D3.2

Catalogue of basic driving manoeuvres and associated task distributions

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Compiled by:	Mark Eilers
Authors:	Mark Eilers, OFF Thibault Griffon, PSA David Käthner, DLR Paulin Pekezou, DLR
Technical Approval:	Fabio Tango, CRF
Issue Authorisation:	Andreas Lüdtke, OFF

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LIST OF ABBREVATIONS	
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
AutoMate	Automation as accepted and trusted TeamMate to enhace traffic safety and efficiency
BASt	Bundesanstalt für Straßenwesen
CoP	Code of Practice
ISO	International Organization for Standardization
NHTSA	National Highway Traffic Safety Administration
PREVENT	Preventive Active Safety Applications Integrated Project
SAE	Society of Automotive Engineers
WP	Workpackage

Table of Contents

1 Introduction

This deliverable describes the results of Task 3.2 “Specify basic driving manoeuvres and appropriate principles for driving task allocations to driver and automation” at the beginning of the first cycle of AutoMate. Based on the scenarios selected for AutoMate, the deliverable defines the first version of a catalogue of basic driving manoeuvres as a prerequisite for the design of adaptive driving manoeuvres and strategies the automation must address. Furthermore, the deliverable describes a first version of the principles for the allocation of driving tasks from the automation to the driver and vice versa. It should be expected that the catalogue of basic driving manoeuvres and the principles for driving task allocation will be extended and detailed in the second and third cycle of AutoMate.

The document is structured as follows: Section 2 summarizes some considerations concerning the Code of Practice developed in the PReVENT subproject RESPONSE 3 analysed at the start of T3.2. Section 3 describes the current state for principles for driving task allocations to driver and automation in the first cycle of AutoMate, while Section 4 provides the current state of a catalogue of basic driving manoeuvres necessary to address the scenarios chosen for AutoMate. The document ends with a conclusion and outlook for future cycles in Section 5.

2 Code of Practice from the PReVENT subproject RESPONSE 3

At the beginning of the project, we were looking for sources in order to fulfil this document. We used most of them to write the next parts and you can find their references at the end of this deliverable. Some of these sources were set aside. However, because one of them is interesting from a general point of view and may be used in other work packages, we wrote the following paragraphs.

The Code of Practice (CoP) has been produced within the PReVENT subproject RESPONSE 3 to contribute to road safety by the development and demonstration of preventive safety applications and technologies. As stated in the CoP (RESPONSE 3, 2006, p. 2), the CoP "comprises a suitable ADAS (Advanced Driver Assistance System) description concept including ADAS specific requirements for system development. It summarizes best practices and proposes methods for risk assessment and controllability evaluation".
The development of this CoP is to provide the vehicle industry with the tools and common understanding to overcome and to help managing the problems about safety concerns and liability of ADAS.

The first idea, regarding this deliverable, was to investigate possible and appropriate ways to allocate a safe driving task considering the definition of necessary prerequisites (capabilities, cognitive or physical constraints). Driver Assistance Systems are supporting the driver in their primary driving task, even if they assist the driver and do not take over the driving task completely. That is not autonomous driving. ADAS inform and warn the driver, provide feedback on driver actions, and reduce the workload by actively stabilising or manoeuvring the car. But all in the CoP aims at serving as a guideline, to assist persons involved in ADAS development only; to adhere to the state-of-the-art knowledge with respect to risk identification and risk assessment as well as methodology for the evaluation of driver controllability.

The CoP is more a first approach and guidelines for safe development process. It will give elements of a safety process and controllability concept, but it cannot be used to specify a basic driving manoeuvre or the appropriate principles for driving task allocations to driver and automation. Besides, it has to be applied only completely with regard to a new development of an ADAS system, and that is not our case.

“The CoP serves as a support tool for the engineer engaged in the development of ADAS. CoP not only means a compilation of currently available procedures, but also offers clues for determining activities to be performed during the individual development phases.

Focus of the CoP is the system design against the background of system controllability and the total vehicle from the field of view of Human Machine Interaction. Of course system influences due to occurring defects/errors do play an important role as well as ADAS behaviour at system limits and foreseeable misuse.” (RESPONSE 3, 2006, p. 2)

However, concerning safety, RESPONSE 3 is focussing on the human-machine interaction safety issues of ADAS, in particular on driver controllability, an ADAS key issue (while the technological safety issues are standardised within ISO TC22). Controllability is a key requirement. As stated in RESPONSE 3 (2006, p. 13) “Controllability refers to the entire ADAS-driver-environment interaction which comprising:

- Normal system use within system limits,
- Usage at and beyond exceeding system limits and
- Usage during and after system failures.”

If it is not exactly the purpose of task 3.2, maybe this CoP can be useful in WP1 for the T1.4 for example. However, we used this summary as an approach for the next parts.

3 Principles for driving task allocations to driver and automation

The driving task consists of many interrelated subtasks. Those subtasks can be executed either by the driver alone, by a machine alone, or in combination (shared control). In case a machine overtakes some or all of these tasks, we speak of automation. This is usually understood to be the allocation of tasks to machines which have been previously been executed by humans. However, for a broad framework of driving task allocation, we will regard the automation as any device that supports drivers with the driving task execution. This can also mean to only assist conducting a task, not necessarily overtaking it entirely.

For the purpose of describing driving task-allocation principles, we will define the subtasks of driving as *longitudinal control*, *lateral control*, and the *monitoring* of the environment. A driver with an automated system on-board may also have to monitor that system. Depending on the allocation of the tasks to either human or machine, we can define distinct driving states which correspond to the possible combinations. Changes between these driving states are defined as transitions. It is important to note that both driver and system are regarded to be not merely low level controllers, but rather *information processing units*. Each can make independent decisions, based on their understanding of the world (and, in case of conflict, an arbitration – e.g. negotiation – is necessary).

Numerous attempts have been made to define conclusive frameworks for these driving states. The most notable ones are those of SAE (SAE, 2014), BASt (Gasser & Westhoff, 2012), and NHTSA (NHTSA, 2013). However, they are based on expected driving behaviour (normative), not actual behaviour (descriptive). This serves well if the goal of the driving task analysis are legal considerations, or if actual behaviour of human drivers is of no importance.

However, for the design of new interaction strategies, such as the TeamMate concept, this poses problems. It is specifically inadequate regarding transitions between driving states. Another issue which remains unaddressed by the aforementioned frameworks is the question of responsibility in a joint human-machine team: In case one of the agents cannot handle a situation, what will the other agent do?

We therefore developed a simplified framework to be able to consider problematic situations regarding driving states and changes between those states. After this, we will describe a more explicit and comprehensive framework from the published literature. It allows for the treatment of driving states and transitions at a joint team level of driver and automation.

3.1 A simplified approach to transitions and driving states

To approach the subject of how tasks should be divided between driver and vehicle, let us investigate a simplified scenario in which no shared control exists. The two alternatives then are full control by either the human driver, or the machine. The agent controlling the vehicle performs all three of primary driving subtasks: longitudinal control, lateral control, and monitoring of the environment.

The claim of automation is to handle the driving task more reliable than human drivers do. Having the automation control the vehicle therefore should increase safety for the driver, which is our ultimate goal. At the same time, currently there are no automation systems able to handle every conceivable situation, i.e. which can drive everywhere, all the time (SAE automation level 5). This means that there will be situations which the automation cannot handle on its own. Further, for legal and ethical reasons, the driver must be given the final decision whether or not to let the automation handle the driving, unless a decision against the automation would endanger the driver.

As basic principles for task allocation, we can therefore state the following:

1. The system should be in control whenever it is able to handle the situation, unless the driver wishes otherwise.
2. The driver should be in control whenever the system is unable to handle the situation, or the driver wishes to control the vehicle.
3. The system should propose to take over tasks from the driver whenever the driver is deemed unable to handle the situation, unless the driver refuses to give control.
4. Whenever the system believes to be not entirely competent to handle the situation, the driver will be prompted to supervise the system's actions.

Unfortunately, there is no way of knowing for sure if the automation is competent in a given situation or not. We only can utilize what the automation thinks about itself, and what the driver thinks about the automation. We therefore obtain three dimensions: the belief of the automation about its competence, the belief of the driver about the automation's competence, and an absolute truth.

Each dimension is in one of two states: for the automation to either be competent to handle the situation, or not. Of course this is a simplification, as there are degrees of competence to be expected. However, for a first principled approach to task allocation between driver and vehicle, we will keep a binary classification. Depending on the future course of the TeamMate-concept, this may have to be adapted.

Table 1 lists the possible combinations obtained if the automation is currently in control. In this table, it is assumed that the human driver is fit to drive. The cells show the resulting transitions or consequences from each combination. The colours denote the criticality of the transition or lack thereof. Green is considered to be safe, red unsafe, beige probably safe, and orange possibly unsafe.

From a safety point of view, the best configuration is if the automation is in truth able to handle the situation, and both the system and the human believe that as well. On the other end of the safety dimension is the situation where the automation is, in fact, not competent to handle the situation, but both the technical system and the driver expect the machine to successfully handle the situation. Here, it is quite plausible for an accident to occur (Schoettle & Sivak, 2015).

Cases where the driver initiates the transition herself can be seen as less problematic. This is always the case when the driver believes the automation to be incompetent to handle the situation, regardless of this actually being the case. To initiate such a transition, the human driver will need to already have build up a representation of the environment, a prerequisite for successfully handling the driving task manually. Otherwise it would be implausible for the driver to feel the need to drive manually.

Table 1: Possible consequences when automation is in control and the driver is competent to drive.

		Truth			
		Automation is incompetent		Automation is competent	
		Belief of the automation about itself			
		Incompetent	Competent	Incompetent	Competent
Belief of the driver about the automation	Incompetent	Necessary and expected transition to driver control	Driver may necessarily take control from automation	Unnecessary and expected transition to driver control	Driver may unnecessarily take control from automation
	Competent	Necessary and unexpected transition to driver control	Dangerous automated driving	Unnecessary and unexpected transition to driver control	No transitions initiated

For the driver grabbing the control from the automation may be complicated if the system believes itself to be competent to drive. In accordance with our stated principle to let the driver have the deciding voice about who should be in control, the automation should not “resist” a transition. Assuming driver who is fit to fulfil the task, the worst case scenario here is for a driver to drive manually when it would not have been necessary. These are the cases when the automation would have been, in truth, able to handle the situation. In cases where it would not have been able to handle the situation, the driver would prevent a very dangerous situation by grabbing the control.

Possibly unsafe transitions can arise if the system believes to be incompetent, but the driver thinks otherwise. Here, the system would have to initiate a transition, which would be unexpected for the driver. After all, she is convinced the system is competent in this situation. The criticality further results from the possible lack of situation awareness on part of the driver. After all, there was no specific need to achieve a situation representation adequate for manual driving. Take-over-times would therefore have to be prolonged compared to transitions the driver initiates on her own.

3.2 Beliefs about driver's competence

There are two obvious drawbacks to the above simplified framework. First, it does not address the competence of the driver. This dimension could be analysed in the same manner as the states of the automation. A driver could be seen as either competent to drive or not, with assigned beliefs of the automation and the driver about the driver's competence.

However, how to treat the resulting combinations is less clear, compared with the previous table. If we assume that the driver is in control of the vehicle, from the basic principles of task allocation it follows that either the automation cannot handle the situation, or that the driver wishes to drive manually. In the first case, the belief of the automation about the driver would not matter, as it would not be able to overtake itself. In the second case, the belief of the automation about the driver would not matter as well:

As stated, we must respect the driver's wishes. Any consideration which involves a) to refuse handing control to the driver or b) forcefully take control from the driver will have to investigate the ethical and legal implications of such a proposal. For this deliverable, this would be out of scope.

If we assume that the automation is currently in control, issues of driver competence cannot be treated either without further assumptions or principles. If the automation is competent and in control, the driver state does not matter. If the automation is incompetent, there is prima facie no other way than handing control back to the driver. The actual or assumed driver competence would not matter.

However, we can introduce the concept of a minimal risk manoeuvre. This proposed solution means that, if both automation and driver are incompetent, the vehicle still finds a way to at least bring the vehicle to a standstill in a safe position.

Table 2 shows the influence of driver's (in)competence on transitions back to the driver. Clear cases are when both automation and driver agree about the driver's competence: The driver takes over the vehicle control. If the driver is competent, safe manual driving will follow. If the driver is incompetent, unsafe manual driving will follow. If the automation believes the driver is not competent to drive, it may have to initiate a minimal risk manoeuvre. If it does so or not depends on the ethical and legal framework used. From a safety point of view, it is the right thing to do. From a Human Factors point of view, it may erode trust in automation.

Table 2: Possible consequences when automation is in control but needs to hand back control while the driver's competence varies.

		Truth			
		Driver is incompetent		Driver is competent	
		Belief of the driver about him/herself			
		Incompetent	Competent	Incompetent	Competent
Belief of the automation about the driver	Incompetent	Necessary and expected minimal risk manoeuvre	Necessary but unexpected minimal risk manoeuvre	Unnecessary but expected minimal risk manoeuvre	Unnecessary and unexpected minimal risk manoeuvre
	Competent	Driver may refuse control, minimal risk manoeuvre may follow	Dangerous manual driving	Driver may refuse control, minimal risk manoeuvre may follow	Driver takes over, safe manual driving

As is well visible from the table, almost all cells contain the minimal risk manoeuvre as the solution for the assumed incompetence of the driver. This may be very challenging from a technical point of view. If an automation is suddenly unable to handle an upcoming situation, e.g. because it is too complex or the situation representation is inadequate, it is hard to see how such an automation would come up with a good solution to bring the vehicle in a safe state. The machine may simply not be able anymore to judge what such a safe state would be, given the entire situation. However, ultimately that decision will have to made by engineers.

3.3 A comprehensive framework

Lu et al. (2016) presented a framework which is much more comprehensive than our considerations above. It has the great advantage to address driver behaviour on a descriptive level, not a normative one. It also explicitly supports the treatment of a joint team of automation and driver.

On the other hand, it does not consider explicitly the believes of either man or machine about each other as we have done. It also does not hold the assumption that the automation should always be in control as we have done.

The framework's core is the diagram shown in Figure 1. It models automation and driver as part of the same control loop. The input this loop receives comes from the environment, it is essentially the specific situation the vehicle is in. This input reaches both automation (via sensors) and driver. Depending on the system configuration, either driver, automation, or both control the actions of the vehicle. They can both give input to the longitudinal control, the lateral control, or both. Additionally, the driver has a parametric value regarding her monitoring of the environment (i.e., the input to the control loop).

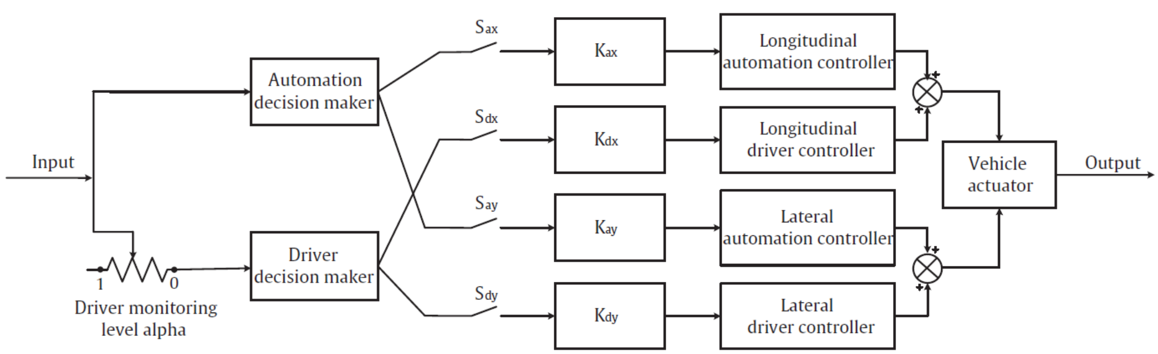

Figure 1: Distributions of driving tasks (from Lu et al. 2016, p. 185).

The inputs are modelled as switches, which can be either on or off. Shared longitudinal control with the driver having the lateral control models an ACC. Shared lateral control with the driver in control of the vehicle's speed could be a lane assist, which supports the driver by giving haptic feedback on the steering wheel.

Any arrangement of open or closed switches represents a discrete driving state. Opening or closing switches means a change in driving state, i.e. a *transition* between control states. Such transitions can be classified into a tree, depicted in Figure 2. Transitions can be either initiated by the driver, or by the automation. Following the transition, either the driver or the automation will be in control. Reasons for the transition can be either optional, or mandatory. The first type would be "will based" (e.g. due to individual preferences), the second "ability based". It is this second type that we addressed in the simplified scenarios above.

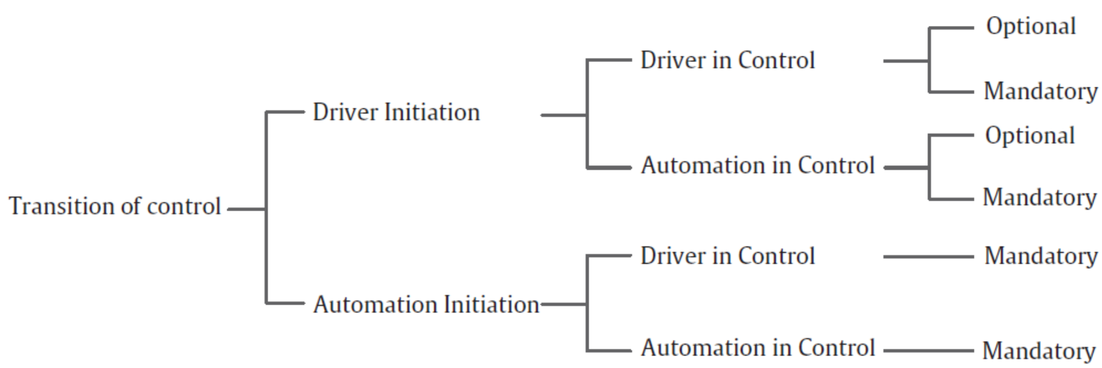

Figure 2: Classification tree of transitions of control (from Lu et al. 2016, p. 188).

Based on who initiates the transition and who controls the vehicle after the transition, the different use cases can be analysed in more detail. For instance, a *mandatory driver initiated / driver in control - transition* would occur if the driver believes something to be wrong with the automation. A *mandatory automation initiated / automation in control - transition* would occur if the automation diagnoses the driver to be unfit to drive. Finally, the category *mandatory automation initiated / driver in control - transition* subsumes those cases where the automation believes not to be able to handle an upcoming situation anymore. This could be due to an exceedance of the automation's operational limits, or equipment failure.

4 Catalogue of basic driving manoeuvres

The human driving task is commonly described as a hierarchical structured task with three levels of skills and control: *strategical*, *manoeuvring*, and *control* (Michon, 1985). At the strategic level, the general planning of a journey is handled, e.g., the driver chooses the route and evaluates resulting costs and time consumption. At the manoeuvring level, the driver has to select manoeuvres, e.g., turning at an intersection or initiating a lane change. Lastly, at the control level, the driver has to execute simple (and for experienced drivers mostly autonomous) action patterns, which together form a manoeuvre or behaviour. Examples are braking manoeuvres in order to keep a safe distance to a leading vehicle or turning the wheel to remain in the middle of the lane. Although originally only addressing the human driving task, this three-level hierarchy has been widely adopted in autonomous driving (e.g., Urmson et al., 2009, Özgüner et al., 2011, Leonard et al., 2007, Montemerlo et al., 2009). At the strategic level, the autonomous vehicle is given a set of long-term goals or plans, e.g. a target destination to be reached. During the journey, context-specific short-term driving manoeuvres like lane-changes are selected at the manoeuvring level, which are then realized on the control level.

In reference to the three-layered hierarchy of the driving task, the goal of the catalogue of driving manoeuvres is the definition of a set of *basic driving manoeuvres* on the *manoeuvring* layer, the TeamMate vehicle

1. *must be able to perform autonomously,*
2. *must be able to communicate and negotiate with the driver,*

both in respect to the scenarios selected in AutoMate.

Based on previously proposed manoeuvre catalogues in the literature described in Section 4.1, Section 4.2 will define a catalogue of seven basic driving manoeuvres adapted to the scope of AutoMate. Although not directly applicable for the definition of basic driving manoeuvres, Sections 4.3 and 4.4 will additionally provide an overview of an alternative decomposition of the driving task in terms of *traffic* and *driving situations*. The resulting classification systems should proof useful for AutoMate as a starting point for the definition of a comprehensive library of generic traffic and driving situations the TeamMate car may need to communicate to the driver.

4.1 Existing catalogues of driving manoeuvres

The first attempt to define a complete catalogue of basic driving manoeuvres for autonomous vehicles was performed by H. H. Nagel and his colleagues. Nagel (1994), also Nagel et al. (1995) proposed a set of 17 "elementary" driving manoeuvres, where elementary should be understood in the sense that "given certain boundary conditions which define a discourse world, all other vehicle manoeuvres admissible in this discourse world can be composed by concatenation of these primitive or elementary manoeuvres" (Nagel, 1994, p. 193). Bajcsy and Nagel (1996) later extended the catalogue by the addition of the "trivial" manoeuvre "Standing". The complete set of driving manoeuvres is provided in Table 3. As noted by Nagel (1994), these manoeuvres are not supposed to be independent, e.g., a u-turn manoeuvre can be interpreted as the composition of two turning manoeuvres, but exhaustive.

Table 3: Overview of 17 elementary manoeuvres for autonomous driving proposed by Nagel (1994) and Bajcsky and Nagel (1996).

Number	Manoeuvre	Comments
1	Start and continue	
2	Follow a road	Includes the case where the road bends and the speed has to be adapted such that the lateral acceleration remains within acceptable limits
3	Approach obstacle ahead	Includes approaching a preceding car as special case; implies a transition from velocity control to distance control
4	Overtake	
5	Stop in front of obstacle	
6	Pass obstacle to the left/right	
7	Start after preceding car	differs from “Start and continue” by the requirement to synchronize the start with the start of the preceding car and by necessitating control over the distance to the preceding car during the motion phase
8	Follow preceding car	
9	Cross intersection	
10	Merge to left/right lane	
11	Turn left/right	
12	Slowdown to right road	

	edge and stop	
13	Back up	Drive backwards without changing the orientation of the vehicle
14	U-turn to the left/right	
15	Reverse direction	I.e. turn vehicle by 180 degrees and drive into the opposite direction as previously
16	Enter parking slot	
17	Exit parking slot	
18	Standing	Added by Bajcsy and Nagel (1996)

As stated by Schreiber (2012)[2], based on the assumption that some of Nagel's manoeuvres can be seen as special cases of the same general manoeuvres, Tölle (1996) reduced the manoeuvres defined by Nagel and colleagues to a set of nine driving manoeuvres, shown in Table 4.

Table 4: Catalogue of nine basic driving manoeuvres defined by Tölle (1996), as stated by Schreiber (2012).

Number	Manoeuvre	Comments
1	Start and continue	Translated from "Anfahren"
2	Follow / Following road	Translated from "Folgen"
3	Approach	Translated from "Annähern"
4	Pass / Overtaking	Translated from "Passieren"
5	Cross intersection	Translated from "Kreuzung überqueren"
6	Change lanes	Translated from "Fahrspurwechsel"

[2] The original reference (Tölle, 1996) was not accessible, but the resulting manoeuvre catalog is provided by Schreiber (2012).

7	Turn	Translated from “Abbiegen”
8	Reverse	Translated from “Umkehren”
9	Park	Translated from “Parken”

Based on the work of Nagel (1994) and Tölle (1996), newer versions of catalogues for driving manoeuvres from the *drivers point of view* have been developed for a shared control paradigm called “Conduct-by-Wire” (Franz et al., 2015, Schreiber et al., 2009, 2010, Schreiber 2012). Within this paradigm, the driver does not control the vehicle directly, but instead only triggers a set of parametrized manoeuvres that are then realized by the automation. As an extension to Nagel and Tölle, Schreiber et al. (2009, 2010), Schreiber (2012), and Franz et al. (2015) distinguish between *explicit* and *implicit* manoeuvres. Explicit manoeuvres are defined as self-contained, finite duration manoeuvres with a clearly defined start and end point that can be initiated by the driver, like e.g., lane changes. In contrast, implicit manoeuvres do not have clearly defined start and end points but instead a potential infinite duration, like e.g., lane-keeping. Within the conduct-by-wire paradigm, it is assumed that after the execution of an explicit manoeuvre initiated by the driver, the automation automatically resumes an implicit manoeuvre, without initiation of the driver. The original catalogue of seven manoeuvres for the conduct-of-wire approach was stated in Schreiber et al. (2010) as shown in Table 5.

Table 5: Catalogue of seven driving manoeuvres defined by Schreiber et al. (2010).

Number	Manoeuvre	Comments
1	Start up	Explicit manoeuvre
2	Braking	Explicit manoeuvre

3	Standstill	Implicit manoeuvre
4	Lane change left/right	Explicit manoeuvre
5	Left/right turn	Explicit manoeuvre
6	Following road	Implicit manoeuvre
7	Overtaking	Explicit manoeuvre, defined as a sequence of a lane change to the left, passing the target, and a lane change to the right (Schreiber et al., 2010).

For the latest version (Franz et al., 2015), the original catalogue of driving manoeuvres (Table 5) was reduced to a final set of only four manoeuvres applicable for motorways, rural roads, and urban settings, shown in Table 6. Each of these manoeuvres can be parametrized by a set of three parameters, the target speed, the time headway to the lead vehicle, and the eccentricity in the lane.

Table 6: Catalogue of four driving manoeuvres defined by Franz et al. (2015).

Number	Manoeuvre	Comments
1	Follow road	Implicit manoeuvre, translated from “dem Straßenverkehr folgen (inclusive bremsen, stehen und anfahren)“
2	Straight ahead	Explicit manoeuvre, translated from “geradeaus”
3	Lane change left/right	Explicit manoeuvre, translated from “Fahrstreifenwechsel links/rechts”
4	Turn left/right	Explicit manoeuvre, translated from “abbiegen (halb) links/rechts”

For the special case of motorway scenarios, Schreiber (2012) additionally defined his own catalogue of five driving manoeuvres, shown in Table 7.

Table 7: Catalogue if five driving manoeuvres on motorways defined by Schreiber (2012).

Number	Manoeuvre	Comments
1	Start and continue	Explicit manoeuvre, translated from “Anfahren
2	Lane change left	Explicit manoeuvre, translated from “Fahrstreifenwechsel links”
3	Lane change right	Explicit manoeuvre, translated from “Fahrstreifenwechsel rechts”
4	Follow road	Implicit manoeuvre, translated from “Straße folgen”
5	Halt	Implicit manoeuvre, translated from “Stillstand”

In contrast to the original catalogue of seven manoeuvres for the conduct-of-wire approach (Schreiber et al., 2010, Table 5) the final catalogue by Franz et al. (2015, Table 6) and the catalogue by Schreiber (2012, Table 7) discard the explicit mention of the manoeuvre “Overtaking”. The reasons for this are twofold. First, the expected duration of an overtaking manoeuvre is hard to define, due to the complication to estimate the potential number of vehicles to overtake prior to execution, which is especially true during automated driving with limited sensor capabilities. Second, the overtaking manoeuvre can be reasonable substituted the sequence of a lane change to the left, passing the target, and a lane change to the right. This coincides with the results of experiments conducted by Schreiber et al. (2010). From the driver’s point of view, the overtaking manoeuvre is composed of lane change to the left and the passing of the vehicle, while the concluding lane change to the right is seen as its own manoeuvre.

4.2 Manoeuvre catalogue for AutoMate

As described in deliverable D1.1 "Definition of framework, scenarios and requirements", AutoMate addresses three scenarios, referred to as the "Peter", "Martha", and "Eva" scenario, focussing on rural roads, motorways, and roundabouts respectively. In the following sections, we will provide the manoeuvres necessary to master each scenario. Although each scenario is comprised of six use cases, these use cases only differ in situational context and response from the automation/driver to this context, but do not introduce any manoeuvres foreign to the initial scenario. As such, we refrain from an in-depth explanation of each use-case. Being the most explicit, we will base the identification of basic driving manoeuvres on the catalogue of elementary driving manoeuvres proposed by Nagel (1994).

4.2.1 Scenario "Peter"

For the sake of completion, Table 8 gives an overview of the "Peter" scenario as provided in D1.1. The scenario addresses a typical overtaking manoeuvre on rural roads. Following Nagel (1994), we can identify the following elementary driving manoeuvres sufficient for the intended scenario:

- Follow a road (while driving on the rural road without lead vehicle, or while passing another vehicle during overtaking)
- Approach obstacle ahead (while approaching a slower lead vehicle)
- Follow a preceding car (while waiting to overtake the lead vehicle)
- Merge to the left/right lane (when performing potential abortable lane changes to the left lane to veer out and performing lane changes to the left to veer back in)

Table 8: Brief description of the "Peter" scenario.

Scenario Peter	Driver out of the loop, maneuver becomes necessary	Rural Road
A driver is reading in full automation when a large vehicle makes an evasive maneuver necessary.		
Sequence of events		
<u>Initial state:</u> Peter hands over the control to the TeamMate. During the fully automated drive, the TeamMate constantly monitors the route for risks and situations, in which input or a take-over becomes necessary. Peter starts reading and thus is fully out of the loop. <u>Scenario Evolvement:</u> The TeamMate receives information by V2V about a slowly driving tractor three kilometers ahead, which it cannot overtake safely on its own. Via the Teammate HMI the system starts an escalating strategy to bring Peter back in the loop. The TeamMate offers him different options how to deal with the occurring situation: (A) slowly drive behind tractor, (B) tell when to initiate an overtaking maneuver, (C) overtake manually. <u>Scenario Resolution:</u> Peter selects option B (exception with option C for the last use case). Thus, the TeamMate approaches the tractor and opens a dialog. Peter carefully checks the traffic and selects the right situation for the maneuver and communicates this to the TeamMate. After double-checking with its sensors the system starts, or not, the overtaking maneuver while constantly controlling safety margins. The TeamMate keeps on communicating with V2V and V2X in order to check for any changing conditions. When the system detects oncoming traffic or a tight curve, it will inform the driver and stop the overtaking maneuver. After the maneuver has been successfully finished, the TeamMate indicates the availability of unobserved		

autonomous driving again.

4.2.2 Scenario “Martha”

Table 9 gives an overview of the “Martha” scenario as provided in D1.1. The basic driving manoeuvres are similar to the “Peter” scenario, but on motorways instead of rural roads. Following Nagel (1994), we can identify the following elementary driving manoeuvres sufficient for the intended scenario:

- Follow a road (while driving on the motorway without lead vehicle, or while passing another vehicle during overtaking)
- Approach obstacle ahead (while approaching a slower lead vehicle)
- Follow a preceding car (either on the right lane or on the left lane during overtaking)
- Merge to the left/right lane (when performing potential abortable lane changes to the left lane to veer out and performing lane changes to the left to veer back in during overtaking manoeuvres)
- Slowdown to the right road edge and stop (as an example for an automated minimum risk manoeuvre)

Table 9: Brief description of the “Martha” scenario.

Scenario Martha	Take-over of automation after driver distraction	Motorway
While driving manually, a driver suddenly receives a distracting message and the system takes over.		

Sequence of events
Initial state: Martha enjoys driving in manual mode in nice weather. The Team Mate assists her with information gathered by its sensors and communication channels (V2V, V2X, traffic information). Above this, the TeamMate steadily monitors the driver's physical and psychological condition (e.g. situational awareness, workload, emotional and affective state) in regard to evaluate her ability to drive. Scenario Evolvement: Martha drives safely on a calm motorway section as she gets an important text message. She grabs her phone and starts reading. The TeamMate identifies her distraction by eye-tracking and her driving parameters. Based on the driver's preferences, the system knows she will be annoyed by an immediate full take-over. Therefore the system communicates in a multi-modal way that a distraction has been noticed and that the TeamMate could take over control. Scenario Resolution: Martha realizes her own distraction and agrees, or not, with the take-over request. If the system takes over full control of the vehicle then Martha is able to continue replying to the text message safely. The TeamMate keeps watching her distribution of attention and after it detects that she has finished texting, the TeamMate asks, if she wishes to take over again. In this process, the system continuously checks for her ability to take over the single functions of the vehicle.

4.2.3 Scenario "Eva"

Table 10 gives an overview of the "Eva" scenario as provided in D1.1. Although driving manoeuvres necessary to traverse roundabouts have not yet been addressed explicitly in the literature, we assume the existing manoeuvres to be sufficient for such scenarios. Following Nagel (1994), we can identify the following elementary driving manoeuvres:

- Stop in front of obstacle (when forced to stop while trying to enter the roundabout)
- Start and continue (after being forced to stop while trying to enter the roundabout)
- Standing (if being forced to stop while trying to enter the roundabout)
- Turn right (when entering and exiting the roundabout)
- Follow a road (while approaching and traversing the roundabout, assuming the absence of a lead vehicle)
- Approach obstacle ahead (while approaching and/or traversing the roundabout, assuming the existence of a lead vehicle)
- Follow preceding car (while traversing the roundabout, assuming the existence of a lead vehicle)
- Merge to the left/right lane (while traversing the roundabout)

Table 10: Brief description of the "Eva" scenario.

User Scenario 3: Eva	**Learning to efficiently manage a roundabout**	**City Traffic**
By driving through a complex roundabout several times, the system learns from the driver how to deal with it efficiently.		
Sequence of events		
Initial state: Eva's TeamMate is approaching a busy two-lane roundabout with five exits. In a complex roundabout like this encountered for the first time, the probability of need for support		

by the driver is high enough to request Eva's attention. When handing over control to the driver, the TeamMate has the capability to learn by observing the solutions of the driver and from other TeamMate cars.

Scenario Evolvement: Before entering the roundabout, the TeamMate starts an escalating HMI strategy to bring Eva back into the loop. The TeamMate has already generated a plan and presents the planned trajectory to Eva. It plans to stay in the outer lane, which is less efficient and safe than using the inside lane when possible.

Scenario Resolution: Eva decides, or not, to help the TeamMate. The system will learn how to efficiently deal with the roundabout. If Eva takes over control, she carefully guides the vehicle into the inner lane. After the roundabout she hands back control to the system. The TeamMate recorded the driving behavior together with all information about the environment and traffic situation to improve its capabilities. After several similar situations and interventions by the driver the TeamMate is able to handle the roundabout in an efficient and safe way. Additionally, the TeamMate can communicate with other cars via V2v in order to solve this complex traffic situation safely and efficient in the future.

4.2.4 Resulting catalogue of basic driving manoeuvres

Summarizing the different manoeuvres identified for the different scenarios and based on the catalogues introduced in Section 4.1, we consequently propose the driving manoeuvre catalogue shown in Table 11 for the context of AutoMate.

Table 11: Proposed driving manoeuvre catalogue for AutoMate.

Number	Manoeuvre	Comments
1	Start and continue	Based on Bajcsky and Nagel (1996), Schreiber et al. (2010), and Schreiber (2012). This manoeuvre covers the ability of the TeamMate car to start from a potential standing, e.g., after stopping prior to entering a roundabout, in traffic jams, or after a minimum risk manoeuvre.
2	Standing	Based on Bajcsky and Nagel (1996), Schreiber et al. (2010), and Schreiber (2012). This manoeuvre covers the ability to stop the vehicle and keep it standing.
3	Slowdown to right road edge and stop	Based on Bajcsky and Nagel (1996). This manoeuvre serves as a non-exhaustive example for a minimum risk manoeuvre.
4	Follow a road	Based on Bajcsky and Nagel (1996), Tölle (1996), Schreiber et al. (2010), Schreiber (2012), and Franz et al. (1995).This manoeuvre covers the ability to perform lane-keeping and speed-keeping behaviour if not influenced by a lead vehicle.
5	Follow preceding car	Based on Bajcsky and Nagel (1996), This manoeuvre covers the ability to approach a preceding car and perform car-following behaviour. We opted to keep the explicit definition usually summarized in the “Follow a road” manoeuvre, but combine it with the explicit notion of the manoeuvre for approaching a preceding car.
6	Lane change left/right	Based on Bajcsky and Nagel (1996), Tölle (1996), Schreiber et al. (2010), Schreiber (2012), and Franz et al. (2015). This manoeuver covers the ability to perform both lane changes to an adjacent left and an adjacent right lane.

7	Turn left/right	Based on Bajcsky and Nagel (1996), Tölle (1996), Schreiber et al. (2010) , and Franz et al. (2015). This manoeuvre both covers the ability to turn into intersecting lanes in intersections as well as entering roundabouts.

4.3 Classification of traffic situations

An alternative to the decomposition of the driving task into driving manoeuvres is based on the notion of *traffic situations*. The resulting classification systems could be useful for AutoMate to define a comprehensive library of generic traffic and driving situations the TeamMate car may need to communicate to the driver.

A traffic situation is defined as "the environment of the man-machine system driver-vehicle from the drivers' perspective" (Fastenmeier and Gstalter, 2007, p.958) and should be understood as a bounded section that the driver is assumed to experience as a unit in time and space. Based on this definition, the driving task can be understood as a sequence of traffic situations, whose transitions originate from changes in the environment or by interactions of the driver.

Based on a classification system developed by Benda et al. (1983), distinguishing 28 million potential traffic situations, Fastenmeier (1995), also Fastenmeier and Gstalter (2007), derived a simplified but more manageable classification system, distinguishing the overall road traffic situations in respect to the road design (Table 12), the road layout (Table 13), and the traffic flow (Table 14). The classification system allows encoding a large variety of possible traffic situations via concatenation, e.g., the code A1.H0.V0.K0.E0.F0 defines a straight even segment on a modern highway with three lanes in each direction, without junctions, lane closures, or directional changes. As possibilities within categories and the categories with respect to the road design are mutual exclusive, the classification system reduces the classification to a set of 2560 distinct traffic situations, which can be further reduced by the elimination of impossible traffic situation constellations.

Table 12: Classification system for road traffic situations in respect to the road design, defined by Fastenmeier (1995) and Fastenmeier and Gstalter (2007).

Category	Code	Description
Motorways	A1	Dual-three-lane motorway, modern type; broad marginal strip: parking and queuing lane or at access points acceleration and deceleration lane
	A2	Dual-two-lane motorway, modern type; broad marginal strip: parking and queuing lane or at access points acceleration and deceleration lane
	A3	Dual-three-lane motorway, older type; slim or no marginal strip, no parking lane or acceleration and deceleration lane
	A4	Dual-two-lane motorway, older type; slim or no marginal strip, no parking lane or acceleration and deceleration lane
	A5	Parking and service areas
Rural roads	L1	Two-lane rural road: modern profile and cross-section, road markings and paved verges, wide shape of curves
	L2	Country road, older type, and side roads: lack of road markings, unpaved verges, narrow shape of curves
City roads	C1	All inner-city roads with two carriageways and separating strip: ring roads etc.
	C2	One carriageway, broad, at least 4 lanes
	C3	As C2, with fixed-guideway transit system
	C4.1	One carriageway, broad, 3 lanes

	C4.2	One carriageway, 2 lanes, in case speed limit of 30 km/h
	C5	As C4.1 and C4.2, with fixed-guideway transit system
	C6	Residential streets, narrow carriageway, narrow thoroughfares
	C7.1	One-way roads, broad, 2–3 lanes
	C7.2	One-way roads, narrow, 1 lane, in case speed limit of 30 km/h

Table 13: Classification system for road traffic situations in respect to the road layout, defined by Fastenmeier (1995) and Fastenmeier and Gstalter (2007).

Category	Code	Description
Horizontal shape	H0	Without curve
	H1	Curve
Vertical shape	V0	Even, straight course
	V1	Incline
Type of junction and junction control	K0	No junction
	K1	Signalised junction with traffic lights
	K2	Unsignalised junction with priority to the right
	K3	Signed junction with priority (including access points on motorways from the driver's point of view on the motorway)
	K4	Signed junction, minor priority or give-way line (including access points on motorways from the driver's point of view approaching on the motorway)

Table 14: Classification system for road traffic situations in respect to the traffic flow, defined by Fastenmeier (1995) and Fastenmeier and Gstalter (2007).

Category	Code	Description
Lane closures and bottlenecks	E0	Straight course
	E1	Lane closures, bottlenecks, narrow tunnel, narrow bridges, etc.

Driving direction	F0	No direction change
	F1	Right turn
	F2	Left turn
	F3	U-turn

4.4 Catalogues of driving tasks

As an extension to the classification system for traffic situations, Fastenmeier and Gstalter (2007) additionally proposed a classification system for *driving situations*, rooted in a method for driving task analysis and driver requirement assessment, called SAFE (Situative Anforderungsanalyse von Fahraufgaben). Within SAFE, navigational and control driving tasks are combined in the generic category of *basic driving tasks*, expected to occur in all kinds of traffic situations and defined as continuous tasks shaped by situational aspects. These basic driving tasks are further divided into three groups: *tasks in longitudinal direction*, *tasks in intersections*, and *other driving tasks*. In respect and distinction to the traffic situation, Fastenmeier and Gstalter (2007) refer to these different tasks as *driving situations.*

As stated by Fastenmeier and Gstalter (2007, p. 963), the "main situational characteristics in longitudinal traffic (intersection-free traffic flow) depend on the manoeuvres and interactions which are built up by the other cars, i.e. on the spatio-temporal configuration in the environment of the car/driver, from whose point of view the situation is observed". They defined a total of eight distinct driving situations in longitudinal traffic, shown in Table 15.

Table 15: Classification of driving situations in longitudinal traffic, defined by Fastenmeier and Gstalter (2007).

Number	Driving Situation	Description and requirements
1	Free Driving	Free choice of lane and velocity (within the limits of traffic regulations) Other cars (beforehand and/or following) do not influence choice of lane and velocity Time interval to cars driving beforehand or following is greater than two seconds.
2	Following	Time interval to cars beforehand on the same lane is less than two seconds. No other vehicle on the adjacent lane.
3	Beforehand Driving	Time interval to cars following on the same lane is less than two seconds. No other vehicles on the adjacent lane.
4	Following and Beforehand Driving	Time interval to cars beforehand on the same lane is less than two seconds. Time interval to cars following on the same lane is less than two seconds. No other vehicles on the adjacent lane.
5	Overtaking	One lane is occupied by one or more slower cars, Overtaking can be conducted either without lane change or with single or double lane change.
6	Being Overtaken	Car is not on the left lane. The adjacent lane is occupied with one or more faster cars.
7	Platoon Driving	No free choice of lane and velocity. All lanes in driving direction are occupied. Low variance of velocity between and within lanes. The velocity is greater than zero.

8	Stop & Go	No free choice of lane and velocity. All lanes in driving direction are occupied. Low variance of velocity between and within lanes. Maximal velocity smaller than 30 km/h. One stop at least.

In contrast to the driving tasks in longitudinal traffic, the driving situations in intersections is "rather influenced by road infrastructure, type of traffic control and further related parameters than by situational characteristics of car interactions" (Fastenmeier and Gstalter, 2007, p. 965) and is therefore defined as a combination of four elements shown in Table 16.

Table 16: Elements distinguishing driving situations in intersections, defined by Fastenmeier and Gstalter (2007).

Number	Discriminative Element	Description
1	Type of intersection	Including e.g., four-access roads, t-junctions, and roundabouts
2	Intersection control	Including e.g., traffic lights, road signs with and without priority, and right hand rules
3	Type of connection	Combination and type of access roads as provided by the classification system for traffic situations
4	Driving direction	Provided by the classification system for traffic situations

As stated by Fastenmeier and Gstalter (2007, p. 964), the proposed driving situations should represent "all relevant constellations in road traffic". We note however the possibility for the existence of additional possible and relevant constellations. Although Fastenmeier and Gstalter (2007) explicitly define the concatenation of "Following" and "Beforehand Driving", as "Following and Beforehand Driving", they do not define other potential concatenations, e.g. the simultaneous application of "Overtaking" and "Being Overtaken" as a possible constellation on motorways with three lanes in each direction, or the possibility of a simultaneous application of "Overtaking" and "Following". Nonetheless, the catalogues provided by Fastenmeier and Gstalter (2007) are a very good starting point for a library of potential generic driving situations to be communicated to or from the driver.

5 Conclusions

Based on the work conducted in T3.2, this document presented a first version for the overall principle of driving task allocations to driver and automation and a first version of a catalogue of basic driving manoeuvres to be addressed AutoMate. As of now, both the principle for task allocation and the catalogue of basic driving manoeuvres are primarily based on existing approaches in the literature and theoretical considerations. As such, we expect potential limitations to emerge once put to test in the future work of AutoMate. Based on corresponding feedback and resulting lessons learned, improved versions will be developed during the second and third cycle of AutoMate.

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