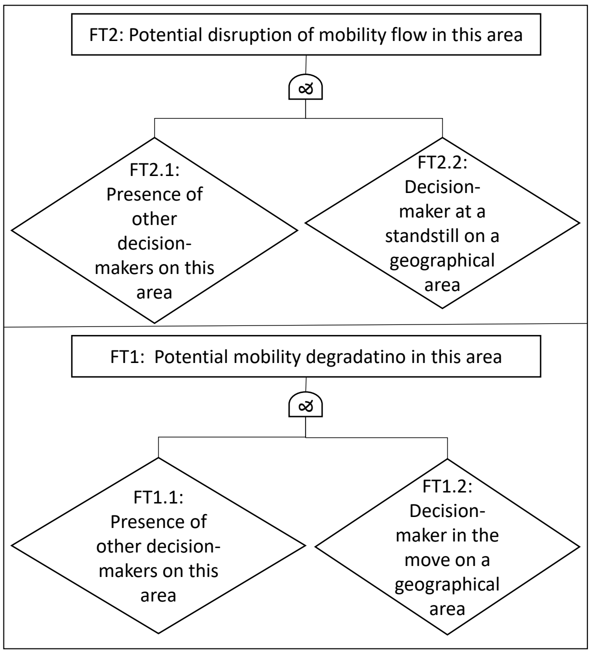

Fig. 4. Holistic fault trees of two undesirable events for inclusive mobility.

3.2 Scenarios and simulation genesis

As R= {R1, R2, R3, R4, R5, R6} et FT = {FT1, FT2}, the application of (1) and (2) generates the set of scenarios S that contains three sub-sets : S={(T3.1, T5.1, FT1), (T3.4, T6.4, FT2), (T4.2, T2.3, FT1)}. For each scenario, interdependencies between Petri nets are studies in order to built sequence of events for being simulated, Fig. 5. For instance, the first scenario (T3.1, T5.1, FT1) was completed by the last transitions of R2 and R1 that are connected with R3.

Fig. 6 represents an example of scenario 2. A car driver turns green and stops on the tramway track to avoid a collision with another vehicle blocked on the roundabout, this stop being managed either by the driver or by ACC activated. During the maneuver, the light can turn red to announce the arrival of a tram which must stop because the track is blocked by a vehicle. The flow is then blocked. Fig. 7 and 8 give another example of the implementation of scenario 3. Two decision-makers are considered for the same scenario: a vehicle that can collide with a pedestrian (Fig. 7) or a tram (Fig. 8). Both simulations make it possible to determine potential risks linked to the focused attention of a car driver on an insertion maneuver without possibly paying attention to the rest of the scene where other road users can move.

The advantage of this approach is double for optimizing future inclusive mobility. It allows, on the one hand, to study distractions of attention which could disrupt road safety or human health, and on the other hand, to determine conflicts of intention between road users or ADAS in situations where each of them behaves normally. This is complementary support to traditional risk assessment methods. Indeed, in the context of the design of driving assistance or autonomous systems, it makes it possible to combine holistic and specific models and to study them by simulation resulting from the identification of links between normal and abnormal behaviors from modelling using Petri nets or fault trees respectively.

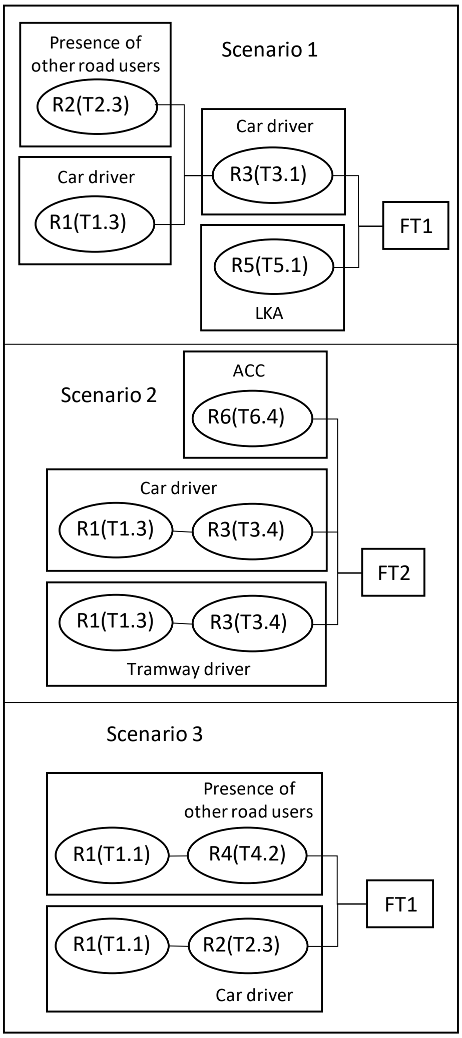

Fig. 5. Risky scenarios genesis.

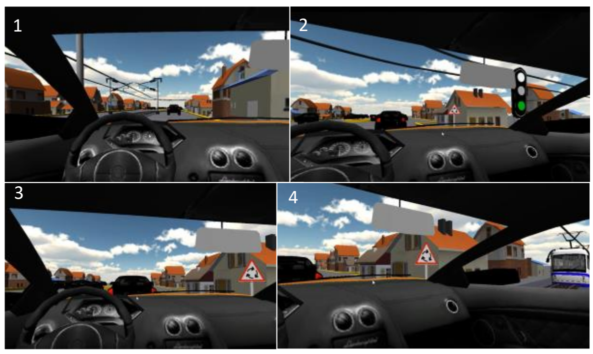

Fig. 6. Example of simulation of scenario 2 for a possible interruption of flow to avoid collision.

Fig. 7. Example of simulation of scenario 3 for a possible collision between a car and a pedestrian.

Fig. 8. Example of another simulation of scenario 2 for a possible collision between a car and a tramway.

4 Conclusion

This article presented a new risk analysis approach based on the genesis of scenarios from normal behaviors of human, or technical decision-makers. This approach makes it possible to determine holistic models representing behaviors common to road users in a given context and specific models specific to a given decision-maker. The modeling is carried out with the formalisms of Petri nets for normal behaviors and fault trees for undesirable behaviors. The analysis of combinations of normal behaviors of the same decision-makers or of several decision-makers that can generate undesirable behaviors makes it possible to produce cause trees and scenarios which are implemented, tested and validated with the MissRail® digital platform. The approach was applied to the field of inclusive mobility in an urban environment with the genesis of simulation scenarios involving a human (i.e., a car driver) interacting with another road users (e.g., a pedestrian, a tram driver) or with ADAS (e.g., the ACC or the LKA). Considering the availability of car drivers who concentrate their attention on a delicate maneuver (e.g., insertion under strong time constraints in a lane with heavy traffic), the proposed method makes it possible to produce simulation of different potential collisions with a third party (e.g., a collision with a pedestrian or a collision with a tram depending on the characteristics of the infrastructure). It also demonstrates that the simulation of combinations of normal behaviors of the same road user or different roads users or ADAS can affect safety, health or traffic flow. Research perspectives will focus on the genesis of other scenarios and the computerized version of the method to study other criteria like accessibility or respect of the environment to achieve goals of future inclusive mobility.

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