D4.1 USE CASE DEFINITION

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Executive summary

This technical report aims to describe the Use Case definition methodology and results completed in Task 4.1 of the SAFE-UP Project. Work Package 4 has the overall objective to increase vehicle occupant safety in future autonomous vehicles (AVs) as AVs are still expected to be exposed to crashes in mixed traffic conditions, e.g. impacted by other passenger vehicles. This will be done by combining an on-board Occupant Monitoring System (OMS) and an occupant restraint system that can adapt to the OMS information of, for example, occupant sitting posture and seat position in relation to the vehicle interior and by that, enhance occupant protection.

T4.1 represents the first step in the development of these technologies: the definition of the main parameters and scope of work for which the OMS and the occupant restraint system shall be evaluated, determining the challenges in terms of use cases that will be addressed in WP4. Thus, the primary objective of this task is to identify distinct and clearly defined use cases for the later evaluation of occupant protection in future AV in Tasks 4.2, 4.3 and 4.4.

For the purpose of SAFE-UP's WP4, and in alignment with the European Project OSCCAR, a use case is defined as the combination of three determining aspects of a crash situation relevant for the occupant assessment, all needed to represent a specific crash by either occupant simulations or mechanical crash tests. Firstly, it describes the crash configuration, including detailed information about the crash opponent, impact point, impact angle and delta velocity all needed for the reconstruction. Secondly it describes the occupant environment situation by detailed information about seating configuration, interior features, seat position and occupant sitting posture. Thirdly, it describes the occupant's human variations themselves by defining the occupants' height, weight gender and age. Additionally, to these three areas, a fourth aspect has been defined that corresponds to the OMS, that includes the description of the occupant status such as accessories, type of clothing and loose objects all relevant for correct occupant monitoring but of less importance for the crash evaluation.

In order to identify the detailed ingredients that define all aspects of the use cases, two main approaches have been followed: identification of relevant crash configurations by means of an accident research investigation conducted in cooperation with Task 2.1 of the SAFE-UP Project and an extensive literature review to determine the individual human variations and occupant use cases; as well as studying the currently available OMS.

Three use cases have been identified that will form the basis for future work in WP4. One use case for a level 3 vehicle in peri-urban environment in manual driving mode representing current vehicles. One use case for a level 3 vehicle in automated mode. Finally, one use case for a level 4 vehicle in highway environment. For each of these use cases, a number of variations has been identified in terms of crash configurations, seating configurations, interior features, seat position and seating posture. All use cases also come with or without an emergency intervention by either steering or braking to avoid the crash. The human variation will be part of the system concept definition in task T4.2 and system analysis in task T4.3.

Keywords: autonomous vehicles, occupant monitoring, restraint system, test case.

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1. Introduction

1.1 Background

Society is rapidly advancing towards the implementation of new technologies to improve quality of life. Further progress towards a cleaner and safer world is a main objective in the EU and is expected in the near future. The rapid increase of electric vehicle developments and sales is a clear example of this trend; together with the expanding interest towards the development of Autonomous Vehicles (AVs). AVs have the potential to fundamentally alter transportation systems by averting fatal crashes, providing critical mobility to the elderly and disabled, increasing road capacity, saving fuel, and lowering emissions. This technology could also contribute to reduce the congestion of traffic and to improve energy efficiency and parking benefits (1). In addition, the use of AVs would also have the potential to remarkably increase quality of life by making it possible to use commuting time to socialize, relax, work or carry out any other chosen activity. This could be an important relief for those people that spend one or two hours commuting from home to work every day, for example.

Regarding safety, many countries and organisations have set their target to achieve zero fatalities on their roads (2) (3) (4). AVs have a big potential to help achieve this aim and enhance vehicle safety, by means of reducing the role of human error. These errors could be, for example, speeding, disregarding others' right of way or traffic lights, and failing to adapt proactively to road and weather conditions (5). Nonetheless, mixed traffic of AVs co-existing with non-AVs poses a big challenge for traffic safety, since there will still be accidents due to many reasons such as the human error factor of the non-AVs impacting against the AVs. (6) (7) , the technological limitations of the AVs in early stages of development or the lack of communication and understanding between AVs and non-AV drivers.

Additionally, the interiors of these vehicles will be much more focused on occupant comfort than today. By increasing the level of comfort inside the vehicle and reducing or eliminating the need to sit in a driving position, new interior concepts are considered e.g. reclined seat backs, rotated seats and rearward position seats for increased legroom space. These features challenge occupant safety in case of a crash (8) (9) (10). Therefore, it is important to investigate new protection principles and safety assessment methods of such, as these positions challenge the current restraint system in many ways, e.g. new type of interaction with the restraint system and possible new type of injury mechanism, difficult to evaluate with current Anthropomorphic Test Devices (ATDs). Virtual assessment using Human Body Models (HBM) might be the most likely way forward.

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1.2 Purpose and Objectives

The main objective of the SAFE-UP project is to proactively address the novel safety challenges of the future road mobility environment, through the development of tools and innovative safety methods, that lead to remarkable improvements in road transport safety.

The project concentrates in the safety challenges that will be faced in a short- to mid-term scenario. Because of this, WP4 focuses on occupant investigations for vehicles that are not fully automated and where driver interaction is still required to some extent. However, one use case at a higher automation level will also be considered, with the objective to also cover longer-term AV trends. As a first step, for easier understanding of the different levels of automation a description of these are done using the SAE terms.

The official stages of autonomous vehicles are defined by the Society of Automotive Engineers (SAE) Autonomy is graded between 0-5 and the levels of automation are defined as follows (11):

- Level 0-2: Human driver monitors the environment.
- Level 3-5: Automated driving system monitors the environment:
    - **Level 3 (L3), conditional automation:** The system has the potential to perform all driving tasks with the expectation that the driver will interact when needed.
    - **Level 4 (L4), high automation:** The system has the potential to perform all driving tasks and can handle all situations even without human interaction.
    - **Level 5 (L5), full automation**: A full-time automated system that handles all environmental and roadway conditions that can be managed by a human.

In this context, Work Package 4 has the main goal to investigate an Occupant Monitoring System (OMS) that provides input to the occupant restraint system in order to optimize occupant protection based on the occupant's position inside L3 and L4 vehicles.

In order to do this work, the first step of this work package, and the primary goal of Task 4.1 is to identify distinct and clearly defined use cases for the later evaluation of occupant protection in future AV. These use cases will specify the parameters that will be used to define the scope and applicability of the OMS and the occupant restraint system layout to be carried out in WP4.

To define these use cases, several questions need to be answered:

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- Which crash configurations would L3 (in both manual and automated driving modes) and L4 cars be exposed to in mixed traffic?
- Who will be sitting in the cars?
  - Anthropometry spread across Europe
  - Male and female weight and length distribution in EU
- How will people sit in the cars and how will the vehicle interior configuration be?
  - Sitting postures and activities done (as they affect the occupant posture)
  - Interior vehicle layout
  - Interior features
  - Seat positions (number of seats) and seat configuration
  - Interior geometries (length, width and height)
- What is the current State-of-the-Art (SotA) in terms of OMS and their use to enhance occupant protection in the event of a crash?

Thus, the main purpose of Task 4.1 and this document will be to provide an answer to all of these questions and explain the methodology followed to reach the resulting conclusions.

1.3 Method to define the SAFE-UP WP4 Use cases

The method followed in this task made it possible to define the final WP4 use cases that will be used to evaluate the OMS and enhance the occupant restraint system in Tasks 4.3 and 4.4 of the SAFE-UP Project. In order to select all the relevant parameters that the SAFE-UP WP4 use cases are composed of, the baseline definition of test case was derived from the. OSCCAR project Grant Agreement Nº768947 D2.1 deliverable (12). The test case matrix from this deliverable represents a manifold of use cases, of which SAFE-UP T4.1 has selected 3 specific use cases to be studied throughout WP4.These three use cases have been selected based on the SAFE-UP Grant Agreement Nº861570 (13) use case pre-selection and the work that has been done throughout T4.1. Furthermore, in comparison to OSCCAR, SAFE-UP WP4 has included a new variable regarding the (real-time) occupant status, which will be covered by the OMS and studied in depth in T4.2 and T4.4. In order to identify and define these three use cases, the relevant basic characteristics, namely: crash configuration, occupant monitoring system and occupant restraint system; were investigated.

The main approaches that have been followed in order to define these characteristics include the identification of relevant crash configurations by means of an accident research investigation conducted in cooperation with Task 2.1, an extensive literature review to determine the occupant restraint system use cases (including a benchmark study of interior vehicle concepts); as well as studying the SotA regarding OMS. Figure 1, visually summarizes this approach.

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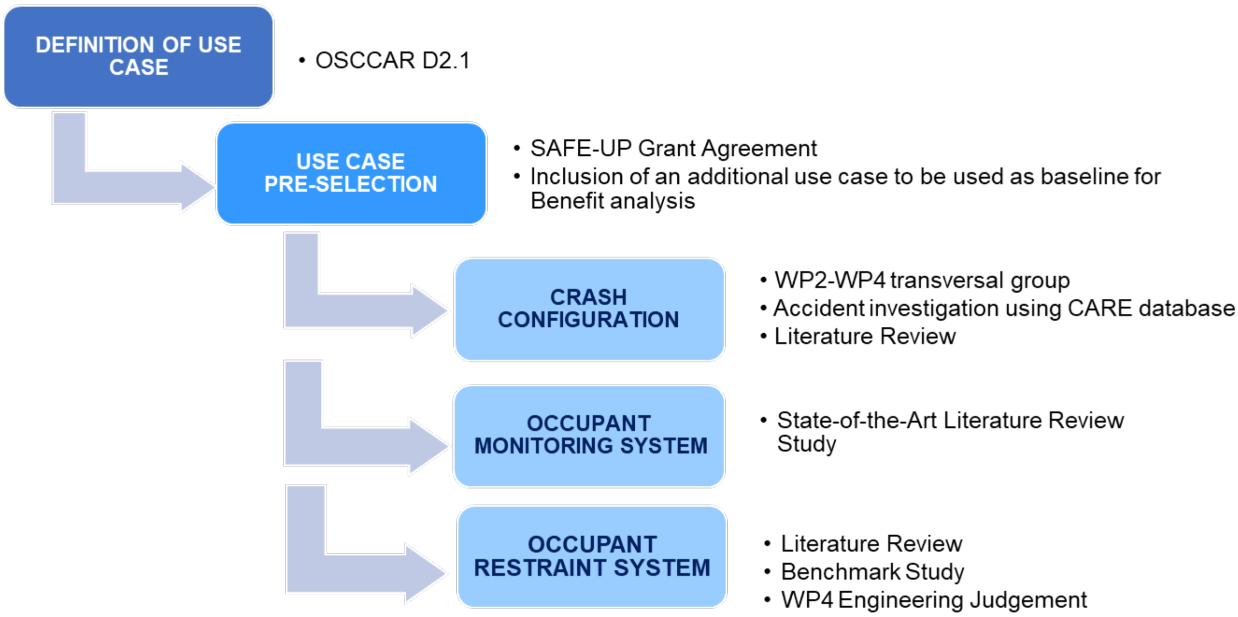

Figure 1. Diagram of Task 4.1 Method approach

SAFE-UP WP4 selected to use the definition of use case as it was determined in OSCCAR project D2.1 deliverable (12), see section 2.1. This definition was further advanced including the (real-time) occupant status, so that all use cases to be identified in WP4 of the SAFE-UP Project are bound by the following four main research variables:

- Crash Configurations – including crash scenarios (highway and rural traffic) and geometrical and dynamical details to be able to set up a vehicle to vehicle crash (opponent vehicle, first point of contact, collision angles and collision velocities)

- Human variation – including height, weight, gender, age, etc. of people inside the vehicle

- Occupant Use Cases – including seating configuration (front / rear seat position, but also includes different seating configurations such as living room and swivel seat), interior features (relevant interior space and interior design details that may affect the outcome in case of a crash), seat position (such as seat back angles, seat cushion angle, seat cushion height, and seat position in x-direction) and sitting posture (occupants posture in terms of upright/slouched/collapsed position of whole body, including arm and leg positions)

- Occupant status – including accessories, type of clothing, loose objects, etc.

The SAFE-UP project has set “future safety-critical scenarios” as being one out of five overall project objectives in the Grant Agreement (GA) page 141 (13). Crashes on highways and in rural areas contribute to 79% of all vehicle occupants’ fatalities in EU in 2018, GA page 144 (13). Therefore, these two crash scenes were pre-selected in the preparation phase of the project to be further analysed within the project as **use case B1**: *Highway setting*

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(automobiles, motorcycles, trucks) and **use case B2**: *"Peri-urban setting (those in B1 plus bikes, PTWs, road workers",* GA page 144. Where a peri-urban environment is characterized by the landscape interface between town and country or, in other words, as a rural - urban transition zone. It is a landscape of its own different from an urban as well as rural area, but from a traffic safety point of view containing similar challenges as in rural traffic. The WP4 use cases have been built on the abovementioned pre-selection stated in the SAFE-UP GA.

Based on these two pre-selected crash scenes it was decided to create three individual use cases. Firstly, a use case for L3 vehicles in peri-urban environment in manual driving mode that will be used as a reference when evaluating the performance of the SAFE-UP advanced Passive Safety System (occupant monitoring and restraint systems). This use case represents a current passenger car interior and can be used later on in the project as a baseline for the benefit analysis to be done in WP5. Secondly, a L3 vehicle in automated mode where the occupant has larger flexibility in terms of seating position were selected. Finally, the third use case represents a L4 vehicle in highway environment. For each of these use cases, a number of variations will be identified in terms of crash configurations, seating configurations, interior features, seat position and seating posture using the method described above and in Figure 1.

When the L3 vehicle is driven in manual mode, use case 1, the driving activity will be done by the human driver with the support from the vehicle's Advanced Driver Assistance Systems (ADAS)- such as Lane Keeping Assist (LKA), Lane Change Assist (LCA), Blind Spot Detection (BSD), Advanced Front Lighting System (AFLS), Electronic Stability Control (ESC), AEB rear-end, AEB reversing, AEB intersection, Emergency Steering (ES), Driver-initiated Evasive Steering Assist (ESA), Driver Monitoring System (DMS), Intelligent Speed Adaptation (ISA), and Alcohol Interlock) (7) (14). On the other hand, both when the L3 vehicle is driven in Automation mode and in all cases regarding the L4 vehicle, the vehicle is ideally expected to not cause any crashes.

To define the crash configurations for the three use cases, collaboration activities were done between the SAFE-UP WP2 and WP4. This transversal group has been responsible for analysing accident statistics to choose the most representative crash configurations applicable to the overall goals of the SAFE-UP WP4 activities (See Section 3). The other use case parameters were selected based on the results from the extensive literature review studies that have been conducted throughout the duration of Task 4.1 (see section 4). These studies aimed at studying the State-of-the-Art regarding the two main pillars of SAFE-UP occupant safety systems, i.e. OMS (sub-section 4.3) and the occupant restraint system definition (sub-section 4.4). Where the last literature review also included a study on future AV concepts. This benchmarking study was done to identify relevant details of the occupant use case parameters seating configuration, interior features and seat position.

The final chosen interior configurations were graphically represented using a design software. The three resulting interior configurations will be shown in section 4.4.4 and will be used as a baseline for all occupant restraint systems to be investigated in WP4.Occupant Monitoring System.

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2. OSCCAR project outcomes as basis for SAFE-UP

Reaching the SAFE-UP WP4 goals is supported by previous work done in the European funded project OSCCAR. OSCCAR started in 2018 and is cross linked with SAFE-UP through the defined knowledge and method transfer. Potential content of transferable OSCCAR methods, models and insights in relation to the questions stated in Section 1.2 is reported in this section. In addition, as explained in section 1.3, the OSCCAR input included in this section is used to determine the overall definition of use case that will be used as baseline for the entire activity developed in T4.1.

2.1 OSCCAR WP2 Test Case Matrix methodology

One of the most relevant outcomes of the OSCCAR project in respect to the SAFE-UP project is the publicly available Deliverable D2.1 "Test Case Matrix and selecting Demonstrator Test Cases" (12). This Test Case Matrix methodology is applied in sections 3 and 5 of this document. OSCCAR's D2.1 contains a methodology to structure combinations of aspects relevant for occupant protection evaluation in future passenger cars. The methodology is created based on a matrix structure and underlying processes. The three-dimensional matrix structure, so called Test Case Matrix, comprises the three dimensions; Occupant Use Cases, Crash Configurations and Individual Human Variations. Within OSCCAR pre-selection processes were created in order to focus the scope and content of the Test Case Matrix for a given application. A so-called Grading Process was developed to identify the relevant Test Cases for a deeper observation. One Test Case contains a combination of the three dimensions, which define the requirements to perform a crash test or occupant simulation. Finally, we have a finite number of Test cases that after a defined process will help us to determine the relevant three SAFE-UP Use Cases.

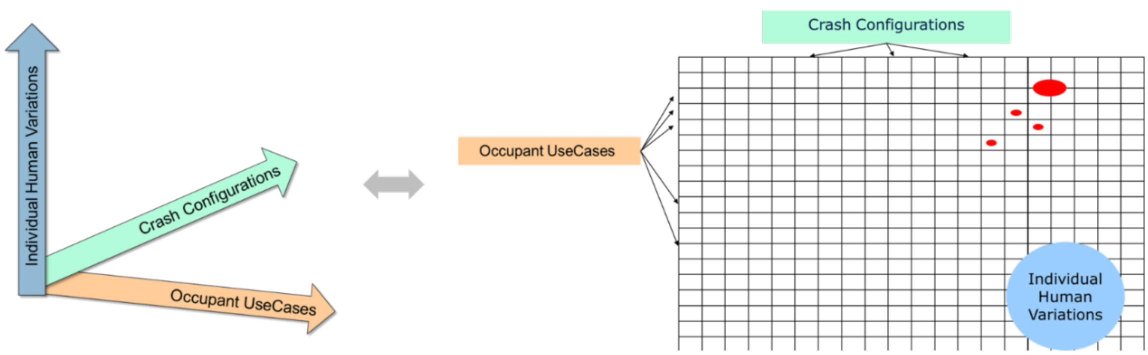

Figure 2. Test Case Matrix methodology The red dots illustrate exemplary test cases (12)

Figure 2 illustrates the Test Case Matrix in two schematic representations. To the left, a three-dimensional illustration is shown. To the right, in order to present the results more clearly, the

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three-dimensional matrix is modified into a two-dimensional matrix focusing on the Crash Configurations and Occupant Use Cases, while the third dimension of Individual Human Variation is illustrated as a spectrum that can be applied all over the other two dimensions. This simplification is motivated by the fact that this spectrum will be limited by the capabilities of the human surrogates i.e. ATDs and human body models (HBMs) available today. The key requirements for development of the Test Case Matrix were to be as generic as possible, to enable several future operational design domains (ODDs) and to be as modular as possible and easy to adapt to selected applications. Finally, this procedure shall allow for requirement identification in terms of details (human variations of occupants, seat position, interior, ODD etc.), to set up a simulation or a crash test design of experiments (DoE) campaign.

Regarding the specific parameters included in each of the use case dimensions; the Crash Configuration specifies the vehicle type, impact point, impact angles and impact velocities of the two vehicles by which a crash pulse can be generated by full vehicle simulations. The Individual Human Variation describes the individual human parameters like size, weight, age, gender adding up to the occupant tool. The Occupant Use Cases provides the level of detail needed to complete the test set-up, including the environment and the occupant posture. In the OSCCAR Deliverable D2.1 (12), the following variables were defined for the Occupant Use Case:

- *Seating configuration* – front seat, rear seat position. But also includes different seating configurations such as living room position (15) and swivel seat.
- *Interior features* – includes information of relevant interior space and interior design details that may affect the outcome in case of a crash.
- *Seat position* – seat orientation such as seat back angles, seat cushion angle, seat cushion height, and seat position in x-direction.
- *Sitting posture* – occupant's posture in terms of upright/slouched/collapsed position of whole body, including arm and leg positions.

The representation of restraint systems is not included in the Test Case description and the focus of OSCCAR laid on only one occupant within the interior. Overall, the defined OSCCAR variables and terminology shall also be considered and applied within SAFE-UP WP4.

2.2 OSCCAR WP1 / WP2 crash pulses

In the first project period of OSCCAR an extensive report on future crash scenarios including the underlying methodology to apply a prospective impact assessment method to identify the most relevant collision situations was created. The work was documented in the publicly available Deliverable D1.1 (6). The focus of the future crash scenarios was set on an analysis of potentially inherently avoidable crashes due to AVs functionality in combination with re-simulations of selected German In-Depth Accident Study (GIDAS) crashes where one vehicle

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was virtually enhanced with automated driving functions. Thus, OSCCAR WP1 provided future crash configurations for urban crossings and highway situations.

After a reduction of the various crash configurations by clustering, crash pulses of the most frequent crash configurations were calculated. Generally, FEM-simulations of defined crash configurations with two vehicles with pre-defined collision speeds, angles etc. as well as vehicle masses were executed in order to extract acceleration-time curves that served as time history for crash pulses to be used in sled-type setups to represent the vehicle compartment and interior in the forthcoming occupant simulations with Human Body Models.

Two activities are relevant for the SAFE-UP project:

- OSCCAR WP2 T2.4: In this task, a two-step test campaign was planned. A physical demonstrator (simplified mechanical representation of a vehicle interior including a seat and crash test dummy within a workshop / lab environment) of selected advanced integral passenger protection principles was built up. In order to carry out the first test loop at the lab, adequate sled pulses (represented by acceleration-time curves) to drive the sled were generated in advance by a simulation-based procedure. Based on an initial evaluation of OSCCAR WP1 urban crossing crash configurations were identified (so-called “Straight Crossing Path (SCP)” and “Left Turn Across Path (LTAP)”). For the purpose of the first test loop in summer 2019 a "crash pulse generation methodology" using freely available vehicle simulation models (the U.S. National Crash Analysis Center (NCAC) in the above crash configurations and characteristics (angle of impact, speed, etc.) was elaborated and applied.

- OSCCAR WP1: In order to ease the work in OSCCAR WP2, in particular the development and assessment of different protection principles crash pulses of the most relevant crash configurations found in WP1 were created. The crash pulses were generated by applying the method above by different OEM partners and averaging over the different results. The generated crash pulses refer to highway and urban crossing crash configurations. In 2020 the OSCCAR project accepted the publication and use of the averaged crash pulses in other research projects. A selection of the generic pulses will also be publicly available via a technical paper publication in the end of 2021.

The first option for use in SAFE-UP is to use the generic crash pulses generated for the highway and urban crossing scenarios directly. The general methodology developed in OSCCAR may be applied to relevant crash configurations in SAFE-UP T4.3. In that case generic vehicle simulation models may be applied (e.g. NCAC models). Alternatively, simulations under consideration of assumptions like higher velocities, varying stiffness or replacement by generic barriers may be applied. Additional options include to use published data (e.g. by Autoliv) and will be reported later.

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2.3 OSCCAR Protection Principles

One of the OSCCAR WP2 objectives was the investigation of generic advanced passenger protection principles that provide improved passenger protection for future interiors of AVs in a crash. For the virtual investigation of advanced passenger protection principles, adequate simulation models were generated representing possible future interior concepts.

Both an adaptation of the restraint systems towards these new boundary conditions and a repositioning of the occupant into a conventional seating configuration prior to a crash were considered. The investigated protection principles in OSCCAR are rotated seats, reclined seat positions, an advanced airbag design for a “living room” configuration (occupants facing each other) as well as occupant restraint in a future interior considering a side crash. Figure 3 presents an overview of all six protection principles developed in OSCCAR.

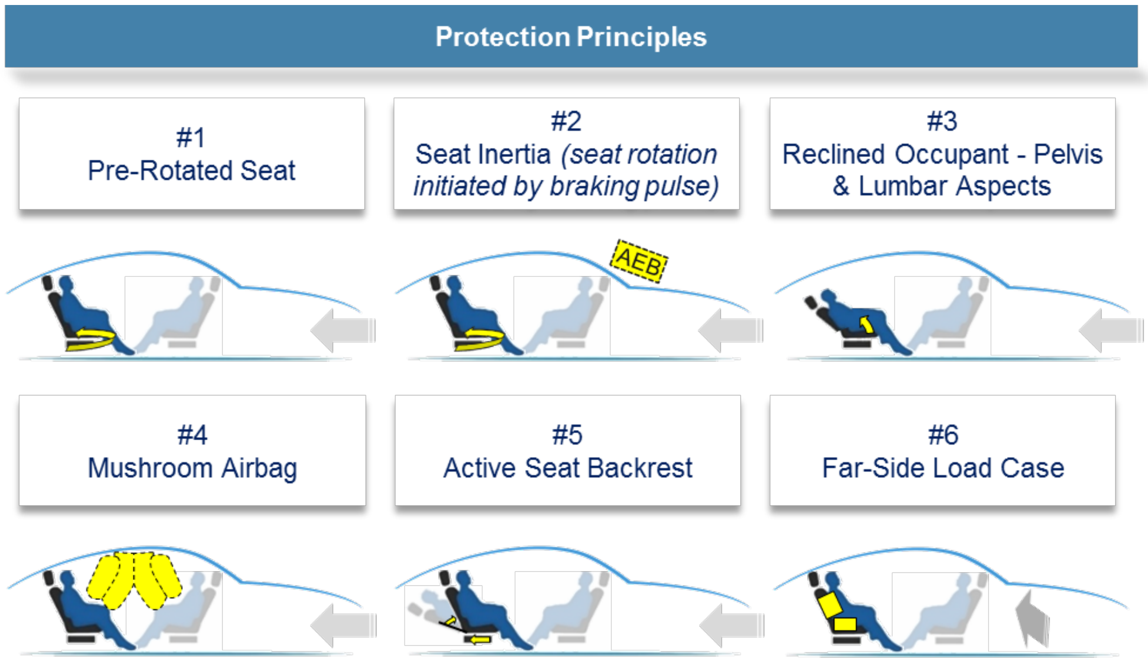

Figure 3. *OSCCAR Protection principles analysed in OSCCAR WP2* (16)

In the course of evaluation and assessment of the OSCCAR protection principles computer-aided engineering (CAE) models in different simulation codes (LS-Dyna, VPS, Simcenter Madymo) were set up. Thereby already existing baseline model setups were used, i.e. a so-called “Generic Interior Model” addressing automated driving SAE Levels 1-3, a “Living Room Interior Model” addressing automated driving SAE Levels 4 & 5 and a so-called “Homologation System Model” as a more generic environment, which serves as a demonstrator test case within OSCCAR. Some of the available protection principle models which may be used in WP4 are generally available through common OSCCAR and SAFE-UP partners, i.e. Autoliv, Bosch, IKA. Evaluations on the “applicability” of these CAE models within SAFE-UP will be done in Task T4.2 and reported in SAFE-UP deliverable D4.2 later on.

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OSCCAR investigates restraint strategies for highly automated vehicles. The focus lies on future accidents in urban environments, especially crossing and intersection scenarios. Project SAFE-UP; on the other hand, addresses future occupant use cases for L3 and L4 vehicles. The focus lies on highway and peri-urban traffic. Nevertheless, in both projects mixed traffic scenarios and intersections will play a key role in relevant accident scenarios.

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3. Crash configurations

This chapter describes how the crash configurations that will be used in SAFE-UP use cases were identified. SAFE-UP targets to address L3 vehicles in peri-urban traffic and L4 vehicles in highway traffic. L3 and L4 vehicles are assumed to be equipped with either Advanced Driver Assistance Systems (ADAS) and/or autonomous functionality making the cars avoid single crashes (17). Therefore, the crash configurations that are of interest could potentially be different compared to traditionally used crash configurations that are included in current consumer ratings. It was the task for a common SAFE-UP WP2-WP4 team to estimate this change, and thereby derive the most relevant crash configurations to be used for occupant protection evaluation of L3 vehicles in rural traffic and L4 vehicles in highway traffic. Having this as starting point, the WP2-WP4 team worked toward refining the crash configurations by describing fatal crashes between two vehicles on highways and rural roads in the EU (following the pre-defined areas set in the GA). As L3 and L4 vehicles are equipped with ADAS and or autonomous functionality each identified crash configuration also includes a pre-crash emergency intervention by either steering or braking to avoid the crash. These crash configurations will later be used when defining the use cases in this report.

3.1 Objective

The objective for this investigation was to identify the most frequent fatal crash scenarios in the EU that occupants of L3 and L4 vehicles would be exposed to and; based on those, determine distinct and clearly defined crash configurations that cover approximately 50% of the fatal crashes in rural and highway areas.

3.2 Future safety-critical scenarios for L3 and L4 vehicles

The EU Community database on Accidents on the Roads in Europe (CARE) year 2018 was queried for crashes with passenger car occupant fatalities where the killed occupant was travelling in a modern passenger car (defined as having registration year 2000 or later, as older cars were judged as not being representative based on crashworthiness in future cars (17)). The count is made on occupant level, which means that if two occupants were killed in the same vehicle that crash is counted twice. This resulted in 6.431 fatalities whereof 1.325 were in urban areas, 4.406 in rural areas and 700 on highways, see Table 1. The dataset was further divided into fatalities in four type of crashes describing number of vehicles involved in the crash, see Table 1.

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Table 1. Occupant fatalities in passenger cars with registration year 2000 and later by number of vehicles involved

	All areas	Urban	Rural	Highway
Single car crashes	2.753	689	1.830	234
Crashes including exactly two vehicles	2.713	509	1.971	233
Crashes including >=3 vehicles	840	115	522	203
Other crashes (e.g. with unknown number of vehicles)	125	12	83	30
Total	6.431	1.325	4.406	700

In further analysis, single car crashes were excluded due to the assumption that L3 and L4 vehicles will not be involved in such crashes (6), (17). Crashes with more than two vehicles and unknown vehicles were also not further analysed as they were judged as being too complex. By this, the considered cases consist of 2.713 crashes between exactly two vehicles. As a next step, the crash opponents in the 2.713 crashes were further examined and it was found that the most common opponents were passenger cars and goods vehicles, see Table 2. As light goods vehicles (<3.5t) have different structures than cars and heavy good vehicles (HGV), they were not grouped together with HGV. Further analysis focused on two groups: car-to-car (C2C) and car-to-heavy goods vehicle (C2HGV) crashes, where HGV includes goods vehicle >=3.5t and road tractors. Together these two groups covering 56% and 23% of the 2.713 fatalities respectively.

As hypothesis, initially it was argued that HGV will usually not cause the crashes as those are driven by professional drivers. Therefore, a check was done in the DESTATIS table 1.5.2 “Share of the main causer in all involved drivers of goods vehicles in %” (page 33) (18). It was found that the crashes were caused not only by the driver of the passenger car, but also in a similar amount by the driver of the HGV. Therefore, it was decided to keep the HGV cases and that two type of crash opponents should be considered in further analysis:

- Car-to-Car (C2C)
- Car-to-Heavy Goods Vehicle (C2HGV)

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Table 2. Occupant fatalities in passenger cars with registration year 2000 and later by crash opponent

Opponent	All areas	Urban	Rural	Highway
Passenger car (of any registration year)	1.515	290	1.121	104
Goods vehicle >=3.5t	451	69	331	51
Goods vehicle <3.5t	306	61	219	26
Road tractor	175	7	129	39
Other	222	70	140	12
Unknown	44	12	31	1
Total	2.713	509	1.971	233

For the same reason that single vehicle crashes were excluded from the dataset, also crashes with parked vehicles were excluded, i.e. L3 and L4 vehicles are likely to avoid such crashes given that they are one of the easiest targets to be tracked by the vehicle; thus, their avoidance will be programmed. This gave 2.085 remaining fatalities, 1.486 in C2C and 599 in C2HGV crashes, see Table 3. Those 2.085 fatalities where then defined as the target population, i.e. 100% of the remaining passenger car occupant fatalities possible to address. Since the GA defined highway and rural cases only, the maximum number of crashes that could be included by the identified crash configuration are 1.731 (1.108+100+451+72), 83% of all C2C and C2HGV crashes.

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Table 3. Occupant fatalities in passenger cars with registration year 2000 and later in C2C and C2HGV crashes for parked and not parked vehicles

	All areas	Urban	Rural	Highway
C2C, not parked	1.486	278	1.108	100
C2HGV, not parked	599	76	451	72
C2C, parked	29	12	13	4
C2HGV, parked	27	0	9	18
Total	2.141	366	1.581	194

The next step to identify distinct and clearly defined crash configurations was to investigate the road infrastructure where the fatal crashes occurred. This was done using CARE variable "R-13: Junction" as defined in the Common Accident Data Set (CADaS) glossary (19) as it indicates the type of junction/interchange the crash occurred at. For highway crashes, naturally almost all cases happen outside junctions, 100% and 96% for C2C and C2HGV respectively. Therefore, only non-junction crashes were analysed further for highway crashes. For rural areas, non-junction and junction crashes (as defined in the CADaS glossary (19)) were evaluated separately. Similar to highways most of the rural crashes occur outside junctions, 84% and 82% for C2C and C2HGV respectively, see Table 4.

Table 4. Occupant fatalities in passenger cars with registration year 2000 and later by road infrastructure for rural and highway in C2C and C2HGV crashes

	C2C Rural	C2C Highway	C2HGV Rural	C2HGV Highway
Not at junction	84%	100%	82%	96%
Crossroad	8%	0%	7%	0%
T or staggered junction	4%	0%	7%	1%

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Roundabout	1%	0%	0%	0%
Other	4%	0%	5%	3%
Sample size	1.108	100	451	72

Next, the CARE variables "A-11: At least two vehicles – No turning (L)" and "A-12: At least two vehicles – Turning or Crossing (L)" in the CADaS glossary (19) were then used to identify the most common crash types for the C2C and C2HGV crashes see Table 10 - Table 15 in Appendix A: Crash configuration. It was observed that the CARE database counted with a large percentage of crashes in which the crash type variable was classified as "unknown". Because of this, instead of providing single percentage values for each crash type, intervals are specified. Lower bound in the interval is the prevalence as coded in CARE and the upper bound in the interval is obtained by disregarding unknown crash types for A-11 respectively A-12.

Highway crashes, not at junction, can be found in Table 10 (C2C) and in Table 11(C2HGV). For both C2C and C2HGV rear-end collision is the largest group representing 1.1 – 2.2% and 1.2 – 2.2% of the target population.

Rural crashes, not at junction, can be found in Table 12 (C2C) and in Table 13 (C2HGV). For both C2C and C2HGV head-on collisions is the largest group representing 11.1 - 25.0% and 5.2 - 11.9% of the target population.

Rural crashes at junction can be found in Table 14 (C2C) and in Table 15 (C2HGV). For both C2C and C2HGV crossing collisions forms the largest groups representing 0.2% - 4.4% and 0.1 - 1.8% of the target population respectively.

The type and intervals of the most frequent crash types are listed below in Table 5. They are sorted in the order of the upper bound percentage of the target population, i.e. percentage out of the 2.085 identified fatal crashes:

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Table 5. Most frequent crash type and percentage interval

Crash type	Percentage
C2C rural Head-On:	11,1 – 25,0%
C2HGV rural Head-On:	5,2 – 11,9%
C2C rural at intersection:	0,2 – 3,8%
C2C Highway Rear-End:	1,1 – 2,2%
C2HGV Highway Rear-End:	1.2 – 2,2%

3.3 Crash configuration to be used in use case definition

Due to limitation in the data collected through the CARE database, it is not possible to generate detailed data about the crash configuration. Therefore, literature and earlier project work in OSCCAR aligned with engineering judgement are used to describe in more detail the crash configurations based on the selected crash types from the CARE database.

- C2C rural Head-On crashes is recommended to be evaluated by the generic full frontal 56 km/h pulses generated in OSCCAR.
- C2HGV rural Head-On crashes was not found in the literature. Because on this, it is proposed to generate new pulses using shareware CAE models of a passenger car and a HGV. As passenger car, it is proposed to use a model of a Honda Accord MY 2011 (20) developed and validated for a full frontal 56 km/h crash, see Figure 4. This model was used successfully in the OSCCAR project to generate pulses based on different intersection crash configurations.

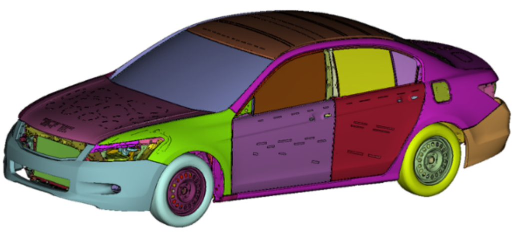

Figure 4. Shareware Ls-Dyna CAE model of a Honda Accord 4-door midsize sedan MY2011 (20).

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As a HGV, it is proposed to use a free ls-dyna model of semi-truck (21), see Figure 5. As the truck will only be used as a rigid “bullet” vehicle and the truck occupant protection will not be assessed, the U.S. type architecture (including a cab-behind-engine design, instead of the cab-over-engine version – which is more common in European trucks) will not be a problem. Proposed crash configurations are 56 km/h full frontal and 50% overlap.

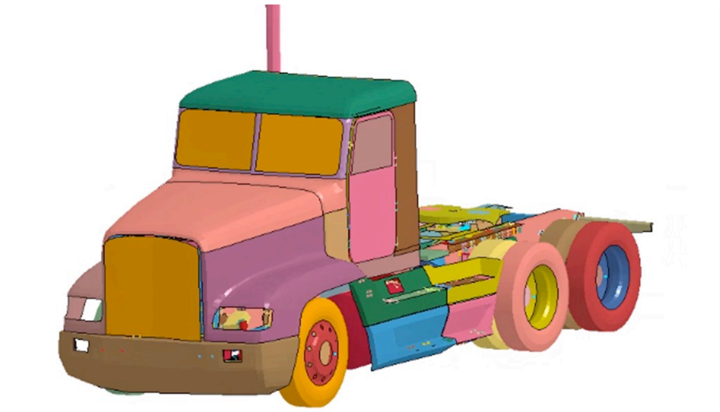

Figure 5. Shareware Ls-Dyna CAE model of a semi-truck (21)

- C2C rural at intersection crashes were found in the literature (7), see Figure 6. It is proposed to use the described crash configuration and generate pulses using a shareware CAE model of a passenger car. Unfortunately, it is not possible to use the generic intersection crash pulses that were created in the OSCCAR project as those where taken from urban traffic condition. Thus, generic peri-urban crash pulses need to be generated additionally in later stages of SAFE-UP WP4.

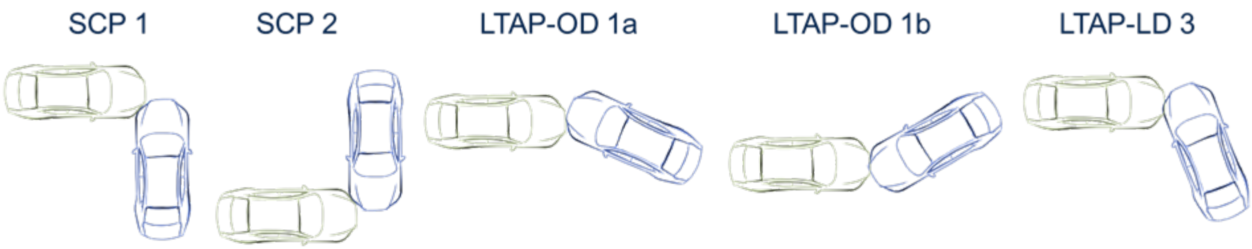

Figure 6. Five crash configurations that best represent the unavoidable intersection crashes (7)

- C2C Highway Rear-End crashes is recommended to be evaluated by the generic full frontal 56 km/h pulses generated in OSCCAR.

- C2HGV Highway Rear-End crashes was not found in the literature. It is proposed to generate those in using described shareware CAE models.

- C2HGV rural at intersection crashes are recommended not to be included in further work as there is no existing data on this crash configuration and it also represents a low number of cases.

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Pre-crash intervention to avoid the crash, like steering and braking, is very likely in L3 and L4 vehicles, therefore it is also recommended to include such in each use case. Due to that this information is not available in the CARE database it is recommended to use braking and steering pulses from the literature (22), shown in Figure 7.

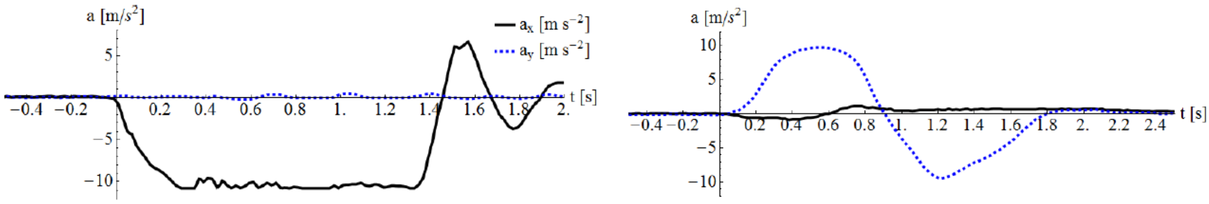

Figure 7. Vehicle kinematics response to braking (50 km/h, left) and a lane change (right) maneuverer to the left of a sample subject from series (22)

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4. Literature Review

4.1 Objective

Two different literature review studies with different objectives have been conducted in task 4.1: the Occupant Monitoring System literature review (see section 4.3 and Appendix C: Occupant Monitoring Literature Review) and the Occupant Restraint System Literature Review (see section 4.4 and Appendix D: Occupant Restraint System Literature Review).

On one hand, given that the development and preliminary assessment of an Occupant Monitoring System (OMS) is one of the main objectives of WP4, a literature review to analyse the current SotA of these systems and their use to enhance occupant restraint systems in the event of a crash has been done. However, the main objective of this literature review was to analyse the novelty of the proposed systems and their comparability with the systems that are currently available in the market. The definition of occupant monitoring system will be done in Tasks 4.2 and Tasks 4.4.

On the other hand, a literature review to support the use case definition and the occupant restraint system definition has been conducted. This literature review intends to find an answer to the research questions that define the use case parameters. As such, this study concentrates on understanding the anthropometry spread across Europe, the activities done by the occupant, the seating configuration and the interior vehicle configuration. Regarding the latter, a benchmark study to compile public images of future autonomous vehicle concepts was conducted inside the same literature review. Based on these pictures and on public reference data (such as the vehicle's overall dimensions or the dimensions of standard parts) potential vehicle dimensions were estimated and used for the use case definition.

4.2 Method

Both literature reviews were done following a common method. First, the research questions for each of the literature reviews were defined. These research questions were used as a guide to select relevant publications and to define the overall scope of each of the literature review studies.

Next, an Excel template to record and summarize the main findings found on each of the relevant sources was prepared. This template was based on the Literature Review Template used in the EU Project L3 Pilot (Grant Agreement No.: 723051) and was adapted to suit the purpose of the SAFE-UP WP4 activities. An empty sample of this template may be found in Appendix B: Excel Template Literature Review.

The following step consisted in creating a list of sources found by means of a systematic search. This systematic search was done by gathering literature available related to the main focus including documents written in English, German and Spanish. The origin of these sources was, primarily: conference proceedings, technical papers, deliverables and reports; open source journal publications, PhD theses, patents (limited) and public information found in websites. In addition, prior literature reviews related to the topics of interest for SAFE-UP WP4 were also consulted (12) (23). Sources published from year 2000 onwards were prioritised over older research studies. However, older publications were not discarded.

Overall, the literature review studies found 138 relevant sources. Once the sources had been selected, collected and documented; the main findings were used for the final SAFE-UP WP4 use case definition.

The most relevant sources are explained in sections 4.3 and 4.4. Additional findings for both literature review studies are found in Appendix C: Occupant Monitoring Literature Review and Appendix D: Occupant Restraint System Literature Review.

4.3 Occupant Monitoring System literature review

The literature study on occupant monitoring systems was carried out under following guiding research question: "What is the current SotA in terms of OMS that can be used to improve occupant protection in AVs?" At the beginning of the literature review, the main focus areas were defined. This was needed, since the field of monitoring systems is a very dynamic and large research area, which includes many scopes of application. Thus, defining thematic priorities allows a pre-selection of sources. The main focus areas of the literature review were:

- OMS in vehicles
- OMS for passenger cars with focus only on the passenger compartment
- Real world tests, laboratory tests and CAE simulation studies
- Software and algorithms

The consideration of these thematic priorities led to a large number of presumably relevant sources. In order to narrow down the sources to a suitable number and to select the most relevant ones regarding the SAFE-UP project, two assessment criterions were defined: The first one assessed the described primary function of the investigated system. If the systems had primary functions related to *Sitting Posture*, *Seat Position*, *Behaviour Monitoring*, *Occupant Classification*, *Anthropometry* or *State Monitoring*, they were considered of high relevance for the SAFE-UP project. It was furthermore possible to classify the literature. On the other hand, if the system focused on environmental or traffic-influenced monitoring (e.g. surveillance camera), vehicle guidance or HMI related distractions, these sources were not considered as relevant. This was the case if either the monitoring systems could not be applied in the passenger compartment, or the data was gained via steering and pedal inputs or the inputs were used for driver assistance functions. Steering wheel handling and pedal inputs, for instance, can be used for e.g. drowsiness detection or breaking assistance. However, the position or posture of the occupant will remain unknown Therefore, these applications were not deemed to be suitable to adjust occupant restraint strategies.

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The second criterion was the ability of the system to actively detect and monitor the occupants. This criterion included dynamic observation (e.g. movements, classification, face detection, etc.) but excluded every source that covered quasi-static system conditions (e.g. on/off, yes/no, etc.) from further examination. The reason for this decision was the very limited meaningfulness for a precise adjustment of restraint systems according to occupant position, posture and behaviour in case of a crash. A continuous monitoring; on the other hand, would offer the possibility to know the exact state and movement of the occupant before crash.

By using these criterions, it was possible to identify 50 sources that were considered as highly relevant. The following classification was done according to the criterion of the primary function. It needs to be mentioned that most system layouts include more than one function. However, the categorisation was done concerning the central statement described in each publication.

Sitting Posture

Sitting posture describes the way of how an occupant sits in the seat. Since the occupant can change his/her posture unforeseeably, a prediction of movements is very challenging. As a result, it is possible that the passenger is in an unfavourable posture regarding occupant protection in case of a crash. In the SAFE-UP project, monitoring of sitting posture is therefore highly relevant to adapt the occupant restraint system strategy and must be included in the research.

Summed up, the major number of sources was connected to airbag deployment decisions. The decision was mostly based on defining critical areas, classification of the occupant and posture and a combination of both. Most of the studies used vision-based systems for monitoring of upper body, body parts or passenger classification. In some cases, sensor combinations e.g. with weight sensors or pressure sensors, were used. However, besides Untaroiu et al. (24) no other source covered prediction of injuries or adjustment of restraint strategies. Detailed explanations of the sources that led to these conclusions are reported in this sub-section.

One way to decide the deployment of an airbag regarding the posture is to divide the passenger compartment in safe and critical zones. If the occupant enters the critical zones e.g. by leaning forward, the airbag will not be deployed. Owechko et al. (25) and Jang et al. (26) used vision-based sensors to identify the entering of unsafe areas for airbag deployment. A combination of a vision-based system with weight sensing was also introduced (27).

Another approach to analyse the occupant’s posture is the tracking of the body or body parts. Such a system was studied by Untaroiu et al. and implemented two different restraint systems for the comparison of injury costs in economic terms e.g. medical treatment for nine posture classes (24). Other systems from Bosch (28), Trivedi et al. (29), Cheng and Trivedi (30), Park et al. (31) and Kumar et al. (32) focused on vision-based approaches to track and assess certain postures of the body or the head. Zhao et al. use several vision-based systems for the prediction of the occupant's posture (33). Also a highly relevant study from Kirscht et al.

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was found, which covered kinematic behaviour of the front passengers in pre-crash scenarios for different driving manoeuvres (22).

A significant number of sources combined both, a segmentation into areas and active tracking of the occupant's posture to decide airbag deployment. A vision-based system from Farmer et al. was used to classify the occupant in combination with track processing and prediction (34). Other systems use a mere camera based approach (35) or a combination with light striping (36) or head pose and eye gaze observation (37), (38). A combination of a vision-based system together with a fluid-filled sensor mat has also been realised (39).

Seat Position

Seat position monitoring is mostly linked to the position adjustability of the seat, also including seatback angle. Obviously, the posture might also be influential. However, in this section, sources which describe the investigation of seat positions are categorised.

It can be resumed, that monitoring of seat positions has not been investigated extensively up to now. In addition, no source covers the potential use of the already existing control units for seats. Nevertheless, all studies try to predict the risk of injury in case of a crash. More research needs to be done in this area, especially with respect to automated driving.

A simulation-based study by Yang et al. focused on a methodology for injury risk prediction, considering different statures and different seat positions by using a THUMS model (40). A patent from Subaru Corp. used a vision-based device to adjust the occupant protection based on the seat position (41). Another system by Forster and Zittlau used cameras to monitor for objects, occupant classification, child seats, seat position, seat configuration, occupant position and seatbelt usage to control the restraint systems (42).

Behaviour Monitoring

Automated driving will offer more freedom for activities. Thus, behaviour monitoring of the occupants, especially the driver, will be of interest. Furthermore, behaviour in certain situations e.g. before crash, will also be relevant. The separation of behaviour monitoring, and posture monitoring is difficult though, since changes in posture happen in both cases. However, the following publications mainly investigate occupant behaviour.

Summed up it can be said, that most studies on behaviour monitoring try to classify certain activities of the driver. In most cases the focus is on head and hand tracking. Several classification algorithms and approaches for enhancing reliability are described. The output of these systems is mainly used for judging both, unsafe or distracted behaviour and judging the awareness of the driver in automated driving mode. These sources are highly relevant for future investigations in the SAFE-UP project. Nevertheless, the variety of different approaches and use of algorithms support the conclusion that this area of occupant monitoring is very broad and needs further research activities.

Two studies analysed occupant behaviour in order to classify the activities or to improve reliability of the systems. Veeraraghavan et al. described a method based on skin colour

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detection to monitor the occupant's movements (43) whilst Cheng et al. used LWIR for activity monitoring in terms of head and hand observation (44).

In some cases, the analysis of behaviour aimed for identification of driver distractions. Systems from Yan et al. (45) (46) and Baheti et al. (47) detected distractions or unsafe behaviour of drivers based on posture recognition.

Furthermore, several sources could be found especially focussing on activity monitoring for autonomous driving. Martin et al. used head and upper body pose tracking for vision-based driver observation (48) and Zhao et al. introduced a system to monitor the non-driving tasks via head movement monitoring (49).

Occupant Classification

Systems for occupant classification detect occupancy of the seat and categorise the detected occupant into certain classes. Mostly, a differentiation between objects, children and adults is done. The classification is used for airbag deployment decisions. Some systems include further applications e.g. posture monitoring.

It can be resumed, that systems for occupant classification focus on airbag deployment decisions due to legal regulations e.g. FMVSS (Federal Motor Vehicle Safety Standard) 208; and are therefore interlinked with systems for sitting posture recognition. In some cases, an outlook to automated driving is given. Some sources also discuss the possibility of adjusting the restraint strategy according to the data. However, no distinct adjustment strategy for the restraint system has been found.

In some cases, classifications of occupants are described for decision making whether to deploy the airbag or not. This relates to the legal standard FMVSS 208, which prohibit airbag deployment in case of a recognised child or infant seat. Thus, Farmer et al. (50), Gao and Duan (51) and Perrett and Mirmehdi (52) used vision based systems to classify mostly into adults (sometimes with subcategorization), children, infant seats and empty seats.

On the other hand, various sources used visual systems to further monitor the occupant's posture for identification of unsafe distances to the airbag e.g. via defining critical areas or distance measuring. Such systems were introduced by Fritzsche et al. (53), Jang et al. (54), Freienstein et al. (55), Hussain et al. (56), Aerojet General Co. (57) and Bosch (58).

An interesting source from Da Cruz et al. was found, which described the creation of a dataset (SVIRO) as a possibility for testing monitoring systems in autonomous vehicles. This dataset aimed to enable the identification of situations in the passenger compartment and thus allowing a reliable classification (37).

Anthropometry

Monitoring of anthropometric variations is not the primary focus of the SAFE-UP project since these data could be gained via other sources e.g. smartphones or wearables. Nevertheless, some publications could be found concerning mainly vision based approaches for gaining

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anthropometric information of the occupants. This could be helpful for adjusting restraint strategies based on human variations. Since vision-based OMS will be mainly used in the SAFE-UP project, gaining anthropometric information might be possible to adapt.

It can be concluded that only few approaches have been done in order to gain data on human variations in vehicles. In three cases, a link to restraint system adjustment was discussed (59), (60) and (61). The first two publications identified height estimation as a key variable to adjust the occupant protection strategy, whereas (61) identified weight and occupant position as key information for adapting the restraint strategy. It can be observed, that it is possible to add functions for gaining anthropometric data to a vision-based system but up to now, not many studies have been carried out.

As an example, Chen et al. estimated the seated height of an occupant by use of major human body joints definition and face detection (59). A patent by Brantman and Wilson described monitoring of height and/or projected trajectory in order to adjust deployment direction of the airbag (60). Klier et al. compared different systems for occupant monitoring, especially for the use in automated driving. The injury risk of occupants in correlation to the human variation was analysed and evaluated by use of multibody simulations with HBMs (61). Furthermore, Yuen and Trivedi described a method to enhance reliable monitoring of the arms which could be used for behaviour monitoring in autonomous driving (62). Shiraishi et al. investigated measuring of the occupant's blood vessel age (63).

State Monitoring

OMS for occupant state monitoring are highly related to behaviour monitoring, since most of them are used to identify unsafe driving situations. State monitoring mostly focuses on driver fatigue and inattention, whilst behaviour monitoring identifies driver activities and resulting distractions. Since L3 automated driving considers take-over requests for the driver, it is necessary to observe the driver's state. Thus, there is potential to implement state monitoring in the investigated OMS of SAFE-UP project.

It can be observed that most systems use similar techniques for face recognition and tracking of eyes and head. Furthermore, interpretation variables of the driver's state are also similar. In addition, several sources also discuss the occlusion of face or head e.g. with sunglasses, good and bad lighting situations and differences in skin colour. However, it is noticeable that the systems differ in large measure regarding the chosen data processing. Thus, it can be stated that the interpretation of the measured indicators and; therefore, the selection of processing algorithms is challenging. Hence, the variety in data processing leads to the conclusion, that there is still an extensive research gap regarding this topic.

Several sources analysed the driver state by drowsiness and fatigue indications. In most cases facial expression as well as eyelid, eye and head (e.g. nodding) movements were observed. The systems described by Sigari et al. (64), Huynh et al. (65), Park et al. (66) and Weng et al. (67) mostly focused on these indicators. Yu et al. described an approach also implementing intrusive measuring e.g. heart rate or pulse rate, together with driving behaviour e.g. steering or pedal operation, and visual-based monitoring for drowsiness detection (68).

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Three sources mentioned drowsiness monitoring paired with distraction monitoring. In general, the approaches were quite similar but additionally included more detailed tracking of head movements and eye gazing directions. Such systems were described by Kang (69), Rengesh et al. (70) and Baker et al. (71).

Reviews

In addition to the classification mentioned above, two studies addressed OMS on multiple levels. Both reviews are highly relevant for the SAFE-UP project because of their relation to occupant restraint systems and monitoring systems. Especially in (72) highly relevant research gaps were stated i.e. sensor data fusion, robustness and versatility, real time monitoring, posture recognition algorithms for depth cameras and lower body recognition.

A review by Kosiak et al. evaluated different sensing and monitoring technologies for the use of driver monitoring and adjustment of airbag deployment. Several OMS were identified to be useful for adjusting the airbag deployment i.e. for occupant classification and seat position detection. Regarding driver distraction monitoring, vision-based eye-tracking was identified as most suitable. Several technologies and their advantages and disadvantages were discussed. (39)

Another review by Wang et al. evaluated 47 publications on OMS, which were categorized into vision-based and non-vision-based posture monitoring systems. The systems were then classified for example into used sensor type, detection technique, objective, etc. In conclusion the review contains a comparison between the vision-based sensors, force sensors and proximity sensors and their advantages and disadvantages (72).

Overall, it can be observed, that the limited studies showing a link between OMS and occupant restraint systems were mostly limited to airbag deployment decisions. Advanced restraint strategies based on OMS information have not been investigated so far. Intensive research efforts were made regarding driver distraction and drowsiness detection. Several approaches with different algorithms could be found, which classify driving situations according their risk. Furthermore, various activities were done to handle occlusions and shading. The observed body parts are mainly head, face and upper body. Different approaches were described to identify human variations e.g. height, weight or skin colour. It can be summarised that vision-based systems are predominantly used e.g. infrared cameras, CMOS cameras or stereo cameras. Several sources gave an outlook for possible application in automated driving.

4.4 Occupant restraint system Literature Review

The literature review that was carried out in order to define the occupant restraint system focused on finding an answer to the main research questions related to the occupant use case definition. These questions are:

1. Who will be sitting in the cars?

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- Anthropometry spread across Europe
- Male and female weight and length distribution in EU

2. How are people sitting?

   - Sitting postures and activities done (as they affect the occupant posture)

3. How will the vehicle interior configuration be?

   - Interior vehicle layout
   - Interior features
   - Seat positions (number of seats) and seat configuration
   - Interior geometries (length, width and height)

The main findings regarding the topics to be addressed in the research questions (anthropometry, activities conducted by L3/L4 vehicle occupants, seating configurations and interior vehicle configurations) are described in the sub-sections found below. In addition, further information on these topics may also be found in Section 2 of Appendix D: Occupant Restraint System Literature Review.

4.4.1 European adult anthropometric data

A first objective from this literature review study has been to find information regarding adult population (both men and women) anthropometry characteristics, concentrating on weight and height. In this way, it was possible to define the occupant heights and weights that the OMS should be able to detect when developed at later stages of the project. Furthermore, this information shall be referred to once the WP4 OMS has been detailed and verified, as a confirmation of the percentage of the population that the system will be able to detect.

Based on the anthropometric sources, it has been concluded that the weight and height ranges shown in Table 6 represent a 90% of the European adult male and female population. Therefore, this should be the minimum target population that the OMS should be able to detect.

Table 6. Mean height and weight ranges representing 90% of the adult human population

Gender	Height range (cm)	Weight Range (kg)
Male	164,1 -186,9	60,1 – 104,2
Female	151,4 -172,5	49,3 – 91,7

In order to find the information regarding the target anthropometry ranges shown in Table 6, a research was conducted to search for sources regarding the height and weight of adult males and females in Europe. Although several sources providing country-specific data were found (for example, the website http://www.dinbelg.be/ (73), where the adult height and weight in Belgium in 2015 is reported); the overall male and female weight were finally taken

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from a source based on adult anthropometric data from the United Kingdom (UK) (74). This source compared the mean weight from the detailed UK statistics (75) to those from other European countries and to the mean European data as reported by the World Health Organization (WHO) (76), showing that they were representative of the overall European population Therefore, the adult male and female 5th and 95th percentile weights were extracted (See summary of anthropometry results in Table 6).

Regarding adult heights, data from the UK Department of Transport was used to find the 5th and 95th percentile adult height values (77) (78). This data was compared to the results obtained from the website “Our World in Data” (79).

4.4.2 Activities

This section summarizes the literature review findings related to the activities that occupants would carry out in future L3 and L4 vehicles. This information has made it possible to understand the potential occupant sitting postures that would be related to the performance of these activities. However, it must be noted that occupant seating posture does not only depend on the activities that the occupant is doing; it is also highly related to other factors such as: trip duration, if the occupant is travelling alone, the level of confidence/social relationship between passengers or the time in which the journey occurs.

The results from the papers described in this section made it possible to identify the most likely activities that occupants would conduct in L3 and L4 vehicles. This information is required in order to better understand the occupants’ postures and the most suitable seating configurations and adjustments to be able to conduct these tasks. In summary, from the studied publications it can be concluded that the activities that people will carry out during travel in L3/L4 vehicles could predominantly lead to three different seating positions: a traditional seating position or with more leg room space (to work or read), a more relaxed position (to sleep, relax, watch a movie, etc.) or a more social position – including rotated seats or a living room configuration, to socialize with other occupants Table 7 (80) (81).

In order to gain information regarding the potential activities that people will conduct inside L3/L4 vehicles, several surveys were studied. A survey published by the Autoinsurance center (82) consisted in asking people what they would do to spend their free time in an autonomous car. As a result, the five most voted activities were: reading, socializing via phone, working and watching a television show or a movie. The choice of reading as the most common activity was also found in other sources, such as the survey made by Koppel. S et al (83).

These results are in alignment with the survey conducted by Schoettle et al. (84) that analysed the most likely leisure activities that the Chinese population would conduct in AVs. The resulting activities were texting/talking to friends and family, watching films and/or playing games. The same results were showed during the survey made by Östling, M, Larsson, A. on (85) where the target population was from China and Sweden.

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In contrast, when people were asked to answer the question “How would you spend your time in an autonomous car if you spent 2 hours every day commuting to your job?” (86) the most selected activities shifted to: working or studying, surfing the web, eating, sleeping / relaxing or productive home activities. In contrast, the less common were related to socializing or talking with another passenger.

Reed et. al (87) conducted a study where cameras were instrumented in 75 privately owned vehicles and driven normally by the owners for two weeks. The frequency of front-seat passenger interactions and behaviours was studied. As a result of this study, 46% of the time, passengers were talking to other occupants; even if participants were traveling with someone they did not know. This same result was also achieved in the survey made by Koppel. S et al (83).

In addition, in the study done by Reed et. al (87) 26,4% of the time passengers were on the phone and a 25,9% of the time they were doing nothing. Other passenger behaviour that showed minor frequencies included food, drink, resting and behaviour classified as “others”. The activities that people carry out during travel have proven to affect the occupants’ seating postures. A study where participants were sitting in the rear of the vehicle on seats facing each other and limiting the view on the driver of the vehicle (simulating an automated driving situation) was done with the objective to identify the most frequent passenger seating postures in the studied test conditions (Köhler et. al (80) (88)). The results from this study are shown in Table 7. These seating postures will be used as a reference in future stages of WP4 when positioning the occupant models used to conduct FE simulations.

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Table 7. Most frequent sitting postures over all participants (80) (88)

Body part	Rank	position			Percentage of time
		lateral	z-rotation	Sagittal	
Lower back	1st	centralized	centralized	contact to backrest	85.04%
Shoulders	1st	centralized	centralized	contact to backrest	65.43%
	2nd	centralized	centralized	slightly away	17.41%
Head	1st			contact to backrest	58.01%
	2nd			slightly away	24.44%
	3rd			further away	10.39%
Legs	1st	centralized			52.49%
	2nd	crossed at knees			21.90%
	3rd	Legs under the seat			13.93%

4.4.3 Seating Configurations

In order to create the seating configurations to be used in the use cases, several factors were considered. Of course, people's preference played an important role, but other factors such as confidence in the autonomous vehicle, trip duration, the influence of previous crash accidents, passenger height, etc. can also have a significant effect. Different factors can affect the preferred vehicle seat layout, such as the activities, the mistrustfulness of giving up full control to the car and motion sickness. These parameters can be decisive when defining the interior vehicle layout.

This section summarizes the main literature findings regarding preferred seating configurations in AVs. As a result of the analysis of these sources, several seating configurations have been selected. On one hand, in the case of the L3 vehicle, the traditional seat configuration with all seats looking forward has been selected both in its conventional form and allowing the seats to recline and/or move rearward to obtain a more relaxed seating position. In the case of the L4 vehicle, a living room configuration with the front row seats turned 180º facing the rear passengers, has been selected. In addition, for this configuration, it has also been assumed that the seats will be able to rotate/swivel up to 20º. These configurations have been based on the studies explained below. The literature sources used to make these seating configuration selections are explained below.

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In 2017, Jorlöv et al. carried out several tests to find out people's preferences regarding seat configurations in AVs (81). Those results were compared in the paper (85), by Östling, et al., where the results of the tests made in Sweden were compared with the ones done in China.

The participants were asked to position four seats within a simplified physical environment representing a highly automated car, visualizing a short drive alone, and a long drive with several occupants. The test included a questionnaire and a structured interview. Figure 8 shows all the possible seating configurations that were contemplated in this study.

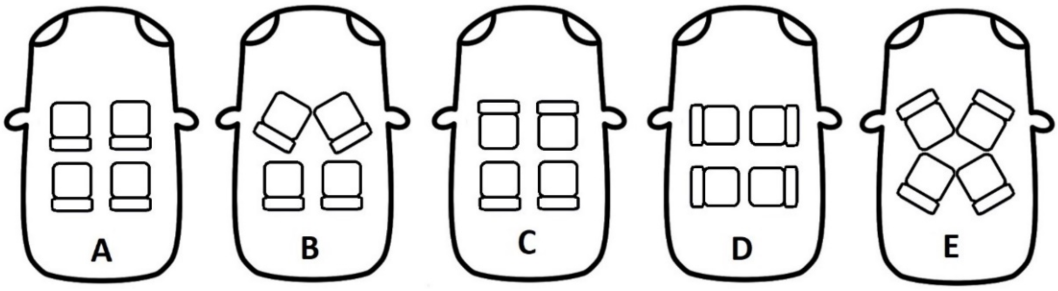

Figure 8. Seating configuration from the study. (81)

Participants in both China and Sweden expected fully automated vehicles to allow for more varied sitting and more comfortable seats. Reclined seats were frequently mentioned, as were swivel seats.

In the study done by Jorlöv et al (81), the most preferred position for longer family drives was the living room position with the front seats rotated 180° (C), followed by the living room positions (E) and (D). In four tests, participants wanted to sit facing forward (A), and one preferred the conversation position (B). Similar results were achieved in the survey made by Koppel. S et al (83) in which across all scenarios, participants from China were most likely to prefer a conventional seating configuration (A) (81). For travelling with family, the preferred position was (A) followed by (C). In terms of seating position preferences, participants preferred the driver seat.

The ability to recline seats for a more comfortable resting or sleeping position was mentioned frequently (81). When considering seating possibility in vehicles with a higher level of automation, few China participants stated that they would like to be able to merge two seats into a bed.

In relation to the topic of occupant use cases when relaxing or sleeping in the vehicle, further information was investigated regarding the seatback angle to be used in these conditions. A study by Stanglmeier et al. (89) was aimed at evaluating the biomechanical quality of different backrest and seat pan angle combinations, and at predicting the most favourable sleeping positions based on vehicle restrictions. The study suggested that a combination of a 40º-seat pan angle and a 155º-backrest angle would provide the biomechanically most favourable pressure properties.

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The above-mentioned studies led to a pre-selection of configuration A for an L3 vehicle (where the possibility to rotate the seat – configuration B – or move it backwards would be contemplated to allow the possibility to drive but also read, work, sleep or relax comfortably, see section 4.4.2) and configuration C for the L4 vehicle (representing for the more social activities mentioned in section 4.4.2.

In order to do a final selection of the interior configuration, it was necessary to do an analysis regarding seating rotation. The rotation of the seat makes a difference in the feeling of comfort, especially when rating the discomfort for the back. In a study conducted by Köhler et al. in the OSCCAR Project (90) (91) volunteers were tested in groups of two in 7 randomly sequenced seat rotations ranging from 0º to 180º (one group of participants was rotated clockwise and the other group counter-clockwise). As a result, it was shown that overall left-wing rotations were preferred over right-wing rotations.

Figure 9 shows the percentage of participants stating that each seat rotation is acceptable for an autonomous vehicle. These results were obtained by means of a questionnaire made after a test track drive in a standardized parkour where several manoeuvres simulating an autonomous vehicle were done. 0º means that rotation was applied in relation to the driving direction. As a result, 100% of people agree that 0º of seat rotation is acceptable for an autonomous vehicle, while less than 20% agree with the 60º seat rotation. The study also concluded that the mirrored seat positions at 60º and 300º were deemed as the most uncomfortable positions by both the left-wing rotation group and the right-wing rotation one.

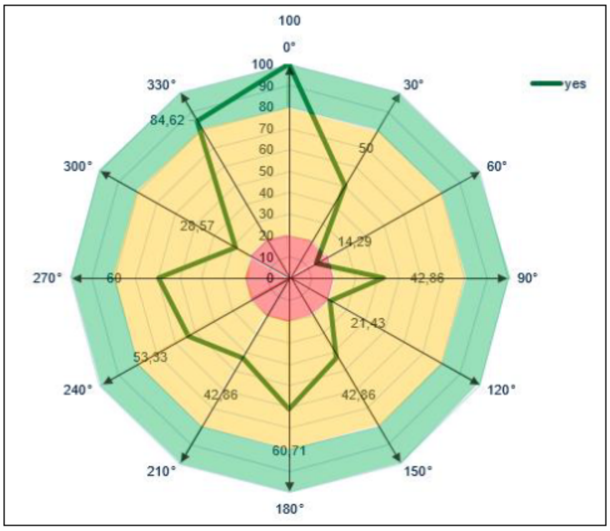

Figure 9. Percentage of participants agreeing to each seat rotation for AVs (90) (91)

As a conclusion, it can be seen that overall, volunteers preferred to sit looking forward (traditional position) with a slight seat rotation of up to 30º or to sit facing backwards entirely. This is in alignment with the conclusions from the previous paper and can be used as a confirmation to discard configurations D and E (Figure 8).

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Passengers' experience and actions in a rotated seat in terms of interaction with an adjacent passenger was studied by Bohman et. al (92). In this study, the seats were rotated 0º, 10º and 20º inboard on both front row seats. The participants were seated in each seating configuration for 10 min; of which during 5 min they engaged in a conversation with each other and the other 5 min they were watching media on an Ipad mounted in front of them. The participants were classified in two groups, tall and short, in order to evaluate the differences between both anthropometric categories.

As a conclusion of this study, it was clear that the vast majority (more than 70%) of short occupants preferred the 20º rotated seat configuration both when having a conversation and watching media. On the contrary, due to the discomfort generated by passenger-to-passenger leg interference, the preferred seat configuration for tall occupants was the 10º seat rotation configuration (40% of the responses). The less chosen option by tall passengers was the reference position when watching media and the 20º rotated seat when having a conversation. Because of this, it has been concluded that when allowing front seat rotation in Configuration B (Figure 8), the maximum seat rotation to be allowed in order to guarantee occupant comfort should be of 20º.

Depending on the activities people do while travelling and the postures they adopt, passengers could suffer motion sickness. Several studies demonstrate that motion sickness is a highly relevant issue to be looked into with special detail in AVs.

Sivak et al presented a paper in 2015 explaining more about motion sickness in self-driving vehicles (93). In this paper, the contributing aspects that influence the impact of the critical factors for motion sickness were analysed. Regarding the features inside the vehicle, this study demonstrates that smaller, opaque, or reduced-visibility windows that would be employed in self-driving vehicles, increase the frequency and severity of motion sickness. The only factors that were identified as having the potential to improve the influence on motion sickness were having eyes closed or sleeping and a sitting in a supine posture.

As a conclusion, the problem of motion sickness could be mitigated by designing bigger interior cabin spaces and avoiding small windows that create a closed atmosphere and could cause claustrophobia.

4.4.4 Interior vehicle configurations

Because of confidentiality reasons no publications on the interior vehicle configurations beyond marketing material and pictures are available. Thus, it was decided to search for available images of new vehicle concepts and to extract interior vehicle dimensions from there. In this way, a benchmarking of future market trends regarding interior configuration designs for future autonomous vehicles was conducted.

Table 8, found below, shows the vehicle interior measurements that have been derived from the benchmarking study for each of the selected SAFE-UP WP4 use cases. For all cases the max height was 105 cm.

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Table 8. Vehicle interior measurements for SAFE-UP WP4 use cases (dimensions in cm)

Use Case	Cabin length	Front legroom Min/Max	Rear legroom Min/Max	Width	Seatback angle
Peri-Urban: Manual driving mode L3	230	105	125	153	23º - 35º
Peri-Urban: Automation mode L3	230	125/145	85/105	153	23º - 45º
Highway L4	315	125/145	170/190	180	25º - 60º

The method and sources used to determine the measurements found in Table 8 are explained below.

Method

Firstly, in order to have a reference regarding interior vehicle measurements in current vehicles, an article in which the interior dimensions for several actual SUVs were shown, was found (See Table 9 (94)).

Table 9. SUV interior measurements (all dimensions in cm) (94)

Vehicle	Cabin length	Front legroom	Rear legroom	Width front/rear	Max height. front/rear
Honda HR-V	185	105	80/80	144/136	98/93
Toyota RAV4	188	105	84/84	146/140	102/98
Audi Q7	191	105	71/82	152/147	99/95
VW Tiguan	185	105	60/77	145/141	92/99

Next, publicly available images of AVs that could be representative of the SAFE-UP WP4 use cases, were searched. In order to estimate the interior measurements in these vehicles, the standard dimensions of a conventional car seat, (seat width of 604 mm (86)) were used as a reference to extrapolate the rest of the interior vehicle measurements. To validate that this

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measurement system led to acceptable values, a case of a vehicle configuration in conventional seating position was successfully compared to the values found in Table 9.

Once the interior dimensions for each use case were estimated and using a drawing software called blender (95), the interior configuration designs were created. Human models and seat models suitable for use in blender (generated using MakeHuman (96)) were used to represent the three different interior configurations to be used for the use case definition.

Peri-urban use case: Manual driving mode L3

The first interior configuration to be considered represents the traditional driving mode, in which the configuration is the same as current vehicles. However, given that both peri-urban use cases (in manual and automated driving modes) are based on the same L3 vehicle, a future vehicle concept that could accommodate both use cases was searched for.

The search for new future concept cars led to the concept car from Yanfeng that was used as a reference to define the interior measurement for the first and second use cases' interior configurations. Yanfeng's "next living space" interior autonomous concept car (97) may be seen in Figure 10. This concept vehicle makes it possible to reorganize the interior configuration for four people in order to keep the driving mode and the automated driving functionality. Thus, the estimated interior vehicle measurements stated in Table 8 have been used to define the interior vehicle configurations of both L3 vehicle use cases.

Figure 10. Yanfeng concept vehicle (97)

Finally, once the overall interior vehicle measurements were defined the seat position inside the vehicle was chosen. In this case, the seat position corresponds to a conventional seating position found in current cars. Thus, the values from Table 9 were used as a reference and combined with those from the Yanfeng concept vehicle. The resulting interior layout may be found in Figure 11.

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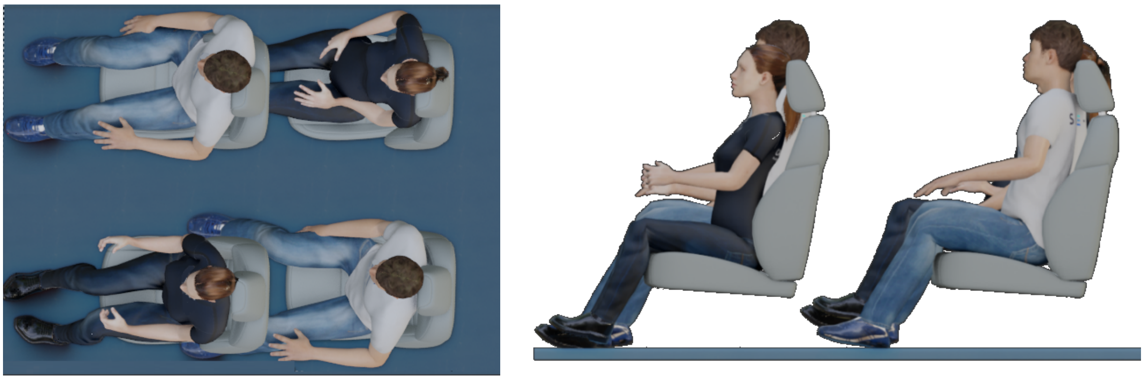

Figure 11. SAFE-UP WP4 Peri-Urban Use Case in Manual driving mode L3 interior vehicle configuration

Peri urban use case: Automation mode L3

The second use case represents a situation where the driver is not driving but must be able to continue driving when required. This interior configuration would allow the occupants to relax, allowing to increase the level of seat recline and the rearward displacement of the seat in order to have more space.

As the first two configurations represent the same L3 vehicle when driven manually or in automated mode, the general interior vehicle measurements are the same than in the previous use case. However, the seat position inside the vehicle cabin differs. In the peri-urban use case in Automated mode, the seats allow for a higher level of recline and rearward seat movement. As a result, the following layouts represent two of the range of relaxed seating positions associated to this use case (See Figure 12).

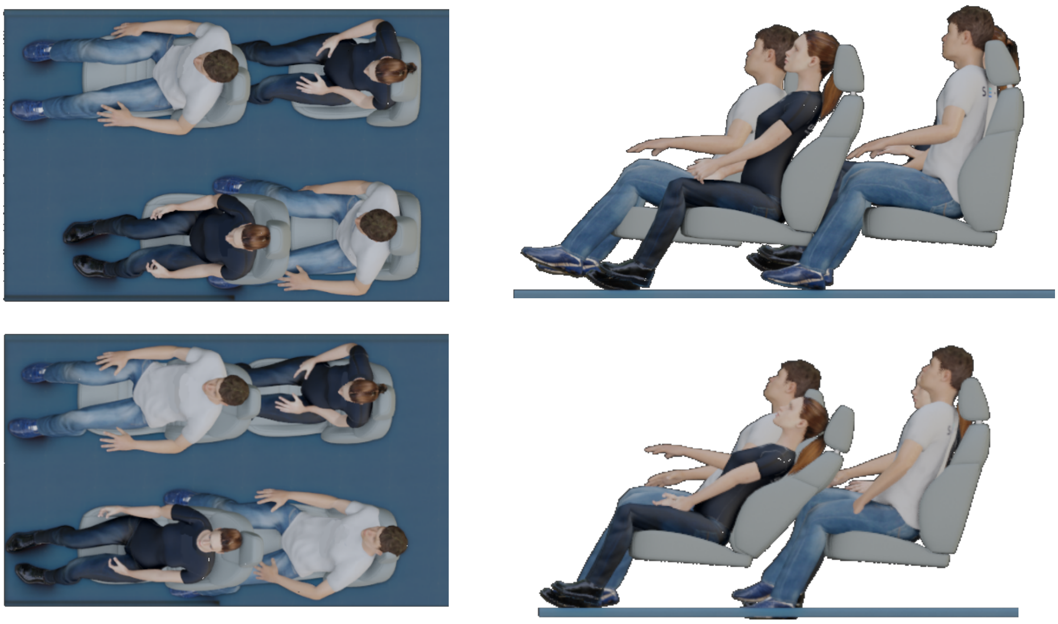

Figure 12. SAFE-UP WP4 Peri-Urban use case in Automation mode L3 interior vehicle configuration

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Highway use case: L4

The third interior configuration represents an L4 vehicle. As there is no driver in this case, and in alignment with the conclusions extracted from the seating configuration literature review (section 4.4.3), this interior configuration has been chosen to be a living room configuration. In this configuration, the front seats will rotate 180º and displace in order to create the living room space.

For this third interior configuration, the overall interior vehicle dimensions (cabin space) will be bigger than in the two previous use cases, because of the space needed to rotate the seats and ensure occupant comfort.

In order to study the potential living room vehicle configurations, several concept vehicles were studied. On one hand, in 2018, Zoox presented their first concept car, shown in Figure 13 (98). Finally, in December 2020, they released their final concept vehicle. This concept vehicle will run as a taxi, is thought for urban spaces and has a living room configuration with fixed seats (See Figure 14).

Figure 13. Old Zoox concept car (98)

Figure 14. Zoox release concept car (128)

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On the other hand, the Mercedes-Benz F015 (See Figure 15 (99)) concept car offers the possibility to rotate the seats in order to transform the interior into a living room, but also allowing to use the vehicle in driving mode.

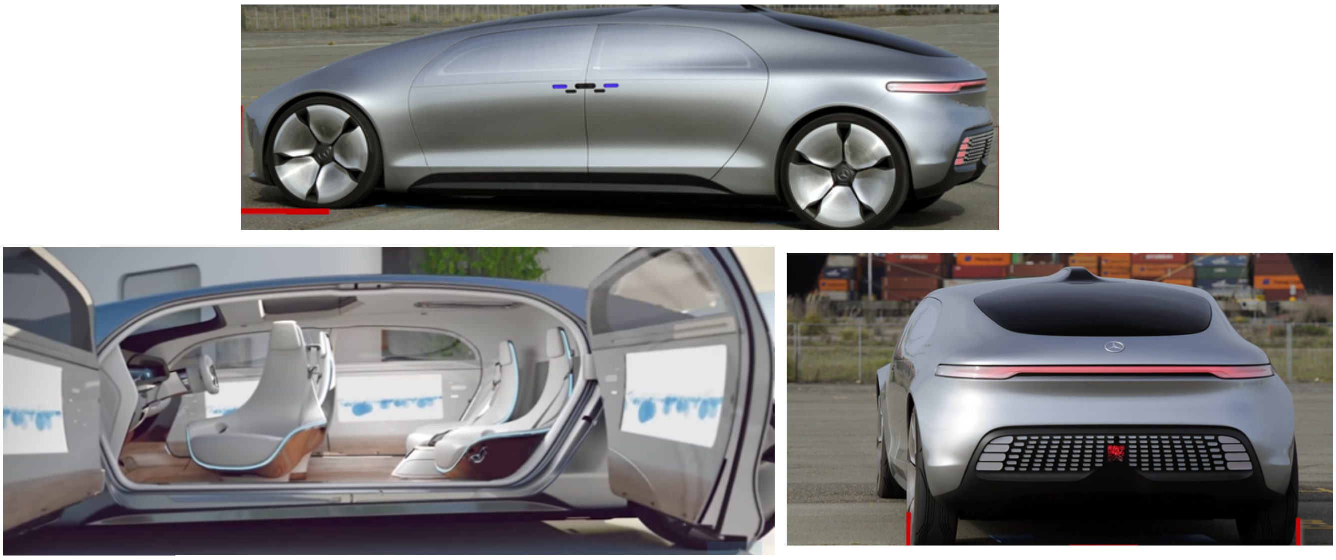

Figure 15. Mercedes F015 concept car (99)

In addition, in this case, the overall exterior dimensions of the vehicle are public (99) being 5,22 meters long, 2,01 meters wide and 1,52 meters high. Thanks to these measurements, it was possible to estimate the interior measurements of the Mercedes F015 vehicle concept. Thus, this vehicle was used as the reference living room configuration concept car to be used in the L4 highway use case to be studied in WP4. However, additional AV concept cars included in this benchmark study may be found in Section 2.8 of Appendix D: Occupant Restraint System Literature Review.

The graphical representation of the final Highway L4 use case interior vehicle configuration is found in Figure 16.

Figure 16. SAFE-UP WP4 Highway L4 use case interior vehicle configuration

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5. Results – SAFE-UP use cases

Based on the methodology and main findings explained in sections 1.3, 3 and 4, three use cases have been identified. For all use cases, the crash configuration and the occupant use case have been defined and will be explained in the following sections. The human variation will be further evaluated and defined in Task 4.2 System concept definition and Task 4.3 Optimisation of system concept for different seating configurations. Therefore, this topic will not be further investigated in T4.1.

In contrast to the literature review on Occupant Restraint Systems the outcomes of the review on Occupant Monitoring Systems cannot be used for consolidating the Task 4.1 use cases scenarios. This is caused by the very technical focus on the monitoring systems themselves in terms of hardware and algorithm. Instead, the outcomes are meant to support the hardware and algorithm definition in Task 4.2 System concept definition and Task 4.4 Algorithm development, which can only be done with previously defined use cases at hand.

Although the OMS will be able to monitor both the position of the driver and the front passenger, WP4 will concentrate on the driver position in the pre-crash phase in all use cases. The main reason behind this is that the driver position is the one affected by the changes between manually driven and autonomous driving use cases, and the decision also limits the number of simulations needed to evaluate the occupant restraint system.

In addition, as mentioned in section 3.3, it is recommended to evaluate all crash configurations described in the three use cases with and without pre-crash braking and steering, as these manoeuvres have a big impact on the pitch of the vehicle, the kinetic energy and the overall occupant movement. This topic will be dealt with in-depth in task 4.3.1. However, relevant pre-crash pulses to be used to simulate the pre-crash vehicle kinematics have already been identified and reported in section 3.3.

5.1 Peri-urban use case: Manual mode L3

The first use case corresponds to a L3 vehicle that is driven in a manual mode (the driver occupant is in charge of driving the vehicle as it is not being driven in automated mode) in a peri-urban environment. This is considered to be the baseline when evaluating the performance of the SAFE-UP advanced Passive Safety system (occupant monitoring and restraint systems) for the similar interiors of the two other use cases.

Crash configuration

Regarding the crash configuration to be studied in the peri-urban use cases (common for both manual driving mode and automated driving mode) the following configurations have been considered:

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- Car-to-Car head on crash

  This crash configuration will be evaluated using crash pulses at 40 km/h and 56 km/h that were used in the OSCCAR Project.

- Car-to-Car intersection crashes

  This crash configuration will be studied by using the most likely intersection crash configurations found in the literature (namely: straight crossing path impacts and left turn across path impacts in both opposite direction and lateral direction (7)) and simulating these crash conditions using CAE tools and shareware CAE vehicle models.

- Car-to-HGV head on crashes

  For this configuration, as no public literature was found in order to define the crash pulses, the suggested approach is to generate the crash pulses via FEM simulation in Task 4.3. For example, by using and adapting freely available CAE vehicle and HGV models.

Occupant Use Case

In this use case, all seats are facing forward in a traditional interior layout. Regarding the vehicle's interior features, given that in this use case the vehicle is manually driven, the vehicle will count with regular features such as steering wheel and knee bolsters.

As to the interior compartment layout, the dimensions to be used have been extracted from the literature review (see section 4.4.4 and Appendix D: Occupant Restraint System Literature Review). The chosen vehicle interior configuration represents a traditional seating configuration. Figure 17, found below shows the resulting interior seating compartment layout chosen for this use case.

Figure 17. 3D view of SAFE-UP WP4 Peri-urban use case in Manual driving mode L3 interior configuration

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As to the seat position, the selected range of seat back angles is from 23º to 35º (80) while the seat cushion angle of 10º. Regarding the fore-aft position and seat height, the seat will be set as per the usual driving settings in current traditional vehicles, with a total seat track range of 350 mm (80).

The driver's sitting posture is defined as the regular driving position with the back against the seat back. The human variation will be part of the system concept definition in task T4.2 and system analysis in task T4.3 and not defined further in T4.1.

5.2 Peri-urban use case: Automation mode L3

For the second use case, the studied vehicle is still an L3 vehicle in a peri-urban environment. However, in this case, the vehicle is being driven in automation mode and; therefore, the driver does not need to maintain the traditional driving position. Nevertheless, as the vehicle is a L3, the driver must continue traveling in a position that allows him/her to take over control from the automated driving mode to the manual driving mode when required or to override the automated driving functionality if/when needed.

The crash configuration for this use case is the same as in the previous use case (Peri-Urban Manual Mode L3);. Thus, for this use case, only the Occupant Use Case will be explained, as the difference in the vehicle interior will have a strong influence on the definition of the restraint system, restraint system timing, etc. to be defined in task T4.2.

Occupant Use Case

In this use case, all seats are still looking forward in a similar layout to a traditional passenger vehicle. However, given that the vehicle is driving itself in automation mode, the driver can move to a more relaxed seating position. This relaxed seating position allows the driver to move rearwards (achieving additional leg space) and recline the seat if desired. More specifically, the selected range of seat back angles is from 23º to 45º while the seat cushion angle ranges from 10º to 20º Regarding the fore-aft position and seat height, the seat will be able to move 200 mm rearward from the usual driving position in current traditional passenger vehicles, with a total seat track range of 200-400 mm. In the case of the L3 vehicle in automation mode, the range of seat back angles and fore-aft movements were selected by the T4.1 partners according to their experience in this field. These values were selected as per the partner's expertise in order to allow for the driver to be in a more relaxed position but still have enough time to return to the driving task when needed.

Regarding the vehicle's interior features, given that in this use case the vehicle is manually driven, the vehicle will count with regular features such as steering wheel and knee bolsters.

The driver's sitting posture is defined as having the back against the seat back, with the possibility to lean sidewise.

Figure 18, found below shows the visual representation of the Peri-urban use case in Automation Mode L3 vehicle interior configuration based on the vehicle concept studies and

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virtual tools that have been used in the occupant restraint system literature review. It is important to highlight that these images include all four passengers purely for representation purposes, as it is understood that the front passengers would not normally travel in the fully relaxed position if there are occupants in the second row to avoid their discomfort.

Figure 18. 3D view of SAFE-UP WP4 Peri-urban use case in Automation mode L3 interior configuration with increased legroom (left) or seatback recline (right)

5.3 Highway L4 use case

The last use case represents an L4 vehicle that drives fully autonomously in a highway environment. This vehicle concept represents a more long-term scenario. However, the selection of this use case has been based on extensive literature studies regarding people's preferences for future AD vehicle interiors, activities to be done inside the vehicle and public AD vehicle concepts.

Crash configuration

For the Highway L4 use case, the following crash configurations have been selected:

- C2C Rear-End

  This crash configuration will be evaluated using the generic full frontal 56 km/h pulses generated in OSCCAR.

- C2HGV Rear-End

  Similarly, as in the previous C2HGV case, C2HGV Highway Rear-End crashes were not found in the literature. It is proposed to generate those in Task 4.3 using previously described shareware CAE models.

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Occupant Use Case

In the case of this use case, as there is no need for the occupants to drive as the vehicle has a Level 4 of automation, a living room interior configuration has been chosen based on the conclusions extracted from section 4.4.3 (studies made where volunteers chose their most preferred seating configurations for AVs (81) (85)). A living room configuration is such that there is one row of seats facing forward and another row of seats facing backward, so that the occupants can interact. In this configuration, it has been assumed that the seats will also be able to rotate/swivel up to 20º (90) (92).

Regarding the interior features, it has been decided that there will be none, and the vehicle interior will simply be an open space. This decision has been made because, although some future vehicle concepts incorporate interior features such as tables, there does not seem to be any clear trend with regards to this topic, and the tables seem to be positioned in very different ways depending on the OEM. Examples of these different layouts may be found in the extended benchmark of vehicle concepts found in Appendix D: Occupant Restraint System Literature Review. Furthermore, given that the main objective of WP4 is to develop an OMS, it is believed that - for consistency-it would be beneficial to avoid adding interior features that could obstruct the field of view.

In the Highway L4 use case, a seat position with a high degree of flexibility has been chosen due to the expectation that people will want to relax or possibly sleep during ride. Thus, higher seat back angles are made possible (in a range from 25º to 60º). The seat cushion angle can range from 15º to 35º. The seat cushion height and seat position in the longitudinal axis; however, are fixed. These values are based on the findings from Stanglmeier et al (89) and slightly modified (5º) based on engineering judgement and the given interior vehicle cabin space.

In the same way as in the Automated mode peri-urban L3 use case, the occupant's sitting posture is defined as having the back against the seat back, with the possibility to lean sidewise. The occupant's lap belt would be placed on the abdominal region.

This case cannot be compared to the L3 baseline from an interior configuration perspective; since the living room interior represents a completely different ingredient when it comes to the evaluation of the performance of the SAFE-UP advanced Passive Safety system (occupant monitoring and restraint systems). However, the baseline case can be used to compare the overall level of occupant safety associated to current vehicle interior configurations to future novel interior vehicle concepts that are expected to be adopted in some AVs.

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Figure 19 shows the visual representation of the Highway L4 use case vehicle interior living room configuration:

Figure 19. 3D view of the SAFE-UP WP4 Highway L4 use case interior configuration

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6. Discussion

6.1 Limitations

The use of CARE data base has the benefit that it includes data from all EU countries on road accidents. The idea with CARE is that every road accident with personal injury in EU is recorded. This make it possible to evaluate crash scenarios valid for all EU countries without additional effort like weighing. However, compared to German in-depth accident study (GIDAS) it lacks details about crash configuration. The work to define future critical scenario for L3 and L4 vehicles; therefore, had to be done in two steps. First step using CARE to find representative crash scenarios and the second step based on these scenarios try to find representative crash configuration in the literature. This was successful in terms of C2C crashes but for C2HGV very little was found in the literature. Because of this, it was proposed to generate pulses based on generic simulation using shareware models of a car and a heavy good vehicle.

Several limitations were found during the execution of the literature review studies. On one hand, given that new vehicle seating positions are still not mainstreamed in currently available vehicle concepts, many literature sources are based on surveys done based on imaginary scenarios, static seating options (using chairs in a non-vehicle environment) or scenarios that do not fully represent future vehicle concepts. Because of this, the results may not be fully accurate and representative of what the general public would prefer with regards to seating positions and activities to be done in an AV. Therefore, a certain degree of subjectivity is unavoidable and has led to occasional contradicting results between studies (especially regarding future activities that occupants will conduct while in AVs).

Also, it is important to mention that several project partners had identified deliverables from other European Funding Projects (such as AEROFLEX as a source of information for the C2HGV crash configuration definition) that could be relevant to the work conducted in this task. However, due to the confidential classification of these deliverables, it has not been possible to share these documents with all of the involved SAFE-UP task partners and they have not been included in the literature review studies. Finally, it is also important to mention that, given the high level of confidentiality of future AV concepts, it has not been possible to find any references that indicate the interior vehicle dimensions of these types of vehicle. Because of this, it has been necessary to estimate these dimensions by using standard values used in current vehicle concepts (such as seat measurements) and virtual tools.

Regarding the literature review on OMS several limitations can be identified. At first it is possible that during the filtering process literature was excluded containing relevant information for sensor definition or algorithm development. The defined main focuses and chosen criterions excluded for instance all efforts made regarding applications for smart devices, surveillance systems or approaches for VRU-detection. That information is not

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directly linked to occupant restraint systems but the chosen hardware or algorithms might be similar and easy to adapt to the SAFE-UP project.

It is noticeable that the area of monitoring, especially of face, body parts, behaviour, etc., is currently a very dynamic field of research. It can be observed that currently many efforts are being made in various sectors, not only in the vehicle development. The results of these efforts could also be relevant for monitoring systems in SAFE-UP but due to the fact that there is no link to monitoring the passenger compartment of vehicles, automated driving or restraint systems and strategies, they were not taken into account.

Furthermore, it was noticeable that some investigated systems have very specific functions and, in some cases, limited versatility. Especially, systems that were developed in simulated and controlled environments are not validated and thus might not be suitable for real world use. As an example, some drowsiness detection systems are based on the “Driver Drowsiness Detection Dataset” from the National Tsinghua University. This dataset claims to cover night/day illumination and obstructions, but the dataset was created under simplified laboratory conditions. Hence, an adoption of the results from these studies needs to be done cautiously.

The literature research is based on a wide variety of available sources. However, it can be estimated that not all relevant literature was found due to limited access to certain publishing media. In addition, references in other languages than German and English were not considered. It is known that further efforts have been made in the area of OMS but they were published in other languages e.g. Chinese.

Finally, it has to be stated that the literature review does not include recent developments that have not been published. It is possible that systems are under investigation at the moment that aim at similar functionalities as the SAFE-UP project but are confidential for competitive reasons.

6.2 Future Work

Regarding Occupant Monitoring Systems, by means of the Literature Review study reported in section 4.3, it has been seen that a major number of studies use non-intrusive measuring devices. Most OMS use vision-based technologies. Consequently, the further consideration of the OMS technologies and the successive development of own solutions should focus on these vision-based systems. Regarding posture monitoring, nearly all systems aim for decision-making whether to deploy the airbags or not. In all cases, areas or postures are defined which are used to judge the airbag deployment. It needs to be mentioned though, that these investigated systems are on a conceptual development level and not introduced into the market. Furthermore, an adjustable restraint strategy that involves for instance the adaption of the belt, e.g. via a fully adjustable load limiter, is uncommon. The same can be said about occupant classification. Most systems classify the occupant into categories like adult, child, infant, object and empty seat. In some cases, these categories are split into subcategories e.g. 50th percentile male, 5th percentile female, forward or rear facing infant

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seat, etc. In most cases the information is only used to decide airbag deployment. As before, these systems were being investigated on a research level but not introduced to the market yet. A combination of monitoring the occupant's seat position, sitting posture and state is mainly used for driver awareness, distraction or drowsiness detection. In many cases the activities of the driver and facial expressions are monitored. This is highly relevant for automated driving, since the driver can concentrate on non-driving tasks. Concerning only the seat position, not much information was found. In most cases, seat position is monitored in order to predict injuries of the passengers in a crash. This information is highly interesting for SAFE-UP. Concerning the monitoring of seat positions in AVs, no source could be found. Regarding anthropometry the main objective is to gain specific data on the body or body parts of the passenger, especially for height estimation. In two cases this information is used for adjusting the restraint strategy in a crash. Furthermore, fusion of multiple sensor data has rarely been done, especially not for restraint system adjustments, but is expected to be promising. Regarding algorithm selection for depth cameras, more research is also needed. No publication investigated real time monitoring of occupants.

Summed up, no publication could be found combining the majority of primary functions for the benefit of occupant restraint systems in autonomous vehicles. Therefore, it can be stated that the premise of SAFE-UP to establish a holistic approach for occupant protection based on OMS in automated driving has never been done before. Thus, it represents a novelty so the systems definition cannot be taken over from other studies but must be specifically investigated.

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7. Conclusions

In Task 4.1, new concepts that are applicable to the development of future autonomous vehicles have been studied. By combining the results from accident statistics analysis, literature review studies and engineering judgement and observation abstraction work done throughout Task 4.1 with previous work done in other EU funded projects (mainly OSCCAR), it has been possible to select three use cases that will be the basis of the occupant monitoring system (OMS) and occupant restraint system developments to be done in WP4 of the SAFE-UP Project. These three use cases represent a wide range of crash situations, from manual driving mode to fully automated mode; and seating configurations in order to develop robust systems that cover a significant portion of the future AV crash scenarios.

Furthermore, the result of the literature review revealed that the chosen approach of combining OMS and occupant restraint systems in the SAFE-UP project has never been carried out before to this extent and; thus, represents a novelty and a relevant research gap.

Different approaches were followed in order to reach these results and answer the main research questions associated to Task 4.1; namely: Which crash configurations would L3 and L4 vehicles be exposed to in mixed traffic? Who will be sitting in the cars? How will people sit in the cars and how will the vehicle interior configuration be? What is the current State-of-the-Art in terms of OMS and their use to enhance occupant protection in the event of a crash?

On one hand, the analysis of the potential future crash configurations that future autonomous vehicles will have to face when in mixed-traffic scenarios, has been conducted This led to different crash configurations compared to those that are often considered in current crash testing protocols, where head-on crashes in rural environment and rear-end crashes in highway have become the highest priority. In addition, the increased relevance of C2HGV crashes has also been discovered, making this type of crashes an additional topic of interest for the occupant restraint system developments to be done throughout WP4.

Two literature review studies have been done as part of Task 4.1. On one hand, an in-depth State-of-the-Art analysis of currently available OMS has been done. The goal was to create a sufficient overview on related research activities and developments in the area of occupant monitoring for the benefit of occupant restraint systems. This shall allow a purposeful definition of the hardware and the algorithms by use of previously published experiences and represents a necessary work for the OMS definition and development to be done in tasks 4.2 and 4.4 of the SAFE-UP Project.

In addition, by means of the occupant restraint system literature review, the definition of the occupant's seating position and the vehicle's interior features has been determined. AVs allow for the occupants to reach a greater variety of seating positions and to be able to conduct activities inside the vehicle while not having to drive. Because of this, reclining seats, increased leg room space and a living room seating configuration have been considered. In addition, the interior vehicle dimensions have also been estimated based on a benchmark study of publicly available autonomous vehicle concepts.

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8. Dissemination and Exploitation

Given the nature of the work described in the deliverable, the activities conducted in Task 4.1 cannot be exploited directly. However, they will have a greater importance from a dissemination point of view.

On one hand, there is a possibility to disseminate the findings from Task 4.1 alone, by means of a SAFE-UP newsletter, article on social media or post in the SAFE-UP website. This could be used to try to promote the activities done in the SAFE-UP project in the early stages of the project, when the safety developments have not yet been completed.

In addition, on the 12th of November 2020 a knowledge transfer webinar with fellow research projects HEADSTART and OSCCAR was performed. Given that OSCCAR and SAFE-UP are majorly linked through the activities conducted in WP4 and described in section 2, this workshop is considered to be part of the dissemination activities related to this work. This webinar was a very good opportunity to share the knowledge and approach between project partners and was a first step to engage with a broader number of relevant R&D&I projects. Further information on this event, together with the presentations shared during the workshop, may be found in the SAFE-UP Project website (100).

Moreover, interesting conclusions have been found throughout this work in several areas. Because of this, there is a probability that sections of this study may be disseminated at a later moment in time by means of publications in a technical conference.

Finally, all WP4 partners intend to widely disseminate the activities done in WP4 of the SAFE-UP Project. Considering that all developments will be based on the use case definition that has been described in this document, the content of D4.1 will be widely disseminated, not as a stand-alone study; but as a baseline study that defines the scope of work for the advanced occupant restraint systems to be done in WP4.

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List of abbreviations

Abbreviation	Meaning
2D	Two-dimensional
3D	Three-dimensional
AAM	Active appearance models
ADAS	Advanced Driver Assistance Systems
AEB	Autonomous Emergency Breaking
AFLS	Advanced Front Lighting System
AI	Artificial intelligence
ASZ	Automatic suppression zone
ATD	Anthropometric Test Device
AVs	Autonomous Vehicles
BMI	Body mass index
BrIC	Brain injury criteria
BSD	Blind Spot Detection
CAE	Computer-aided engineering
CCD	Charge-coupled device
CDC	Collision Deformation Classification
CMOS	Complementary metal-oxide-semiconductor
CNN	Convolutional neuronal network
CSI	Captive sensing images
Δv	Delta velocity
D	Deliverable

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DBN	Deep belief network
DCNN	Deep convolutional neuronal network
DFKI	German Research Center for Artificial Intelligence
DMC	Driver monitoring camera
DMS	Driver Monitoring System
e.g.	Exempli gratia
EC	European Commission
ECG	Electrocardiogram
ECU	Electronic control unit
EEG	Electroencephalogram
ES	Emergency Steering
ESA	Evasive Steering Assist
ESC	Electronic Stability Control
EU	European Union
et al.	et alii
etc.	etcetera
FFIS	Forward facing infant child seat
FMVSS	Federal Motor Vehicle Safety Standard
FOV	Field of view
GA	Grant Agreement
GPU	Graphics processing unit
HA	Highway Assist
HBM	Human Body Model
HIC	Head injury criteria

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HMM	Hidden Markov model
i.e.	id est
IIA	Individual identification and adaptation
IR	Infrared
ISA	Intelligent Speed Adaptation
ISD	Interior sensing device
k-NN	K-nearest-neighbour
L3	Level 3 of automation on autonomous vehicles
L4	Level 4 of automation on autonomous vehicles
LB	Lower Bound
LCA	Lane Change Assist
LDC	Linear discriminant classifiers
LED	Light emitting diode
LKA	Lane Keeping Assist
LWIR	Longwave infrared
NASS CDS	National Automotive Sampling System Crashworthiness Data System (US)
NCAC	National Crash Analysis Center
NN	Nearest neighbour
OCA	Occupant classification and adaptation
OEM	Original Equipment Manufacturer
OMS	Occupant Monitoring Systems
OOP	Out of position
OSA	Observable situational awareness

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PCM	Part confidence maps
PDA	Occupant position detection and adaptation
PMHS	Post-Mortem Human Surrogates
PPD	Passenger presence detection
QDC	Quadratic discriminant classifiers
R&D	Research and Development
RF	Random forest
RFIS	Rear facing infant child seat
RGB	RGB colour space (red green blue)
RMDB	Research Mobile Deformable Barrier
SAE	Society of Automotive Engineers
SotA	State-of-the-Art
SVIRO	Synthetic dataset for Vehicle Interior Rear seat Occupancy
SVM	Support Vector Machine
T	Task
THUMS	Total Human Model for Safety
TJA	Traffic Jam Assist
TOF	Time-of-flight
UB	Upper Bound
UMTRI	University of Michigan Transportation Research Institute
VRU	Vulnerable road user
WHO	World Health Organization
WP	Work Package

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Appendix A: Crash configuration

Table 10. Occupant fatalities in passenger cars with registration year 2000 and later by crash type for C2C highway (not at junction); LB is the lower bound; UB is the upper bound

	C2C Highway, not at junction, LB*	C2C Highway, not at junction, UB*	% of target population, LB	% of target population, UB
Crossing or turning, opposite direction	4%	15%	0,2%	0,7%
Crossing or turning, same direction	2%	8%	0,1%	0,4%
Entering traffic	2%	4%	0,1%	0,2%
Head-on collision	7%	14%	0,3%	0,7%
Neither A-11, nor A-12 is applicable	8%	8%	0,4%	0,4%
Overtaking	2%	4%	0,1%	0,2%
Rear-end collision	23%	45%	1,1%	2,2%
Side collision	1%	2%	0,0%	0,1%
Sample size	100		2.085	

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Table 11. Occupant fatalities in passenger cars with registration year 2000 and later by crash type, C2HGV, highway (not at junction) ; LB is the lower bound; UB is the upper bound

	C2HGV Highway, not at junction, LB*	C2HGV Highway, not at junction, UB*	% of target population, LB	% of target population, UB
Crossing or turning, opposite direction	0%	0%	0,0%	0,0%
Crossing or turning, same direction	1%	22%	0,0%	0,7%
Entering traffic	1%	3%	0,0%	0,1%
Head-on collision	1%	3%	0,0%	0,1%
Neither A-11, nor A-12 is applicable	1%	1%	0,0%	0,0%
Overtaking	1%	3%	0,0%	0,1%
Rear-end collision	36%	66%	1,2%	2,2%
Side collision	1%	3%	0,0%	0,1%
Sample size	69		2.085	

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Table 12. Occupant fatalities in passenger cars with registration year 2000 and later by crash type, C2C, rural, not at junction; LB is the lower bound; UB is the upper bound

	C2C Rural, not at junction, LB*	C2C Rural, not at junction, UB*	% of target population, LB	% of target population, UB
Crossing or turning, opposite direction	3%	22%	1,4%	9,6%
Crossing or turning, same direction	1%	4%	0,2%	1,7%
Entering traffic	0%	0%	0,1%	0,2%
Head-on collision	25%	56%	11,1%	25,0%
Neither A-11, nor A-12 is applicable	7%	7%	2,9%	2,9%
Overtaking	0%	1%	0,2%	0,4%
Rear-end collision	2%	5%	1,0%	2,2%
Side collision	3%	6%	1,2%	2,6%
Sample size	930		2.085	

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Table 13. Occupant fatalities in passenger cars with registration year 2000 and later by crash type, C2HGV, rural, not at junction; LB is the lower bound; UB is the upper bound

	C2HGV Rural, not at junction, LB*	C2HGV Rural, not at junction, UB*	% of target population, LB	% of target population, UB
Crossing or turning, opposite direction	2%	20%	0,4%	3,5%
Crossing or turning, same direction	0%	0%	0,0%	0,0%
Entering traffic	0%	0%	0,0%	0,0%
Head-on collision	30%	67%	5,2%	11,9%
Neither A-11, nor A-12 is applicable	7%	7%	1,2%	1,2%
Overtaking	0%	0%	0,0%	0,0%
Rear-end collision	2%	4%	0,3%	0,7%
Side collision	1%	2%	0,2%	0,4%
Sample size	368		2.085	

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Table 14. Occupant fatalities in passenger cars with registration year 2000 and later by crash type, C2C, rural, at junction; LB is the lower bound; UB is the upper bound

	C2C Rural, at junction, LB*	C2C Rural, at junction, UB*	% of target population, LB	% of target population, UB
Crossing or turning, different roads	3%	38%	0,2%	3,2%
Crossing or turning, opposite direction	1%	8%	0,0%	0,6%
Crossing or turning, same direction	1%	8%	0,0%	0,6%
Entering traffic	1%	1%	0,0%	0,1%
Head-on collision	4%	10%	0,4%	0,9%
Neither A-11, nor A-12 is applicable	6%	6%	0,5%	0,5%
Overtaking	0%	0%	0,0%	0,0%
Rear-end collision	2%	4%	0,1%	0,3%
Side collision	11%	26%	1,0%	2,2%
Sample size	178		2.085	

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Table 15. Occupant fatalities in passenger cars with registration year 2000 and later by crash type, C2HGV, at junction, Rural; LB is the lower bound; UB is the upper bound

	C2HGV Rural, at junction, LB*	C2HGV Rural, at junction, UB*	% of target population, LB	% of target population, UB
Crossing or turning, different roads	2%	31%	0,1%	1,2%
Crossing or turning, opposite direction	0%	0%	0,0%	0,0%
Crossing or turning, same direction	1%	15%	0,0%	0,6%
Entering traffic	0%	0%	0,0%	0,0%
Head-on collision	5%	10%	0,2%	0,4%
Neither A-11, nor A-12 is applicable	10%	10%	0,4%	0,4%
Overtaking	0%	0%	0,0%	0,0%
Rear-end collision	2%	5%	0,1%	0,2%
Side collision	13%	29%	0,5%	1,1%
Sample size	83		2.085	

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Appendix B: Excel Template Literature Review

Table 16: Excel template for LR. Blue lettering corresponds to action item in Excel

Bibliographical information	
Number	Document number in the bibliographical database
Title	Title of publication
Author(s)	Author(s) of the document
Year	Publication year
Document type	Document type: Scientific article, PhD thesis, conference paper, project report etc. *Click the cell and you can see the drop-down list on the rights side of the cell.*
Publication source	Conference/ Journal name
URL link to paper	*Only when available*
Study information	
Abstract	Main objective(s)
	Main results
	Short summary *Including method, etc*
	Keywords relevant to SAFE-UP WP4
Spatial scope	Spatial scope: Local, national, European, international etc. *Click the cell on the right and you can see the drop-down list on the right side of the cell.*
	Countries, *please specify*
Approach, *please select all relevant*	Theoretical/Bibliographical
	Expert assessment (estimation without data or modelling)

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	(Experiment) data analysis	
	Accident record analysis	
	Simulation (micro, macro), *please specify*	
	Other modelling (system dynamics, etc.), *please specify*	
	Other, *please specify*	
Data source, *please select all relevant*	Expert assumptions, *please specify*	
	Literature, *please specify*	
	Simulator study, *please specify*	
	Wizard of Oz vehicles, *please specify*	
	Real test vehicles on test track, *please specify*	
	Real test vehicles on open roads, *please specify*	
	Road accident data, *please specify*	
	Other, *please specify*	
Sample	Sample of study (e.g. number and type of test vehicles and subjects) and details where available	
Investigated variables		
Variables of Interest inside WP4, *please select all relevant*	Occupant Monitoring, *please specify*	
	Occupant Monitoring Technology, *please specify*	
	Occupant Use Cases, *please specify*	
	Crash Configurations, *please specify*	
	Individual Human Variations, please specify	
	Other, *please specify*	
	Passenger cars (incl. taxis)	

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Type of vehicle, *please select all relevant*	Shuttles/vans	
	Trucks and/or buses	
	Other, *please specify*	
Studied Operational Design Domain, *please select all relevant*	Highway	
	Urban	
	Rural	
	Other, *please specify*	
Vehicle driver, *please select all relevant*	Automated	
	Manual with ADAS	
	Manual without ADAS	
	Non applicable	
Studied occupant, *please select all relevant*	Driver position	
	Front passenger	
	Rear row occupants	
	Non applicable	
Occupant Monitoring	Activities affecting the seating posture	
	Accessories	
	Type of clothing	
	Object	
	Skin tone	
	Interior design	
	Other, *please specify*	
Occupant Monitoring Technology	Acquisition hardware	

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	Processing hardware	
	Synchronization	
	Other, *please specify*	
Occupant Use Cases	Seating configuration	
	Interior features	
	Seat position	
	Sitting Posture	
	Activity	
	Other, *please specify*	
Crash Configurations	Crash scenario (indicating initial directions)	
	Overall crash configuration (e.g. front-to-side)	
	CDC codes available	
	Detailed geometrical description (e.g. impact point, impact angle, ΔV)	
	Other, *please specify*	
Individual Human Variations - Spectra of Anthropometries across Europe	Gender	
	Age	
	Weight	
	Height	
	Other, *please specify*	

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Appendix C: Occupant Monitoring Literature Review

1. Introduction

In SAFE-UP WP4, a major focus will lie on monitoring of occupants for the benefit of occupant protection systems. The usage of current occupant monitoring systems in vehicles varies though. In general, they are used to observe the driver, other occupants and objects. As a result, the data could be used to deploy and adjust the restraint systems e.g. by changing the deployment of an airbag or the belt force and thus help to reduce the injury risk for passengers in a crash. Most hardware systems use non-intrusive vision-based technologies. Besides the detection hardware, the processing algorithms of such occupant monitoring systems are essential to interpret the achieved data. Hence, processing algorithms for airbag deployment were also part of the literature review. Those algorithms can classify the occupants or decide whether the occupant is in a position and posture for a safe airbag deployment with low injury risk. The classification through these algorithms may be used by the airbag control unit and the corresponding restraint triggering algorithm for an adapted airbag deployment.

2. Method

A methodology was developed in order to approach the literature. First, main focuses of the literature research were defined, which are listed below and explained in detail:

Occupant Monitoring Systems in vehicles: Current research on monitoring systems in vehicles mainly focuses on the vehicle's surroundings, since automated driving is a very dynamic field at the moment. Hence, the literature needed to be limited to occupant monitoring systems alone, bearing in mind that technologies for other purposes e.g. surrounding monitoring, traffic monitoring, motion capturing or surveillance systems also have further potential to be adapted for occupant monitoring.

Systems for passenger cars with focus only on the passenger compartment: The field of occupant monitoring systems in vehicles also includes buses, shuttles, trains, trams etc. Those systems are mostly used for surveillance purposes and have no potential to be adapted for occupant protection purposes. Therefore, the focus was set on passenger cars only and concentrating on the passenger compartment. This was necessary in order to exclude systems which use, for instance, driving input via the steering wheel or pedals. This data does not allow the determination of occupant position or posture, and therefore is not relevant for the scope of this work.

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Real-world test, laboratory test and simulation studies: Since SAFE-UP will realise monitoring systems for the use of occupant protection, it was seen as beneficial to look into research work done by real-world testing of these systems. Thus, it was possible to find limitations for hardware definition and algorithm development. In addition, relevant patents were added to the literature review since they describe viable technologies. Laboratory tests are interesting, but most likely show limitations when it comes to usability in real-world environments. CAE simulation studies are mainly used to define prediction algorithms for injury risks. Since SAFE-UP will address similar challenges, these studies were considered of high relevance.

Software and algorithms: Different studies and patents explicitly investigate software and algorithms to be used in occupant monitoring and protection systems. Since similar solutions might be evaluated in SAFE-UP, those sources were very relevant, especially for gaining knowledge about possible limitations.

These main priorities were used to gather sources with relevant content in German and English. Furthermore, a considerable time period (2000–now) was determined. The methodical approach of gathering literature is shown in Figure 20.

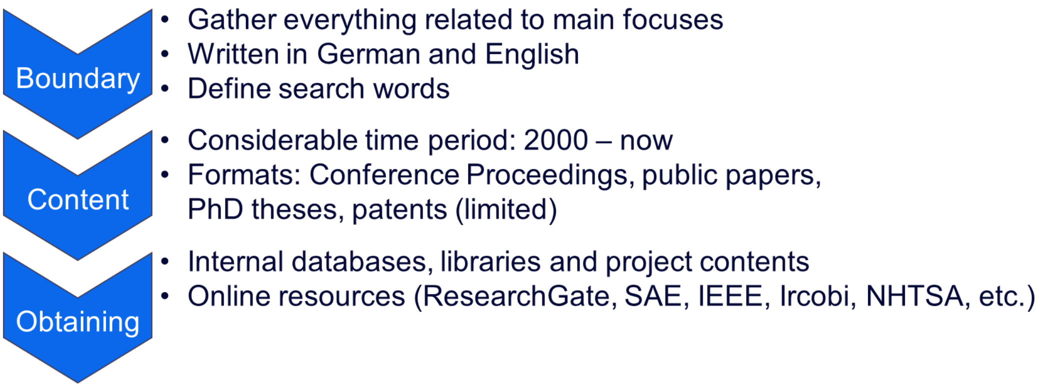

Figure 20. Methodical approach for gathering sources considering the main focuses

Since the research topics of the sources were still very diverse, it was necessary to identify the most relevant literature for the SAFE-UP project. Therefore, the findings were examined and included or excluded from the further evaluation by the use of two criteria. The selection process is illustrated in Figure 21.

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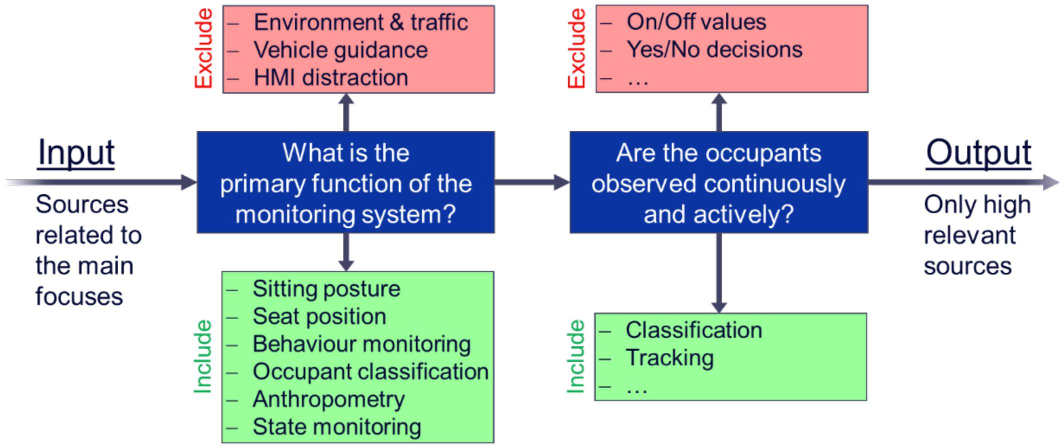

Figure 21. Process of including/excluding sources for further examination

Further technically detailed investigations are done using the SAFE-UP T4.1 focused research questions documented in section 4.3 of the deliverable.

3. Results

Considering the main focuses of the literature review described in section 2 of Appendix D, more than 150 sources were found. The objectives of the sources showed a wide variation and thus are not always relevant for SAFE-UP. With the two criteria it was possible to narrow down the literature to 50 highly relevant sources. After that, the literature was classified into the following categories regarding the described primary function: *Sitting Posture*, *Seat Position*, *Behaviour Monitoring*, *Occupant Classification*, *Anthropometry* and *State Monitoring*. This classification was advantageous, since the main focusses described in section 2 of this Appendix were not specific enough for classification and the SAFE-UP related research questions evaluate certain system properties which made it challenging to clearly identify and separate the main purpose of the analysed systems. The main discussion and assessment of the findings is done in the deliverable and can be found in section 4.3, section 6 and section 7. The following descriptions in section 3 of this Appendix give deeper insights in all highly relevant sources and serve as additional information to the evaluation done in the main deliverable.

3.1 Sitting posture

Sitting posture describes the way in which an occupant sits in the seat. Since the passenger might change his/her posture unforeseeably it is possible that he/she is in an unfavourable position in case of a crash with regards to the occupant restraint systems. Thus, monitoring of the sitting posture might be beneficial to adapt the restraint system strategy.

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The system by Owechko et al. used a pair of vision sensors placed near the rear-view mirrors and created a classifier to categorise different classes of positions of the occupant. If the occupant was detected too close to the airbag, a vision fusion engine decided whether to deploy the airbag or not (25).

Another vision-based system which detected the position of the occupant was introduced by Hannan et al. This system used weight sensing to classify the occupant into adult, child, non-human object or empty seat and fused all information with vehicle crash information for airbag deployment decision (27).

A similar system was developed by Farmer et al. The system was divided into two parts: classification processing and track processing. The classification processing included static segmentation, feature extraction and an occupant classifier. It was updated every 5 seconds with the use of the input image. The track processing included motion segmentation, ellipse fit and a head/torso tracker and predictor. Thus, every 1/40 of a second an automatic suppression zone (ASZ) intrusion flag was created. The airbag was suppressed if the classifier detected a child or if the occupant was in the ASZ (34).

The occupant position classification method by Jang et al. consisted of a pair of CCD cameras mounted on the rear-view mirror. With the use of a SVM classifier the occupant was classified in- or out-of-position. In case of in-position the airbag was deployed normally. The system required two digital signal processors, one for the stereo matching algorithm and one for the SVM classification calculation (26).

A patent on monitoring the cabin of a vehicle by Bosch described a method to detect occupants inside a vehicle with a connection to different restraint systems such as airbags or seat belts. Therefore, a first sensor was connected with a camera behind the seat. The camera detected a passenger on the seat including his head position and sent signals to a control unit. The control unit was connected to an airbag control unit which received signals from velocity sensors, environment sensors and other occupant sensors. The airbag control unit controlled the restraint systems. In order to detect occupants even in bad lighting situations infrared (IR) lighting was used (28).

Another patent was developed by Breed Automotive Tech and the University of South Florida. Image data with depth information was created with the use of a plenoptic camera. The cabin was separated into a first and a second partial region of deploying the airbag module. On the basis of the depth information, an evaluation device determined whether an object or an occupant was located in the first or second partial region. A control apparatus controlled the airbag deployment depending on the location of the object or occupant. The airbag was deployed if the occupant was located in the first partial region and partially in the second region. Depending on the size of the occupant, the control apparatus did not deploy or just partially deployed the airbag module (35).

A system developed by Untaroiu et al. implemented two different restraint systems and compared injury costs, in economic terms: the first was a restraint system with a catalogue controller and the second was a restraint system with a nominal restraint law. Each

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occupant's space was divided into a grid of nine posture classes. The posture classes were defined by the head position i.e. in-position, out-of-position, critically-out-of-position e.g. with head/legs on dashboard. A Bayesian approach was used to assign a restraint law to each posture class. Parametric (LDC, QDC) and non-parametric (SVM, PARZ, NN) supervised learning classifiers were tested. (24).

The system by Trivedi et al. used testbeds and a vehicle which were equipped with three different types of cameras and evaluated with a basic edge-based algorithm. The stereo and LWIR methods were tested and compared in head tracking on a frame-by-frame basis. Then the occupant was given different tasks (occupant positioning) to check the head detection of both methods. To evaluate the robustness, hand motion and object tests were run. Correct head detection and whether the occupant is in-position, out-of-position or critically-out-of-position lead to the task of airbag deployment by using distance measuring between occupant and the camera. However, it was discussed that the posture detection algorithms were not ready for commercial use yet (29).

A further system was based on a high-speed CMOS camera together with a light striping technique. The system was able to evaluate the height and position of the occupant through infrared light striping technology. The contours of the occupant created a line which could be interpreted via a logic. The position of the occupant was divided into different zones: a keep-out-zone around the airbag where the airbag was enabled, an out-of-position zone (depowered-firing-zone) and zones to detect the occupancy status of a seat (36).

The system by Kumar et al. separated between sitting in a normal position and leaning to the side or forward and backward. In order to monitor the sitting posture of an occupant, a prototype sensor mat was used. The system consisted of a capacitive-sensing mat that was embedded with copper foils, a capacitive signal processing unit, a computer to generate capacitive-sensing images (CSI) and image processing for posture detection. The sensing mat detected "touch-nodes" and created CSIs with 10x11 pixels. The sensor was only tested in prototype phase on a static seat under laboratory conditions (32).

The paper by Cheng and Trivedi examined the feasibility of a four-camera setup to describe the passenger seat and body modelling with voxel reconstructions. The method proposed a shape-from-silhouette based system that monitors the posture of the occupant. The location of the body parts was estimated and monitored with voxel reconstruction of the occupant's body. The head was tracked with an implemented Kalman filter. The driver was asked to get into six different poses and each of them is captured with 50 frames. The average difference between the estimated head position and the ground-truth was 10,7 cm. In 300 frames 6,33 % resulted in a head detection error. Experiments demonstrated an estimation accuracy of 7,55 cm from ground-truth for head positions (30).

Zhao et al. used a Microsoft Kinect sensor which created a skeleton of the occupant with 10 body parts for the occupant posture monitoring system. The database was constructed with a 14-infared camera Vicon system where the occupant was captured in primary and secondary driving tasks. With a k-NN algorithm the Microsoft Kinect sensor detects the body

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parts of the occupant. A prediction of the occupant's posture is delivered by a Kalman filter, which consists of a corrector and a predictor (33).

The German Research Center for Artificial Intelligence (DFKI) developed a test platform for monitoring systems of the vehicle cabin with 2D or 3D camera systems called SVIRO. It was used to analyse occupancy detection and classification, driver recognition and object detection functions. The AutoPose dataset was used to analyse the head pose and eye gaze with an IR camera at the driver's dashboard (37), (38).

Park et al. proposed a 3D head tracking system using a Microsoft Kinect camera to create a 3D head scan of the occupant with OpenPose. The system detected five facial key points from a 2D image and converted these into 3D coordinates with depth information from IR images. It was explained that the system performed better than previous systems regarding correct tracking of the head (31).

Kirscht et al. observed the driver's posture during driving manoeuvres to analyse the kinematic behaviour of the driver and the front passengers in pre-crash scenarios. The change in posture and motion of front seat passengers in several manoeuvres such as braking with different acceleration levels and lane change with different amplitudes were assessed using a fixed track with defined scenarios. The occupant's change of posture resulting from the pre-impact manoeuvres are important input parameters for occupant protection measures. It was filmed from several perspectives and the movement was tracked (22).

3.2 Seat position

The seat position takes the adjustability of the seat into account, including seatback angle and seat pan tilt. However, in most cases there was a strong connection between seat position and sitting posture.

Concerning the seat position, Yang et al. studied the injury risk of an occupant with different statures from short to tall and different seating positions from sitting forward or backward by simulation. In the defined use case, a THUMS model was used in a 30 km/h frontal crash. The injury risk was classified into separate body parts i.e. neck (NIC), thorax, femur. Skull fracture and brain injuries were characterised by the head injury criterion (HIC) / brain injury criterion (BrIC). The result indicated low injury risks of skull and femur fracture. Between two different occupants with variation in statures, sitting postures and BMIs injury risks were estimated (40).

Forster and Zittlau stated that the most promising sensor technology for occupant monitoring is a 3D camera based on ambient light-independent IR technology. It provides a greyscale image in addition to the information of distance between objects. Therefore, machine learning can be used to train an algorithm by feeding with image data. The technologies can be used to monitor for example objects, occupant classification, child seats, seat position, seat configuration, occupant position and seatbelt usage. This should allow the system to decide

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about the airbag deployment in the future. This could be done via a safety domain control unit which uses fused data of an interior and exterior control unit to control the elements of a restraint system (42).

A patent by Subaru Corp. included the use of a light projector, an imaging device and a processor which is configured to capture an image of the occupant in case of a predicted or detected collision. The algorithm used the image data to change the performance of the restraint systems of the vehicle (41).

3.3 Behaviour Monitoring

Behaviour monitoring addresses the tracking of the occupant during the driving tasks. Different studies proposed systems to analyse the driver's activities or the driver's posture during driving manoeuvres. Thus, the boundaries of behaviour monitoring and posture monitoring are fluid. It is important to note that, although all the sources reviewed below focused on the driver, these technologies can also be applicable to other seating positions.

The aim of a study by Cheng et al. was to monitor the driver's behaviour during driving manoeuvres with the use of a video-based system for head and hand tracking. Therefore, a system based on head images and hand LWIR images was used. The driver's activities were limited by "go-forward", "turn left" and "turn right" and were analysed through the movements of the head and the two hands during the manoeuvre. The results were the basis for classification with the Hidden Markov model (HMM). The HMM was built to recognize the driver activity patterns (44).

The system of Veeraraghavan et al. used skin colour detection to monitor the occupant's movements. If the skin colour was detected, the changes in behaviour were then observed. The change in the binary skin tone masks indicated the need to start recording an action model. The activity was monitored through evaluating each image with a set of training images for each activity. Activities were classified into safe and unsafe driving behaviour. Activities with almost equal probabilities for both classes, were rejected and not classified as belonging to either class (43).

Different studies analysed systems that evaluate driving and non-driving tasks such as smoking, eating, interacting with a mobile phone, etc.

In order to monitor the non-driving tasks of a driver of an automated driving vehicle, a head movement monitoring system based on twin orientation sensors was used by Zhao et al. For face detection, two methods were used: Dlib, a machine learning toolkit, and Pixel Intensity Comparisons Organised. As a result, a 3D model could be built out of the points of the region of interest using a 3D projection. The investigation was done under laboratory conditions as well as in real-world testing (49).

Yan et al. investigated a recognition system which worked in three steps: unsupervised pre-train the network with unlabelled data, fine-tune the network with four classes of labelled data and the usage of the network to extract features from input for classification. The pre-leaned

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filters were used to detect the edge, point and junction information of the driver. In the study, four different driving poses were examined such as driving, gear shifting, eating/smoking or responding to a cell phone (46).

Another system of Yan et al. also worked with three classification steps for classifying the driver's behaviour into shifting gear and not shifting gear related tasks. The proposed method for posture recognition consisted of pre-processing for illumination variation, action segmentation, feature representation and hierarchal classification. The driver tasks were separated into eight different tasks, for example interacting with head or the dashboard, shifting gear, etc. With action clips from the original video, motion frequency images were created. Classification took place in the following three steps. Level one classification consisted of a support vector machine (SVM) classifier which decided whether it was a shift gear related or non-related task. The level two classifier consisted of a random forest classifier which was trained to separate between only shifting gear tasks and not only shifting gear tasks. The level three classification defined three subclasses of not only shift gear classes. The approach was based on a dataset created under laboratory conditions by the Southeast University (45).

The system introduced by Martin et al. monitored the driver's behaviour through head and upper body pose tracking in order to build up a dataset. The dataset was collected using two types of cameras which determined the 3D upper body pose. The dataset consisted of 83 activities on three levels based on a complexity and duration hierarchy. The first level consisted of 12 tasks, the second level of 34 fine-grained activities and the third of atomic action units with 372 possible combinations of the action, object and location triplets. The dataset was created under laboratory conditions but in a real vehicle (60).

Motivated by the performance of convolutional neural networks (CNN) in computer vision, Baheti et al. developed a VGG-16 architecture for detecting distracted drivers. It implemented various regularization techniques in order to improve the performance. The method was used to detect the distraction of the driver in case of activities that are not related to the driving task. Different classes of tasks were run through the network, for instance, texting with both hands, drinking, talking or reaching behind. The paper presented a robust CNN based system. Experimental results showed that the system outperformed earlier methods from literature, achieving a high accuracy of 96,31 % and processing 42 images per second on GPU. Furthermore, a modified version of the architecture with a significant reduction of parameters was tested and showed only minor loss in accuracy (47).

3.4 Occupant Classification

Monitoring for occupant classification is mostly limited to detection of occupancy and categorisation of the occupant into classes. In many cases, a differentiation between objects, children and adults was done. The classification was used for airbag deployment decisions and mainly related to the current statutory requirement FMVSS 208, which demands for low risk deployment. Some systems included further applications e.g. posture monitoring.

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A study by Fritzsche et al. used a 3D-optical time-of-flight (TOF) sensor which used a LED light beam to detect objects or occupants. The reflection of the light beam was detected by a receiver. With the use of a Kalman filter, first the head-like regions were found, then key points and coordinates were extracted. The different occupant classes were forward-facing or rear-facing child seats (FFIS, RFIS), adults and empty seats. It was mentioned that the most common error of the classification was caused between adults and FFIS (53).

The patent by Aerojet General Co. described a method to combine the inputs of an infrared sensor and an ultrasonic sensor in a microprocessor circuit to produce a merged output signal for the airbag controller. The inputs were the classification of the occupant into human occupant, empty seat, RFIS and FFIS, animal, packages, etc. The airbag was either enabled or disabled accordingly. Every input from one sensor required to be compared with all other sensors of the system. The system detected an out-of-position scenario and decided about the airbag deployment if the passenger was too close to the airbag (57).

The system from Farmer et al. was developed to classify between four different classes of occupants: RFIS, child, adult and empty seat. The system contained a single monochrome digital CMOS camera with a wide field of view lens, a bank of infrared LED illuminators, a digital signal processor and a control microprocessor. After the segmentation of the inside, shape features were extracted from the resultant region of interest. For lower lighting conditions silhouette features were considered, for good lighting edge-based features were evaluated. The classifier used four different nearest neighbour (NN) classifiers on the basis of traditional k-NN and distance-based k-NN classifier. The overall accuracy of the classification system was claimed to be better than 95 %. The classification system should be used for airbag suppression and was installed in a vehicle. Testing took place indoors and outdoors but without vehicle movement (50).

The occupant vision detection system by Gao and Duan used a CMOS camera and a pattern recognition algorithm. The system classified into 50th percentile adult male, 5th percentile adult female, 50th percentile six-year-old child and empty seat. The algorithm consisted of three parts: generation of measurement space based on image edge detection, occupant feature space extraction and occupant class space partition with an SVM. First the original colour image was transformed into a greyscale image, then the region of interest was determined and filtered (51).

Jang et al. used a pair of stereo-cameras to classify the occupants into the different classes: 5th percentile female, six-year-old child, infant seat and empty seat. By using a fast sum of the absolute difference, a disparity map was created and a down-sampled image was used as an input for the SVM classifier. First the classifier separated between child and female as first class, infant seat as second class and empty seat as third class. In the second step the first-class case was classified between 5th percentile female and six-year-old child. The system deployed the airbag if the occupant was classified as a female. For the pose recognition system, the passenger area was divided into seven different areas. The occupant's head position was extracted by a head contour model. The occupant classification system showed a correction rate of 91,47 % by using the SVM classifier. A success case was counted if one of the two algorithms recognized the occupant's head (54).

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Another system that combined occupant classification and position sensing was provided by Freienstein et al. The 3D video module was mounted in the roof module of the vehicle and gave an input to the electronic control unit which created a cloud of 3D points from the grey-level stereo images. The occupants were then classified into empty seat, one year-old child or adult with the comparison of the measured 3D points to a 3D model database. For out-of-position monitoring the occupant's head was detected based on 3D dots (55).

Hussain et al. proposed a decision algorithm for airbag deployment on the base of the occupancy status of each seat and the measured distance between occupant and airbag. The occupant decision module was activated if the occupancy was detected. On the basis of the occupant's weight the module decided whether the occupant was an adult or a child. The deployment decision of the airbag relied on the safe distance decision module. If the distance between airbag and occupant was lower than a minimum safe distance the airbag was not deploy (56).

In the study by Perrett and Mirmehdi a fisheye camera was used to detect which type of occupant was sitting in the different seats in a vehicle. Four classifications were made: empty seat, adult, small child or large child. In addition, there were three weighted classification accuracy matrices: occupant detection, child locks and airbag suppression. For occupancy detection, a histogram of oriented gradients features was used. In every weighted classification the proposed method had the highest accuracy for every seat that was evaluated (52).

Da Cruz et al. created a synthetic vehicle interior rear seat occupancy dataset and benchmark (SVIRO). To create 3D models, a Microsoft Kinect camera and an Artec Eva structured light scanner were used. For each scenery randomly generated passengers were used. For each car 5000 test sceneries were created. For the synthetic images an active red lamp was placed next to a camera inside the car illuminating the rear seat. Then for each scenery a RGB image without an active red lamp, a greyscale image, an instance segmentation map, bounding boxes, key points and a depth map were created. To classify the object/occupant into seven different classes a rectangular greyscale image was used and trained a single classifier for each seat. Different deep learning methods were used and compared to a SVM (37).

A patent by Bosch used stereo-based cameras with a minimum of one optical sensor to detect the occupancy status of the vehicle. Throughout the detected scene a depth map was created and divided into different parts of the vehicle cabin. With triangulation methods the distance between image object and reference object for example an airbag could be measured. Due to various lighting situations one optic sensor had a converter curve between light intensity and electrical output signal (58).

3.5 Anthropometry

Only a few sources have been found mentioning monitoring of anthropometric variations. In most cases vision-based approaches were taken. Nevertheless, detecting anthropometric properties might also be beneficial for the use of adjusting restraint strategies. Since human

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variations will be investigated in SAFE-UP, monitoring anthropometry might also be advantageous to implement.

Chen et al. proposed a precise system to measure the seated height of an occupant. First the depth information data from a Microsoft Kinect sensor was used for major human body joints. Then face detection was performed to keep body frames with frontal faces only by the estimation of pitch and roll values. Haar-cascade detectors were used for eye localisation to determine 2D coordinates on the RGB frames. With both, 2D and 3D coordinates the eye location was transferred into real-world 3D coordinates. Finally, the seating body height was estimated based on ergonomics data (59).

The model network by Yuen and Trivedi received a three-channel image as an input and modified it into eight-part confidence maps, eight affinity field maps and a background heat map. Each arm of the front passengers had two-part affinity field images linking the elbow to the wrist. For any of the eight key points a PCM image was generated. The results for the eight-part's localisation performance showed a detection rate of 95 %, where the results were within 5° of the ground-truth angle. Problems with the system were detected i.e. if one arm overlaid another (62).

Another patent described a vehicle occupant restraint system which adjusted the deployment of an airbag in accordance with vehicle occupant's height and/or projected trajectory. The height of an occupant could be measured directly by IR, electromagnetic or acoustic sensors, or indirectly by measuring vehicle occupant weight. The orientation of the airbag module could be adjusted by rotating the airbag module or by mounting the module on an adjustable platform. The platform could be adjusted by a piston that operates pneumatically, hydraulically, pyrotechnically or electrically (101).

A different way to monitor the anthropometry of an occupant was developed by Shiraishi et al. In order to measure the blood vessel age of occupants by a non-contact method, this paper proposed a method where the facial area is detected in the first step. Using this image data, the method predicted a facial age by deep learning from the facial image. Then an algorithm calculated the blood vessel age by measuring the blood pulse from facial colour fluctuation. The blood vessel age was estimated from both statuses of blood vessel and age parameters. The method compared the blood vessel age based on the actual age and based on the facial age of the occupants. As a result, 28 subjects showed a lower facial age than the actual age. It was resumed that the method did not work reliably and needs to be improved (63).

The review by Klier et al. compared different systems of occupant monitoring. Functions for OMS were identified through accident research, legal and consumer requirements tests. Several potential functions which are passenger presence detection (PPD), occupant classification and adaptation (OCA), occupant position detection and adaptation (PDA) and individual identification and adaptation (IIA) were discussed. The aim was to improve the restraint strategy by the use of more information about the occupant's variation. Furthermore, the study mapped different sensor technologies to the evaluated functions, such as a driver monitoring camera (DMC) and interior sensing device 1st and 2nd generation (ISD). A DMC

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could only be used for IIA and PDA on the driver seat. The ISD 1st generation includes the systems PDA, OCA and PPD for current regulations. In addition to these systems, the 2nd generation of ISD could be used for future functions and systems such as dynamic head position detection, especially in automated driving. In order to show the effectiveness and benefits of such systems, Klier et.al conducted simulations with a generic interior and Hybrid III dummies in Madymo (61).

3.6 State Monitoring

In most cases, research work for state monitoring was mostly done in terms of driver fatigue observation. Together with behaviour monitoring this is very relevant for L3 automated driving because of possible take-over requests for the driver. In order to observe the driver’s state, facial expressions were tracked through symptoms like eye closure, eyelid distance, blink speed, head movement, etc. in order to monitor driver distractions.

A review by Kang discussed different ways to evaluate the driver's state and drowsiness monitoring. Percentage of eyelid closure (PERCLOS), the percentage of total time that the driver's eyelid is closed 80 %, was discussed as a method with good performance. Therefore, the monitoring of the eye area including the pupil of a driver is necessary. Due to lighting conditions an IR illuminator with about 850 nm wavelength was claimed as advantageous. The review concluded that physiological signals (ECG, EEG, etc.) show better results detecting the driver's state or drowsiness than visual signals. Driver distraction was stated to be best detected through head pose and gaze direction (69).

Another review by Sigari et al. discussed driver face monitoring systems as one of the main approaches for driver fatigue or distraction detection and accident prevention. Driver face monitoring systems capture the images from driver face and extract the symptoms of fatigue and distraction from eyes, mouth and head. These symptoms are usually PERCLOS, eyelid distance, eye blink rate, blink speed, gaze direction, eye saccadic movement, yawning, head nodding and head orientation. Furthermore, a comprehensive review on driver face monitoring systems for fatigue and distraction detection was presented. The method for fatigue and distraction detection is effective to achieve a robust system, but current driver face monitoring systems suffer from two main problems: precise detection and tracking of face and facial components and precise symptom extraction (64).

In the paper by Huynh et al., a 3D CNN to extract key features in terms of spatial and temporal domains was designed. To master the challenging task of accurate monitoring of facial behaviour such as eye closure, nodding and yawning, an approach based on recent machine learning techniques was purposed. First, a 3D CNN to extract features in spatial-temporal domain was used. Secondly, gradient boosting for drowsiness classification was applied. Thirdly, a semi-supervised learning was added for enhancing overall performance. The reliable face detection system was the most important component. It was also found that gradient boosting machine was very useful as a binary classifier in making a decision either drowsy or non-drowsy. In addition, it was possible to improve the performance of the whole system by using semi-supervised learning and transfer learning methods (65).

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Referring to a deep drowsiness detection , Park et al. proposed a network for learning effective features and detecting drowsiness by a given input image of a driver. Based on the proposed deep drowsiness detection network, competitive experimental results in terms of a drowsy driver detection video dataset could be provided. Due to the lack of previous benchmark performance on this dataset, a comparison with the performance of several well-known classification algorithms such as variants of CNN's was done. In this experiment the deep drowsiness detection for five different situations e.g. bare face, glasses, sunglasses, night-bare face and night-glasses, were tested. Experimental results show that the system achieves 73,06 % detection accuracy on deep drowsiness detection benchmark dataset (66).

Another method for drowsiness detection through a hierarchical temporal Deep Belief Network (DBN) was introduced in a publication by Weng et al. The scheme first extracted high-level facial and head feature representations and then used them to recognize drowsiness-related symptoms. Two continuous HMM's were constructed on top of the DBNs. These were used to model and capture the interactive relations between eyes, mouth and head motions. A large comprehensive dataset containing various ethnicities, genders, lighting conditions and driving scenarios was collected. Experimental results on various kinds of scenarios and fusion all together demonstrated the performance of the proposed framework in estimating the driver's drowsiness level (67).

Another drowsiness detection system was proposed by Yu et al. With the use of the driver drowsiness detection dataset from the National Tsuing Hua University, it exploited extra scene condition prediction for enhancing drowsiness detection. The framework consisted of 3D-DCNN, classification model, fusion model and detection model. It was stated that the framework was suitable to detect sleepiness of driver at various wearing and illumination conditions e.g. with and without glasses or sunglasses. Furthermore, the framework provided an automated and efficient feature learning which helped to classify the scene conditions and the drowsiness of driver. It was claimed that the framework achieved an average accuracy of 0,712. It was further observed that the detection results in night illumination categories with and without glasses were lower than in other categories (68).

The proposed monitoring system for automated vehicles by Rengesh et al. included the monitoring of the cabin and occupant's posture, the gaze (zone) of the driver, eye and mouth landmarks, the head pose, hand position and upper body pose using depth cameras, IR cameras and RGB cameras with different types of algorithms. The correlation between the observable situational awareness (OSA) and the gaze zones, distance to wheel, object held by driver, hand activity classes and joint locations from pose estimation was investigated. The monitoring system showed negative correlation e.g. in distance to wheel, hand activity class in air or a phone as an object in hand. Positive correlation regarding OSA was measured for hovering the wheel, no object in hand or looking at the right-side mirror (70).

The paper of Baker et al. proposed four different algorithms for head tracking using active appearance models (AAM). The first one was a 2D AAM which consisted of shape and appearance. The second was a real-time non-rigid 2D tracking with AAM algorithm, which tracked rigid motion of the head and the non-rigid motion of the mouth and eyes. The algorithm was extended with real-time non-rigid tracking with occlusion. The third algorithm

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was an extension from a 2D AAM to a 3D AAM, which then covered 3D head motion and the non-rigid motion of the face as a fourth solution (71).

3.7 Reviews

In addition to the previous proposed methods for occupant monitoring systems, two reviews have been found which evaluated various systems for different primary functions.

Kosiak et al. discussed the use of different sensing and monitoring applications for the benefit of behaviour monitoring and restraint systems. For example, they described a fluid-filled sensor mat to monitor the occupant's position through the pressure of the fluid. An occupant position and recognition system detected whether an occupant's head was out-of-position (OOP) and disabled the airbag then. If only the occupant's hands entered the OOP zone, the system allowed to deploy the airbag. Eye tracking was discussed in order to monitor the point of gaze of the driver (39).

The review by Wang et al. had the goal of presenting the SotA of driver posture monitoring systems and included 47 publications up to and including 2018. The systems were first categorised into vision-based and non-vision-based posture monitoring systems. The vision-based systems were then subcategorised into monocular camera-based systems, traditional stereovision systems, structured light depth cameras and time-of-flight (TOF) depth cameras. Considering these subcategories, every publication was evaluated regarding the sensor type, detection technique, objective, etc. The non-vision-based systems were subcategorised into force sensor arrays and proximity sensors. In conclusion, the review contained a comparison between the vision-based and non-vision-based sensor techniques and discussed their advantages and disadvantages. Finally, a substantial evaluation of research gaps and future research potential areas was given (72).

During the definition of the Use Cases for further investigation in SAFE-UP (see section 5), several specific issues regarding OMS have been discussed. Against this backdrop, more specific and technically detailed research questions were defined and answered by the sources. This enhances the understanding of the SotA and allows a more detailed and technology-focused excerption of information from the literature. This information will be useful for defining the OMS layout in Task 4.2 and Task 4.4. The research questions and answers are listed below.

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Question: How are the occupants monitored?

Answer	Sources
Infrared/Longwave Infrared	(29) (35) (38) (44) (48) (70)
CMOS camera	(36) (50) (51) (55)
Weight sensor/sensor mat	(39) (27) (32)
Stereo cameras	(29) (54)
Microsoft Kinect	(31) (33) (37) (48) (59)
Other	(26) (41) (49) (52) (53) (61)

Question: Which part of the occupant's body is monitored?

Answer	Sources
Head detection (for airbag deployment decision)	(28) (29) (30) (31) (34) (38) (44) (69)
Head detection for tracking	(45) (48) (49) (71)
Upper body	(22) (45) (46) (48)
Face	(31) (49) (59) (67) (71)
Eye (gaze)	(38) (45)
Eyelid, especially eyelid closure for driver distraction detection	(64) (65)
Hand detection and tracking (for behaviour monitoring	(44) (45)

Question: How are the occupants classified?

Answer	Sources
Rear facing infant seat, Forward facing infant seat, empty seat, adult	(25) (53) (57)
Rear facing infant seat, child, adult, empty seat	(50)
50th percentile adult male, 5th percentile adult female, child, empty seat	(51) (54)
Empty seat, (1-year-old) child, adult	(34) (55) (56)
Empty seat, small child, large child, adult	(52)
Empty seat, infant seat, child seat, adult, object, empty infant seat, empty child seat	(37)

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Question: In case of a direct link, how does the monitoring system interact with the restraint system?

Answer	Sources
No airbag deployment if an infant seat or a child is detected	(25) (34) (41) (50) (51) (52) (54) (56) (61)
No deployment if the occupant is too close to the airbag (leaning forward)	(39) (24) (26) (27) (28) (29) (32) (35) (36) (42)

Question: Which processing algorithms are integrated into the system and how are they applied?

Answer	Sources
K-nearest-neighbour	(33) (34) (50)
Support Vector Machine	(26) (34) (45) (51) (52) (54)
Kalman filter	(30) (53)
OpenPose, AutoPose, OpenFace	(31) (38) (48)
Convolutional Neuronal Network	(45) (47) (65) (68)
Other	(24) (25) (28) (32) (37) (42) (44) (49) (55) (56) (57) (58) (62) (63) (66) (67) (69) (71)

Question: Is there a direct relation to the topic automated driving?

Answer	Sources
Yes: awareness, behaviour/activity, seat position	(37) (42) (48) (49) (62) (70) (61)

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Appendix D: Occupant Restraint System Literature Review

1. Introduction

The new vehicle interior configurations that are being considered for future AVs pose a big challenge for vehicle manufacturers from an occupant protection point of view. Linkenbach, et al. (102) made a study in which the benefits of autonomous vehicles and also the future challenges related to them were analysed. Seats in comfort position or even swivel seats, for instance, will mean that there is in fact no more defined position, and therefore, also no more “Out-of-Position” (OoP).

This appendix complements the information that has been detailed in Section 4.4 in order to understand the effect of AVs on the occupant restraint system and how these parameters affect the use cases that have been defined in Task 4.1 and reported in this deliverable.

2. Results

The results of the occupant restraint system literature review research to be discussed in this appendix are divided according to their main focus topics; namely: crash configuration, anthropometry, activities, posture and comfort, motion sickness, biomechanics and restraint system performance, interior vehicle configurations and interior vehicle concept .

2.1 Crash configuration

As stated in Section 3, collaborative work between T4.1 and T2.1 has been done in order to define the future crash configurations that AVs will face in mixed traffic scenarios in highway and peri-urban environments. This section summarizes the results from publications that have been found regarding this topic, as a complement to the work described in section 3.

On one hand, Östling et al. (48) published data regarding passenger vehicle to passenger vehicle accidents and single passenger vehicle accidents extracted from the US National Automotive Sampling System Crashworthiness Data System (NASS CDS). This was collected in order to create a data definition of ADAS rulesets, a verification of the ADAS rulesets to make an accident description and the analysis of the deformation pattern of the accidents that would remain when ADAS avoided or mitigated some of the crashes. Following this method, it was possible to conclude that the use of ADAS can reduce the number of passenger vehicle accidents impressively.

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The aim of the previously mentioned paper (48) was to identify several crash configurations to be studied in the future. After applying ADAS technologies, 15 in total; to modern passenger vehicles, accidents with severe injury outcome (almost 90% of the remaining accidents) were divided into four accident types: head-on, turn across path, turn into path opposite direction and straight crossing paths. The latter three are intersection accidents and represent as much as three quarters of all remaining accidents. In this paper, it was shown that when ADAS technologies are implemented fleet-wide, future C2C accidents are predicted to be dominated by intersection crashes.

Crash configurations in C2C crashes were predicted in order to guide the development of future passenger car safety. Five load cases for the development and evaluation of future occupant restraint systems were identified during another study made by Östling et al. (103) presented in 2019 at the IRCOBI conference. The impact angle, delta velocity (Δv), occupant position and possible variations for these five load cases may be found in Table 17.

Table 17. Five load cases to be used as a basis in the future assessment of occupant safety and possible variations to each load case. (103)

Crash configuration	Impact angle	Delta velocity	Occupant position	Variations	
Frontal Oblique Far Side	60 degrees	26 km/h	Occupant in the driver's seat	Impact angles between 30 and 90 degrees	Δv between 16 and 26 km/h
Frontal Oblique Near-Side	30 degrees	44 km/h	Occupant in the driver's seat	Impact angles between -30 and -60 degrees	Δv between 29 and 44 km/h
Side Near-Side, impact forward of compartment,	90 degrees	22 km/h	Occupant in the driver's seat	Impact to either left (driver) or right (passenger) side, impact angles between -90 and -120 degrees	Δv between 8 and 22 km/h
Side Far-Side, impact forward of compartment	90 degrees	44 km/h	Occupant in the driver's seat	-	Δv between 23 and 44 km/h
Side Near-Side, impact	60 degrees	29 km/h	Occupant in the passenger seat	Include impact to either left (driver) or right	Δv between

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of compartment				(passenger) side, impact angles between 60 and 90 degrees	12 and 37 km/h

2.2 European adult anthropometric data

The aim for this part of the literature review is to be able to define the anthropometry limits to be used as a target for the Occupant Monitoring System.

As explained in Section 4.4.1 the height and weight ranges that have been chosen as preliminary limits for the OMS detection have been defined (see Table 18)

Table 18. Height and weight ranges representing 90% of the adult human population

Gender	Height range (cm)	Weight Range (kg)
Male	164,1 -186,9	60,1 – 104.2
Female	151,4 -172,5	49,3 – 91.7

In order to validate that the choice of these ranges was complete and represented the overall EU population, this was cross-checked with available data from individual countries (such as Belgium (73), Germany (104) and Spain (105). Additionally, several sources showing mean heights and weights of the adult population across Europe or by regions were also reviewed (106), (107) In addition, some worldwide data for adult height distributions was also found (79). These sources confirm that the selected height and weight ranges shown above are representative of the European population and can be used as a baseline target for WP4's OMS detection capabilities.

2.3 Activities

This section concentrates on detailing the activities that occupants are likely to carry out in AVs. Although this topic is discussed extensively in Section 4.4.2, the extended results from the studies mentioned in Section 4.4.2 have been summarized in Table 7.This table makes it possible to easily compare the preferred activities resulting from each of the studied publications.

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Table 19. Summary of literature review studies on activities in AVs

Author	Type of study	Method	Target population	Prio 1	Prio 2	Prio 3	Prio 4	Prio 5	Prio 6	Prio 7	Prio 8
Auto insurance (2017) (82)	Survey	Asking question: What would you do in an autonomous vehicle?	U.S.	Reading	Catching up with friends via phone	Working	Watching Tv	Watching movies	Eating	Playing video games	Sleeping
Schoettle and Sivak 2017 (84), Bengtsson (86)	Survey	Activities people would do in an autonomous car for 2 hours	China	Working/ Studying (83%)	Surfing the web (83%)	Eating (66%)	Sleep/ Relax (66%)	Productive home activities (66%)	Listening to music (50%)	Playing music (33%)	Reading (33%)
Reed et al. 2020. UMTRI. (108)	Study passenger behaviour in current vehicles	75 cameras installed on participant's vehicles	U.S.	Talking (46%)	Phone (26,4%)	Nothing (25,9%)	Other (5,7%)	Food (3,2%)	Resting (2,2%)	Drink (1,6%)	-
Köhler et al. 2019 (80)	Study	Living room configuration was simulated	Germany Peers-Business	Talking to others (100%)	-	-	-	-	-	-	-

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		by conducting tests with a modified vehicle.	- Active in group								
			Peers-Leisure-Active in group	Playing table games (100%)	-	-	-	-	-	-	-
			Peers-Business-Active alone	Working and studying (91,43%)	Texting and social media (0,06%)	-	-	-	-	-	-
			Peers-Leisure-Active alone	Music and radio (40,2%)	Reading (27,18%)	Texting and social media (8,07%)	-	-	-	-	-
			Strangers-Business-Active alone	Music and radio (43,75%)	Reading (20,75%)	Work and studying (18,93%)	-	-	-	-	-
			Strangers-visual passive - by day	Music and radio (61,05%)	Doing nothing (18,8%)	Looking out of the	-	-	-	-	-

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						window (13,09%)					
			Strangers -visual passive- by night	Music and radio (68,99%)	Doing nothing (17,82%)	Sleeping (12,54%)	-	-	-	-	-
Sivak and Schoettle (93)*	Test and questions to the participants	Question: If you were to ride in a completely self-driving vehicle, what do you think you would use the extra time doing instead of driving?"*	U.S*.	Watch the road (23%)	Not ride in an AV (23%)	Reading (10,8%)	Text or talk with friend/family (9,8%)	Sleeping (6,8%)	Watching movies (6%)	Work (4,8%)	Play games (2%)
			China*	Watch the road (36,1%)	Text or talk with friend/family (20,8%)	Watching movies (11,3%)	Sleeping (10,8%)	Reading (10,5%)	Working(5,4%)	Not ride in an AV (3,1%)	Play games (1,3%)
			India*	Watch the road (30,7%)	Work (16,3%)	Text or talk with friend/family (15%)	Watching movies (12,3%)	Reading (10,2%)	Not ride in an AV (7,8%)	Sleeping (4,7%)	Play games (2,1%)
			Japan*	Watch the road (33,2%)	Not ride in an AV (33%)	Sleeping (12,6%)	Text or talk with friend/fa	Watching movies (6,2%)	Reading (5,6%)	Play games (1,2%)	Work (0,7%)

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							mily (7,4%)				
			UK*	Watch the road (44%)	Not ride in an AV (23%)	Reading (7,6%)	Sleeping (7,2%)	Text or talk with friend/fa mily (5,5%)	Work (4,9%)	Play games (2%)	Play games (1,9%)
			Australia *	Watch the road (43,4%)	Not ride in an AV (21,2%)	Text or talk with friend/fa mily (7,9%)	Sleeping (7,1%)	Reading (6,5%)	Watching movies (5,7%)	Work (5,1%)	Play games (2%)

*Note: The percentage of responses that answered “I would not ride in a self-driving vehicle” in this study have been omitted from this table and represent the missing percentage to reach a total of 100% of responses for each country.

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2.4 Posture and comfort

The activities that occupants are conducting in the vehicle can greatly affect their posture. For example, the posture when using a mobile phone or an electronic device is commonly associated with a downward pitched head. In the study conducted by Reed et al. (108), where 75 vehicles were equipped with cameras to observe the occupants during 2 weeks of their usual driving activities, the rotation of the head and torso to the left or to the right was present in about 10% of the time and the torso was pitched forward. The front of the thighs was lifted off the seat due to the feet being shifted rearward about 40% of the time and the legs were crossed in about 5% of frames. Resting behaviour was observed more frequently in longer-duration trips and when travelling at higher speeds, while phone use increased and talking with vehicle occupants decreased with increased sitting time.

On the other hand, Kilincsoy et al. made a study consisting of the digitalization of posture-based seat design developing car interiors by involving user demands and activities. (109) This paper identified the three typical postures for the automotive context: upright, standard, and relaxed.

The upright position was observed for activities such as eating, drinking, using a smart phone or working, the standard position represents the typical sitting posture for looking out of the window or being entertained, and finally the relaxed position is preferred for activities like relaxing, dozing and sleeping. In addition, Van Veen (110) showed that when using smart phones and tablets, special features in the interior are preferable to support the arms and prevent the neck bending while using these devices. Bhiwapurkar et al. (111)investigated use case scenarios of laptops on a table during train rides. As a result, typing was more difficult on a table than placed on the lap. When using larger electronic devices, the user’s trunk was in a slumped position. This is aligned with the research of Khan and Sundström (112) who proved that people put their books, writing materials, and portable computers on their laps during use to avoid the vibrations from the vehicle.

In addition, another paper was found in which automobile driver posture (72) was studied. In this paper, it was shown that during long trips, discomfort for drivers increased, often leading to lower back pain regardless of how good the car seat is. Previous studies (113) indicate that driver posture movement is a reliable indicator of discomfort. Meanwhile, drivers prefer to get distracted by doing activities to relieve discomfort, thereby increasing the risk of accident. Dynamically fitting the contouring of the seat to the individual and physical environment could help to maximize comfort. In addition, long term analysis of driver posture movement can provide useful insight into the crash and near crash events, can incorporate the ergonomic consideration on the vehicle interior design and may help explore inter-individual differences due to driver behaviour attributes.

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2.5 Motion sickness

Keeping the head down for so long during a trip or being rotated when the vehicle is moving could cause the passenger to suffer motion sickness. It was demonstrated in several studies that due to the wide variety of possibilities the passenger can undertake in AVs, occupants are very susceptible to have problems related to motion sickness. (114) (115)

A study made by researchers at the University of Michigan's Transportation Research Institute (UMTRI) (114) revealed that some people are expected to experience motion sickness often, while others may actually feel sick every time they're riding in an autonomous vehicle. Moreover, it was indicated how several activities could affect the occupants' motion sickness. Watching the road and sleeping could have a positive effect to reduce motion sickness, while reading, texting, talking on the phone, watching media, working and playing games were identified as activities with negative influence on motion sickness.

Lin et al. (8) studied the contributing aspects that influence the impact of the critical factors for motion sickness. The only factors considered to improve the influence were having eyes closed or sleeping with a supine posture. Regarding vehicle features, this study demonstrated that smaller, opaque, or reduced-visibility windows, that could potentially be employed in AVs; increase the frequency and severity of motion sickness, but on the other hand, if AVs provide a smoother ride than conventional vehicles, the frequency and severity of motion sickness would decrease.

Schoettle et al. published a paper (115) in 2009 in which a study was made and consisted of a brief literature review of motion sickness and a paper-and pencil survey that focused on the frequency and severity of motion sickness of respondents' past experiences while viewing video in a moving vehicle. Also included in the survey were questions related to the frequency of installation of in-vehicle video technology, the physical aspects of the video display, and the frequency of viewing video while travelling in a vehicle. Completed paper-and-pencil surveys were obtained for 136 adults and 32 children.

The results indicate that viewing video is less often the cause of motion sickness than reading but when motion sickness is caused by watching a video, it is also less severe than that caused by reading. Therefore, motion sickness while viewing video is less likely to occur and less severe for children than for adults.

2.6 Biomechanics and restraint system performance

AVs could potentially change occupant behaviour while travelling and the vehicle's seat design. In order to study this topic, it is important to analyse the different seat orientations with respect to the vehicle, and increased seatback recline angles, which are some novel factors that may challenge occupant restraint systems currently available for vehicle manufacturers.

In 2018, Lin et al. presented a paper about this topic (8) and the effect of seatback recline on occupant model response in frontal crashes. This study evaluated the usability of the Global Human Body Model Consortium (GHBMC) owned 50^{th} percentile male occupant models in various reclined seating positions during frontal collisions. Three recline positions were evaluated: nominal-upright (25˚), semi-reclined (45˚) and fully reclined (60˚); in which occupant models were sat in the right front passenger seating position. Impacts were simulated with a Research Mobile Deformable Barrier (RMDB) in frontal crash with closing speed of 56 km/h. In order to accommodate the variations in seat reclined positions, both occupants were positioned starting with an equilibrated position achieved from a pre-simulation.

The results showed that reclining the seatback angle exaggerated the submarining, which resulted in pronounced posterior rotation and forward excursion of the pelvis with substantial lap belt intrusion into the abdomen. With the standard d-ring shoulder belt, the delay in torso engagement resulted in more forward excursion of the pelvis, this was partially mitigated using the seat integrated shoulder belt. However, the use of an integrated shoulder belt did not eliminate the submarining effect.

Jin et al. (116) analysed the influence of the seatbelt position and the restraint system in rotated seats. This publication discussed the concept of an active seat rotation strategy that changes seat orientation during the pre-collision time frame. The first part of the study evaluated the relatively safer seat orientations of 0º, 90º, 135º and 180º in a frontal collision load case.

The 0° seating orientation represents a forward-facing position where the shoulder belt restrained ribcage to top upper torso. In the 90º and 135º configurations, although the upper torso was successfully stopped by the seatbelt, the restraint was applied through the neck engaging with the belt, which led to a higher risk of suffering head and neck injuries. The excessive neck load due to that engagement will not occur in a conventional seating configuration. In the 180º (rear-facing) configuration, the occupant was stopped by the seatback while minimum head rotation was observed.

Simulation results indicate that the 180º seating configuration had the least injury risk among the four tested positions. In the second part of this study, pre-collision seat rotation was simulated. The aimed rotation angle was set at ±45º and ±90º. The seat was rotated within 200 ms of pre-collision time.

It was shown that the predicted injury criteria was lower in the ±45º rotation cases. Therefore, it could be seen that it was safe to rotate the seat 45º within the pre-collision time. In contrast, an increased neck ligament stretching and one rib fracture occurred in the ±90º rotation cases, indicating that the rotation velocity was too high, leading to an increased injury risk when increasing rotational velocity.

2.7 Interior Vehicle Configurations

In addition to the parameters detailed in previous sections of this deliverable (4.4.2 and 4.4.3), Lopez-Valdes et al. showed that a previous personal or close crash experience can also influence the occupant's level of trust in the vehicle or his/her seating preference in AVs (117). In addition, the yearly exposure to traffic may also have an effect on these parameters.

The first part of the study by Lopez-Valdes et al. was related to the influence of exposure to traffic in order to choose a seating position. When participants were driving alone there was little change to the preference of the highly automated vehicle configuration and the seating position. Participants with high exposure to traffic tended to not chose the "driver" seat or the rear right passenger seat.

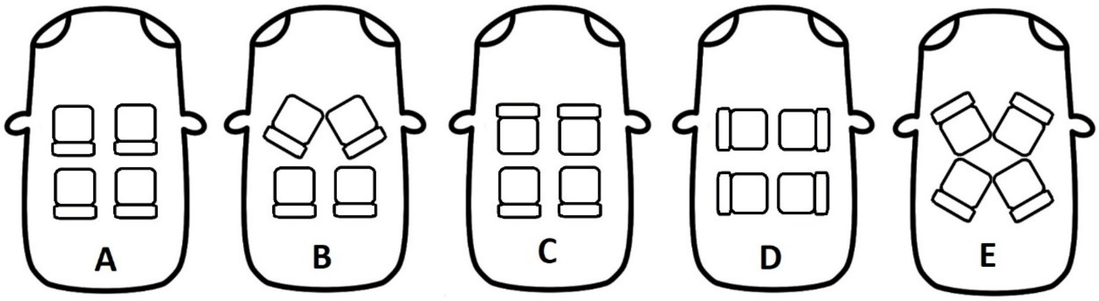

Figure 22. Seating configuration from the study (117)

When participants were asked about travelling with their partners, configuration C was chosen more frequently than configuration A (see Figure 22). In this scenario, exposure to traffic was not significantly related to seating position preferences.

The other aspect that may influence the selection of the configuration and the seating position preference, would be if participants have had a previous crash. In this case, when participants were travelling alone, the previous experience of a crash, had no influence on the vehicle configuration, although it was related to choosing the front right passenger seat or the rear left passenger seat over the traditional "driver" seat. These results were statistically significant considering age and sex.

But when participants were travelling with their partner, the previous experience of a crash significantly influenced the preferred configuration D, A and E. Interestingly those participants with previous crash experience did not change the chosen seating position.

It must be noted, though, that the conclusions related to interior configuration preferences depending on previous crash experiences will certainly have a strong impact on those people that have experienced a crash before, but will not be representative of the entire population as a high proportion of vehicle occupants will probably never experience a crash in their lives.

2.8 Interior vehicle concept

The final topic to be investigated is regarding how future AV interiors will be. This must also be covered using the following considerations:

- Interior vehicle layout
- Interior features
- Seat positions (number of seats) and seat configuration
- Interior geometry (length, width and height)

In order to define the interior layout of the use case, a benchmark study was conducted in order to search for future autonomous vehicle interior configuration concepts. This section shows the most significant vehicle concepts for T4.1 that have not been explained already in Section 4.4.4.

In order to measure the interior configurations found in the reference concept vehicles explained in Section 4.4.4 (Yanfeng concept vehicle, Zoox concept vehicle and Mercedes F 015), it was necessary to search for the dimensions of a regular seat to use this value as a reference. In (86) a study of the dimensions of a current standard seat was conducted, resulting in a seat width of 604 mm. This dimension has been used in order to estimate the interior measurements of the concept vehicles.

Several brands like Ford (118) have investigated the design of new seating concepts for their vehicles. This is the case with the Ford F-150 model for 2021 that will offer seats whose reclining position can achieve more than 77º, this then creates an almost horizontal recline position similar to a sleeping position. Figure 23shows the seat angle measured with a protractor.

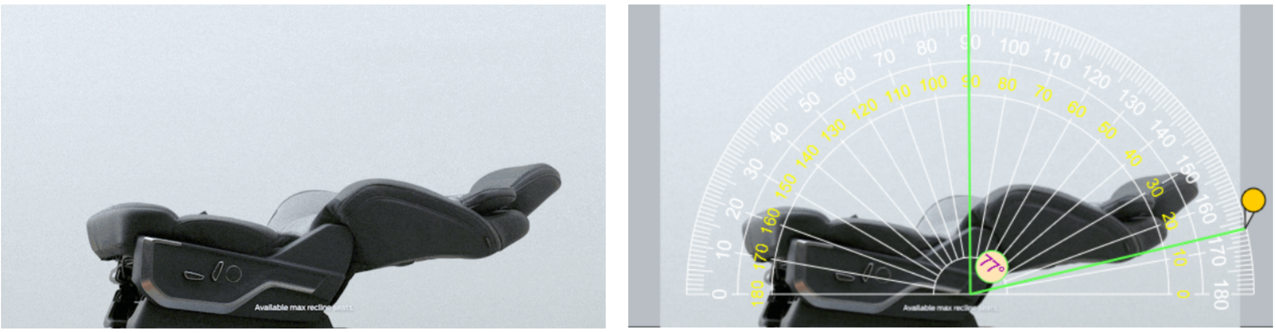

Figure 23. Seat recline with angle. Source (Ford F-150 2020) (118)

Mercedes has also created several concept cars for future autonomous vehicles. In this case, the Mercedes EQ concept reveals a futuristic interior showing the unusual and spacious design of its interior and seats Figure 24 (119).

Figure 24. Mercedes EQ concept. (119)

The new NEVS Sango concept car (120) has the possibility of using the vehicle with different configurations, such as a bus with more privacy, living room configuration for social mode and a family mode. Figure 25 shows the three modes (from left to right). This concept vehicle could make it possible to study in more detail people's preferences. These preferences could change depending on various factors, such as the duration of the trip, the passengers' confidence, etc.

Privacy Mode | Social Mode | Family Mode

Figure 25. NEVS Sango concept (120)

BMW has also designed a reclining seat concept: the BMW X7 ZeroG lounger, in which the extreme recline of the passenger seat allows a more comfortable and relaxed position, see Figure 26. (121)

Figure 26. BMW X7 ZeroG Lounger features. (121)

On the other hand, in 2016, Wired presented their concept of "Self-Driving Car of the Future", this features a bookshelf running along the fascia panel, see Figure 27. (122) With this design, when fully autonomous driving mode is activated, the steering wheel collapses into the fascia panel, in a similar way as in the concept from Volvo. (123) leaving the driver with free space and able to use the displays in front of them.

Figure 27. Concept car with a bookshelf. Source (Wired 2016) (122)

Renault has also presented their Renault presented their concept vehicle for future autonomous vehicles, the Renault EZ-GO Concept (124) shown in Figure 28.

Figure 28. Renault EZ-GO Concept (124)

Volvo 360c (123) is another concept proposal with an interesting interior space. Volvo presents an autonomous car with a real bed inside, as shown in Figure 29 This concept gives the possibility to transform the interior configuration depending on the passenger needs. This concept is considered for a L5 of automation, therefore not fully representative of the T4.1 scope of work. However, it is an interesting approach to be considered regarding future AV conceptual design.

Figure 29. Volvo 360c concept vehicle. (123)

In 2015, Yanfeng presented their vision into the future of vehicle interiors (46), see Figure 30. This concept makes it possible to reorganise the interior configuration for four people in order to keep the driving mode and the living room configuration in a L4 level of automation.

Figure 30. Yanfeng interior vehicle concept (46)

In 2018, Grammer vision presented their concept design of an autonomous car interior with flexibility to modify the interior layout depending on the passenger needs. Some examples of these layout options are found in Figure 31 (125).

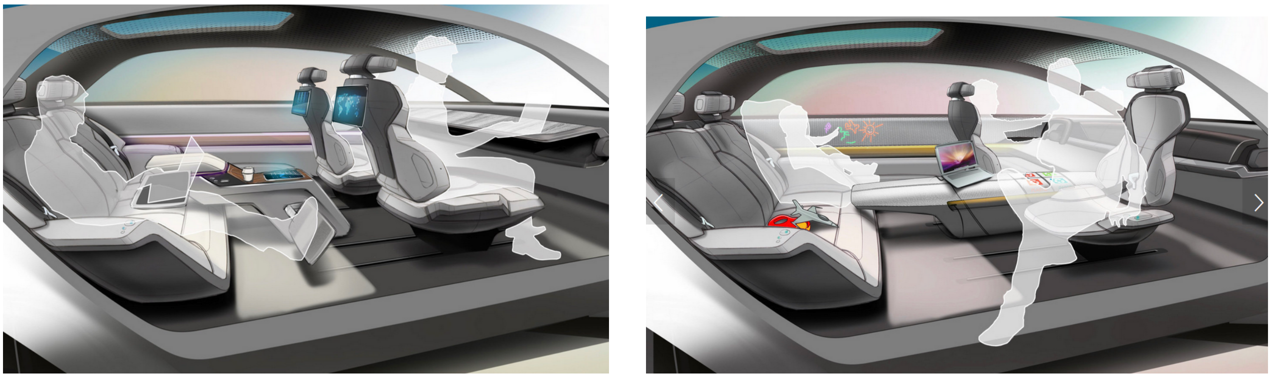

Figure 31. Grammer concept car (125)

During research into conceptual seat design for autonomous vehicles, an article referring to a new seating design patent from Porsche that allowed for three different seating positions was found (126).The first position is the conventional driving posture, similar to traditional seats, the second one is the working mode, in which the seats keep an upright position but the position of the steering wheel and pedals are altered to allow for a working space; and the third posture is for a complete relaxed mode, in which the seat reclines almost completely, in a similar way to business class seating on an aircraft. In this relaxed mode the steering wheel and pedals also retract into the fascia panel. In addition, the relaxed position also has an integral footrest for more comfort. Figure 32 shown below, shows a schematic of two of these three positions.

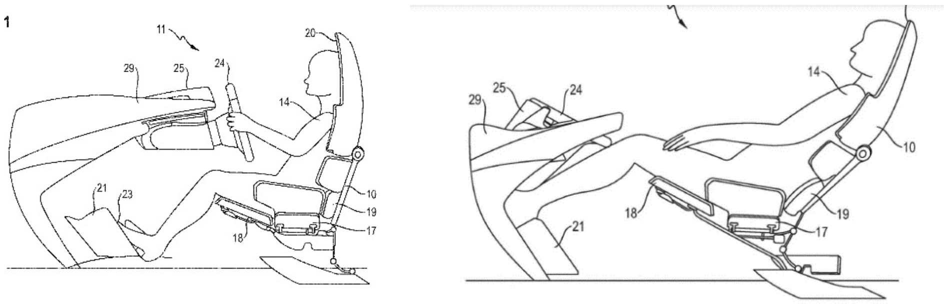

Figure 32. Porsche seat. (126)

As has been seen in the benchmarking images found above, the currently released AV concepts show several options regarding interior features. Most vehicles consider an open interior vehicle layout with no added features (other than tables or extended centre consoles). However, some studies such as the previously mentioned survey from the Autoinsurance center (82) show the following results: the most chosen option was to have the same interior design as current vehicles (31.6%), but when people think about new devices options they would like to have in first place a refrigerator (even though eating was only the 6th most likely activity reported) followed by beds (sleeping was the 8th most likely action), tables and chairs (14.7%), a lounge, a fully stocked bar and finally a massage table (2.9%).

The information extracted from this benchmark study, together with the reference concept vehicles explained in Section 4.4.4, has been used to define the interior configurations to be used in WP4 using design software. These interior configurations are explained in greater detail in Sections 4.4.4 and 5.