ODD – Operational Design Domain as Test Arrangement for the Future Automatisation of Road Traffic

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1 ABSTRACT

Following contribution refers to preceding results presented in German at CORP 2019 and CORP 2020 on the issue how automatization will change and shape future mobility. Some recent knowledge of our work should be a topic for further critical discussion about technical progress triggered by automotive industries. However, are we as planners from the outside prepared for that?

Within the year 2024, the equipment of new vehicles with ADAS (Advanced Driving Assistance Systems) will be obligatory by law. Have been such applications according to automation grade 3 efficient proved in respect of daily road traffic? Who can give answers to new cars assessment of it? One of the proving approaches are so-called Operational Design Domains (ODD). A professional guideline defines an ODD as "operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics." ODD is the design domain of an ADAS or a feature thereof with respect to its operation." This approach can serve as a strategic instrument to prepare the implementation of autonomous driving via the automatization of road traffic into the mobility system on the long view. Now, what tasks of testing activities are required?

- Testing technical efficiency of relevant instruments (off-road)
- Finding practical insufficiencies of functionalities based on test arrangements (on test grounds)
- System proving of driving practice (feasibility-check on-road)
- Authorization of vehicle´s types (reliability- and safety-checks)
- Adaptions of road-network for automatization of road traffic (as task by road providers)
- Assessment of sociability in settlement areas (need of regional regulations in urban road spaces)

Therefore, a broad field of interrogative activities ought to have done before a deployment of highly automated or even autonomous moving vehicles penetrates the markets. If they reach a considerable amount within the car´s stock, it might be too late for assessment studies. "We will look what would happen" as negligent political strategy seems indolent facing the historical developed miscellaneous road network in Europe, which somewhere lacks of large scale in comparison with America´s grid of streets and highways.

Automatization of cars deals with a manifold topic driven by automotive industrial progress using hard- and software tools of digitalization, automatization and interconnectivity.

The topic, what technical support needs automatization of road operations, stands at the very beginning of the discourse about future motorized mobility. At first, we focus the view on a vehicle as moving body flowing in traffic and interacting with other traffic participants. Dependent on automation-grade of vehicle´s stock different with automat-functionalities equipped cars are objects for testing arrangements (Fig. 1). Pure technical capacities and the reliability of quality to cope with a certain functional task are next to prove. That represents the view into the car, though it effects outside other traffic participants. On the contrary, a bird´s eye-view on the cars flowing onto carriageways represents the complementary view (Fig. 3). These antagonistic views on the automatization of motor vehicles unveils possibly weaknesses of the usage of technologies hardware-side, like sensors for detection of open paths (Fig. 2), and software-side, where signals are processed to car-inherent scenarios. Bearers of homologation of single functionalities ought to complement their proving by holistic arrangements aiming at the car-inherent system architecture to evaluate the effects affecting other road users in respect of its personal integrity and safety (Fig. 5).

Keywords: road traffic, test proceedings, urban planning, ODD, ADAS

2 ADVANCED DRIVING ASSISTANCE SYSTEMS (ADAS) AS AN AUTOMAT-CHAIN

ADAS as driver´s supporting functionalities for cruise control concern speed limitation, distance keeping, lane keeping, overtaking assistance, death angle warning, parking manoeuvers and other useful tasks. While responsibility for driving actions remains to the driver who has to be present fully, but a deskilling of routine may affect drivers, who trust too much in ADAS. Then ADAS in general fulfil simple tasks as divided effective functions, which are not able to generate a complex driving scenario as base for controlling the car autonomously. Anyhow, ADAS can be useful as risk reducing and traffic modulating instruments to cut extremities of driving-manoeuvers. As reminder, we have to do with human beings sometimes suspected as source of insecurity on the roadway. How to ensure human needs for an anxious free mobility for all traffic participants, if motorized or not? On the other hand, how to retain sovereignty of car-holders over its vehicles but without to be responsible for malfunctions of automatization tools?

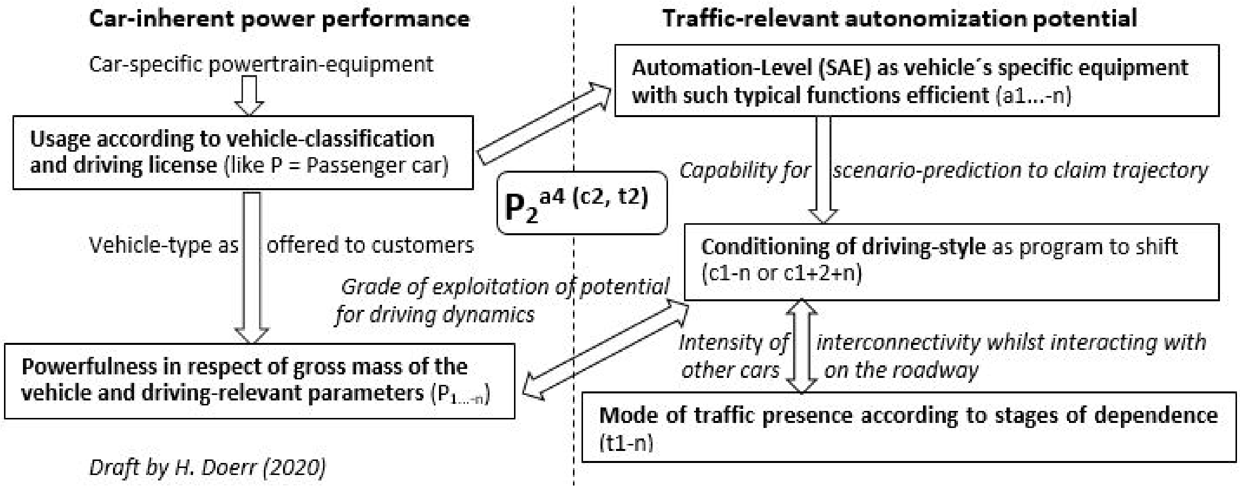

Figure 1: Vehicle´s potential for autonomization connecting power performance with automation functions

The functionalities of automation are arranged as an operative chain being vehicle-inherent installed and possibly external supported. Each of them fulfils tasks step-by-step as there are:

2.1 Detection of open fields by sensory technologies

The sensors detect open trajectory spaces on the pathway (Fig. 2). The interpretation of signals has to find out what obstacles or interventions might threaten. That includes behavioural estimations of what opponents involved in interactions or other living beings could bring about. Sensory technologies, as LiDAR, Ultrasonic or simple Camera-Viewes, deliver different prospections, so that a equalizing by data-fusion-software between them is required. This fusion of data either internally detected, externally fed or already inherent deposited under some rules of vehicle-side typical conditioning shaped by the manufactures prepares decision-making for claiming the best trajectory. That seems the crucial point within the automat chain, how data are weighted and input in decision-preparing algorithms.

Figure 2: Fields of vision detected by a solitary car to claim a trajectory onto his pathway

2.2 Scene prospection and scenario construction

The scene prospection depends on proposed driving manoeuvres, like overtaking other cars, turning the direction or changing the lanes. It contains not only the car-own options but the expected options of opponents too. Then a scenario construction can follow whereabouts interactions between traffic participants, like vehicles as opponents and other not-motorized or weakly supported actors like cyclists or pedestrians, would take place. That car-inherent construction of scenarios leads to a decision, what of the options to pave one´s way would be the best. A scenario as option of handling car´s drive consists of logical connected driving manoeuvers as steps to move forward. We have to consider that automated decision-making needs a permanent processing to claim an optimal trajectory for the next seconds of driving on the roadway. Therefore, it deals with a permanent processing in a chain of decisive control mastering hidden in the backend of the car-inherent automatic chain. That sounds complex in theory and views complicate in road traffic practice. At that, a car-typical conditioning-software has to evaluate in the background a selection of driving options as far as such behavioural strategies are not deeply standardized by general automotive specifications. If a car-driver might select one of a sample of driving styles for an intended route, then economic (to be in rush), ecologic (emission-reduced ride) or ethic (considerateness against vulnerable others) motives stand in the fore. For instance in the way that a downgrading (a++ to a+) of automat-potencies is available (Fig. 3). Sometimes it may be also that the driver will enjoy the ride by steering oneself.

2.3 Commands for driving manoeuvers

Driving manoeuvers need commands to the steering chassis and the powertrain of the vehicle. Each of the several commands to realize driving manoeuvers requires a calibration of tracking the right trajectory according to power and velocity parameters suitable to the taken pathway. Moreover, “an exit strategy” for surprising events is not to forget. That leads in a cascade of challenges for software developers to master complexity of boundary conditions and insecurity in respect of peculiar behaviours of adjacent opponents. Because roadway´s traffic does not work like an industrial production line. If at some time artificial intelligence would take over responsibility for handling the car from humans, then a part of that “brain” should be a module of ethic conscience as modulator of car-typical power mightiness to prevent careless or dangerous driving actions. We call that “Conditioning” of the car-inherent automotive chain of high-automated vehicles from SAE-Level 3 (= highly assisted driving as recent standard) upwards. SAE-Level 4 would enable a car to move partly autonomous, if the pathway allows it, but a driver is present in the car. Level 5 means, that the vehicle moves driverless and even without any passengers on board.

3 OPERATIONAL DESIGN DOMAINS (ODD)

3.1 Methodic Remarks

ODD defines a test location according to a relevant scenery. The testing institution has to formulate a test program in the direction, what tasks of vehicle´s automation are to prove. If results of testing are available, ODD could serve as a warning method to prevent some system-immanent mistakes, if systematic grounded as pretesting instrument. That proceeding can perform as a missing link between automotive software-hardware developers and traffic planning resp. road constructing engineers, if the latter professionals are involved in the selection of test sections and embedded in the definition of testing tasks. In such a way, both world of expertise could connect their interrogative interests to gain more knowledge about automated operations on road. A multitude of boundary conditions, as exogenous preconditions fixed, like roadway´s infrastructure and local regulations, or as external conditions limiting the freedom of driving, for instance as timely traffic jams or bad weather. Referring to urban and regional planning following issues are considerable, although these have not been key questions of spatial planning yet. Like zoning areas due to landuse in the vicinage, wherein vehicle´s operations of higher automation levels should be either admitted or restricted. Secondly, traffic planning could select proper sections within the road-net, where the usage of certain functionalities is allowed or ordered obligatory. Thinking about required duration of working out a mobility plan (2-3 years) and its realization (+/-10 years), it seems not too early to engage with such ticklish topics. Otherwise, technical progress might overrun planning processes and political decision-making .

3.2 Basic database for construction of scenarios

Making scenario construction operative to the automat-chain of an autonomized car there will be a need of systematic categorization of relevant subjects, of which characteristics and attributes more or less are suited to master challenging tasks of automatized driving. As they are (maybe in an incomplete listing):

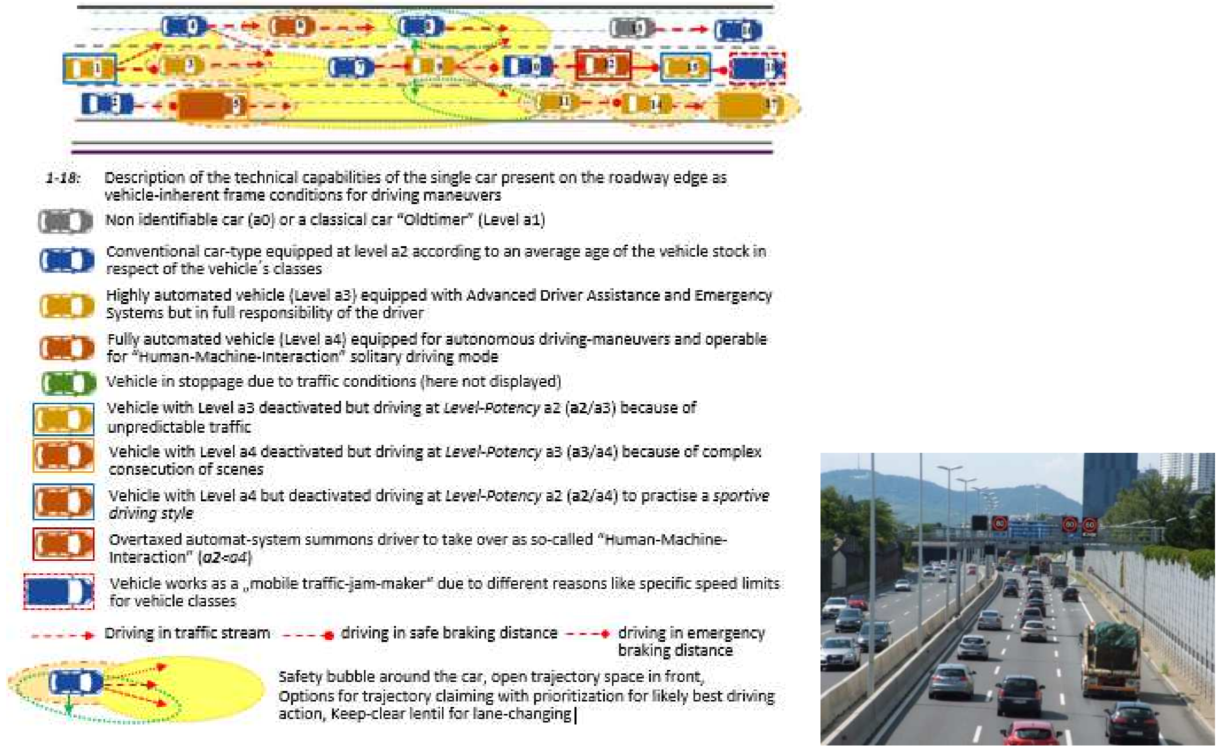

Figure 3: Construction of a scenario field onto a three-lane carriageway of Danube-Embankment-Highway (A22) in Vienna as scenery. The section shows a mixture of vehicles typical for urban traffic.

This scenario "Mixed vehicle traffic onto a 3-lanes carriageway" bases on the assumption that each vehicle shows its own specific characteristic of motor power and automat-level. It seems to be the most realistic as well as the most complex scenario of partly automated road traffic under the rule of indiscriminate traffic participation of motorists. All the vehicles behave as solitary moving actors. Such a mixture of cars causes a heterogeneous nearly unpredictable traffic flow. Hence, the prevention of critical interactions stands in focus.

List of useful databases for drafting ODDs:

- Vehicle´s automation equipment corresponding to the SAE-levels
- Vehicle´s motorization corresponding to vehicle utility classes and automotive brands
- Roadway´s tracing characteristics embedded in the landscape
- Roadway infrastructure to master typical traffic function within the road network
- Roadway surrounding tract in respect of traffic generating land uses and external intervening risks
- Rhythm of daily traffic flows occurring onto sections of the road network
- Local caused circumstances by the natural environment and the built-up area
- List of mobile groups of traffic participants with their movement behaviours and handicaps
- List of vulnerable road users and their special safety needs
- List of supporting means of moving which are not or weakly motorized (like e-scooter)
- Standardized scenes of driving manoeuvers as they can be often observed
- Systematization of interactions between traffic participants ("opponents")

Driving manoeuvers and traffic interactions between vehicles or with other road users have several formal dimensions measured as frequency and estimated as likelihood, if actions are operable defined. The localisation of them over the road net is crucial to identify critical interaction boxes and critical interaction´s relations between members of different mobility groups. Its interactions on roadways distinguishes by a broad variability of the participants mix and their driving habits. That´s why no interactions within a short-time lasting and dynamic "Sailing Interactions Space" are exactly predictable (Fig. 5).

3.3 Some approaches to draft an ODD

Drafting an ODD depends on what results the testing institutions expect by the test arrangements. In general, a technical assessment stands in the foreground, when possible effects of vehicle´s automatization meet sensitivities of other traffic participants, here so called "opponents" involved in interactions as tribute to the Gaming theory. Furthermore, beyond single traffic interactions onto roadways, automated movements of vehicles could affect potentially the interests of inhabitants of surrounding urban places (Fig. 2).

3.3.1 ODD by urban sceneries as preconditions

Urbanist´s interests concern a multitude of issues referring to quality of urban life. Therefore, it means to beware and to optimize environmental conditions in coexistence with economical requirements and its traffic needs. Consequently, such an approach focuses on the effects of vehicle´s automatization in both direction, what of the equipment of cars in interconnection with roadway´s infrastructure will be useful and what usage of car-inherent functionalites might be contraproductive in specific sceneries of urban traffic events. Within this context, town- and traffic-planning has to define its part, which will be not only an enduring one as a passive observer. Nevertheless, such technological driven changes in automotive equipments are sneaking processes and the penetration into vehicles stock is hitherto not on record. Any problems occurring become obvious for the first time in traffic statistics, if accidents accumulates somewhere. Sceneries as key approach to provide an ODD are typical urban spaces within the zoning of metropolises in respect of land use patterns and built-up densities. As a starting point serves the gradient of urbanisation, which structures all of our urbanized regions beginning with the core of central and inner urban districts, surrounded by suburban and periurban belts. Each of these urbanized sectors has its typical characteristics and sensitivities as spatial preconditions for traffic events there, which a story telling can describe similar to a script for a movie.

3.3.2 ODD by roadway´s network as spaces of traffic events

A road-network represents a hierarchical order of road categories according to its service functions for open up the vicinage and for ensure traffic capacity needed there. So, "form follows function" as we know from urbanism. Road´s constructive characteristics (number of lanes, traffic surface organisation, traffic flow management and so on) on the one hand and the embedded situation in urban public spaces on the other hand built a framework for car´s driving style and for traffic operations of road providers. The dynamics of driving manoeuvres of different car types, for instance heavy or light vehicles for passenger transport or goods´ deliveries, have to be calibrated as well as the constructive dimensions of roadways for that. As key questions to answer might be, what adaptions for highly automated vehicles operation on the roadside will make sense and what regulations on the side of motor traffic might be necessary. That concerns also modulations of driving dynamics within the car-inherent automat chain to be compatible with the respective roadway category and considerates specific sensitivities of inhabited land use in the surrounding (Fig. 4).

3.3.3 ODD by typical interactions between motorists and other road using groups

In such test cases, road-traffic is seen as participation of all road-using members of mobility groups, who interacts within a typical section of a roadway called as interaction space (Fig. 5). Intersections are the most critical of them, where the participant´s emerging is highly coincidentally and a prediction of its behaviours seems a hardly task for car´s inherent automate chain. Deep learning to gain artificial intelligence has the difficulty that no one of each situations would be the same. Therefore, it might be a question of conditioning the car´s automat system in respect of consideratness – as an ethical pretension – when interacting with more weak opponents. Besides, road traffic planning has mostly done to mitigate conflicts what the urban scenery spatially allows. However, it represents the most complicate, but daily trivial traffic events. Automatization of such interactions are hardly to expect on the short view, because of the complexity of movement habits, which characterize all different mobility groups. If they are motorized or not motorized, free of handicaps or burdend with mobility restrictions, which are not only due to bodily infirmities. Vulnerability of the interacting opponents would be a crucial moment to modulate dynamics of motor vehicles.

3.3.4 ODD by coincidental collectives of vehicles

Promotors of further automatization of road traffic tend towards to put a home play among motorists on the stage. Carriageways with three lanes along motorways out of town are actually the preferred ODD to test automated driving manoeuvres like distance keeping, speed control or over-taking actions. A crucial issue would be to put up a realistic mixture of different equipped vehicles on different levels of automatization (Fig. 3). That calls for a coordination by means of interconnectivity as well as for a right-time traffic management by the road-operating provider according to current traffic conditions within the road-net.

3.4 Interconnectivity as an asset?

Establishing of interconnectvity between adjacent vehicles makes data-exchange possible for a better coordination of their driving manoeuvers. That means each of the involved cars resp. car-holders has to give up some of its sovereignty for the favour of a collective optimization of moving forwards. Such a collective behaviour as moving bulk of vehicles could effect in more safety and less emissions through harmonization of traffic flow in view of modulating speed and keeping secure distances.

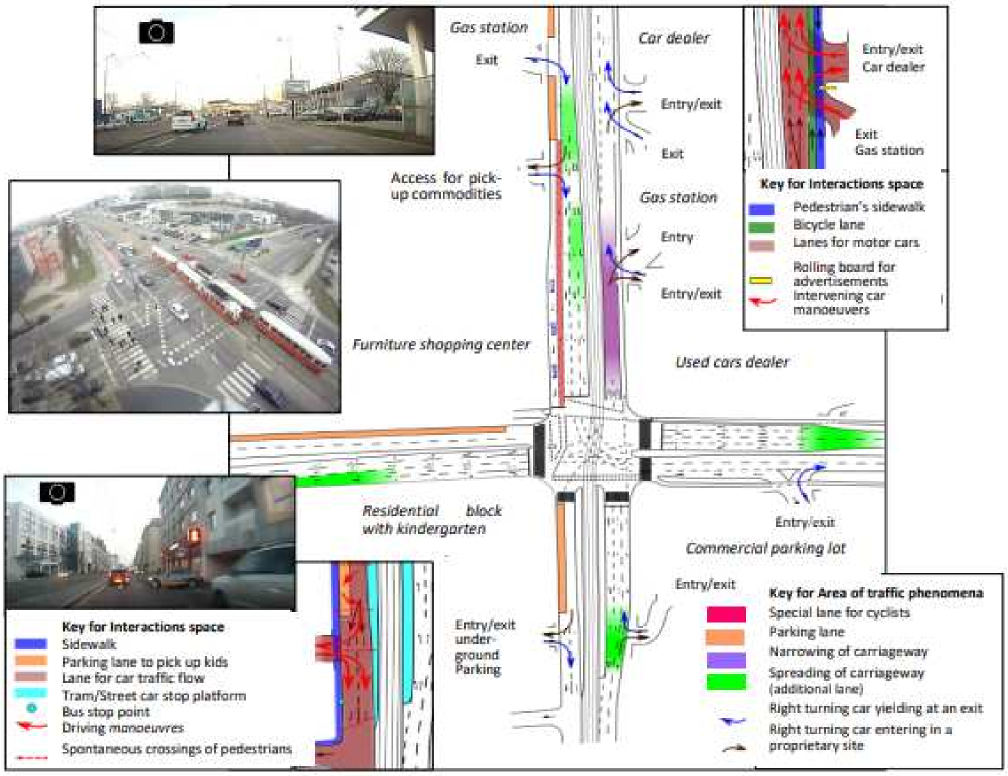

Figure 4: Intervened interactions spaces as phenotypical characteristic of a radial urban trunk road

Mainly we know three applications of interconnectivity:

3.4.1 Vehicle(s) to vehicle(s) (V2V) as motor-traffic internal communication

Car-to-Car-Communication serves as tooling to inform about intended driving actions, to keep distance by controlling the own car or to exchange data for harmonizing movements each another (bilateral or multilateral reactive between for that equipped motor vehicles). In fact, each car acts as a solitary moving body, but with a sufficient consideratness to prevent critical interactions with others. Bilateral V2V-communication concerns actually in interactions "nearfield" involved vehicles and multilateral with opponents within the detection-field (Fig. 2), where trajectory claiming could be touched or even threatened.

3.4.2 Vehicle to Infrastructure (V2I) as motor-traffic external communication

Each vehicle dispatches data of the ride and receives useful information about traffic conditions from the cloud. Thus, it deals with a bidirectional-individualized communication mainly on demand. First, data of car´s operation goes to the automotive manufacturer, who observes in such a way presumably customers as well. Additional a bidirectional data-exchange takes place for the disposition of commercial car-holders active in transport businesses. Nowadays the receiver of orders is the driver, but in a further future the control system of vehicles might receive steering commands by an external control master. Which one acts dislocated from the car as remote controller maybe supported by artificial intelligence. Proven since decades are traffic light regulated intersections coordinated along urban trunk roads to facilitate an unbroken traffic flow. In a first approach in-coming vehicles can receive a previous information to modulate the approaching velocity. Bidirectional the car makes known to the traffic management the intended directions at the next intersections tracking the route. As further enhancements, the remote traffic management might take over steering of the car instead of the control of a driver present in the car. In times out of traffic rush an ordinary car would ask for green light on demand wireless by air. With that, traffic management has a lot of coordination to do, if a majority of vehicles would be on track in this way. Notwithstanding road providers have to avoid improper discrimination of under-equipped motorists. So we can conclude, that to establish interconnectivity between motor vehicles is technical feasible but in organisational respect full of restraints.

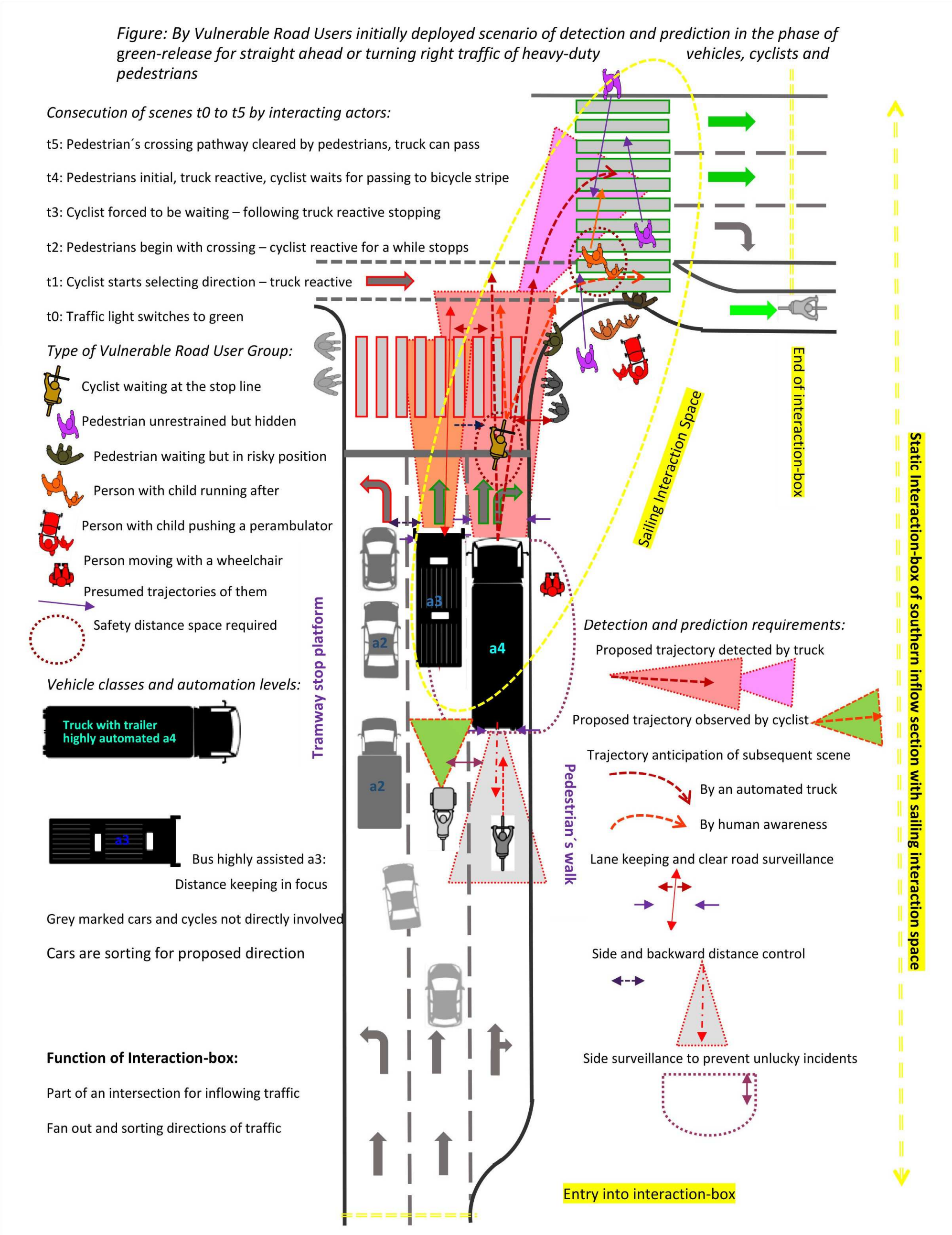

Figure 5: Heavy duty vehicles starting to cross intersection straight ahead and turn right

3.4.3 Vehicle to other traffic participants (V2X) as road-users-relations

It becomes more difficult, if road users of all mobility groups come into play. Among them are not motorized pedestrians, especially vulnerable persons or cyclists, which are extremely occupied by mechanical steering to hold its path. Maybe that all of them have smart phones with them, but would all of them be guided in this way on the way. Looking on a smart phone´s screen less or more steadily causes stress. The scenario depicted in Figure 5 dealt with the task how an automated driving system would be challenged, if vulnerable road users will be the initial actors on the scene. The short story hereby tells a scenario of interactions between a cyclist as initiative actor at the beginning, a heavy-duty truck as reactive actor and pedestrians as independent co-players. The interactions between them take place in an interaction box as part of an intersection as depicted in Figure 5. The traffic light gives the starting signal when it shows green release for going straight ahead or turning to the right. The initial actor is a cyclist waiting for green light at the stop line while a heavy truck is approaching. The cyclist has two options to direct himself: forwards straight ahead or turning right. If both participants are going for turning towards right, it will be a tremendous challenge for an autonomized heavy vehicle detecting the forefield, predicting the behaviours of the others and controlling his own driving dynamics. This story leads to a setting for test arrangements proving the automatic system of the vehicle based on requirements of the "real world" which cannot be done convincingly by computer simulations.

So, what are practicable solutions to integrate non-motorists into interconnected road traffic operations. They can get messages about general traffic circumstances in the surrounding, what is usual nowadays, if demanded. Smart phone holders can be especially addressed, if target groups with its information needs have been constituted. All applications at the present state of the art effect monodirectional as warning signal, either X2V or V2X, if a critical approaching threatens. Though, such helping instruments are not deployed yet. Therefore, an integration into a system of automated road traffic is not expected for the close future. Nevertheless, a mobility strategy as political guideline for traffic planning has to consider, that instead of integrating non-motorists into automatic traffic operations a forced spatial desintegration within the network of pathways will not be a satiesfying solution.

4 RÉSUMÉ FOR AN OPEN DISCOURSE

Technical progress has its utilities but also weaknesses, which the draft of ODDs can help to unveil as some disadvantages for free mobility. Scenario generating for that means combining static and dynamic recurring frame conditions as rules of an interaction box respectively a "playing ground" with the behaviour of traffic participating players coping with tasks of driving or moving in a consecution of interactions between them. Approaches derived from real world as exemplified do not solve technical problems as that are tasks for automotive research and development. Rather it should help to trace out challenging traffic events and to put up framing conditions, which influence traffic flows exogenously. In such a multidisciplinary manner deficiencies untied from pure technical quality requirements and standardization, like ISO 26262 and as newst ISO 34503-2023 concerning ODD (which have been not discussed here to stay independent), could be revealed. Embedded in a chain of test and implementation procedures all relevant stakeholders, experts and affected groups from the mobility milieu can be addressed. Not at least, because this methodical approaching should enable them to reflect the evoked changes by the arising innovations within the mobility system and to encourage them to contribute their considerations to that in a democratic discourse.

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