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Design of autonomous vehicles in terms of inclusivity and urban mobility

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PROHLÁŠENÍ O AUTORSTVÍ

Předkládám tímto k posouzení disertační práci, jejíž téma je „Design of Autonomous Vehicles in terms of Inclusivity and Urban Mobility “.

Tato práce je koncipována dle požadavků Studijního a zkušebního řádu Západočeské univerzity v Plzni, tj. obsahuje zejména shrnutí a zhodnocení poznatků ve studované oblasti a seznam souvisejících publikací.

Prohlašuji, že jsem tuto písemnou práci vypracoval samostatně, s použitím odborné literatury a pramenů uvedených v seznamu, který je součástí této práce.

V Plzni dne: ………………….. Podpis ……………………….

UPOZORNĚNÍ

Podle Zákona o právu autorském. č.121/2000 Sb. § 12-17 a Zákona o vysokých školách č. 111/1998 Sb. je využití a společenské uplatnění výsledků disertační práce, včetně uváděných vědeckých a výrobně-technických poznatků nebo jakékoliv nakládání s nimi možné pouze na základě autorské smlouvy za souhlasu autora a Fakulty strojní Západočeské univerzity v Plzni.

ANOTACE

Motivací této diplomové práce je navržení inkluzívního dopravního prostředku pro obyvatele metropolí a velkoměst, pro osoby jež dojíždějí denně za prací či osoby se zdravotním postižením. Práce se zaměřuje na koncept vozidla v kontextu městské mobility a zkoumá potenciál zvyšování mobility prostřednictvím technologie autonomních vozidel. Práce nahlíží na městskou dopravu v širších souvislostech a bere v úvahu problémy, kterým čelí stárnoucí světová populace. Časová osa je zohledněna od roku 2020 do roku 2030, což odráží potřebu okamžitého designového řešení s koncepčním výstupem.

Úvodní kapitola práce se zabývá problémem stárnutí a demo-grafickými změnami v populaci.

Popisuje a zohledňuje fyzické, kognitivní a sociální aspekty, které se týkají starších řidičů. Je zde vysvětlen pojem inkluzivní design, jeho vztah k ergonomii a designu autonomního vozidla. S ohledem na inkluzivní design jsou vyčísleny a kvantifikovány osoby, které mohou hypotetický koncept vozidla používat.

V druhé kapitole jsou popsány způsoby cestování. Analyzováno a vyhodnoceno je dojíždění obyvatel tří světových metropolí na základě současných relevantních statistik. Návrh vozidla v městském kontextu je přezkoumán ve vztahu ke konfiguraci zástavby vozidla, jeho životnosti a velikosti baterie. Výsledky analýzy jsou použity pro návrh podnikatelského plánu mobility, který odhaduje finanční projekce. Rovněž je zde porovnáno několik současných elektrických vozidel navržených a určených především pro městské prostředí.

Třetí kapitola definuje autonomní řízení a všechna důležitá zařízení potřebná k tomu, aby vozidlo bylo plně autonomní. Uvádí příklady lidarů, radarů, kamer a dalších souvisejících komponent charakteristických pro autonomní vozidla a jejich použití. Tato kapitola také vysvětluje současné právní aspekty týkající se konvenčního i autonomního řízení a zkoumá technologie, jež budou v blízké době uvedeny na trh. Dále poskytuje přehled o současné mezinárodní situaci týkající se autonomní dopravy spolu s doporučeními ke koncepčnímu návrhu autonomního vozidla.

Závěrečná kapitola definuje seznam požadavků a relevantních vlastností autonomního vozidla jakožto technického systému. Tyto informace jsou integrovány do konceptu nového typu lehkého autonomního vozidla. Podoba vozidla je vytvořena na základě předchozích zjištění společně se stylingem, architekturou a zástavbou, které vyhovují potřebám starších uživatelů.

Dizertační práce vychází z více jak desetiletých zkušeností v automobilovém průmyslu, kde autor vykonával především designové inženýrství a prototypové práce na konstrukcích karoserií, exteriérech, interiérech, podvozcích, pohonných jednotkách a výrobních linkách. Práce byla vytvořena bez spolupráce s externí firmou či sponzorem.

ANNOTATION

The motivation behind this dissertation thesis is to help to provide a more inclusive environment for urban citizens, daily commuters, disabled persons, and communities by bringing innovative technologies to anyone focusing on autonomous driving solutions.

The work will look at the vehicle design in the context of urban mobility and investigate the potential of making mobility more inclusive through the design of driverless vehicles. It will explore this against the wider backdrop of urban transportation and take account of current challenges we face in an increasingly ageing society. The timeline will stretch from 2020 to 2030, balancing the need for immediate design solutions with the concept-based outcome.

The initial chapter of the thesis is taking into consideration the design for ageing which is associated with demographic changes in population, physical, cognitive and social aspects that affect the elderly drivers. The term inclusive design is explained, evaluated and assessed in relation to the human factor design and driverless vehicles. Design exclusions are quantified and countered.

The second chapter explains types of travelling and analyses commuting, and journey purposes of urban citizens based on current international statistics. Vehicle design in an urban context is reviewed in relation to the package configuration, vehicle life and battery size. The findings are used for a mobility business plan that estimates financial projections. Benchmarking of recent electric vehicles designed primarily for the urban environment is also evaluated.

The third chapter defines autonomous driving and all significant devices required for making vehicle fully driverless. Examples of recent lidars, radars, cameras and other related components are characterized, and examples of their application are provided. This chapter also explains current legal aspects related to conventional and autonomous driving, examines close to market technologies and provides an overview of the current international situation together with design recommendations.

The last chapter establishes a list of requirements and a detailed list of all relevant system properties. This information is translated into a new type of lightweight driverless vehicle design. A vehicle form is generated based on findings together with styling and basic packaging layout which accommodates the needs of older users.

The dissertation work is based on ten-year experience within automotive industry where the author performed mainly design engineering and prototyping work on vehicle body structures, exteriors and interiors, chassis, powertrains and assembly lines. The thesis has been created solely without any company cooperation.

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1 INTRODUCTION

Automated vehicle technology will profoundly change the way we travel, making road transport safer, smoother, and smarter. We are on the pathway to autonomous cars, where fully automated vehicles will transport people and goods to their destination without any need for a driver [1]. The utilisation of 'autopilot' cars will lead to a wide range of economic, productivity and time efficiency benefits. It opens a fresh market for a variety of Car-Sharing business models and brings trade expansion opportunities (mail & food delivery). Car-sharing programs would become more prevalent as autonomous vehicles could arrive at destinations and then be used by other passengers.

Driverless cars would allow people of all ages and abilities to use the vehicles and would thus eliminate the need for a driver's licence because it removes all constraints on the occupants' physical and mental state. This increases accessibility and mobility improves the quality of social life and independence.

Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication would let traffic flow more freely and without the use of traffic lights. Ability to control, automate and optimise traffic will lead to a balanced distribution of traffic during peak times and therefore less wasted commuting time and fewer traffic accidents. Consequentially road capacity will increase, while demand for parking spaces will fall. Most importantly, the energy efficiency of autonomous vehicles will reduce carbon emissions and the global environmental impact of the entire automotive industry.

Thinking about autonomous mobility systems involves thinking about human needs holistically. It is essential to understand not just vehicle architecture and design itself, but also the statistics related to our global population, commuting patterns, social needs and issues related to the urban environment.

The ability to successfully package an utterly driverless car is about understanding a vehicle as a system and seeing the complete product as a complex arrangement of interrelated subsystems. Car designers will therefore increasingly hear the term “systems thinking", as the world within which we live becomes more interconnected and more complex, professional car designers can no longer think just about the specific product on which they are working. They are increasingly required to understand the context within which their vehicle is going to operate [2].

1.1 PROJECT PURPOSE

This thesis investigates the potential of new innovative vehicle design in the context of driverless transportation, inclusive design and urban environment. It will focus on the systematic design and development approach of a concept car for high volume production.

The primary intention is to develop a tool and design a mainstream modular concept car that is accessible to, and usable by, as many as reasonably possible, on a global basis, in a wide variety of situations and to the most significant extent possible without the need for special adaptation or specialized design. The timeline horizon to be considered from 2020 to 2030, balancing the need for immediate design solutions with more aspirational scenario-based outcomes. Figure 1.1 below illustrates the point that bridging any two research areas can inspire a series of research topics. However, the darker middle area of the diagram represents the research domain which may have been ignored by the design-research community because the broken lines do not pass through it. Although some research projects focus on any two of these areas, studies combining three such separated fields are little explored.

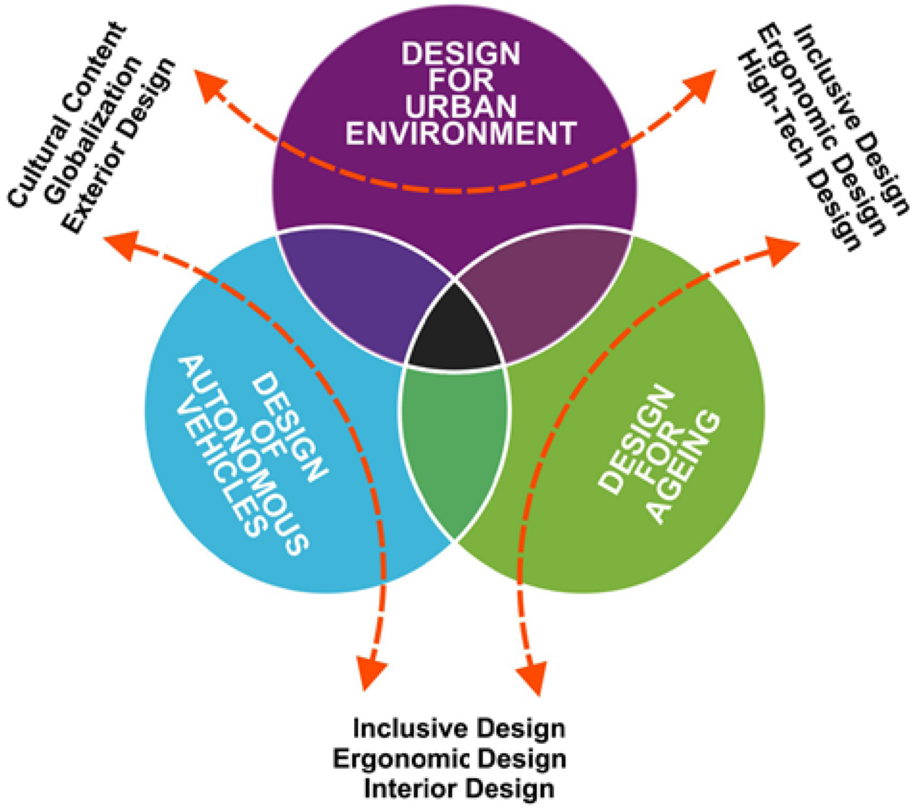


Fig. 1.1 - The initial theoretical concept

1.2 DESIGN ASSUMPTIONS, STRUCTURE AND PROCESSES

Figure 1.2 shows the linear schematic of the industrial process, moving from design of autonomous vehicles to production to distribution and recycling. Figure 1.3 shows how optimization of such efficiency can be considered from a mathematical point of view, as minimization or maximisation of some functional. When we are talking about efficiency, we can consider the problem as a maximisation of the production function f_p

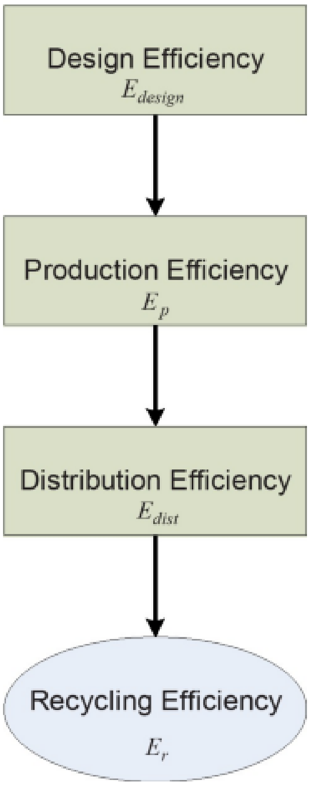
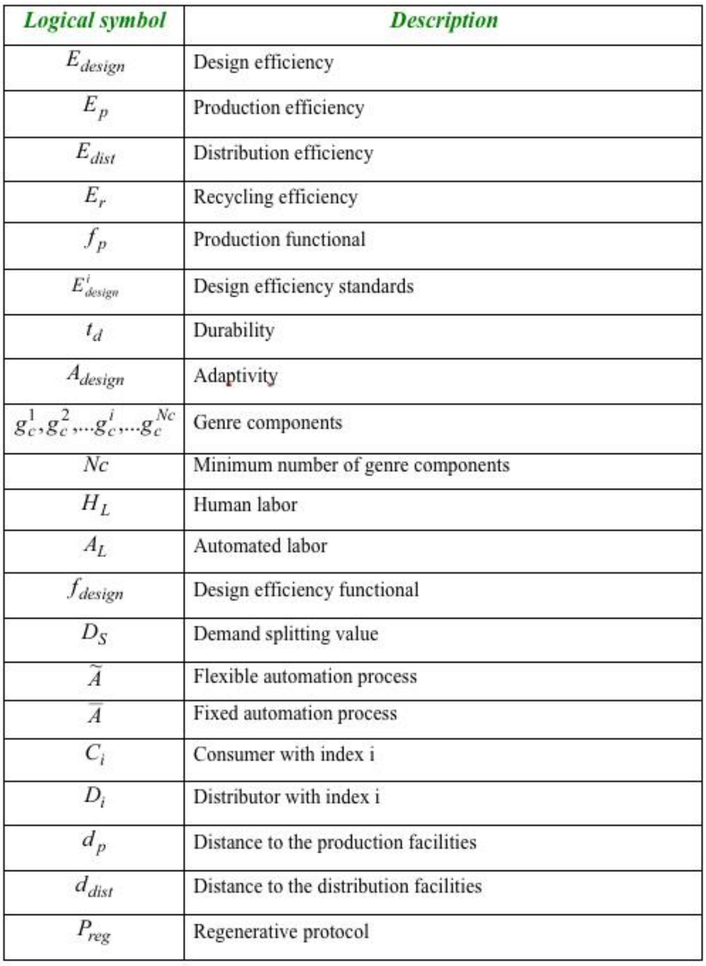


Fig. 1.2 - Block Scheme of System Process [3]

$$\boldsymbol{f_p\left(E_{design}, E_p, E_{dist}, E_r\right) \to max}$$

Fig. 1.3 - System Process as Expression



Logical symbol	Description
E_{design}	Design efficiency
E_p	Production efficiency
E_{dist}	Distribution efficiency
E_r	Recycling efficiency
f_p	Production functional
E_{design}^{i}	Design efficiency standards
t_d	Durability
A_{design}	Adaptivity
$g_c^1, g_c^2, \ldots g_c^i, \ldots g_c^{Nc}$	Genre components
Nc	Minimum number of genre components
H_L	Human labor
A_L	Automated labor
f_{design}	Design efficiency functional
D_S	Demand splitting value
$\widetilde{A}$	Flexible automation process
$\overline{A}$	Fixed automation process
C_i	Consumer with index i
D_i	Distributor with index i
d_p	Distance to the production facilities
d_{dist}	Distance to the distribution facilities
P_{reg}	Regenerative protocol

Fig. 1.4 - Logic Symbols and Description

Figure 1.4 is a table of symbols and descriptions, as will be used in the following explanations. [2]

1.3 OPTIMIZED EFFICIENCY

If we were to look at good design in the broadest possible way concerning industrial unfolding, we end up with about four functions or processes, each relating to the four dominant, linear stages, including design, production, distribution and recycling [3]. The following propositions apply (Fig. 1.2) where all vehicle designs must adapt to:

1.3.1 OPTIMIZED DESIGN EFFICIENCY

A vehicle design must meet or adapt to criteria set by [Current Efficiency Standards] E_{design}^{i} [Current Efficiency Standards] have five evaluative sub-processes:

[Durability] = d_t ;
[Adaptability] = A_{design}
[Standardization] = $N_c N$
[Recycling Conduciveness] = c_r
[Automation Conduciveness] = H_L

Efficiency standards listed below are standards by which a given design must conform.

- Strategically Maximized Durability
- Strategically Maximized Adaptability
- Strategic Standardization of Genre Components
- Strategically Integrated Recycling Conduciveness
- Strategic Conduciveness for Labour Automation Figure

As per figure 1.4, design efficiency, E_{design} is one of the main factors that can affect the overall efficiency of the manufacturing and distribution process. This design efficiency depends on several key factors, which can be called current efficiency standards E^{i}_{design}. Here the index *i* corresponds to some particular standard. Each standard will generally be explored as follows, expanding in some instances with respect to the symbolic logic associated, for the sake of clarity.

1.3.1.1 Strategically Maximized Durability

Strategically Maximized Durability means to make the vehicle as durable and lasting as relevant. The materials utilized, comparatively assuming possible substitutions due to levels of scarcity or other factors can be dynamically calculated, to be most conducive to an optimized durability standard. Durability $t_d (d_1, d_2,..., d_i)$ maximization can be considered as a local optimization issue. It can be analyzed by introducing the factors d_i which affect it where $d_1^o, d_2^o ,..., d_i^o$ are some optimal values of the factors.[2]

$$t_d(d_1,d_2,...,d_i) \rightarrow \max, t_d = t_{\max}(d_1^o,d_2^o,...,d_i^o)$$

As will be explained later, classic purchased based vehicle ownership will be replaced by autonomous mobility services. The durability factor will, therefore, play a significant role in the design process. Estimated annual mileage of a driverless taxis is many times higher in comparison to a conventional family car.

1.3.1.2 Strategically Maximized Adaptability

Strategically Maximized Adaptability A_{design} means the highest state of flexibility for replacing component parts is made. In the event a component part of a vehicle becomes defective, or out of date, the design facilitates that such components are easily replaced to maximize full vehicle lifespan, always avoiding the interest to replace the vehicle as a whole.[3]

It is expected that some of the electronic devices, batteries and sensors integrated into the driverless vehicle will require upgrading or replacement during the vehicle lifetime. The requirement for vehicle range associated with battery capacity may also vary in certain regions; it is, therefore, worth to consider various battery pack sizes to adapt the vehicle to these circumstances and minimize its weight and maximize the efficiency of the entire fleet.

1.3.1.3 Strategic Standardization of Genre Components

Strategic Standardization of Genre Components means all new designs either conform to or replace existing components which are either already in existence or outdated due to a lack of comparative efficiency. This logic should not only apply to a given vehicle model; it should apply to the entire vehicle brand, however possible.

$$g_c^1, g_c^2, \ldots g_c^i, \ldots g_c^{Nc}$$

$$Nc -> \min$$

The aim is to minimize the total number of brand components N_c. In other words, the standardization of the process will enable the possibility of lowering the number N_c to a possible minimum. [2]

1.3.1.4 Recycling Conduciveness

Recycling Conducivenes**s** c_r means every design must conform to the current state of regenerative possibility. The breakdown of any vehicle must be anticipated in the initial design and allowed for in the most optimized way [3]. It is therefore critical to investigate those design processes and technologies that are already taking the recyclability and the usage of already recycled material into account.

1.3.1.5 Strategic Conduciveness for Labour Automation

Strategic Conduciveness for Labour Automation means that the state of optimized, automated production is also taken into account, seeking to refine the design to be most conducive to production with the least amount of complexity, investment, human labour or monitoring. Again, we seek to simplify the way materials, and production means are used so that the maximum number of vehicles can be produced with the least variation of materials and production equipment. This is denoted by human labour H_L and automated labour A_L. The aim is to minimize the human interaction with the production process. This can be written as:

$$H_L / (H_L + A_L) \rightarrow \min$$

Using this equation, we could also write a simpler condition:

$$H_L(l_1, \ldots, l_i) / A_L(l_1, \ldots, l_i) \rightarrow \min$$

where l_i are factors that influence human and automatic labour. So, returning to Figure 1.4, this “Optimized Design Efficiency” function can be described by a function f_{design} where t_d is durability, A_{design} is adaptability, c_r is recycling conduciveness, N_c is the minimum number of genre components, and H_L is human labour. [2]

1.3.2 OPTIMIZED PRODUCTION EFFICIENCY

These parameters can change based on the nature of the facilities and how much machine variation in production (fixed automation vs flexible automation) is required at a given time. For the purpose of expression, two facility types can be distinguished: one for high demand or mass production and one for low demand or short-run, custom vehicles.

Very simply, a class determination is made which splits D_S the destination facilities based upon the nature of production requirements. The 'high demand' target assumes fixed automation, meaning unvaried production methods ideal for high demand/mass production. The 'low demand' target uses flexible automation, which can do a variety of things but usually in shorter runs.

Also, both the manufacturing of [Low Consumer Demand] and [High Consumer Demand] product designs will be regionally allocated as per the [Proximity Strategy] d_p of the manufacturing facilities.

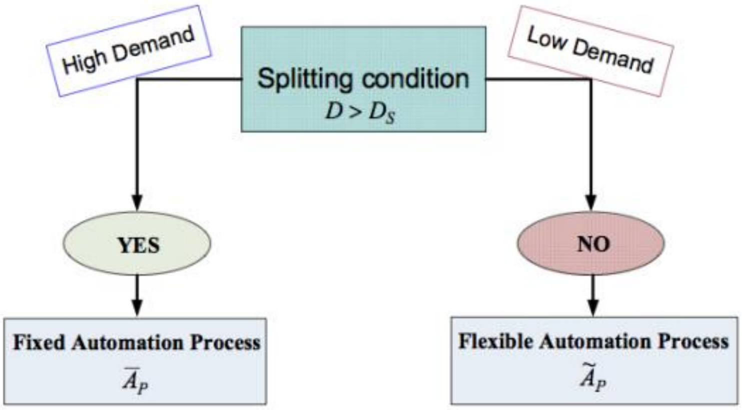


Fig. 1.5 - Dividing by low and high - Application of the class determination process

1.3.3 OPTIMIZED DISTRIBUTION EFFICIENCY

Once process 2 is finished, the vehicle design becomes an 'autonomous vehicle' and moves to the [Optimized Distribution Efficiency] filter. In short, all vehicles are allocated based on its prior [Demand Class Determination]. [Low Consumer Demand] products follow the [Direct Distribution] process. [High Consumer Demand] productions follow the [Mass Distribution] process, which would likely be the, e.g. airport, rail station, shopping mall, stadium or university car parks. Both the [Low Consumer Demand] and [High Consumer Demand] product will be regionally allocated as per the [Proximity Strategy].

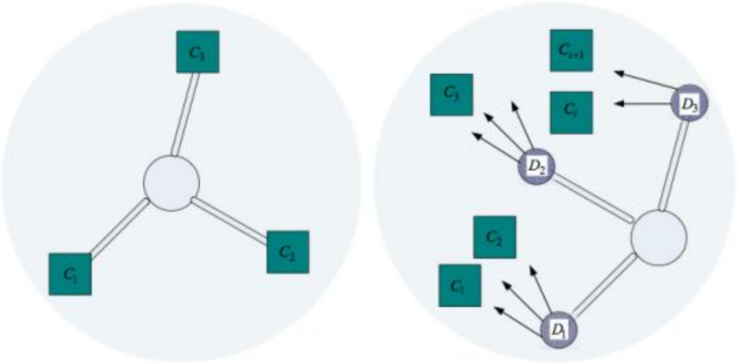


Fig. 1.6 - Illustration of the distribution schemes
A (left) – Direct Distribution – low demand case,
B (right) – Mass Distribution – high demand case

1.3.4 OPTIMIZED RECYCLING EFFICIENCY

Once vehicle's life-cycle ends, the vehicle becomes "void" and moves to the recycling process. In short, all voided vehicles will follow the current [Regenerative Protocol] P_{reg} . This protocol embraces the standards employed at that time to ensure the optimized reuse or reincorporation of any given vehicle or component. Naturally, the sub-processes of this are vast and complicated, and it is the role of engineers, embracing natural law physics, to best understand what parameters will be set. [3]

1.4 DESIRABLE RESULT AND IMPACT

Outcome shall result in several benefits in economic, environmental, social, manufacturing and market sectors. The study complete study will be designed to protect our future personal mobility and freedom. Once the self-driving technology is considered sufficiently mature, human and goods mobility will entirely change.

CAR SHARING - It is highly likely there will be no more personal vehicles as all vehicles will be driverless and shared, just like cabs without a driver. The vehicle will be called upon necessity, and once the destination is reached, the vehicle will be available to the next passenger. Nearly the same mobility can be delivered with 10% of the cars. As a result, car sharing business will decrease the total amount of cars in use but increase their reliability and overall efficiency cars.

OPTIMIZED TRAFFIC FLOW - Vehicles, thanks to their car-to-car communication capabilities, will coordinate to pass through intersections with a constant flow, without interfering with each other. Therefore there will be no need for traffic jams and traffic lights. The vehicle will be intelligently coordinated, avoiding hitting congested areas in order to minimize travel time and decrease delays caused by congestion in urban areas. This will also lead to a reduction of running costs and CO2 emissions. Vehicles will be able to move at high speeds and with a short inter-vehicle distance so that the current road network will be able to host a more substantial number of vehicles; the throughput of each existing lane will be significantly incremented. The overall volume of car travel will likely increase.

PARKING - Once reaching its destination, the vehicle will be available to the next passenger or will autonomously reach a parking space, which may also be in a remote location. This scenario will drastically reduce the number of parked cars alongside roads and therefore free up significant public and private space.

NO MORE DRIVING LICENCES - Everyone will enjoy enhanced mobility on roads without the need for a driving license, included elderly, young, and handicapped individuals. These cars would allow people of all ages and abilities to use the vehicles and would thus eliminate the need for a driver's license, because of the complete removal of constraints on occupants' state. This will drastically improve quality of social life and independence especially for elderly people, namely access to health care and shops.

ECONOMY - They will cause unprecedented job loss and a fundamental restructuring of our economy, but it will save millions of hours with increased productivity and create entire new industries that we can hardly even imagine from our current vantage point. Autonomous car will have a significant impact on trade expansion as it brings a wide range of new business opportunities (e.g. mail and food delivery).

ACCIDENTS - The road will be almost an accident-free environment, and fatal road casualties will be a thing of the past. 93% of road accidents are due to human errors: distraction, driving under the influence of substances, impairment. [4]

1.5 RESEARCH PROGRAM & OBJECTIVES

- Establish a list of requirements (Factors for all life phases; Requirements on technical processes, Technical systems, environment, etc.)

DESIGN FOR AGEING

- Analysis and evaluation of global population
- Analysis of physical aspects of older adults (individuals who are over 60 years of age) from an ergonomic perspective and classify most significant hurdles to inclusive design in the vehicle development.
- Research of recent vehicles with user-centred interior design
- Application of Inclusive Design approach in the automotive industry – discover users' needs
- Quantifying & Countering design exclusion

DESIGN FOR URBAN ENVIRONMENT

- Research travelling needs and patterns of current urban young, middle-aged and elderly drivers in capital cities
- Analysis and evaluation transportation and commuting statistics in selected metropolitan areas
- Research of recent electric vehicles designed for the urban environment
- Determine future trends that will shape piloted driving in an urban mobility context

DESIGN OF AUTONOMOUS VEHICLES

- Research of recent advanced technology and digital devices used by autonomous cars for sensing surrounding environment. Overview of all fundamental devices required for autonomous driving and application examples.
- Research of conventional and new regulations related to autonomous driving

CONCEPTUAL VEHICLE DESIGN

- Translate all gathered information and build a plan for the design work for a new type and class of personal ultra-lightweight driverless vehicle
- Establish a detailed list of all relevant system properties (function properties, functionally determined properties, operational properties, manufacturing properties, distribution properties, liquidation properties)
- Generate a vehicle form and body styling based on the findings and generate packaging layout in CAD which accommodates the needs of older users.

  A detailed plan for the design work can be found in **Appendix A**.

1.6 ESTABLISHING PROPERTIES OF DESIGNED TECHNICAL SYSTEM

The primary procedure follows the general procedural model (Appendix VIII), using the captions from that figure to guide the process. It is augmented by the basic operations of problem-solving (Appendix VIII - Fig. 1). This procedure is adapted to the problem, as demonstrated in this case.

P1 ESTABLISHING A LIST OF REQUIREMENTS FOR A CONCEPTUAL DRIVERLESS VEHICLE

P1.1 ESTABLISH ROUGH FACTORS FOR ALL LIFE PHASES

(technology, operators, inputs, outputs of each life stage)

- Person (Operand/Operator – Driver/Passenger) to be transported in an environmental friendly compact vehicle from location A to destination B in the shortest possible time.
- Modern cities demand compact vehicles
- New personal transportation TS to be designed with respect to inclusive design and customer-centred design approaches (ageing society, vehicle sharing, etc.)
- Passengers need seamless in-and-out access; they want to perform daily tasks while riding in a comfortable, safe and clean environment
- Conceptual vehicle to be designed in order to meet the mobility requirements of a person throughout life, from infancy to old age.
- Conceptual vehicle (Fleet) owners seek to reduce the total cost of ownership of their vehicle (fleet) through vehicles with low fuel / energy consumption and minimal servicing expenses.
- An ageing world population is raising focus on senior citizens' complex transportation needs.
- Authorities are increasingly exerting limitations on vehicle emissions, which vary between cities' specific regulator policies
- The aesthetic appearance of its shape plays a fundamental role in determining the commercial success of a vehicle

P1.2 ANALYSE LIFE PHASES, ESTABLISH REQUIREMENTS ON THE TECHNICAL PROCESS & SYSTEM

- Conceptual vehicle to be designed as a compact driverless electric taxi suitable for an urban environment
- Conceptual vehicle must be designed with respect to inclusive design approach respecting the needs of elderly and impaired persons
- Conceptual vehicle must be designed with respect to inclusive design approach respecting the needs of elderly and impaired persons
- Autonomous technology integrated into the conceptual design must comfort with level 5 autonomy (SAE J3016_201609)
- Conceptual vehicle battery must have the ability to withstand daily rush hours
- Conceptual vehicle body structure to be designed as a lightweight parametric platform
- Conceptual vehicle battery to be designed as a replaceable structural component
- Conceptual vehicle to be designed as a rear wheel drive vehicle
- Conceptual vehicle to be designed as wheelchair accessible
- Conceptual vehicle to be designed with respect to vehicle platform modularity
- Conceptual vehicle to have a high mileage longevity

P1.3 ANALYSE ENVIRONMENT OF THE INDIVIDUAL LIFE CYCLE PROCESSES ESPECIALLY TS(S) – OPERATIONAL PROCESS, THE TP(S), AND ITS USERS

- Vehicle to be driven outdoors – Mainly roads in the urban and suburban traffic system and affiliated motorways
- Conceptual vehicle to be considered as a vehicle connected to the 'cloud' network system to receive actual traffic data
- Conceptual vehicle to be engineered in a way to perform in both hot and cold climates
- Conceptual vehicle function systems must increase traffic flow
- Recyclable and environmentally friendly materials to be used wherever possible

P1.4 ESTABLISH IMPORTANCE (PRIORITY LEVEL) OF INDIVIDUAL REQUIREMENTS, PROCESSES AND OPERATORS (FIXED REQUIREMENTS – WISHES)

- Low running and operating expenses
- Should offer a unique solution for commuters, companies (taxi), tourists, students, elderly people and disabled people
- Easy and quick way how to recharge the battery
- Conceptual vehicle must conform to practical and social acceptability (exterior accents and customizable interior)
- Conceptual vehicle design should be equipped with a simple and intuitive human-machine interface
- Customisable and modular design to fit specific fleet requirements and demographic needs
- Battery and driving efficiency
- Ergonomy to be optimized for low physical effort
- Easy parking and accessible loading

P1.5 QUANTIFY AND TOLERANCE THE REQUIREMENTS WHERE POSSIBLE

- Minimum transportation range must withstand morning or afternoon rush hour without charging intervals

P1.6 ALLOCATE THE REQUIREMENTS TO LIFE PHASES, OPERATORS, AND CLASSES OF PROPERTIES

- Easy to drive and operate
- Ergonomic operating and dashboard layout is important
- Easily accessible (easy to get in and out of the vehicle)

P1.7 ESTABLISH REQUIREMENTS FOR A SUPPLY CHAIN, AND ENVIRONMENTAL CONCERNS

- Materials and components used for the vehicle must conform to international standards
- Lifetime, efficiency and recyclability of the vehicle and its components to consider

P1.8 REVIEWED

(1)	**Output (Design Specification)**
	Requirements are listed only under most relevant TP or TS(s) property as judged by the design engineer, and, not repeated in any other relevant property class. An indication of priority: **F** fixed requirement must be fulfilled; **S** strong wish; **W** wish; **N** not considered
Pr1	**Purpose**
F	Vehicle to be designed with an aim to safely transfer passengers from location A to destination B in shortest possible time with respect to inclusive design principles
F	Conceptual vehicle to be designed mainly for urban mobility
F	Conceptual driverless vehicle must be designed according to the level 5 autonomy
F	The new vehicle concept must be both: socially + practically acceptable
Pr1A	**Function Properties**
F	Should be accessible to wide range of passengers considering age, skills, body proportions, impairments
F	Should provide easy boarding for passengers with body impairment or wheelchair users
F	Should offer spacious seating room and enabling customization according to individual needs
F	Should be able to accommodate 95 percentile manikins
W	Should be able to carry a folded bicycle
F	Passenger to be protected by wholly enclosed bodywork
S	Panoramic glass roof (allows passengers to remain in contact with the surroundings cityscapes)
F	Should have attractive and flexible seat options and seating arrangements that allow all passengers to travel comfortably.
F	Vehicle customization for wheelchair users should be considered
F	The flexible layout should support a variety of uses
Pr1B	**Functionally Determined Properties**
F	Conceptual vehicle to be designed as a modular two-seater or an optional wheelchair configuration
F	The boot should be spacious enough for 28-32" large suitcases or folding bike
F	Turning Circle <8m
F	Length <3.2m
S	Trunk space of 300 l min (up to the roof)
Pr1C	**Operational Properties**
F	Battery capacity should withstand rush hour traffic demand
Pr2	**Manufacturing Properties**
F	Use OEM-available system components where possible (e.g. powertrain, seats, sensing devices)
W	Design for Assembly (Fender benders to be quickly replaced if damaged or crashed – lower insurance rating)
Pr3	**Distribution Properties**
F	Vehicle to be operated on the autonomous fleet basis
N	- If used by share vehicle companies: Parking space required
N	- If used by share vehicle companies: Vehicle to be self-driven to the designated area, driver/passenger to be contacted subsequently

N	- If used by share vehicle companies: Vehicle to be reserved and picked up on its allocated parking place
N	- If used by share vehicle companies: Online system, account, booking forms, managing driving plan
Pr4	**Liquidation Properties**
W	Recyclable material to be used where possible (Battery recyclability issues, 100% recyclable plastic body panels)
N	Easy disassembly
Pr5	**Human-System Factor – for all life cycle phases**
F	User Wants / Aspirations to be satisfied
F	- Practical Acceptability
F	-- Usefulness (Usability: Easy to learn, Efficient to use, Easy to remember, Low error rates, Fun to use; Utility; Accessibility)
F	-- Cost
F	-- Passengers with functional impairments to be considered within the design process
F	- Social Acceptability
F	-- Visual Appearance
F	-- Effect of impairments (Ergonomic issues with respect to ageing society to be investigated and considered)
N	Visually and ergonomically optimized human control interface (Inclusive design approaches to be applied)
Pr6	**Technical System Factor – for all life cycle phases**
N	Minimum maintenance requirements on other TS (as operator) during the life cycle of the vehicle
W	Minimum repair costs – Replaceable body panels
W	Minimal wear of tires because of lightweight, thereby extending their overall life.
Pr7	**Environmental Factors – for all life cycle phases**
W	Minimum environmental impact of materials used in vehicle
F	High energy efficiency / Low energy consumption (Lightweight Design)
Pr8	**Information System Factors**
N	Satnav & AI driving control system
N	Persistently connected to the "Cloud' network
N	Dashboard control interface (GUI)
N	Minimum training requirement
Pr9	**Management and economic factors—for all life cycle phases**
F	Mobility business model to be evaluated for specified metropolitan cities
S	Mobility service to be cheaper than vehicle ownership

It is important to point out that this paper is not concerned with promoting "design patches" as the ultimate goal, which, sad to say, is what the vast majority of automotive manufacturers on the planet are currently doing. This study wants to promote the highest efficiency set of solutions available for a driverless vehicle at a given time, aligned with natural processes, to improve the lives of all, while securing the integrity of our habitat.

2 DESIGN FOR AGEING

The proportion of older drivers in the population is rising. Their needs and abilities, therefore, need to be considered in the development & design process of an autonomous or driverless vehicle. All current conventional cars exclude some drivers, often unnecessarily, and Inclusive Design in conjunction with Autonomous Driving aims to highlight and reduce such exclusion. This chapter extracts findings from international studies, statistics and surveys associated with automotive design mostly for older drivers and highlights difficulties that are experienced significantly more often by this demographic group. This part of our population experiences changes in sensory capabilities, cognitive capabilities, physical health, mobility and dexterity. For automotive design engineers, this raises many questions about the ways we think about the conceptual design and development of autonomous vehicles.

Driving plays a key role in older drivers' mobility, as 90% of older drivers rely on a private car as their primary mode of transport. This is due to the fact that most people, especially older adults, live in suburbs, exurbs, and rural areas where transportation strongly depends on the automobile [5]. Autonomous transportation is a means of conveyance. It is the key to continued independence of older adults and essential for engagement in the community, social, and everyday activities. Having access to adequate transportation enables individuals to access needed healthcare and community resources, perform activities and engage in social activities.

During the last decade, the design of cars has mainly focused on safety, fuel consumption and pollution decrease of carbon oxides. The challenge of our very next future is to design cars that not only address those aspects but also face the specific needs of the older generation [6].

2.1 DEMOGRAPHIC CHANGES IN POPULATION

People are living longer today for several reasons including advances in medical science, technology, healthcare, nutrition, and sanitation. An essential consequence of this progress is that those aged 60 or older are the fastest growing age group in the world [7]. Furthermore, John Thackara, director of Doors of Perception, says: "Imagine a world where every second European adult is over fifty years old and where two-thirds of disposable consumer income is held by this age-group. By 2020 this will be a reality. There will be a huge demand for services that enable older people to live independently in their own communities as they age." [8]

Global population structure varies demographically according to the quality of life in specific regions. In developed countries like in the EU, the age group of people 65+ years has increased by 7% during last 20 years. The projection in figure 2.1 shows the predicted scenario in 2050 when over 30% of the entire population will be more than 65 years old [Eurostat, 2015]. This data clearly shows a need to investigate the potential of an Inclusive Design approach in the urban context and the significance of personal mobility in maintaining and improving quality of life.

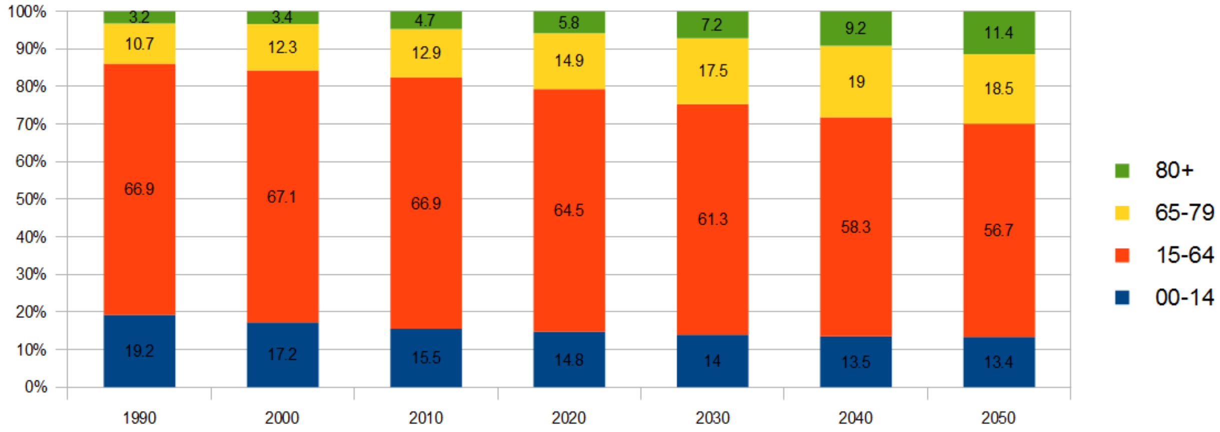


Fig 2.1 - Population structure by major age groups [Eurostat 2015]

2.1.1 PHYSICAL AND COGNITIVE ASPECTS THAT AFFECT ELDERLY DRIVERS

There are many age-related changes in physiological, sensory, perceptual, motor and cognitive abilities that may impact on how older drivers interact with vehicles and driving. These changes include the following relevant declines in ability [9]:

- Decreased mobility & strength
- Reduced ability to process information
- Decreased ability to focus
- Vision problems
- Slower reaction time
- Hearing problems

Decreased Mobility & Strength: There is an array of medical conditions that affect elderly drivers such as Arthritic conditions. Arthritic conditions reduce the person's range of motion, the rate of movement, strength, and motor skill [10].

Reduced Ability to Process Information: The Mayo Foundation estimates that approximately 20% of people over 65 years old suffer from Mild Cognitive Impairment (MCI) which is a mental state prior to dementia. MCI is characterized by loss of a range of cognitive abilities such as declarative/spatial memory (medial temporal lobe system) or higher-order/executive functions (prefrontal cortex).

Decreased Ability to Focus: Older drivers are generally more susceptible to fatigue than younger drivers. Research has shown, however, that older drivers are better at gauging their state of fatigue than younger drivers [11]. Older drivers can also feel nervous or anxious which can also reduce their ability to focus.

Vision Problems: Most aspects of vision typically deteriorate with age. Static acuity - the ability for the eyes to focus on a stationary object - is measured on drivers' tests. Dynamic acuity, the ability for the eyes to stay focused on moving objects, decreases greatly with age, and it's not tested in drivers' vision tests. Even if an older driver might have a perfect static vision, that person's dynamic vision is probably much worse than that of a younger driver with vision [11].

Slower Reaction Time: In average reaction time is estimated by some researchers at 0.2 to 0.3 second slower for drivers 65 and older, with an accompanying drop in motor skills that can further exaggerate the delay [11]. Furthermore, due to arthritis, stiff joints, reduced muscle mass, or other health problems, older drivers have slower reactions such as turning their head quickly enough to scan side streets or backing up.

Hearing Problems: Hearing sensitivity deteriorates over time. Some drivers may experience very little hearing loss over time, but keep in mind that the brain's ability to distinguish one sound over another (for example, to hear an approaching siren over music playing on the radio) might still deteriorate [11].

2.1.2 SOCIAL ASPECTS THAT AFFECT THE ELDERLY

However, physical and mental changes are not the only characteristics to take into consideration. Social changes such as social isolation, lack of mobility and loss of independence are other factors that have a large influence as to why people don't want to give up driving [5]. Research shows that loneliness and isolation are some of the reasons that cause depression among the elderly. Of Americans ages 65 and older, two million suffer from full-blown depression and another five million suffer from a less severe form of the illness [12].

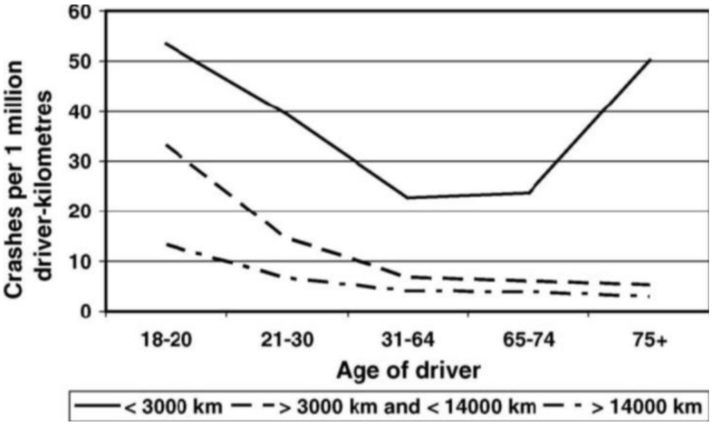


Fig. 2.2 - Annual crash involvement for different driver ages

2.1.3 CRASH INVOLVEMENT FOR DIFFERENT DRIVERS AGES

As an essential result of the growing research interest it can be now proven that although the risk of older drivers of being injured or killed in accidents is very high, older drivers are not a road hazard, having a higher risk of accidents than younger drivers. Only drivers with a mileage bias under 3000 km per year and over the age of 74 are over-involved in accidents. In general older drivers seem to be very safe drivers as shown in Figure 2.2 [13].

If we imagine this figure for the expected population in 20-30 years, we can expect a rising number of accidents in the age group over 65 as this part of the population will significantly grow.

The law in the UK states that when you reach 70 years of age, you will need to renew your licence and complete medical questionnaire every three years to make sure that you can still drive safely.

2.1.4 BRITISH DISABILITY SURVEYS

The UK government assembled data as a means of assessing future care-provision requirements in Great Britain. These data include the Survey of Disability in Great Britain and the Disability Follow-up (DFS) to the 1996/97 Family Resources Survey (FRS) and may be adapted for autonomous vehicle evaluation.

The Survey of Disability in Great Britain

The Survey of Disability in Great Britain [14] was carried out between 1985 and 1988. It aimed to provide up-to-date information about the number of disabled people in Britain with different levels of severity of functional impairment. The survey used 13 different types of disabilities based on those identified in the ICIDH [15] and gave estimates of the prevalence of each type. It showed that musculoskeletal complaints, most notably arthritis, were the most commonly cited causes of disability among adults [16].

The Disability Follow-up Survey

The 1996/97 Disability follow-up to the Family Resources Survey was primarily designed to provide data on entitlement to state benefits. The results showed that an estimated 8 579 000 (total 58.3 million in 1997) adults in Great Britain - 20% of the adult population - had a disability according to the definition used. 34% of these disabled people had mild levels of impairment (i.e. high capability), 45% had a moderate impairment (medium capability), and 21% had a severe impairment (low capability). It was also found that 48% of the disabled population were aged 65 or older and 29% were aged 75 years or more [17].

This survey specifies 13 capability scales of which 7 are particularly pertinent to vehicle evaluation (Locomotion, Reaching and Stretching, Dexterity, Vision, Hearing, Communication, Intellectual Functioning). Each of these scales is subdivided into various levels of impairment, ranging from 0 (fully able) to 10 (most severe impairment).

AGE	OVERALL SCORE											TOTALS				
	0	1	2	3	4	5	6	7	8	9	10	Able	Disabled	Total	Able	Disabled
16-49	25885	485	259	215	229	253	252	227	177	85	23	25885	2205	28090	92.15%	7.85%
50-64	7249	442	323	249	331	246	208	208	185	96	7	7249	2295	9544	75.95%	24.05%
65-74	3429	277	231	182	188	189	174	133	113	66	23	3429	1576	5005	68.51%	31.49%
75+	1765	572	323	343	272	288	216	219	127	119	24	1765	2503	4268	41.35%	58.65%
16+	38328	1776	1136	989	1020	976	850	787	602	366	77	38328	8579	46907	81.71%	18.29%

Tab.2.1 - 1996/97 Disability Survey in Great Britain

Scale of Impairment (0 = fully able; 10 = most severe impairment)

For inclusive design, the range of user capabilities rather than disabilities is of most importance: high capability demands that exceed the capabilities of the users gives rise to design exclusion. The figure below shows the overall capability loss segregated by age bands and severity levels (1-10 from slight to severe). It can be seen that frequency and severity of impairment increase with age [17].

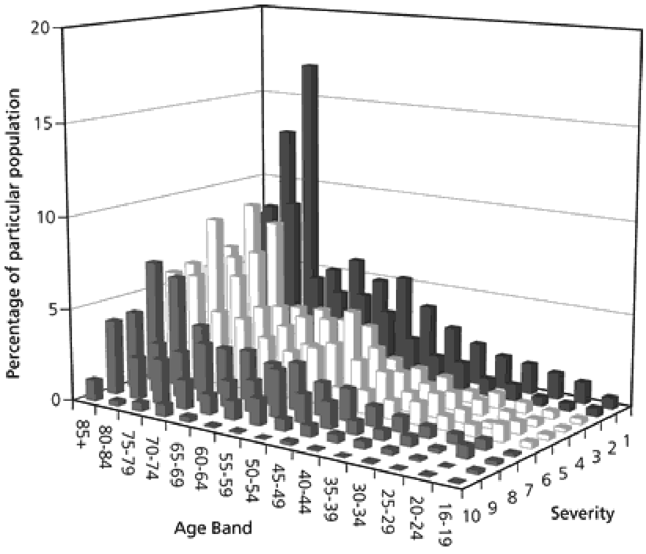


Fig. 2.3 - Inclusive Design Survey [16]

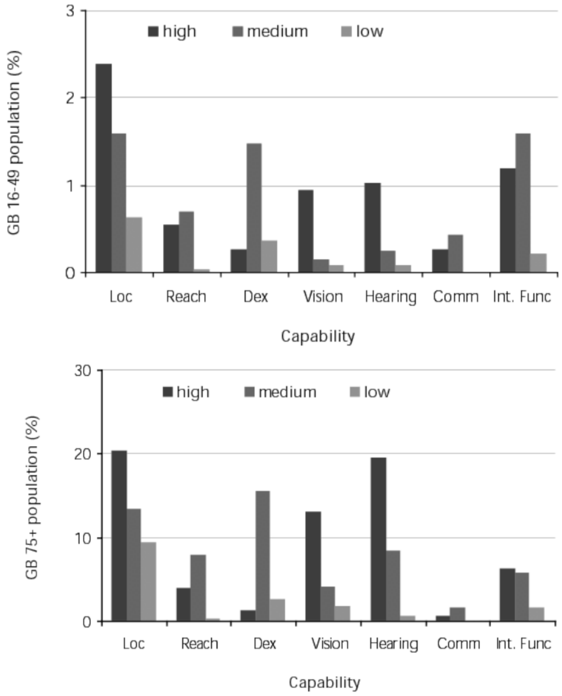


Fig. 2.4 & Fig. 2.5 - Capabilities for GB 16-49; Capabilities for GB 75+ population [16]

A summary of the DFS data is presented in Figures 2.4 and 2.5 for the 16-49 years old and 75+ populations. Perhaps the most striking feature is the order of magnitude difference in the scales used for each figure. While the graphs have similar distributions, the percentage of those with a loss of capability in the 75+ age band is 10 times higher than for the 16-49 band [18].

In terms of the prevalence of capability losses, the expected distribution for each capability would show the most considerable proportion of adults with little or no impairment of that capability. Fewer adults would exhibit moderate impairments, and fewer still would be severely impaired.

Loss of Capability	Number of GB 16+ population	Percentage of GB 16+ population
Motion	6710000	14.30%
Sensory	3979000	8.50%
Cognitive	2622000	5.60%
Motion Only	2915000	6.20%
Sensory Only	771000	1.60%
Cognitive Only	431000	0.90%
Motion and Sensory Only	1819000	3.90%
Sensory and Cognitive Only	213000	0.50%
Congitive and Motion Only	801000	1.70%
Motion, Sensory and Cognitive	1175000	2.50%
Motion, Sensory or Cognitive	8126000	17.30%

Tab. 2.2 - Multiple capability losses for GB [18]

Many people will, at some stage of their life, exhibit more than one capability loss. From a design perspective, this is important since each loss has the potential to cause exclusion. Design improvement needs to address each capability loss if the full benefit of the improvements is to be realized. The disability surveys provide valuable information for analysing multiple capability losses. For example, Table 2.2 summarizes the data extracted from the Disability Follow-up Survey. It is evident that at least half of those with some loss of capability has more than one loss of capability [18].

2.2 INCLUSIVE DESIGN

Inclusive design as introduced by Roger Coleman and further developed through the research team around P. John Clarkson builds upon this need and can be defined as “a methodology aiming at enabling designers to ensure that their products and services address the needs of the widest possible audience” [16].

The term “inclusive design” is mainly used in European countries, whereas in the U.S. and Japan researchers mainly talk about “universal design”. Experts at the US Centre for Universal Design have introduced 7 principles that they suggest designers use when designing products [19].

1. **Equitable use** - the design is useful and marketable to people with diverse abilities.
2. **Flexibility in use** - the design accommodates a wide range of individual preferences and abilities.
3. **Simple and intuitive use** - use of the design is easy to understand, regardless of the user’s experience, knowledge, language skills, or current concentration level.
4. **Perceptible information** - the design communicates necessary information effectively to the user, regardless of ambient conditions or the user’s sensory abilities.
5. **Tolerance for error** - the design minimizes hazards and the adverse consequences of accidental or unintended actions.
6. **Low physical effort** - the design can be used efficiently and comfortably and with a minimum of fatigue.
7. **Size and space for approach and use** - appropriate size and space is provided for approach, reach, manipulation, and use regardless of user’s body size, posture, or mobility.

This methodology of inclusive design represents an essential step for the design of autonomous vehicles. The consideration of inclusive design elements can help to establish a new market position and design autonomous vehicles that are accessible to the whole population [20].

Design typically involves the identification of a need, creation of solutions to meet that need, and then a review to ensure that the need is met. Consequently, when considering a design approach, it is also necessary to consider the measure of success, i.e. the point at which the design is considered to have met the stipulated requirements. However, the stipulated requirements themselves have the potential to exclude certain sections of the population from using the resultant product [16].

2.2.1 TYPES OF USER CAPABILITIES

User capabilities can be broken down into various categories, of which the following five are particularly relevant for vehicle interaction. All of these should be considered when designing or assessing a vehicle [21].

- **Vision** is the ability to use the colour and brightness of light to detect objects, discriminate between different surfaces and discern the detail on a surface.
- **Hearing** is the ability to discriminate specific tones or speech from ambient noise and to tell where sounds are coming from.
- **Thinking** is the ability to process information, hold attention, store and retrieve memories and select appropriate responses and actions. The ability to understand other people and express oneself to others can also be categorised under thinking.
- **Reach and Dexterity** concerns the abilities of the arms. It is composed of the ability to reach to various places around the body, perform fine finger manipulation, pick up and carry objects and grasp and squeeze objects.
- **Mobility** is the ability to move around, climb steps and balance

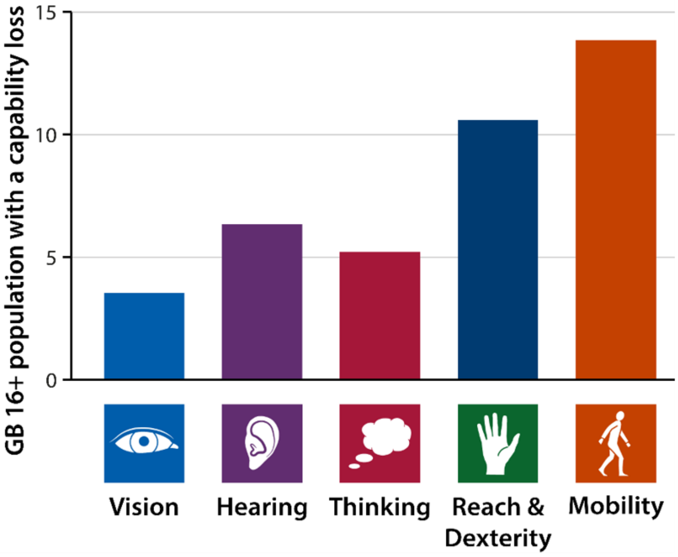


Fig. 2.6 - User Capabilities - 1996/97 Disability Follow-up Survey - Great Britain [22]

2.2.2 A MODEL OF VEHICLE INTERACTION

An interaction with an autonomous vehicle or mobility service typically requires a cycle where the user:

- Perceives
- Thinks
- Acts

Perceiving involves sensory capabilities like Vision and Hearing. Thinking is also required to process the information received through the senses. Motor capabilities like Reach & Dexterity may also be needed. Acting typically involves motor capabilities like Reach & Dexterity and Mobility, as well as Thinking to control the action. Sensory capabilities like Vision are also necessary but not crucial (e.g. to guide the fingers to press the right buttons) [21].

Thus, multiple capabilities are involved in using an autonomous vehicle or mobility service, and these are intertwined. It is inadequate to consider an individual capability in isolation. To create an effective inclusive design, capabilities need to be considered together.

2.3 HUMAN FACTOR DESIGN

Human factors design of the autonomous vehicle should address the areas posing difficulty of older people, which can be simplified as follows:

- Entry and Egress (Getting in and out of the car)
- Finding a comfortable driving position
- Human Machine Interface (HMI)

Other difficulties like mechanical controls, nigh use, visual factors such as glare and field of view, fuelling or maintenance will become obsolete. These are all issues related mainly to the conventional driving and conventional vehicles, not to autonomous taxi services.

2.3.1 INGRESS & EGRESS

It is essential that driverless cars used in the robotic taxi service are suited to the needs of elderly and mobility impaired people. Therefore, the cars should be easy and comfortable to enter and leave as well as comfortable to travel in. Entering and leaving has relatively high importance in the taxi service as the journeys often are short and there are many entries and exits.

A sizeable proportion of older drivers reports difficulty getting in and out of their cars. Getting out is more widely reported as a problem, with around one third (32.2%) of older drivers experiencing difficulty, while around one quarter (25.5%) of older drivers experience difficulty getting into their cars [23].

Fig. 2.7 - Car features causing issues to the older drivers experiencing difficulties getting in and out.

Part of the survey conducted by Paul Herriots in 2005 was a follow-up questionnaire. Those respondents (of all ages) who had trouble getting in and out were asked to identify on a diagram the areas of the car causing them problems. The car features that caused problems when getting in and out for older drivers are shown in Figure 2.7 (percentages relate only to those older drivers who experienced difficulties getting in and out). As an open-ended follow-up question, those respondents who experienced difficulty were asked to write down their 'biggest problem' when getting into and also getting out of a car [18]. In the literature, only very few studies have investigated egress motion. Moreover, egress motions were found to be more difficult for older or disabled people than ingress motions [24].

In 1985 British Institute for Consumer Ergonomics carried out a study of elderly and disabled people entering and leaving cars interviews, postal surveys and practical trials in different cars, and in a dimensionally variable car-buck. The results in table 2.3 (Column - Experimental Study) show the nature of problems and establish dimensional limits to the doorway which would cause minimal problems [25].

For cars used in autonomous taxi service, all these dimensions should as far as possible be in the comfortable range as the journeys often are short so the entering and exiting get relatively high importance. For driverless taxis, with their slightly short journeys, it is essential that the passengers can enter and leave the car quickly, easily and comfortably. That will make the taxi service more attractive for the elderly and disabled passengers.

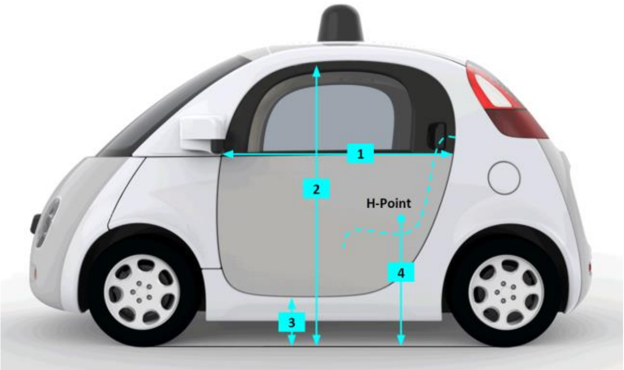


Fig. 2.8 - Ingress & Egress - Critical Benchmarking Dimensions [SAE 1998]

CRITICAL BENCHMARKING DIMENSIONS	Fig. 2.8	SAE J1100	Exp. Study	SC	MC	SCV	MV	TX4	TX5
Doorway Width	1	L508	900	760	800	830	790	880	900
Doorway Height Above the Ground	2	H50	1380	1180	1185	1510	1550	1720	1655
Sill Height above the Ground	3	H115	350	360	375	430	440	370	360
Seat Height above the Ground	4	H5	540	530	520	660	790	880	887

Tab. 2.3 - Ingress & Egress - Critical Benchmarking Dimensions [SAE 1998]
(SC: Small Car; MC: Medium Car; SCV: Small Commercial Vehicle;
MV: Minivan; London Taxi TX4 and TX5)

2.3.1.1 DOORWAY WIDTH (SAE J1100 - L508)

The doorway had to be broad enough to let the wheelchair be positioned outside the doorway just beside the seat. At a doorway width of 900 mm or more, the back door-post did not interfere with the transfer operation. It has been reported that at a doorway width of 800 mm the subjects had to move slightly forward around the back door-post and then move sideways into the car. All the ambulant disabled could manage a doorway width of 800 mm, but 900 mm was felt to be more comfortable [25].

2.3.1.2 SLIDING DOOR

Sliding door brings a considerable advantage to busy urban roads and tight car parks making the entry more accessible, as sliding doors protrude from the body of the car when they open. Main disadvantage from an inclusive design perspective is that sliding doors are very uncomfortable for the passengers to open since they need to put in force when compared to the hinged doors.

Fig. 2.9 - Brubaker Box (1972)

An automatic electronically operated side sliding door system would be therefore a suitable solution for driverless taxis. However, they are not widely used as they are expensive to integrate and maintain. It also increases the weight of the car making it heavier compared to cars with hinged doors. The mechanism also has narrower tolerances than conventional hinged designs.

2.3.1.3 DOORWAY HEIGHT (SAE J1100 - H50)

The doorway height must be at least 1330 mm from the ground to the upper part of the door frame. Wheelchair users who transfer from the wheelchair to the car seat in a sitting position can manage the operation with this height, but a height of 1380 mm makes it more

comfortable and safe. The height should be 1380 mm or more for an assistant and for people who stand up when transferring to the car seat [25].

2.3.1.4 DOOR-SILL HEIGHT

The height of the door-sill affects the ease or difficulty in the phase of lifting one’s legs in or out of the car. The higher the sill, the more strain the subjects had to exert to lift their feet over the sill, and this was also found to affect the phase of moving their bodies in or out of the car. The recommended value is 350 mm above the ground [25].

2.3.1.5 SEAT POSITION AND BACK DOOR-POST

The best position of the seat in relation to the back door-post was when the upper portion of the seat backrest was placed at the same horizontal position as the back door-post. Then the whole seat was within reach for the subject, and the back door-post could serve as a support. A distance of about 840 mm between the backrest of the seat and the front door-post is needed when the passenger lifts and swings his/her legs to pass the front door-post, while a long distance gives better comfort [25].

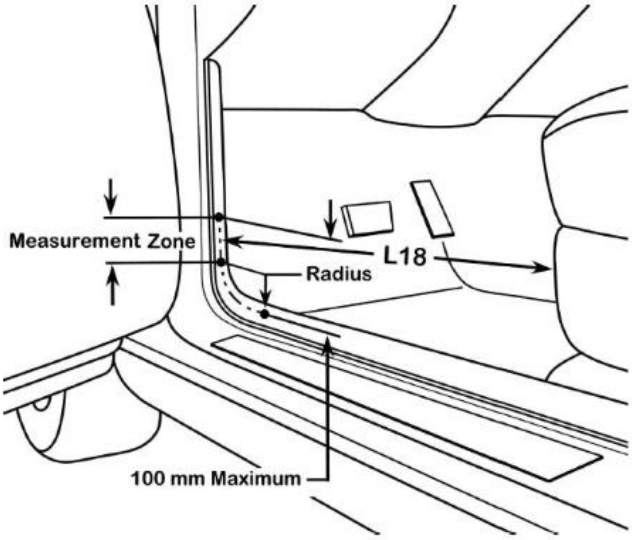


Fig.2.10 - Foot Clearance (SAE J1100 - L18)

2.3.1.6 FOOT ENTRANCE CLEARANCE (SAE J1100 - L18)

A space of at least 300 mm and for comfort 350 mm from the seat corner to the front door-post, measured longitudinally or skew, is needed to make room for the feet when lifting them in or out of the car. The length of shoes can be 300 mm or sometimes more [25].

2.3.1.7 HANDLES

Figure 10 represents the interior of the London Taxi TX4. Highly visible yellow handles helped the passengers when getting into and out of the taxi and made it more comfortable and safe. The handles on the doorposts are used as support when lifting the feet in or out. The handle on the door was used when lifting the feet in or out or when sitting down and raising from the rear facing swivel seat.

Figure 2.11. - London Taxi TX4 - Interior

In the driverless taxi, suitable handles should be mounted on the dashboard, the upper part of the front post, the roof just inside the upper part of the door frame and on the door just beneath the window.

2.3.1.8 WHEELCHAIR ACCESS

In some areas (mainly larger cities), licensed taxis must be wheelchair accessible. For example, every licensed London taxi is wheelchair accessible and features a host of accessibility aids. For wheelchair users, access via the ramps allows comfortable boarding. The large, spacious interior allows the chair to be moved into the securing position where the seatbelts restraints secure the chair safely and securely. For passengers with limited mobility, the swivel seat extends to the exterior of the vehicle to allow seamless movement of the vehicle. An intermediate step can also assist passengers with limited accessibility.

The minimum ramp width, including the lending, should be 915mm. The recommended landing length should be a minimum of 1525mm [26]. When considering the integration of a wheelchair ramp into the vehicle, the door width has to be at least equal to the minimum ramp width.

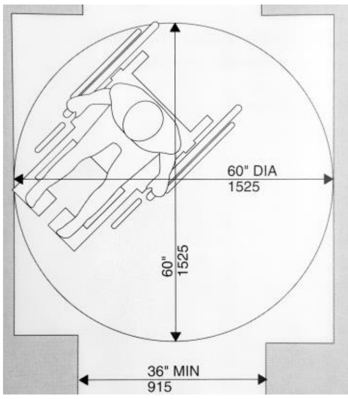


Fig. 2.12 - Wheelchair Access Dimensions [26]

2.3.2 PASSENGER DRIVING COMFORT

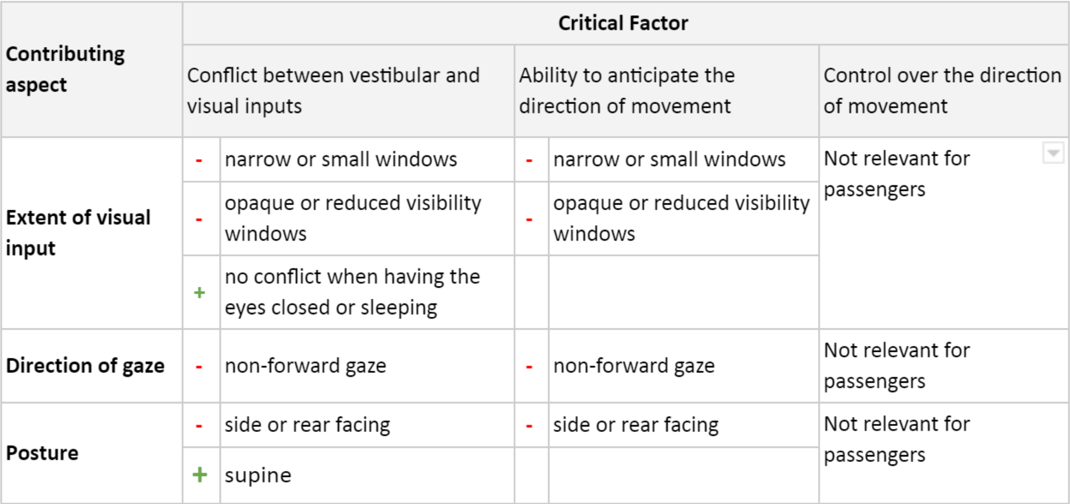
Driving creates significant stress to the neck and the upper and lower back. Everyone ends up feeling stiff if he or she travels for long enough. However, people with musculoskeletal disorders (MSDs), especially neck and back disorders, suffer from increased stiffness and pain after much shorter periods of time. This means that the length of time for which you can sit comfortably in a car is dependent upon whether you have such a problem.

Almost all the drivers surveyed (95.2%) by Paul Herriots [23] recorded that they were able to get a comfortable driving position. However, significantly older drivers used additional items within their cars that may have helped them achieve this: 6% of older drivers used a bead mat while no younger drivers in the survey did so. 24.9% used a seat cushion compared to 2.1% of younger drivers.

2.3.2.1 MOTION SICKNESS

Being a passenger in a driverless vehicle will be entirely different from riding along in a train or other mode of public transportation, for, unlike trains, self-driving cars will be subject to more lateral acceleration/deceleration as well as longitudinal acceleration/deceleration that is drastically less smooth.

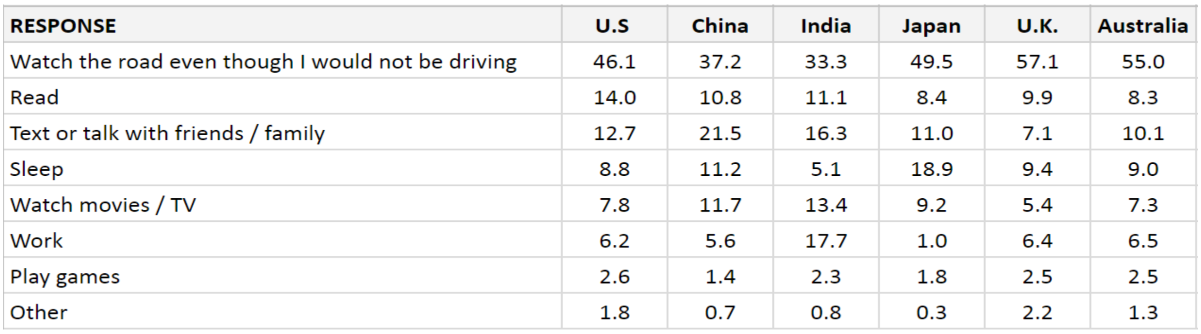
Motion sickness, also known as kinetosis and travel sickness, is expected to be more prevalent among users of driverless vehicles than of conventional ones, according to a new study by the University of Michigan Transportation Research Institute (UMTRI). That’s because the three main factors that trigger nausea (conflict between the inner ear and visual inputs, inability to anticipate the direction of motion, and lack of control over the direction of motion) are all exacerbated in self-driving cars [27].



Contributing aspect	Critical Factor				
		Conflict between vestibular and visual inputs		Ability to anticipate the direction of movement	Control over the direction of movement
Extent of visual input	-	narrow or small windows	-	narrow or small windows	Not relevant for passengers
	-	opaque or reduced visibility windows	-	opaque or reduced visibility windows	
	+	no conflict when having the eyes closed or sleeping			
Direction of gaze	-	non-forward gaze	-	non-forward gaze	Not relevant for passengers
Posture	-	side or rear facing	-	side or rear facing	Not relevant for passengers
	+	supine			

Tab. 2.4 - Contributing aspects that influence the impact of the critical factors for motion sickness. An adverse effect (-) indicates a worsening of motion sickness, while a positive effect (+) indicates an improvement.

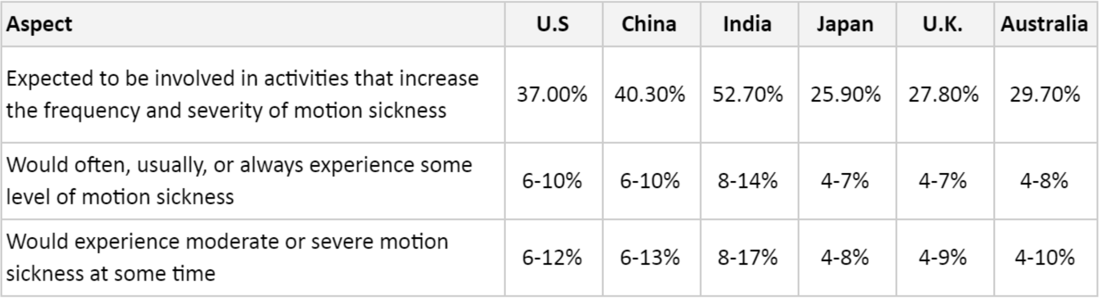
Whether or not passengers experience motion sickness is mostly determined by the type of activity, they’re engaged in in the vehicle. In an opinion survey of 3,255 adults from the U.S., China, India, Japan, Australia and the U.K., respondents named reading, talking/texting, sleeping, watching movies/TV, working and playing games as the activities they’ll engage in while riding in self-driving cars. According to the study, almost all of the activities mentioned worsening the frequency and severity of motion sickness.



RESPONSE	U.S	China	India	Japan	U.K.	Australia
Watch the road even though I would not be driving	46.1	37.2	33.3	49.5	57.1	55.0
Read	14.0	10.8	11.1	8.4	9.9	8.3
Text or talk with friends / family	12.7	21.5	16.3	11.0	7.1	10.1
Sleep	8.8	11.2	5.1	18.9	9.4	9.0
Watch movies / TV	7.8	11.7	13.4	9.2	5.4	7.3
Work	6.2	5.6	17.7	1.0	6.4	6.5
Play games	2.6	1.4	2.3	1.8	2.5	2.5
Other	1.8	0.7	0.8	0.3	2.2	1.3

Tab. 2.5 - Percentage of responses to the 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?" Those who would not ride in self-driving vehicles were excluded [28].

The UMTRI report calculated the expected frequency and severity of motion sickness in autonomous vehicles, based on a survey of what more than 3,200 adults in six different countries are likely to do in a fully autonomous car [27].



Aspect	U.S	China	India	Japan	U.K.	Australia
Expected to be involved in activities that increase the frequency and severity of motion sickness	37.00%	40.30%	52.70%	25.90%	27.80%	29.70%
Would often, usually, or always experience some level of motion sickness	6-10%	6-10%	8-14%	4-7%	4-7%	4-8%
Would experience moderate or severe motion sickness at some time	6-12%	6-13%	8-17%	4-8%	4-9%	4-10%

Tab. 2.6 - Percentage of adult passengers in fully self-driving vehicles who are expected to participate in motion-sickness-related activities, and the resultant percentages of adult passengers expected to experience motion sickness.

The calculations in this report were based on the assumptions that the cabin of self-driving vehicles would be similar to that of conventional vehicles, as would be the lateral and longitudinal acceleration profiles. To the extent that smaller, opaque, or reduced-visibility windows would be employed in self-driving vehicles, the frequency and severity of motion sickness would increase. Conversely, if self-driving vehicles would provide a smoother ride than conventional vehicles, the frequency and severity of motion sickness would decrease [28]**.**

2.3.2.2 SEAT

The seat should be relatively hard and flat to make it easy to sit down on the edge of the seat, and then move into the right position on the seat. The seat surface must not have too much friction, as this makes it more difficult for the passengers to swivel while getting in and out and to find a proper sitting position [25].

The seat height influences the height necessary for the top part of the door frame. If there is a pavement, the effective seat height and the height of the upper part of the door frame is lower in relation to the subject. A lower seat would make it more difficult for ambulant disabled to sit down and rise, and a lower door frame would cause a higher risk of hitting their heads on the edge of the roof. It is therefore essential that the seat for driverless taxis should be designed to allow more adjustment in the vertical direction than the conventional seats to make the cars suitable for elderly and disabled people.

The seat height should ideally be between 430mm and 460mm above the floor. Sloping seat cushions should be kept to a minimum as these can make it more difficult for a disabled passenger to get up from their seat. Where a slope is provided with the centre of the cushion should not be less than 400mm above the foot space in front of the seat [29]. This recommendation is unfortunately outside the range stated in SAE J1100 where the seat height should be positioned between 127mm and 405mm for Class A vehicles.

The seat position should also be automatically adjustable in driverless taxis. The car can use its integrated devices (e.g. Lidar, Radar) to sense the height of the longitudinal surroundings. When booked, the vehicle recognizes passenger’s predefined profile and set the seat to the desired position prior to passenger boarding.

Fig. 2.13 - Multi-Axis Suspension Seat by Bose

The ideal seat in a driverless taxi should isolate passengers from road vibrations, shaking and unwanted motion. As Amar Bose (founder of Bose Corporation) says, it's about adapting the single-axis technology used in heavy trucks to a multi-axis design more appropriate for passenger or driverless vehicles.

Lear Corporation, a major supplier of interior components to the global automobile industry, developed a concept interior that demonstrated how seating, instrument panels, environmental controls, and window and door controls could be made more usable for older people. Lear called their concept interior the “TransG” for trans-generational. It had a feature such as swivelling power front seats. The seats rotate out at a 45° angle to facilitate getting in and out and reduced dependence on right balance or strength.

Fig. 2.14 - Swivel Seat developed by Lear Corporation

The integrated seat belts had a four-point arrangement with a centre-positioned buckle that was easy to latch and see. This design made the act of fastening the belt much more comfortable for people with limited dexterity or a limited range of head movement. They secured the occupant more uniformly and were more comfortable. A memory control automatically adjusted the seat, instruments, and pedals for each user.

2.3.2.3 ARMREST

In an automotive context, an armrest is a feature found in many modern vehicles on which occupants can rest their arms during the journey. Frequently armrests are built into the door of the car. Many people with little or no strength or flexibility in their limbs are likely to use a seat by sitting first so that their body is supported, and then moving their legs gradually round until they are seated comfortably. In some cases, this is done by physically lifting the leg or legs with the hands. Where seats do not have moveable armrests, this manoeuvre is not possible. Ideally, all armrests within the vehicle should be moveable.

2.3.3 HUMAN MACHINE INTERFACE (HMI)

The human-machine interface (HMI) in a vehicle is subject to constant change. The growth in number and complexity of technical systems in the vehicle cockpit confronts the driver with new displays, components, and interaction logic. It is estimated that the majority of all automotive innovations is in the area of electronics [30].

In autonomous vehicles, most of these electronic innovations communicate with the passenger and need to be monitored and/or eventually controlled by the passenger. Therefore, an appropriate HMI is of fundamental relevance for the smooth and safe control of a vehicle.

Customer research has demonstrated that positive and negative experiences with these systems can massively influence the overall acceptance of a vehicle (Ford internal investigations) [30]. For the definition of system requirements, the understanding of the user from a psychological and physiological perspective is fundamental for safe system operation and product acceptance [30].

Perception

In terms of using an autonomous car and operating HMI, visual perception is the prime source of information. Visual perception reflects the activity of the peripheral sensor ("eye") and its signal analysis visual cortex. Beyond readability, four typical characteristics of that system have to be considered:

- Contrast Perception
- Colour Blindness (about 8% of the population)
- Movement Perception (guiding the user's eyes to the position of interest on a screen)
- Geometrical feature extraction (minimalistic design for faster detection and reaction)

Cognition

Cognition deals with attention (essential for correct information selection, processing, and reaction), information reduction, and semantic interpretation.

Learning and memory

Comprehensibility is not sufficient for an efficient HMI operation. Particularly with elderly users, it is well known that memory plays a fundamental role in the smooth and correct operation. It always recommended using same logical rules, terminology, and symbols. It is beneficial to use widely accepted open standards of operation - so-called stereotypes - to make the system intuitive.

Emotion and Motivation

User experience is one of the key terms within the HMI-expert language. A pleasant HMI experience can be triggered by comprehensible dialogues and emotionally appealing visualizations. Fulfilling such requirements is a key to success and product acceptance [26].

Psychomotor performance and age influence

HMI designers need to pay particular attention to the presbyopia effect. This means that the distance for clear vision is moving from 40 cm for 25-year-old to 4m for 70-year-old people [27]. Even this impairment can be (partially) compensated by spectacles; it is accompanied by a slower refocusing from near to distance view (slower "accommodation"). This effect requires the legibility of "big-fonts views" and may be as well a reason to think about head-up displays having the projected virtual display in front of the car.

2.3.3.1 INTERFACE DESIGN

Interface design is concerned with the classification of displays, controls, and other input possibilities such as voice control or other modalities (e.g., gestures). In terms of the classification of controls, the development engineer needs to choose, for example, between discrete (e.g., on/off) versus analogue (e.g., volume control) control modalities, touch versus controller-based operation of the system or a combination of both.

Voice Control

Voice control is a well-known and accepted technology of interaction. In autonomous vehicles, it is used for all menu operations as well as a selection of specific content, primarily for navigation. This technology will be the first point of contact with the autonomous system from an inclusive design point of view

2.3.3.2 INTERACTION DESIGN

In a first step, decisions that have to be made on the overall screen layout include the choice of which information is presented where on display (s). An important design goal for the overall screen layout is that a consistent grid of information enables a fast orientation of the user and results in a faster finding of content [30].

Fig. 2.15 - An example, a variant of a multifunctional display of Tesla

The second step of interaction design is the implemented logic of operations and menus. This means that the organization of screen flows has to be designed. For example, the presented content of the cluster can be organized based on a hierarchical logic. Using a hierarchical logic allows the user to operate with popular stereotypes like those from other devices such as a mobile phone. A system that uses a hierarchical logic of operation supports the user to quickly understand the geometric logic in which the menus and menu entries are arranged within the system [30].

And in the third step, interaction design deals with the visualization, which metaphors and stereotypes should be used to facilitate the users' operation, and the logic of operations and menus [30].

2.3.3.3 FUTURE PLATFORMS

In terms of HMI, all future autonomous platforms will be mostly controlled by touch screens. All the participants interviewed during the research conducted by Marcus Cervantez [10] expressed their preference for touchscreen interfaces over physical ones. They said that touchscreen interfaces are larger, which makes them more legible and easier to use, especially, when it comes to pressing buttons.

2.4 INCLUSIVE DESIGN ASSESSING DEMAND AND EXCLUSION

As stated previously, interactions with driverless vehicle place demands on the users' capabilities. Users may be excluded from using a driverless vehicle if any of its demands are higher than their capabilities. For example, a vehicle with very low roof height requires a high level of bending capability to ingress. People with age-related reduced mobility will be excluded from its use.

This chapter explains how to assess the demands that a driverless vehicle places on various user capabilities. These demand ratings can be used together with survey data to estimate the proportion of the population who would be excluded from using a conventional and a driverless vehicle.

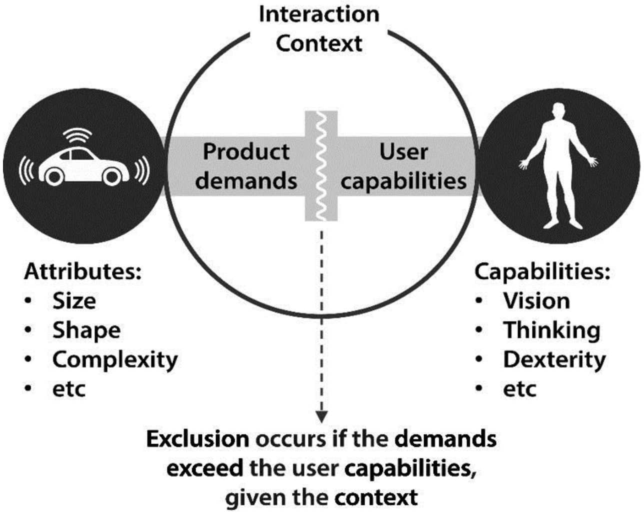


Fig. 2.16 - Assessing Demand and Exclusion [21]

2.4.1 INTRODUCTION TO ASSESSING DEMAND

An initial assessment can be made by rating the demand on each capability on a scale from Low to High. To do this, there are various factors that should be considered [16]:

- For **Vision**, consider the size, shape, contrast, colour and placement of the graphical and text elements.
- For **Hearing**, consider the volume, pitch, clarity and location of sounds produced by the HMI or the vehicle itself.
- For **Thinking**, consider how much demand the vehicle places on a user's memory, how much it helps the user to interpret its interface, how much attention it demands, and how much prior experience it assumes.
- For **Reach and Dexterity**, consider the forces, movements and types of grip required to use the vehicle.
- For **Mobility**, consider whether the vehicle requires the user to control it and how difficult it is for the user to get in and out. If designing a vehicle interior, it necessary to consider whether it provides suitable features to assist balance and support mobility aids.

2.4.2 INCLUSIVE DESIGN TOOLKIT

ASSESSING DEMAND USING DEFINED SCALES

The Inclusive Design Toolkit and Inclusive Design Calculator was created by the Cambridge Engineering Design Centre, as part of the ID-3 Inclusive Design Consortium run by the Centre for Business Innovation. This calculator estimates the proportion of the British population who would be unable to use a vehicle or service because of the demands that it places on the users' capabilities.

As stated in previously, data is available on how many people in the British population have various levels of capability. This data from the 1996/97 Family Resources Survey and the Disability Follow-up to the Family Resources Survey can be used to calculate how many people would be excluded from a product with a set of demands. The 1996/97 Family Resources Survey [18] was commissioned by the UK government to provide statistics about households in Great Britain.

This survey data can be linked to demand assessments to estimate how many people would be excluded from using a driverless vehicle. To do this, pre-defined scales are used for assessing the vehicle demands. The Inclusive Design Calculator scales have been constructed based on the questions in the Disability Follow-up Survey.

The survey asked participants questions about whether they could perform specific tasks, e.g. 'Can you see well enough to read a newspaper headline?'. These tasks were then arranged into ordered scales, such as the one shown in figure 2.17. Some of the capability categories have several scales. For example, the category 'Reach & Dexterity' has scales dealing with strength, dexterity, reaching forward and up, and reaching down. To assess a vehicle, assessors consider each scale in turn. For each, they determine the level of that capability needed in order to use the vehicle and compare this level of capability to each of the tasks in the survey [21]. The number of people who would be excluded as a result of these demands is then calculated from the survey data using the Exclusion Calculator at calc.inclusivedesigntoolkit.com [31].

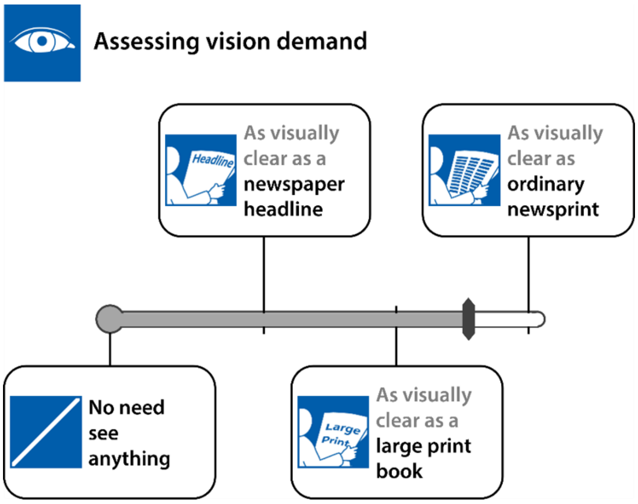


Fig. 2.17 - A scale for assessing vision demand based on data from the Disability Follow-up Survey.

2.4.3 INCLUSIVE DESIGN TOOLKIT - CASE STUDY - DRIVERLESS VEHICLE

Conventional vehicles require the driver to have a driving license and to be able to control the car over the entire journey. They are equipped with a steering wheel, pedals, automatic or manual gear shift and many other buttons and controls. Driving such a car requires driver's full attention over the entire journey. This demands the driver to have the physical and mental capability to perform a complex sequence of tasks. An autonomous car is a vehicle that can sense its environment and navigate without human input. The recent arrival of this technology should completely resolve this issue and should guarantee better inclusivity in terms of mobility.

2.4.3.1 SPECIFICATION OF CONTEXT OF USE - VISIONARY SCENARIO

The first step of the assessment process is to state any assumptions regarding the environment in which the driverless vehicle is to be used and the sequence of actions encountered when using it. In this case, it will be assumed that a ride with the driverless taxi will be requested using a digital device and the vehicle will arrive at the pick up the user and take him or her to the desired destination.

The primary actions required would be:

1) Requesting or scheduling up a journey using a digital device (e.g. mobile phone, tablet or laptop). To make the first step of the mobility service fully inclusive, it is crucial to consider users capabilities when using the device or to access its interface. For example, visually impaired people could use Screen Readers software, Braille Keyboards or Refreshable Braille Displays, paralyzed wheelchair users could use Hands-Free Mouse Tracking systems or Voice Controls to request a journey. To provide ideal comfort and pleasurable journey experience, the user should have the ability to create a personal profile or user account which allows custom specification and requirements to fit the user's needs (e.g. a wheelchair ramp).
2) The user is informed that the journey request has been processed the vehicle is on its way to the pick-up location, and he or she could await the vehicle in a certain period. It allows the user to plan. When the vehicle arrives, it will check users identity (e.g. by entering an access code or by face or voice recognition device), then automatically set up the seat position according to the users pre-set profile and opens the door to allow the user to enter to the vehicle.
3) The user will find a comfortable driving position and will be asked to confirm the journey destination (e.g. using voice, gesture command or by pressing a device button)
4) Once confirmed, the person is asked to fasten a seat belt prior the departure. The car won't move unless everyone has his seat belt buckled.
5) As in a conventional car, the person will be able to command the car to make an additional stop, set up the interior temperature or play music. But on the top of it, one will able to read the news, watch movies, sleep or just to enjoy the ride without the need for being in control.
6) At the end of the journey, the car will park itself at a suitable spot, provide the passenger with journey details, it will automatically open the door alongside a pavement, and the passenger will be asked to lose the seat belt and leave the car. Using cameras, the car will sense the interior to check if the passenger hasn't left anything behind, it will shut the door and charge passengers account.

2.4.3.2 ASSESS CAPABILITY DEMAND

The second step of the assessment requires the determination of the number of users excluded from using the vehicle because of the mismatch between their capabilities and the functional demands made by the driverless taxi. This is calculated by assessing the levels of each of the functional capabilities required to undertake the actions listed above.

Consequently, by re-designing the vehicle to lessen the demand, a more extensive range of users can potentially be included, and no one is excluded unnecessarily by considering one cause to the detriment of others. To support this concept of countering design exclusion, it is necessary to consider methods of assessing the features of a vehicle and the user's interaction with them to establish the capability demands placed upon the user.

Many factors can diminish the driving performance of older adults. Among these factors are age-related changes in reaction time and visual, cognitive, and/or muscle disorders that become more common with age. Drugs are commonly used to treat disorders in older people, and some classes can be quite sedating and also impair driving performance.

2.4.3.3 VISION

In an automobile, monitoring the path ahead is purely a human act. Several actions take place when a driver looks away from forwarding view. Eyes must search for the new target (a temperature control, for instance). Eyes must also adapt to light and adjust focus. Then there is the time taken to manipulate the control (setting temperature to a specific numeric level). Decision time can be an added factor. Eyes must then return to forward view, refocus and readapt to the light. All this takes place typically within one second. It is primarily a challenge for older drivers, whose physiological processes such as a change in focus and light adaptation are, on average, slower when compared to younger or middle-aged drivers [32].

Drivers need to monitor the road ahead constantly. A driver who glances away from forwarding view for more than 1.0 second is putting himself or herself, the passengers, and anyone nearby, at risk. In a moving car, drivers' glance times away from forwarding view typically last 0.6 to 1.0 seconds. They rarely last more than 1.6seconds. Risk increases rapidly within this time frame. A look away of 2.0 seconds, as reported by the "Driver Inattention" study mentioned above, puts drivers at serious risk [32].

In terms of general eyesight requirements, for example, the law in the UK states that to drive you must be able to read the registration plate of another vehicle from 20 metres away whilst in good daylight (with contact lenses or glasses, if you wear them) [33].

Visual acuity - This is how well you can see detail and is measured with eye charts of letters, which get smaller with each row – it's called a Snellen scale and results are given per eye with two numbers. To be able to drive, you will need to have a Snellen score of at least 6/12, meaning that you can see at 6 metres what can typically be seen at 12 metres with normal vision (with contact lenses or glasses, if you wear them) [33].

Field of vision - The UK law also states that your minimum field of vision (the breadth of your central and peripheral/side vision) should be 120 degrees. This test is usually done by you focusing on one point with small lights being turned on and off in your peripheral vision, and you count how many you saw [33].

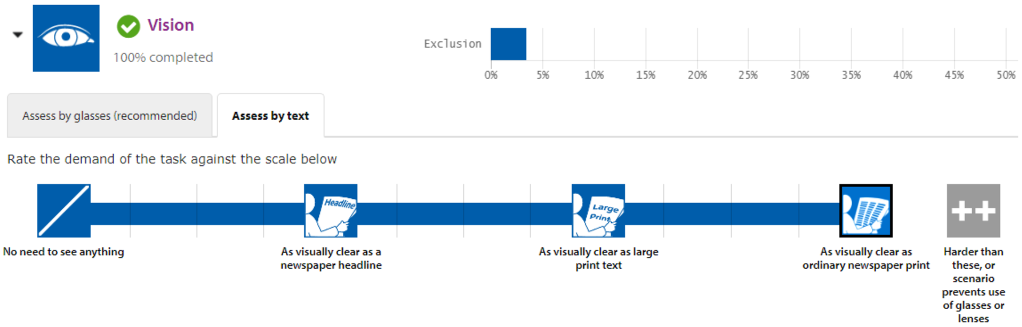


Fig. 2.18 - Exclusion Calculator - Vision demand for a conventional vehicle

Using the Exclusion Calculator [31], the demand for the vision task was rated to the level when the driver of a conventional vehicle must be able to “Clearly see ordinary newspaper print”. This is considered when the driver wears glasses or lenses if required. The result in figure 2.18 shows that there is about 3.5% of the population of 16+ age excluded. In comparison with a driverless vehicle, there will be no exclusion as the driver is basically a passenger only, therefore can be eventually blind. So, from a vision perspective, the driverless vehicle is fully inclusive.

2.4.3.4 HEARING

Deafness usually causes an issue to the bus, coaches and lorry drivers as they must inform the driving license issuer about their impairment. This is not the case for a conventional car or a motorcycle driver, therefore is the no exclusion as per by the UK law there is no need to hear anything. The same scenario meets the driverless vehicles.

2.4.3.5 THINKING

Thinking, also known as ‘cognition’, refers to the ability to process information, hold attention, store and retrieve memories and select appropriate responses and actions [21]. Thinking factors can profoundly affect the driving of a conventional vehicle, but the capability demand will differ for an autonomous one. When driving, thinking is essential for interacting with a vehicle and its surroundings product, as the user needs to process the information and decide what to do. Many different aspects of thinking may be involved.

THINKING – Conventional Vehicle

Conventional vehicle and its relation to Thinking capability are estimated on figure X. Thinking is a more complicated task when driving and requires concentration, long-term memory, literacy, speech comprehension and some speaking skills. Using the Exclusion Calculator, the Concentration demand is set to the highest possible level (++) as driving requires a very high level of attention. Long-term memory rate is set to the highest possible level (++) as well too as the driver has to remember all the traffic rules, road signs, etc.

It is difficult to assess Literacy and Speech Comprehension related to driving task. Based on my personal judgement, both Literacy and Speech Comprehension demands are set to the level where the driver should be able to “Read and understand a short newspaper article” or “Understand a short audio report” that can be, e.g. related to the driving conditions or a traffic situation. The Speaking demand is set to “No need to speak”, as mentioned above, deaf people can obtain a driving license.

The result in the Fig. 2.19 shows that there is nearly 4.8% of the population of age 16+ excluded. For people over 70s, this exclusion value rises to 12.1%. The range of the Disability Follow-Up Survey exceeded the Concentration and Long-term memory level due to the higher-demand for the difficulties related to the conventional driving. These two percentages values are therefore unproven.

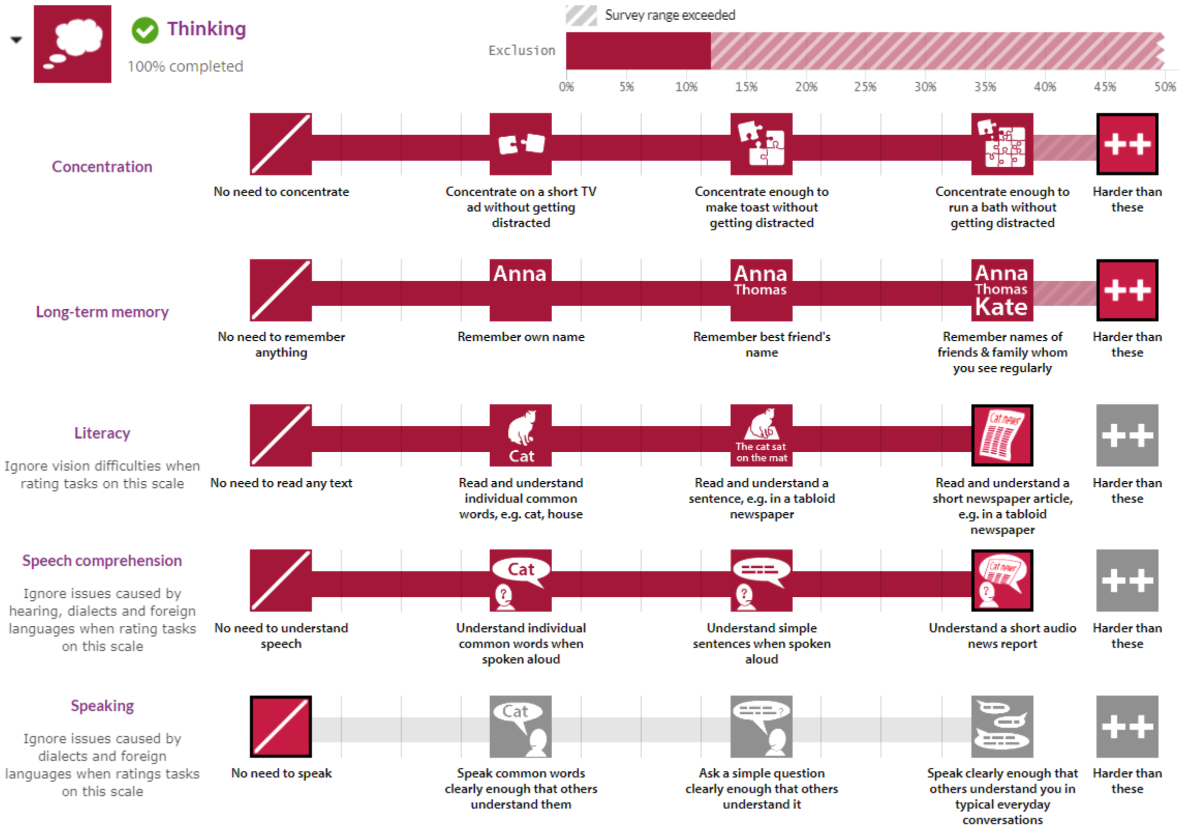


Fig. 2.19 - Exclusion Calculator - Thinking demand for a conventional vehicle

THINKING – Driverless Vehicle

Demand for Thinking capability plays a different role when using a driverless vehicle. During the ride in a fully driverless vehicle, the driver is factically out of the loop and became a passenger. But the car still needs to get some initial inputs about the journey from the user, therefore some level of Concentration to select a pick-up location and a destination, alternatively with some stops on the route. Also, some general level of a Long-term memory will be required to remember locations of frequent destinations (e.g. grocery stores, hospital or family members). Literacy and Speech comprehension demand will be crucial for booking a ride, communicating with the vehicle or a service operator. To “Read and understand a short newspaper article” and to “Understand a short audio news report” is therefore selected as an appropriate demand level. Speaking demand level is set to “No need to speak”. To make the autonomous service fully inclusive, it is expected that the vehicle would be equipped with a sophisticated HMI allowing people with, deafness, muteness or similar speech disorder to communicate with the service using digital devices or gestures.

The result in the figure 2.20 shows that there is 4.8% of the population of age 16+ excluded. For people over 70s, this exclusion value rises to 12.1%. Again, these two output values are identical to the conventional vehicle but can be considered as authentic for the driverless taxis.

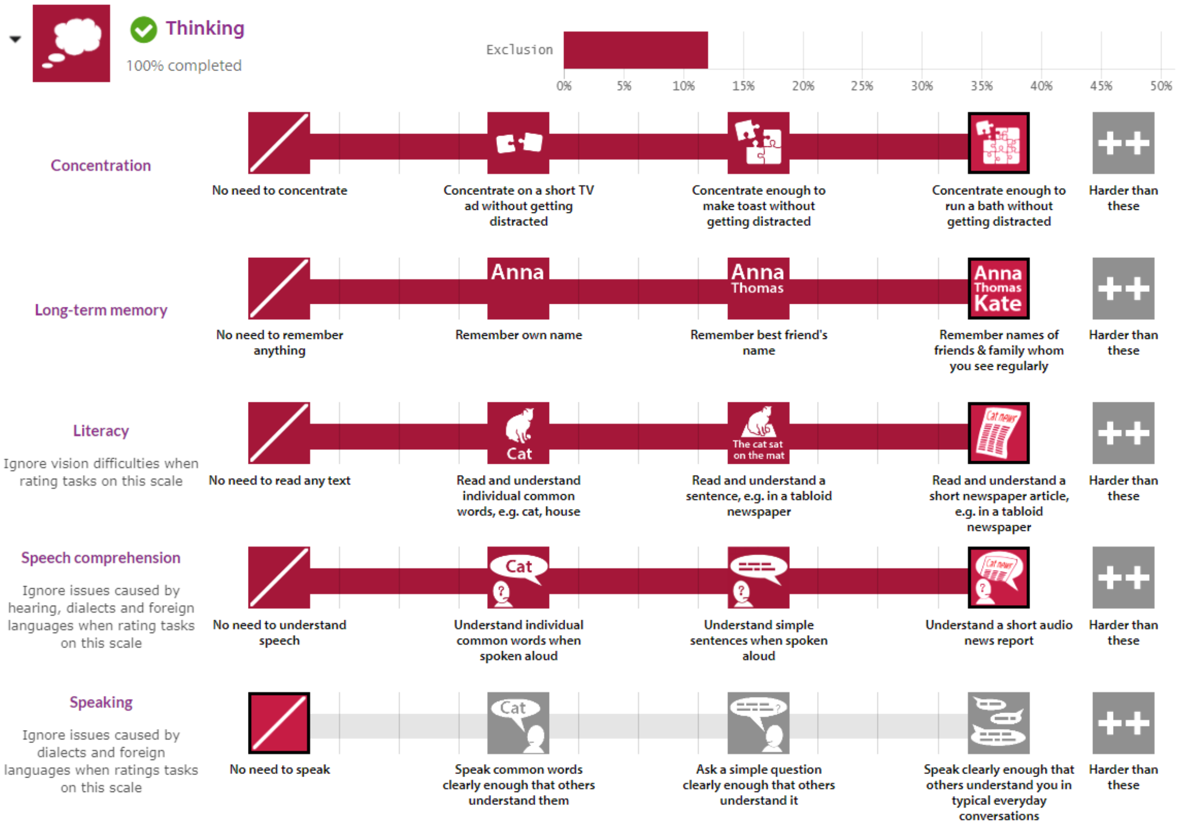


Fig. 2.20 - Exclusion Calculator - Thinking demand for a driverless vehicle

2.4.3.6 DOMINANT & NON-DOMINANT HAND

All conventional vehicles rely on the user's hands and arms to manipulate steering wheel and other controls, move objects and exert force, e.g. to turn a lever or push open a door. This paragraph describes how vehicle use is affected by various user capabilities related to the hands and arms, which can be broadly categorised under Reach & Dexterity.

DOMINANT & NON-DOMINANT HAND – Conventional Vehicle

To determine the level of capability needed in order to use a conventional vehicle, it is crucial to evaluate the following four tasks: Lifting strength, Dexterity, Reaching forward and up and Reaching down. Studies suggest that 70–95% of the world population is right-handed, but for simplicity, it is considered that there are identical demands for both dominant and non-dominant hand. Especially when considering the asymmetric distribution of the control devices in a car (e.g. Handbrake) in relation to the Left-Hand Drive and Right-Hand Drive vehicles.

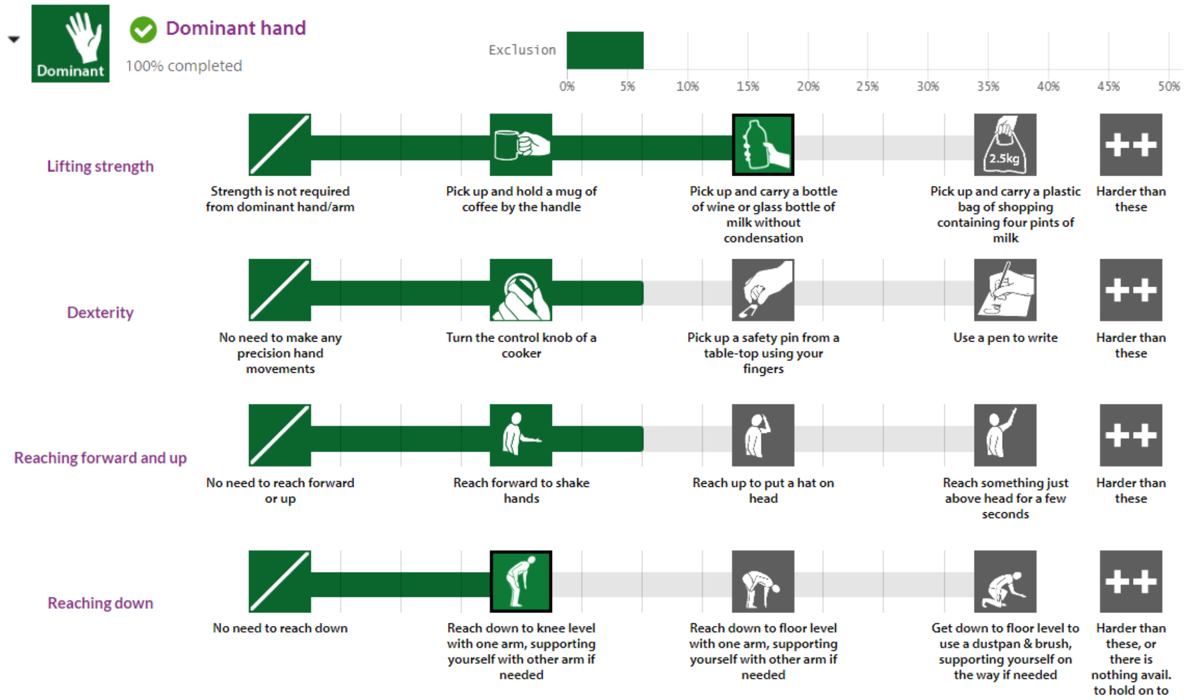


Fig. 2.21 - Exclusion Calculator - Dominant hand demand for a conventional vehicle

For the Lifting strength, the demand is set to “Pick up and carry a bottle of milk without condensation” as there is a need to have hands on a steering wheel and exert force using both arms in a slight bend horizontal position to control the steering. Dexterity is set to a level between the “Control Knob” and the ability to pick up a “Safety pin” as there are various control devices of various shapes and sizes that are required to run the conventional vehicle properly (e.g. ignition switch, windscreen wiper switch or HVAC controllers). For “Reaching forward and up” the demand is set to the level that is appropriate for using the steering wheel and the ability to fasten a seat belt. The last “Reaching down” demand meets approximately the requirement of getting in and out of the vehicle. The result on the Fig. X shows that there is approximately 12.4% of the population of age 16+ excluded. For people over 70s, this exclusion value rises to approximately 20%.

DOMINANT & NON-DOMINANT HAND – Driverless Vehicle

The main advantage of a driverless vehicle is that there is no human intervention required. The removal of the steering wheel brings a huge advantage for people with limited capabilities. The automatic door will allow the passenger to get in and out of the car comfortably without the need for opening or shutting it. Fastening a seat belt seems to be the only primary requirement for the passenger. Other features can be controlled by using, e.g. voice command or gesture command device. It is therefore expected that a driverless will require a little demand for dexterity, strength and reaching. Therefore the estimated levels of both hands are characterized subsequently. The estimated result in figure 20 shows that there will be only 3.3% of the population of age 16+ excluded. For people over 70s, this estimated exclusion value rises to approximately 10%.

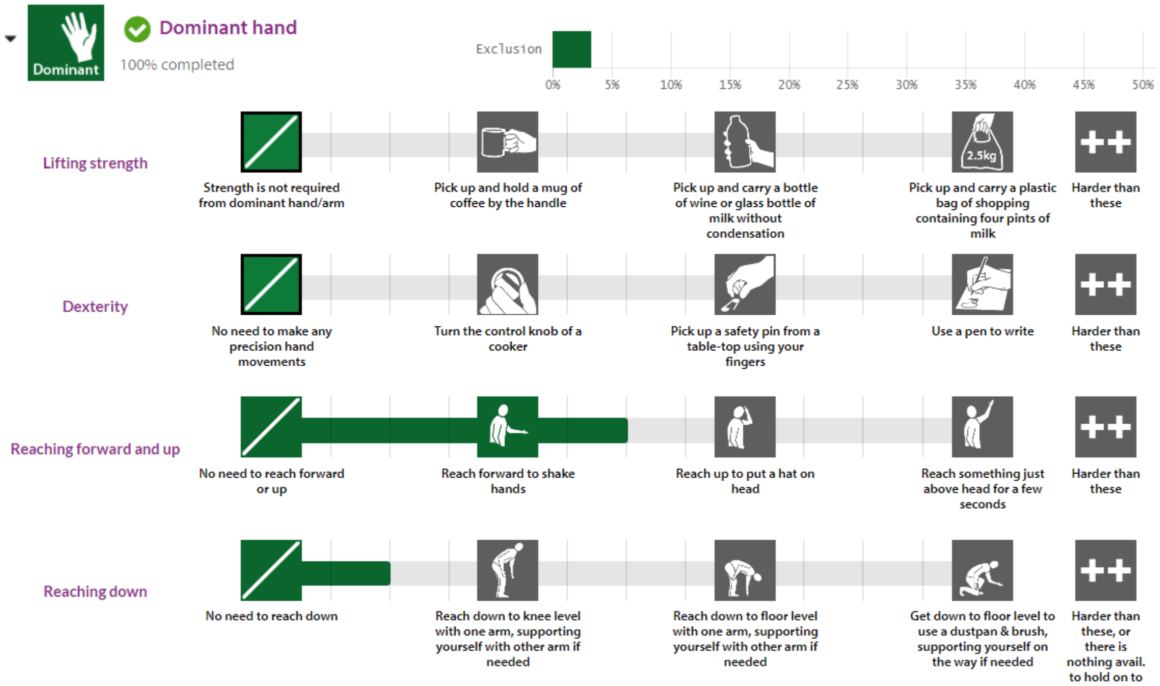


Fig. 2.22 - Exclusion Calculator - Dominant hand demand for a driverless vehicle

2.4.3.7 MOBILITY

Mobility is the ability to move around in the environment. Activities such as walking, getting in and out of vehicles and maintaining balance are affected by the loss of mobility. Vehicles may be more difficult to access or use for people who have difficulties with balance or who use a mobility aid, such as a wheelchair or walking stick. Muscle strength gradually deteriorates with age, while degenerative conditions such as arthritis and Parkinson's disease further limit joint mobility and muscle control.

MOBILITY – Conventional Vehicle

In terms of the demand for Mobility all three tasks (Walking, Stair Climbing, Standing and Balancing) are set to an equal level. When considering conventional vehicle without any special modification for less capable or disabled people, all three levels are mostly related to using the pedals and to the getting in and out of the car process, especially at narrow car parks. It is also difficult to distinguish between mobility demand for small compact cars a big SUVs where the demand level can vary. The estimated result on the Fig. X shows that there is approximately 5.1% of the population of age 16+ excluded. The exclusion rises to 12.8% for people for people over their 70s.

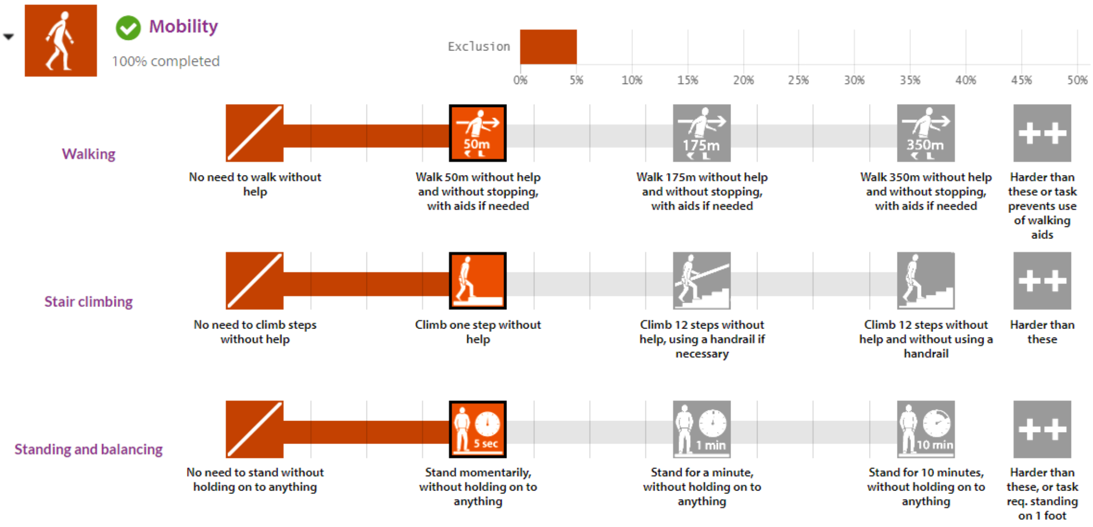


Fig. 2.23 - Exclusion Calculator - Mobility demand for a conventional vehicle

MOBILITY – Driverless Vehicle

Driverless vehicles provide a more inclusive environment for the people with limited mobility. The removal of pedals and steering wheel brings an adequate space for getting on and off the transport and moving between standing and sitting position. When considering appropriate handles and surfaces so that the arms can be used to assist in transferring the body between various positions, this advantage lowers the demand for mobility capabilities. Presumably, most of the driverless vehicles in future will be powered by an electric battery integrated into the vehicle floor. This design solution offers an entirely flat floor which also helps those with limited mobility and also implement the opportunity to make the car easily accessible for wheelchairs users if the interior provides adequate space (e.g. by removing seats and providing a wheelchair ramp). Therefore, all the Mobility levels can be set to zero level making the vehicle fully inclusive.

2.4.3.8 COUNTERING DESIGN EXCLUSION

The result estimated from the inclusive design assessment can be seen in table 2.7. The results provide straightforward evidence of the benefits that will provide a driverless vehicle. Estimated exclusion for driving a conventional vehicle is higher by approximately 2.6% of the first targeted population (age 16-64) in comparison with a driverless vehicle. The estimated exclusion difference is the second targeted population (age 65-76) rises to 10.3%. The last group which represents the oldest generation (age 80-100) brings the highest difference of 21.2%.

	CONVENTIONAL VEHICLE						AUTONOMOUS VEHICLE					
TARGET POPULATION by AGE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
	16	64	65	79	80	100	16	64	65	79	80	100
VISION	1.80%		7.20%		23.50%		0.00%		0.00%		0.00%	
HEARING	0.00%		0.00%		0.00%		0.00%		0.00%		0.00%	
THINKING	3.50%		8.00%		18.90%		3.50%		8.00%		18.90%	
DOMINANT HAND	4.00%		13.00%		28.60%		2.00%		6.80%		15.50%	
NON-DOMINANT HAND	4.30%		14.30%		31.30%		2.20%		7.10%		16.70%	
MOBILITY	2.90%		10.80%		26.40%		0.00%		0.00%		0.00%	
TOTAL EXCLUSION	**7.80%**		**23.70%**		**52.70%**		**5.20%**		**13.40%**		**31.60%**	

Tab. 2.7 - Comparison of estimated exclusions - Conventional Vehicle & Driverless vehicle

To justify the estimated exclusion results for the conventional driving, a comparison with actual driving license holders in the United Kingdom is generated in table 2.8. As can be seen, the date from the table 2.8 correlates with the specified age bands in table 7, where the first group of the population differs by 0.64% only. Apparently, almost every person in this age group that can drive a conventional vehicle holds a driving licence.

Age Band	POPULATION UK (2016)	DRIVING LICENSE HOLDERS (2016)	DRIVING LICENCE HOLDERS (%)	WITHOUT DRIVING LICENCE (%)
16-64	41,212,975	38,261,243	92.84%	**7.16%**
65-79	8,643,100	6,834,518	79.07%	**20.93%**
80+	3,116,900	1,232,368	39.54%	**60.46%**

Tab. 2.8 - Driving License Holders in the UK (Office for National Statistics 2016)

The estimated difference for the second age group correlates with the predicted results similarly by only 2.77%. The highest difference of 7.76% belongs to the oldest group. Supposedly, some older individuals from this group opt-out from driving voluntarily. Even when having the ability to drive a conventional vehicle, they don't merely want to undertake the risk of endangering themselves or other drivers.

YEAR	ESTIMATED POPULATION [UK]	EXCLUSION - CONVENTIONAL VEHICLE			EXCLUSION - AUTONOMOUS VEHICLE		
		16-64	65+	Combined	16-64	65+	Combined
2016	65,648,054	3,231,066	3,521,362	6,752,428	2,154,044	2,032,464	4,186,508
2026	69,843,515	3,306,811	4,266,740	7,573,551	2,204,541	2,462,682	4,667,223
2036	73,360,907	3,330,292	5,224,911	8,555,202	2,220,194	3,015,720	5,235,915
2046	76,342,235	3,435,859	5,619,247	9,055,105	2,290,572	3,243,324	5,533,896

Tab. 2.9 - Comparison of estimated exclusions in the UK- Conventional & Driverless vehicle

The age distribution of the UK population is changing. Knowing previous and projected proportions of the older age groups is interesting and useful for planning. Table 2.9 shows how this is changing in terms of using a conventional and an autonomous vehicle for different age groups; people who are most likely to be working (aged 16 to 64 years) and people most likely to be retired (aged 65 and over).

The estimated amount of people that will be excluded from driving a conventional vehicle in 2046 is about 9 million, approximately 12% of the entire UK population (including children). It is about 3.5 million higher proportion of the population in comparison to autonomous driving. The estimated data from table 2.9 indicates that a driverless taxi will help to reduce the exclusion from conventional driving by 39% for those people that would be excluded initially from driving a conventional vehicle.

2.5 CHAPTER SUMMARY

As most people take having transportation options as a given, people with disabilities and the elderly may benefit most from these new developments. Autonomous driving technology has the potential to transform life for populations that are not able to get a driver's license today. People with epilepsy and blind people are continually managing the logistical challenges associated with getting groceries, taking the kids to school or going out for the evening - or just not going out at all. The employment rate for people with disabilities continues to decline even after the modest recovery from the great recession. Game-changing technology has the potential to halt this decline and hopefully allow more people with disabilities to go to work each day as these barriers to transportation are taken down by technology [34].

At least but not last, to achieve highest possible inclusivity, elderly and mobility impaired people must be used as a design resource throughout the development of a new car. This inclusive design approach, if applied to the fundamental architecture of the driverless vehicles and to detail design aspects, will improve the likelihood that future car designs are suitable for a wide range of passengers, and that older one is catered for.

3 DESIGN FOR URBAN ENVIRONMENT

Today, the majority of our societies are urban citizens, due to the dense, social and economic interaction created by the modern world. These environments provide endless and convenient possibilities. However, the modern urbanization trends resulting from increasingly densely-populated cities don't leave much room for cars. Each megacity is unique, but there are some traits they share - even a short distance can be drawn out by heavy traffic.

City life has its share of inconveniences, notably traffic and parking scarcity, etc. These trends led to various social barriers, which in turn triggered complementary ways of communication. As a result, people such as the elderly, obese, pregnant, disabled or others with various mobility impairments have become increasingly homebound and alienated from the external environment.

Transportation solutions have always been diverse, but with a rapidly rising global population spreading out of cities into the suburbs, many people have made their cars the only form of mobility, but this trend is changing. With migration back into city centres, a greater understanding of the environment and breakthroughs in communication technologies, many people are looking for and accepting other modes of transportation [2].

The introduction of autonomous mobility systems requires attention to human needs and designing the system in a holistic way. It's important to understand not just vehicle architecture and design process itself, but also the statistics and surveys related to our global population, commuting patterns, social needs and issues related to the urban environment.

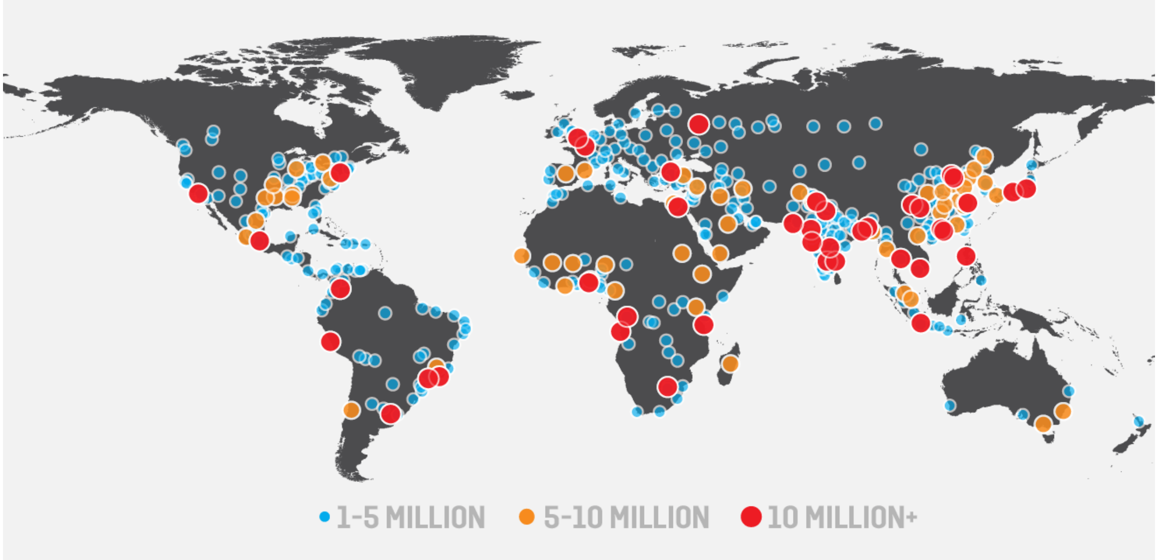


Fig.3.1 - The Future Megacities – 2030 [35]

3.1 POPULATION

Today 60% of our societies are urban citizens, due to the dense social and economic interactions created by the modern world. Almost 9% of the 7.4 billion global population live in megacities (2015). There are 37 megacities around the world exceeding the population of 650 million [36]. According to the actual forecast, there will be 10.9 billion people in 2050, and 12.6 billion people in 2100 , with a 70% chance of a continuous rise [37].

THREE LARGEST **MEGACITIES IN THE WORLD**	THREE LARGEST **EUROPEAN MEGACITIES**
Tokyo 37.9 million	Moscow 16.9 million
Jakarta 30.3 million	London 13.9 million
Delhi 26.4 million	Paris 12.2 million

Tab. 3.1 - The biggest megacities [38]

Global population structure varies demographically according to the quality of life in specific regions. In developed countries like in the EU, the age group of people 65+ years has increased by 7% during last 20 years. The projection in figure 2.1 shows the predicted scenario in 2050 when over 30% of the entire population will be more than 65 years old. This data clearly shows a need to investigate the potential of an Inclusive Design approach in the urban context and the significance of personal mobility in maintaining and improving quality of life.

3.2 CAR FLEET

Transportation links people to essential spaces enables access to work and a wide range of essential services (e.g. shops, healthcare), but modern urbanization trends, resulting from increasingly densely-populated cities, don't leave much room for cars.

In contrast with rising population density in megacities and decreasing road space for transportation, the automotive industry has moved from the recession (2009) and produced 89,747,430 passenger and commercial vehicles in 2014.

GLOBAL PRODUCTION	PASSENGER CARS	COMMERCIAL CARS	**TOTAL**
2014	67.525 mil	22.222 mil	89.747 mil
2009	47.773 mil	13.989 mil	61.762 mil

VEHICLES IN USE	PASSENGER CARS	COMMERCIAL CARS	**TOTAL**
2013	865.280 mil	317.932 mil	1183.212 mil
2009	747.394 mil	272.895 mil	1020.289 mil

Tab. 3.2 - Global Car Fleet [39], [40]

Data in table 3.2 above is showing that the world car fleet reached 1 billion 5 years ago and started rising more rapidly. It is predicted that there will be 2 billion cars in use in 2020. It is essential to understand that all cars consume energy and generate emissions whilst being designed, manufactured, maintained and disposed of. This entire lifecycle must be considered as the starting point for design and development of a new platform for driverless vehicles. An entirely new type of lightweight intelligent vehicle must be designed with the aim of minimising environmental impact.

Morgan Stanley’s research shows that cars are driven just 4% of the time [41] , which is an astonishing waste considering that the average cost of car ownership is nearly $9,000 per year [42]. Next, to a house, an automobile is the second most expensive asset that most people will ever buy –

it is no surprise that ride-sharing services like Uber and car sharing services like Zipcar are quickly gaining popularity as an alternative to car ownership [43]. Based on my own experience and comparison of both models [44] (when we consider depreciation, fuel cost, interest, insurance, maintenance, repairs, registration and taxes), it is more economical to use share car services if you live in metropolitan cities and drive less than 6.000miles per year (related to the UK).

Cars are the most popular passenger mode across the EU: they represent some 72% of all passenger kilometres. However, the private car is rarely the most energy-efficient form of transport. According to data from the UK, 60% of cars have only one occupant. The percentage increases to approximately 85% for commuting and business trips. [45]

3.3 COMMUTING & JOURNEY PURPOSES

Commuting time is a measure of how long people spend travelling to work, by whatever means. It could be by foot, bus, car, boat, train, bicycle or other means. The world average commuting time is 40 minutes, one-way. This is the average for 3,314 billion people that are able to work. [46]

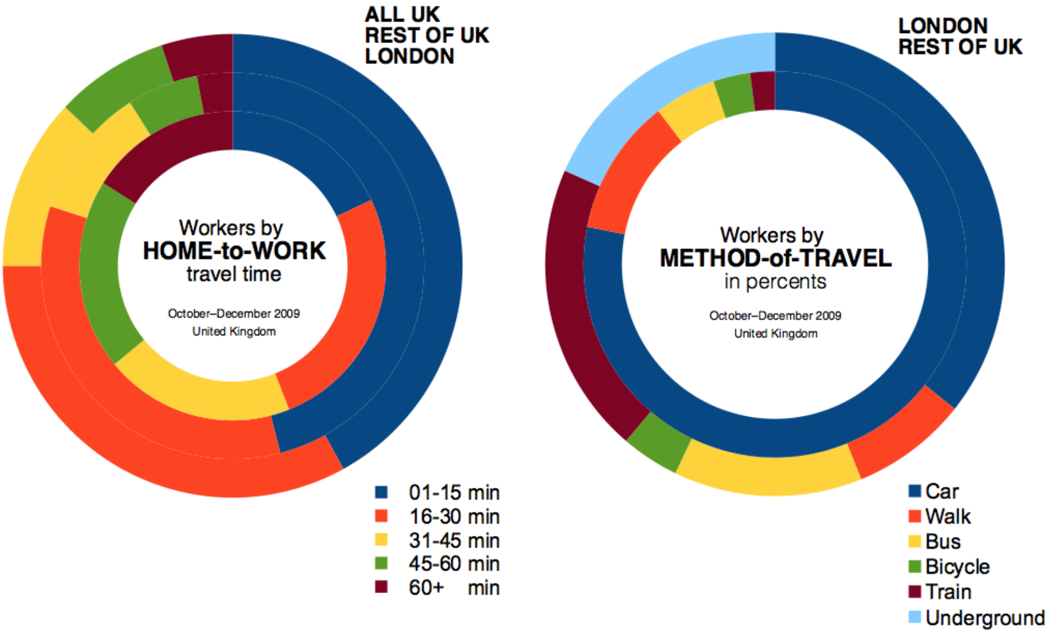


Fig. 3.2 - Home to Work travel time & Method of travel [47]

Increasing population numbers will call for more optimized transportation infrastructure. City life has its share of traffic congestion, parking inconveniences and environmental issues. These will not improve without self-driving vehicles, new models of transportation, new models of ownership and advanced intelligent mobility.

The pie charts above illustrate commuting statistics in the UK in comparison with the capital, London. Home-to-Work travel time is drastically different between urban and rural areas (Fig. 3.2). People in megacities are willing to travel longer distances usually using a more extensive range of public transportation services. Usability of cars for commuting within capitals is reduced to 50% of average due to the more convenient and more affordable travelling methods.

3.3.1 TYPES OF TRAVELLING

Three basic types of car travelling are explained below:

RUSH HOUR TRAVEL

A rush hour is a part of the day during which traffic congestion on roads and crowding on public transport is at its highest. Usually, this happens twice every weekday—once in the morning and once in the afternoon or evening, the times during which the most people commute [48].

Those who are still working are restricted as to when they could travel to and from work and are usually obliged to travel during rush hour periods. These commuters commonly complain about the time it took to travel to their workplace.

TRIP-CHAINING

Trip-chaining involves carrying out a series of journeys for different purposes as part of the same overall journey. There are four broad reasons for trip-chaining: saving time, managing health conditions and reducing personal wear and tear, lack of local facilities, saving money

NIGHT-TIME TRAVEL

For car drivers, driving at night was sometimes described as a stressful experience. Poor visibility and having to distinguish street and car lights jumping around on the windscreen made night drives, for some, stressful and exhausting. Especially for older drivers, driving at night can be exhausting and risky activity.

RIDE-SHARING

Ride-Sharing (also carpooling) is the sharing of car journeys so that more than one-person travels in a car and prevents the need for others to have to drive to a location themselves. By having more people using one vehicle, carpooling reduces each person's travel costs such as fuel costs, tolls, and the stress of driving. Carpooling is also a more environmentally friendly and sustainable way to travel as sharing journeys reduces air pollution, carbon emissions, traffic congestion on the roads, and the need for parking spaces [49].

3.3.2 JOURNEY PURPOSES

Each age group uses a vehicle for various purposes. The shift of car use with increasing age has been analysed in the following survey [50], prepared for the Department of Transport, led to following insights: The sample was recruited in four age groups: 50-59 years old, 60- 69 years old and 70 years old and over. People described a wide range of journey purposes. These fell into three categories:

- **Social and recreational:** These included activities such as going out for a meal, visiting friends or a local club or taking part in hobbies and activities.
- **Domestic and personal**: These included activities such as going shopping or making visits to the doctor, dentist or hairdresser.
- **Work-based:** These included travelling to and from work but also included travel undertaken as part of a job.

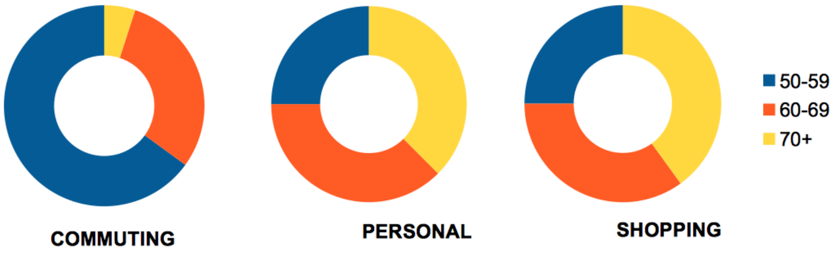


Fig. 3.3 - Shift of car use with an increase of age [2006] [51]

For 50-59-year-olds, commuting to work accounted for 22% of all journeys made. For 60-69-year-olds this figure was 8%, and amongst those aged 70 and over it was 1%. As a corollary of this, journeys for some other purposes also increased as a proportion of all travel for these age groups. For example, shopping accounted for 22% of all journeys amongst 50-59-year-olds, compared to 32% for 60-69-year-olds and 38% amongst those aged 70 and over. In addition, personal business, which includes trips to services, such as the bank, doctor or library, accounted for 11% of all journeys amongst 50-59-year-olds, compared to 15% for 50-59-year-olds and 19% for those aged 70 and over 29 [51].

3.4 ANALYSIS OF COMMUTERS

In terms of mobility, it is critical to analyse the group of car commuters as it will be the primary source of mobility revenue. Vehicle commuters in three different cities were analysed to bring some insights in the commuting statistics. London and Prague were picked based on the author's preference and availability of related statistical data. Data for the Denver commuters is sourced from Denver commuter analysis conducted by Rutt Bridges in 2015 [52].

Figure 3.4 and Table 3.3 illustrates the proportion of inbound and outbound commuters in each of these cities in relation to the overall metropolitan population. As can be seen in table 3.3, there is an average of 2.5 times more inbound commuters than those who commute travel out of the metropolis.

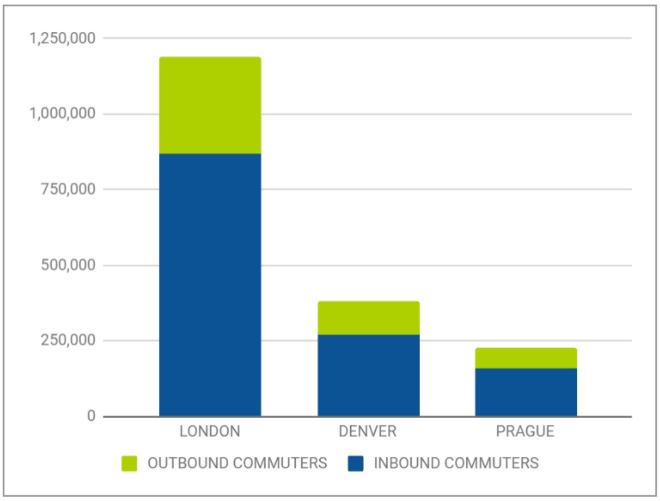
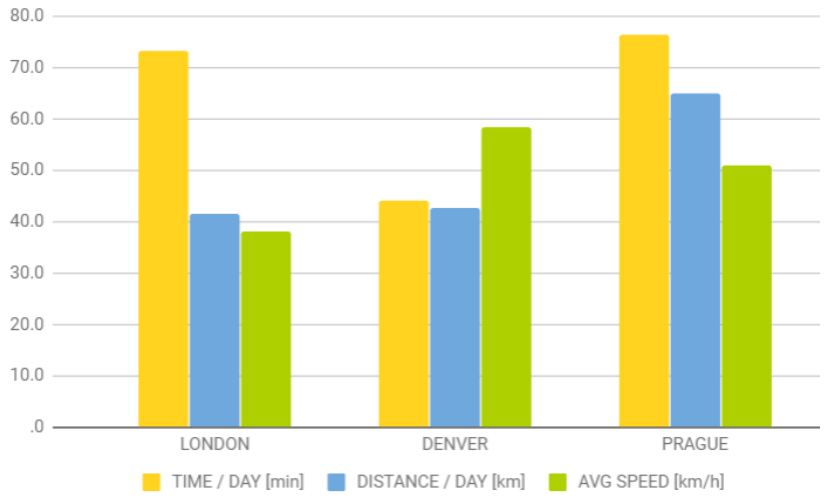


Fig. 3.4 - Analysis of commuters - London, Prague, Denver [53], [54], [55]

	METROPOLITAN POPULATION	INBOUND COMMUTERS	OUTBOUND COMMUTERS	TOTAL COMMUTERS	RATIO I-O	PERCENTAGE OF CAR COMMUTERS
LONDON	**13,879,757**	869,000	322,000	**1,191,000**	2.70	8.58%
DENVER	**2,697,479**	268,512	112,382	**380,894**	2.39	14.12%
PRAGUE	**1,999,732**	158,282	69,784	**228,066**	2.27	11.40%

Tab. 3.3 - Analysis of commuters - London, Prague, Denver [53], [54], [55]

Table 3.4 summarizes the average time a day that a commuter spends driving a vehicle, the average distance travelled daily and averaged travelling speed. In Prague, an average commuter spends about 76 minutes, in London 73 minutes and in Denver only 44 minutes. In Prague and London, average commuters spend more 6 hours per week travelling to and from work, which is close to one working day a week. For simplicity and lack of statistical data, inbound and outbound times are equal to London and Prague. More detailed data would be required to deliver more accurate analysis as the average outbound travelling speed is estimated to be higher due to the more convenient congestion for a lower number of outbound commuters.



	INBOUND [min]	OUTBOUND [min]	TIME / DAY [min]	INBOUND [km]	OUBOUND [km]	DISTANCE / DAY [km]	INBOUND [km/h]	OUTBOUND [km/h]	AVG SPEED [km/h]
LONDON	36.6	36.6	**73.2**	40.2	42.5	**41.4**	38.0	38.0	**38.0**
DENVER	24.1	20.0	**44.1**	42.1	42.9	**42.5**	52.5	64.4	**58.4**
PRAGUE	38.2	38.2	**76.4**	59.4	70.3	**64.9**	46.7	55.2	**50.9**

Tab. 3.4 - London, Denver, Prague - Average commuting time [min]/ distance [km] / speed [km/h]
Source: [53], [56], [54], [55], [53], [57], [58], [59], Google maps, Waze.com

To deliver accurate analysis, both average travel speeds on motorways and city streets were considered. Also, the ratio between motorways and city streets is included in the average overall speed. More details can be found in Appendix IV.

As can be seen in table 3.4, people in Prague spend daily approximately same time as people in London, but the distance travelled differs by 24 kilometres. This is apparently caused by the density of traffic congestion in London. Driving a car is usually not the most convenient travelling option, but for some commuters, it can be the only one. In Prague, people are willing to travel longer distances but within a modest time period similar to London.

MOBILITY & CAR SHARING

The utilization of driverless taxis will lead to a wide range of economic, productivity and time efficiency benefits. It opens a fresh market for a variety of mobility business models and brings trade expansion opportunities (mail & food delivery). Mobility programs would become more prevalent as driverless vehicles could arrive at destinations and then be used by other passengers.

MOBILITY SERVICE VALUE PROPOSITION

The proposition is to provide a safe and efficient transportation service that can save you money. It will contribute to accurate arrival times, short and predictable waits and bring low-stress door-to-door service. As there will be no need to drive or hunt for parking spaces, you will be free to work or pursue other personal interests during your trip.

The mobility service will shorten the travel time, significantly reduce air pollution and even reduce the need for expanding roads. There won’t be a need to fuel, wash and service a vehicle, or pay parking tickets, insurance brokers or car payments. Everyone will arrive at work, or back home relaxed and focused on the people and things that really matter [52]. In summary, the mobility service delivers the following:

- Safe, efficient transportation for half to a fourth the cost of car ownership
- Less congestion, faster commutes, less pollution, with no parking or vehicle ownership hassles
- Low-stress door-to-door service while you work, read, relax

MOBILITY’S IMPACT ON CONGESTION

Mobility means less congestion when presuming that driverless taxis are smaller, lightweight vehicles. They are on the road only when needed and share data to avoid the busiest streets. This will result in far less congestion. Closely spaced platooning vehicles could use bus lanes to maximize roadway passenger capacity, further cutting congestion.

- Vehicles share information and bypass congestion
- Far fewer accidents to clog the highways
- Fewer highway expansion delays
- Mobility cars “platoon” in express lanes at high speeds

CAR SHARING

Incumbent manufacturers recognise the double threat posed by technology, as car-sharing takes off and autonomous vehicles come closer. First, some people who might hitherto have wanted to own a car may no longer do so, cancelling out the growth the motor industry might otherwise have expected from the rising middle classes in developing countries (Fig. 3.5). Second, technology firms may be better placed than carmakers to develop and profit from the software that will underpin both automated driving and vehicle-sharing [60].

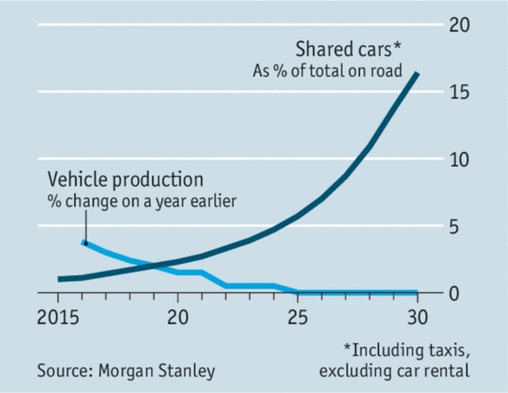


Fig. 3.5 - Sharing, Not Growing - Worldwide forecast [60]

Hitherto, new cars—even quite modest ones—have tended to be bought as status symbols and expressions of personal style, but if consumers become more interested in what software and entertainment systems a car can run, rather than what it looks like, the industry's whole business model may come apart. Ride-sharing, car clubs and other alternatives to ownership are already growing fast. Young city-dwellers are turning their backs on owning a precious asset that sits mostly unused and loses value the moment it is first driven [60].

Membership of car clubs, which let people book by an app for periods as short as 15 minutes, is growing by over 30% a year, according to Alix Partners, a consulting firm, and should hit 26 million members worldwide by 2020. At the same time, app-based taxi services such as Uber and its Chinese counterpart Didi Dache, which are often cheaper and more efficient than conventional cabs, are also proliferating. Once these are able to dispense with drivers for their vehicles, the taxi, car-club and car-sharing businesses will in effect merge into one significant, convenient and affordable alternative to owning a car [60].

It will be very challenging for the auto industry to compete in the field of mobility and autonomous driving because it means cannibalizing their own products, completely transforming their purchase-oriented business model which has served them well for more than a century towards a service-oriented model and fundamentally rethinking the concept of a car [52].

Today, car manufacturers depend on regular customer purchases to run their businesses. Mobility and shared ownership, which is highly likely to become the norm, can create chaos within their traditional business models. The only way to survive is to manage the change gradually and incrementally, otherwise many of today's car manufacturers are at significant risk.

In summary, the low-cost mobility that driverless taxis provide can empower our society: young people, seniors, and the physically disabled. For these and many others, driverless cars offer life-changing benefits. And a lot of other Mobility customers will be compelled by the money saved, and of course the opportunity to sit back and enjoy the ride instead of playing rush-hour roulette [52].

3.5 VEHICLE DESIGN IN URBAN CONTEXT

Small cars are ideal for minimizing cost and impact on the environment, but a huge advantage can be gained from dramatically reducing the overall width [2]. More than 90% of the time cars are carrying only one person. This number rises up to 95% during morning and afternoon rush hours.

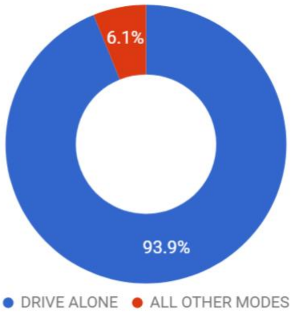


Fig. 3.6 - Share of commuting increase; Drive Alone (USA 2007-2012) [61]

This leads into overloaded infrastructures within inner cities and massive problems with parking. The narrow cars, therefore, seem like an ideal solution to address these problems. For most major cities, the most significant challenges are to find space and funding for additional roadways. The solutions shown on the following images are inexpensive and use existing space. They are also very flexible, allowing the narrow lanes to be introduced as the number of vehicles increase. The lanes can also be repurposed during rush hours, versus low traffic times.

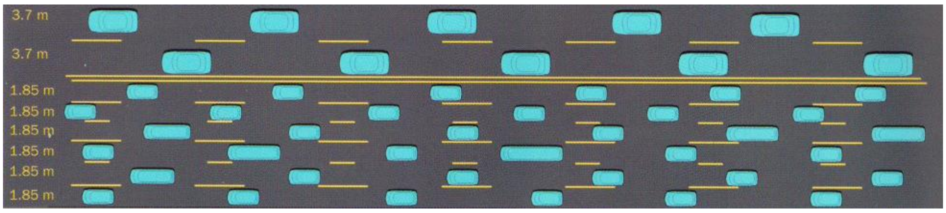


Fig. 3.7 - Freeway with ultra-narrow lane division (Increasing capacity by about 80%) [2]

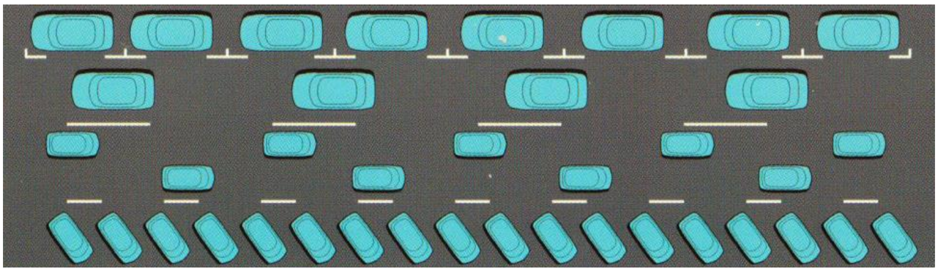


Fig. 3.8 - Typical side street with curbside parking (narrow vehicles are shown lower) [2]

But here comes one of the most significant challenges to the designers. The goal is to create an aspirational mobility product, but customers are usually turned off by the size of small cars due to their appearance and safety concerns.

According to the increased sales and popularity of SUV cars, it is evident that the possible safety concerns are related to the robust appearance and the ability to protect the occupants more efficiently than any other vehicle. The overall market share of SUV cars in the EU has risen by more than 440% over the last 13 years [62]. The KPMG findings suggest [63] that people interested in self-driving cars and autonomous mobility are focused more on handling, safety, innovation and trust and less on traditional aspects such as the engine, transmission, and styling. People won't be tempted by a narrow driverless car they won't trust allegedly from the first instance.

3.5.1 PACKAGE CONFIGURATION

There are many options how to configure the vehicle package. The interior can be configured for ultimate luxury commuter travel or for swallowing up large amounts of cargo in the flexible interior volume. The Mobility fleet will need to include cars with a variety of range and seating capacities to adapt the vehicle to actual demand.

As most commuters travel on their own, we can estimate that there will be a high proportion of single seaters where the seat can be positioned in the centre. This layout benefits from all-around visibility, road awareness and also delivers wider legroom. Other configuration may include two or three seats, or even a layout without a seat to accommodate a wheelchair user. The mobility taxi can also be used for package delivery. There will a need for a custom interior design to satisfy the demand for these services (e.g. Amazon, eBay, food delivery).

One example of such a configuration is shown in figure 3.9. In 2009, British automotive design company Gordon Murray revealed a new car seating layout concept, destined to be used in their city car, offering 6 internal layouts within the same vehicle. Each layout can be easily achieved within thirty seconds, around a central driving position [64]. The central driving position gives unparalleled control and visibility whilst supporting the ultra-flexible interior space. The small city car can be driven only but offers 750 litres of storage space which is equal to 6 shopping trolleys in volume.

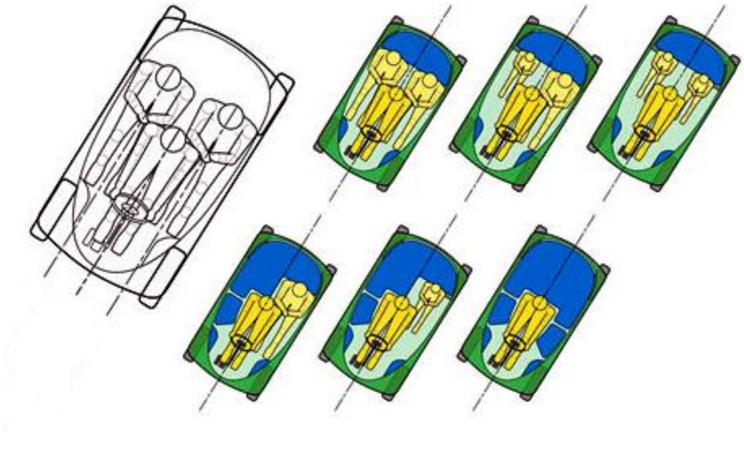


Fig. 3.9 - Central Driving Position [64]

3.5.2 WHY ELECTRIC VEHICLES FOR MOBILITY?

Current prices of the most saleable electric vehicles start at $37.288 for Nissan Leaf, $38.000 for Mitsubishi I, $46.400 for BMW i3, $47.800 for VW e-Golf and $75.000 for Tesla Model S 70D. Aren't these vehicles too expensive purchase to justify their sitting idle over 90 percent of the time? If we also consider a lack of charging spots and fear of being stranded with a flat battery, is the investment still worth this barrier of range anxiety? According to global sales, only Tesla got it right, the freedom of long trips is essential to many customers. Customers don't want to be limited in this way.

With Mobility taxis, range limits are only a function of the distance to the nearest rapid charging facility. Since the market is focused on urban/ suburban transportation, and shorter trips are the norm, driverless taxis need only enough range to handle rush-hour commutes (6–10am and 4-8pm) [52].

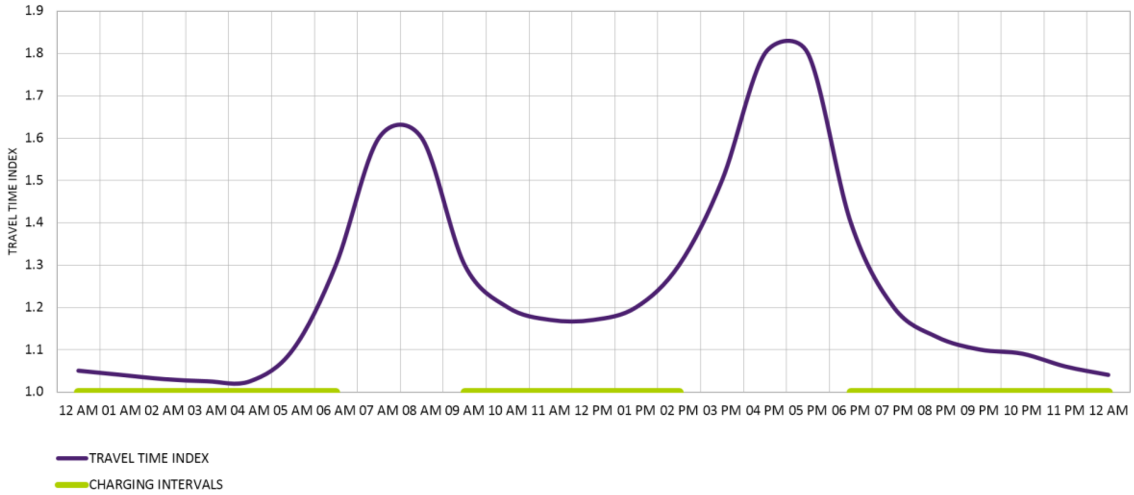


Fig. 3.10 - Daily rush-hour intensity

There is always a sufficient time gap between rush hours to drive to the nearest charging facility. These stations must be distributed efficiently to minimize dead mileage. The most critical number here is to have a sufficient number of vehicles to cover the rush hour demand to ensure that customers won't have to wait long for a ride.

Cars are predominantly used for commuting or short trips. For example, average commuting distance (round trip) in London is about in 26.4 miles [59]. Fully charged vehicles should be equipped with a battery capacity allowing to cover 4-morning trips and repeat the same scenario in the evening. Based on this assumption and taking into consideration 25 percentage of empty miles the minimum mileage range of a driverless vehicle should be approximately 140 miles.

The concept of autonomous mobility is going to turn this deficit of EVs to its advantage through high utilization rates of a long-life, low maintenance vehicles. Mobility model also benefits from little EV fuel cost combined with a strong customer value proposition and zero emissions. This scenario will naturally lead to a significant drop in consumer spending on personal vehicles. According to Rutt Bridges, this is the secret economic formula through which electric vehicles can capture a considerable share of total vehicle miles travelled while saving.

3.5.3 VEHICLE LIFE

If we consider the fact that all mobility vehicles are computer-monitored and managed in terms of their maintenance, collisions will be relatively rare; it is reasonable to expect to operate a driverless car for eight years [65]. According to Alexander Hars' approach taken in evaluating depreciation will be one that maintains the essential components of the vehicle while replacing individual components as required [66]s. Depreciation is based on eight years at 75,000 miles per year, 600,000 miles total. Apparently, there will be some additional repairs for individual vehicles, but most of the structural parts and chassis should easily last ten years.

Brushless electric motors also have a very long useful life, and those that might fail can be replaced or rebuilt if problems occur. Specific components, including the batteries, passenger interior furnishings plus some of the sensors and electronics, will be scheduled for replacement [52].

From an operating-life-of-vehicle perspective, EV Autos have some tremendous benefits in terms of weight, reliability and maintenance considerations. Many of the advantages come from what it doesn't have: internal combustion engine, gearbox, starter, catalytic converter, gas tank, alternator, various filters, timing belts, spark plugs, etc. Auto is basically an electric motor with a large battery, power-inverter, brakes, a soft exterior on a strong body, four wheels, comfortable seats and a significant content of electronics.

3.5.4 LITHIUM BATTERY

Batteries have historically been the most expensive and the heaviest single component for electric vehicles. To cover the rush hour 140-mile range using a fully charged lightweight two-passenger vehicle we will need to integrate a 40kWh battery pack. This estimation is based on batteries and mileage range of the electric car mentioned earlier in this article and taking into consideration the deterioration of lithium batteries over time. This range could be greater based on the gentle driving style using software optimization, but we must also consider the use of HVAC systems in terms of variable temperature conditions in different geographical areas.

Battery life will be monitored to determine when a battery pack needs to be replaced. Rutt Bridge's Denver Mobility Model also assumes that by 2020 Tesla's battery packs will have an average life of 250,000 miles or 3.33 years with recharging twice a day. Regarding battery life, Straubel has said, "We've optimized for around a 10-year life." [67] Assuming a two to three-daily charges under regular use, this equates to about 3-5 years. Therefore, a 3.33-year life estimate seems quite realistic.

It is also necessary to bear in mind that the battery lifespan increases and energy density improve in the next five years. This will undoubtedly lead to downsizing the batteries, decreasing their weight or increasing the range.

3.6 MOBILITY BUSINESS PLAN

Before generating a business plan, an analysis of capital requirements and operating expenses always was completed in the highest possible detail. It is a challenging task to accurately estimate expenses for a service that has never actually existed.

The short version is that Mobility plan for London can provide solo rides in driverless taxis for $0.49/mile , or $0.24/mile if you rideshare with one other person, and still make a profit of almost 50% [52]. This mileage cost can vary for other cities due to different electricity rates and operating expenses.

This chapter provides a broad overview, while the specifics are contained in the following Appendices:

Appendix I:	Mobility's operating expenses
Appendix II:	Cost of a 2025 Mobility Taxi
Appendix III:	Rapid Charging Facilities
Appendix IV:	London, Prague and Denver commuter market opportunity
Appendix V:	Mobility Model - London, Prague, Denver

3.6.1 MOBILITY'S EXPENSES

It is worth to estimate an annual cost of operating a driverless taxi mobility service. Conventional taxicab service that is the closest existing business model, but autonomous mobility brings vast benefits. Table 3.5 summarizes these expense categories [52]. In comparison to the conventional taxis, there are either very low or non-existent.

EXPENSE	LOWER COST EXPLANATION
Maintenance	Brake Fluid and Chassis Lube every 30.000 miles. No engine, Exhaus system, transmission, oil changes, etc. Brake pads need less frequent replacement due to low weight, gentle driving and regenerative breaking
Tires	Assuming that autonomous taxis are gently driven, lightweight vehicles (60.000miles tire replacement, $450/year in house service)
Repairs	Replacement is budgeted for one battery pack, interior furnishings, computers, and sensors over the life of the vehicle
Fuel	Cost per mile can vary based on the local rates per kW/h. Calculated cost for London is $0.053/mile based on $0.252 per kW/h (UK Average - 2016 May) including 10% efficiency losses by the charging process. At 33mpg and $1.552/litre of petrol (2016 May), London Taxi TX5 spends $0.178/mile
Insurance	Estimating that accidents are very rare. $1000/year/auto can be allocated for an $10 million annual self-insurance fund.
Driver Salary & Benefits	Zero
Fare Meters	Zero
Dispatch Management	Mostly automated
Overhead and Accounting	Mostly automated

Tab. 3.5 - Mobility Expenses - Lower Cost Explanation

3.6.2 LONDON MODEL CASE

The Greater London is the ideal test market for the Mobility economic model. This model is based on a similar study conducted by Rutt Bridges for the Denver City and County of Denver [52]. According to the GLA Intelligence, the Greater London Area had a population of 13,879,757 while London’s population was only 8,538,698 [68].

London, however, is a major centre of employment and the area where the highest density of working commuters. The GLA Intelligence [54] estimates that on an average day, London has 869,000 inbound commuters and 322,000 outbound commuters, with average commutes of 36.6minutes both ways [69] (To achieve more accurate data, there would be a need to consider that inbound commutes are usually longer than the outbound due to a higher number of inbound commuters and its effect on the congestion).

3.6.3 ESTIMATES OF TRAVEL SPEED AND REVENUE MILES

Using inbound commute time and distance data from Travel In London report [70], average travel speeds of 40mph for highways and 14.4mph inbound and 15.8mph for outbound for city streets were estimated. For these purposes, it was assumed that one-fifth of the commute was on highways and four-fifth on city streets, which is reasonable for London [58].

This equates to an approximate average speed of 23.6mph for inbound and outbound commutes. If based on Office for National Statistics data, the calculated average inbound commute distance is at 12.5 miles and 13.2miles for outbound distance [59].

3.6.4 THE LONDON MOBILITY MODEL

Assuming driverless taxis could capture four inbounds and three outbound commute trips each morning (6 - 10 am), plus the return trips in the evening commute (4 - 8 pm) that would total 179 revenue miles per driverless taxi from weekday commuters alone. Assuming an average of 1.06 commuters per taxi [54] and seven round-trips per day, 10,000 driverless taxis could service a total of 74,200 commuters per day. This implies a 5% market share of all 869,000 inbound commuters and an approximately 10% share of all 322,000 outbound commuters (see Appendix IV for more details).

When considering a 30% discount, outbound ridesharing commuters pay as little as $4.44 per day round-trip. Why significant discounts for outbound commuters? Mobility needs customers to fill the return trips to pick up the much more numerous inbound commuters. A steep 30% discount is intended to lure outbound commute customers. Empty miles are the bane of any taxi service, and 70% of regular revenue is better than none [52]. Also, having a solid base of downtown London residents as regular customers will help generate evening and weekend full-fare trips.

How many days per year do workers commute? In fact, as a group, they commute 52 weeks a year, and some on holidays and weekends, since taxis will operate 24/7, every day of the year. But when looking at market share, throughout most of this thesis, we'll assume an average of three weeks of vacation plus 10 holidays or 47 weeks/235 days per year of "normal" daily miles [52]. The seven round-trips per day work out to a total of 42,276 annual revenue miles per Auto, with 20,562 as regular-fare inbound revenue miles and 21,714 outbound discounted revenue miles (see Appendices IV and V).

Since the London Mobility Model is based on 60,000 revenue miles annually per driverless taxi, 17,724 additional revenue miles will need to be added outside the core commute times, including evenings, weekends, holidays and airport trips. A fair number of people, especially in the service industries, work downtown on the weekends and holidays. There are also off-peak demand trips for shopping, entertainment, and recreation [52]. The evaluated commuter customer base plus the other 13.9 million Greater London area residents should be more than enough to generate these additional full-fare revenue miles.

3.6.5 EMPTY MILES

Unfortunately, not all miles, such as those driven to pick up a customer, are chargeable. A 2012 study by The Earth Institute at Columbia University for a similar Ann Arbor, Michigan [71] mobility fleet estimated 15% of total miles travelled would be empty miles with no passenger onboard.

This study considers a more conservative 25% empty miles factor for these financial projections. Adding 25% empty miles to the total 60,000 revenue-mile base totals 75,000 miles per year per driverless taxi. An eight-year life, with substantial battery/ cabin/ electronics retrofits during those years, equates to 600,000 miles, far more than you would expect to get from a conventional internal combustion engine car [52]. This is explained in detail in Appendices I and II.

3.6.6 POTENTIAL IMPACT ON COMMUTE TIMES

The London Mobility Model provides transportation for 74,200 commuters when considering a fleet of 10,000 driverless taxis. According to GLA Intelligence surveys, vehicles commuting to London hold an average of 1.06 people per car, truck or van, it usually takes 74,200/1.06 = 70,000 vehicles to move these commuters [54].

When considering the entire amount of 1,191,000 London commuters with an average 1.06 rider per vehicle, it fills London roads with approximately 1,123,585 vehicles. A fleet of 10,000 driverless taxis can potentially lower this number down by 5.34% to 1,063,585 vehicles. For a more extensive fleet of 100,000 driverless taxis, the overall number of cars required to serve the commuters would hypothetically drop down by 53.4% to 523,585 vehicles only. That is 600,000 fewer vehicles than is usually required. Such a considerable fleet would be theoretically able to serve 98.88% of the entire group of outbound commuters.

With so many commuters using driverless taxi service, the overall average commute speeds would likely increase appreciably from the estimates used for the London Mobility Model. Congestion also benefits from the ability of taxis to know the most efficient ways to bypass traffic jams. If average commute speeds increase, more rush-hour round-trip fares will be possible, and the revenues and profits projected in Appendix V will increase [52]. However, it is better to ignore these potential benefits for the purpose of this financial modelling as this industry does not exist yet.

Finally, if just half of the taxis are allowed to platoon, moving as one with a mere 3 meters between these 3-meter-long vehicles, the number of commuters serviced by driverless taxis could significantly increase. If provided their own lane, these taxi “trains" could safely travel at 70 mph, which would result in a significant decrease in travel times for all commuters. But again, that is an unknown speculative benefit [52].

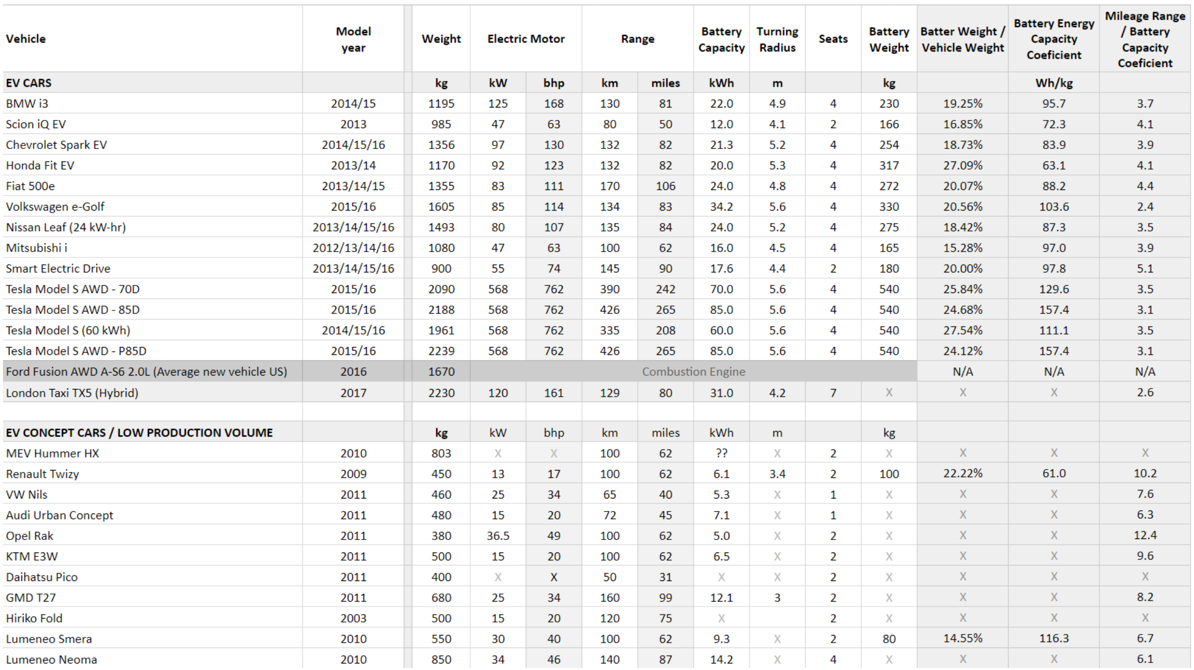
3.6.7 PROFIT PROJECTION

Based on Appendix IV, London commuter market opportunity, and Appendix V, The London Mobility Model, 10,000 Autos providing mostly transport for inbound and outbound commuters could generate a pre-tax profit of $138.8 million on revenues of $266 million. Inbound commuters choosing to ride alone would pay $12.25/day for door-to-door service on a typical 12.5-mile one-way/ 25-mile round-trip commute. Customers who share a ride with another passenger pay only $6.00/day. And for outbound commuters, those prices are 30% less: $9.06 and $4.44/day.

Mobility customers not only enjoy comfortable, productive accommodations, but they will also get over 70 minutes of newly found free time.

3.7 ELECTRIC VEHICLES - BENCHMARKING

Benchmarking study was conducted to evaluate specification of modern electric vehicles and present findings associated with vehicle weight, battery weight, battery capacity and mileage range. The study includes both, 13 vehicle models that are already in production, 11 concept cars, an average US car (Ford Fusion AWD) and the latest hybrid London Taxi TX. Data was gathered from OEM brochures, from journal reviews and from other public sources. The data presented for London Taxi TX are related to the electric drive only, the extended range using combustion engine is not considered.



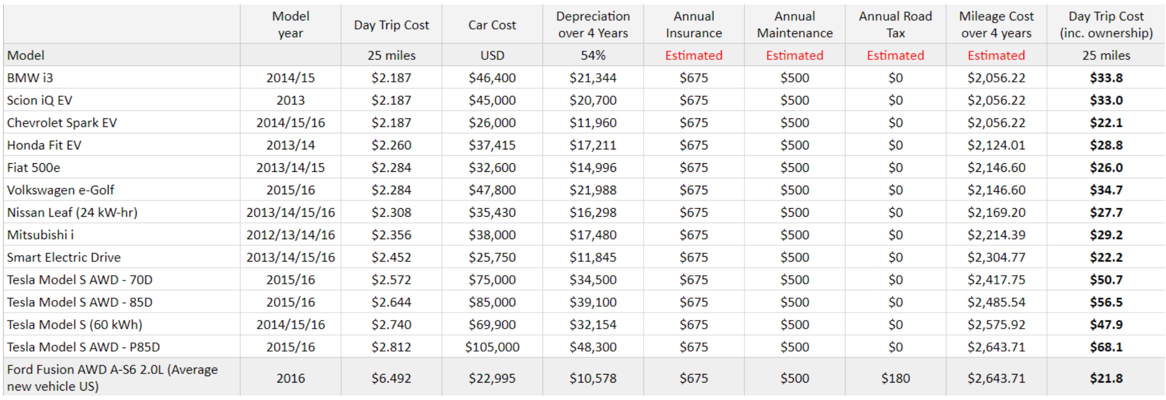
Vehicle	Model year	Weight	Electric Motor		Range		Battery Capacity	Turning Radius	Seats	Battery Weight	Batter Weight / Vehicle Weight	Battery Energy Capacity Coeficient	Mileage Range / Battery Capacity Coeficient
EV CARS		kg	kW	bhp	km	miles	kWh	m		kg		Wh/kg	
BMW i3	2014/15	1195	125	168	130	81	22.0	4.9	4	230	19.25%	95.7	3.7
Scion iQ EV	2013	985	47	63	80	50	12.0	4.1	2	166	16.85%	72.3	4.1
Chevrolet Spark EV	2014/15/16	1356	97	130	132	82	21.3	5.2	4	254	18.73%	83.9	3.9
Honda Fit EV	2013/14	1170	92	123	132	82	20.0	5.3	4	317	27.09%	63.1	4.1
Fiat 500e	2013/14/15	1355	83	111	170	106	24.0	4.8	4	272	20.07%	88.2	4.4
Volkswagen e-Golf	2015/16	1605	85	114	134	83	34.2	5.6	4	330	20.56%	103.6	2.4
Nissan Leaf (24 kW-hr)	2013/14/15/16	1493	80	107	135	84	24.0	5.2	4	275	18.42%	87.3	3.5
Mitsubishi i	2012/13/14/16	1080	47	63	100	62	16.0	4.5	4	165	15.28%	97.0	3.9
Smart Electric Drive	2013/14/15/16	900	55	74	145	90	17.6	4.4	2	180	20.00%	97.8	5.1
Tesla Model S AWD - 70D	2015/16	2090	568	762	390	242	70.0	5.6	4	540	25.84%	129.6	3.5
Tesla Model S AWD - 85D	2015/16	2188	568	762	426	265	85.0	5.6	4	540	24.68%	157.4	3.1
Tesla Model S (60 kWh)	2014/15/16	1961	568	762	335	208	60.0	5.6	4	540	27.54%	111.1	3.5
Tesla Model S AWD - P85D	2015/16	2239	568	762	426	265	85.0	5.6	4	540	24.12%	157.4	3.1
Ford Fusion AWD A-S6 2.0L (Average new vehicle US)	2016	1670	Combustion Engine								N/A	N/A	N/A
London Taxi TX5 (Hybrid)	2017	2230	120	161	129	80	31.0	4.2	7	X	X	X	2.6
EV CONCEPT CARS / LOW PRODUCTION VOLUME		kg	kW	bhp	km	miles	kWh	m		kg			
MEV Hummer HX	2010	803	X	X	100	62	??	X	2	X	X	X	X
Renault Twizy	2009	450	13	17	100	62	6.1	3.4	2	100	22.22%	61.0	10.2
VW Nils	2011	460	25	34	65	40	5.3	X	1	X	X	X	7.6
Audi Urban Concept	2011	480	15	20	72	45	7.1	X	1	X	X	X	6.3
Opel Rak	2011	380	36.5	49	100	62	5.0	X	2	X	X	X	12.4
KTM E3W	2011	500	15	20	100	62	6.5	X	2	X	X	X	9.6
Daihatsu Pico	2011	400	X	X	50	31	X	X	2	X	X	X	X
GMD T27	2011	680	25	34	160	99	12.1	3	2	X	X	X	8.2
Hiriko Fold	2003	500	15	20	120	75	X		2	X	X	X	X
Lumeneo Smera	2010	550	30	40	100	62	9.3	X	2	80	14.55%	116.3	6.7
Lumeneo Neoma	2010	850	34	46	140	87	14.2	X	4	X	X	X	6.1

Tab. 3.6 - Benchmarking of Electric Vehicles

The only vehicle that would be able to withstand the range of 140 miles calculated in the “Lithium Battery” chapter (3.5.4) is Tesla Model S in all presented calculations. All four models have the range over 200 miles, therefore would be suitable for the initial testing of the Mobility Business model. All other purely electric models require at least one stop in the Charging Facility during the rush hours. They were designed for the obsolete purchase-oriented business model.

Due to its low kerb weight, Smart Electric Drive achieves the best mileage range (90 miles) to battery capacity (17.6 kW-h) ratio of 5.1 from the list of electric vehicles that are already in production. On the other hand, the worst result belongs to VW e-Golf where the ratio is only 2.4. Without considering the Tesla Models, the kerb weight of VW e-Golf (1605 kg) is higher by approximately 35% than its competitors. It is clear the ratio between battery weight and vehicle kerb weight plays a significant role in the vehicle range.

Table 3.7 compares an evaluation of a Day Trip cost of a newly bought electric vehicle over a period of 4 years. It takes into consideration comparable aspects as were used for the Mobility: Fuel Cost, Car Cost, Depreciation, Insurance, Maintenance and Road Tax.



	Model year	Day Trip Cost	Car Cost	Depreciation over 4 Years	Annual Insurance	Annual Maintenance	Annual Road Tax	Mileage Cost over 4 years	Day Trip Cost (inc. ownership)
Model		25 miles	USD	54%	Estimated	Estimated	Estimated	Estimated	25 miles
BMW i3	2014/15	$2.187	$46,400	$21,344	$675	$500	$0	$2,056.22	**$33.8**
Scion iQ EV	2013	$2.187	$45,000	$20,700	$675	$500	$0	$2,056.22	**$33.0**
Chevrolet Spark EV	2014/15/16	$2.187	$26,000	$11,960	$675	$500	$0	$2,056.22	**$22.1**
Honda Fit EV	2013/14	$2.260	$37,415	$17,211	$675	$500	$0	$2,124.01	**$28.8**
Fiat 500e	2013/14/15	$2.284	$32,600	$14,996	$675	$500	$0	$2,146.60	**$26.0**
Volkswagen e-Golf	2015/16	$2.284	$47,800	$21,988	$675	$500	$0	$2,146.60	**$34.7**
Nissan Leaf (24 kW-hr)	2013/14/15/16	$2.308	$35,430	$16,298	$675	$500	$0	$2,169.20	**$27.7**
Mitsubishi i	2012/13/14/16	$2.356	$38,000	$17,480	$675	$500	$0	$2,214.39	**$29.2**
Smart Electric Drive	2013/14/15/16	$2.452	$25,750	$11,845	$675	$500	$0	$2,304.77	**$22.2**
Tesla Model S AWD - 70D	2015/16	$2.572	$75,000	$34,500	$675	$500	$0	$2,417.75	**$50.7**
Tesla Model S AWD - 85D	2015/16	$2.644	$85,000	$39,100	$675	$500	$0	$2,485.54	**$56.5**
Tesla Model S (60 kWh)	2014/15/16	$2.740	$69,900	$32,154	$675	$500	$0	$2,575.92	**$47.9**
Tesla Model S AWD - P85D	2015/16	$2.812	$105,000	$48,300	$675	$500	$0	$2,643.71	**$68.1**
Ford Fusion AWD A-S6 2.0L (Average new vehicle US)	2016	$6.492	$22,995	$10,578	$675	$500	$180	$2,643.71	**$21.8**

Tab. 3.7 - Day trip cost for purchase oriented model of Electric Vehicles over 4-year ownership [72]

The data presented in Table 3.7 were calculated based on the following:

- **Day Trip Cost** - Using the London average daily commuting distance of 25 miles, comparison of “fuel” cost for all listed models was calculated and adjusted based on the average electricity cost in the UK. [72] [73]
- **Car Cost** - Purchase costs of vehicle models presented in Table 3.7 are sourced from various US dealers and may vary in different states, therefore needs to be considered as approximate. The purchase costs may differ in the UK due to the additional taxes however the purchase cost ratio between listed models should remain comparable.
- **Depreciation** - Assuming that the new car will lose 25% of its purchase cost during the first year of ownership and 15% every following will result in estimated depreciation of 54% over the 4 years of ownership. [74]
- **Annual Insurance** - Estimation is based on the UK average and converted to USD. [75]
- **Annual Maintenance Cost** - The estimation of the maintenance cost of $500 is considered to be similar to the mobility model (Appendix I), this includes changing tires, brake fluid and, e.g. cabin air filters.
- **Road Tax** - EVs are currently free from Road Tax in the UK. The annual road tax of $180 for Ford Fusion is calculated using identical Ford Mondeo model available in the UK. [76]

The day trip costs presented in the third column in table 3.7 vary between $2.187 - $2.812 for the listed electric vehicles. Day trip cost in an average non-electric vehicle (Ford Fusion-Mondeo AWD 2.0) is approximately three times higher $6.492/25 miles (for average petrol prices in the UK).

To validate the Mobility business model, we need to take into consideration the ownership cost and depreciation cost listed above. As can be seen in the last column of Table 3.7, the estimated costs for a day trip rise dramatically. Apparently, the average non-electric vehicle seems to be more economically friendly than the electric vehicles, as the purchase cost together with the depreciation value play a significant role here. The actual day trip cost in a BMW i3 is in fact approximately 50% more expensive than the day trip cost in an average American car. The most comparable ones are the small city cars Chevrolet Spark EV and Smart Electric Drive with their day-trip cost of $22.

Anyway, there is a significant price drop of approximately $10/day, when comparing ownership of an electric vehicle with an autonomous taxi service. An average London commuter can hypothetically save $2350 annually using the mobility service, plus the free “non-driving” hours that can be used productively.

3.8 CHAPTER SUMMARY

Some people will be motivated by how much money they can save. Others will see this as an opportunity to arrive at work, and home relaxed rather than stressed from the drive. Environmentalists will appreciate the low-emissions, low-impact Autos. Workaholics will see this as an opportunity to get a half-hour jump on their day's work and head home earlier in the evening while still finishing those last emails during the commute. How individuals perceive Mobility will depend on their personal values, and Mobility needs to understand and speak to those values when communicating with targeted customer demographics [52].

4 AUTONOMOUS DRIVING

An automobile equipped with an autopilot system is an autonomous car. The system allows it to safely move from one place to another without help from a human driver. Desirably, the passenger's only role in such a vehicle would be choosing the destination.

Self-driving cars have been around in one form or another since the 1970s, but three DARPA Grand Challenges, in 2004, 2005, and 2007, jump-started the field. Grand Challenge alumni now populate self-driving laboratories worldwide. Arguably the most important outcome of the DARPA field trials was the development of a robust and reliable laser rangefinder. It's not just Google that's developing the technology, but also most of the major car manufacturers: Audi, Volkswagen, Toyota, GM, Volvo, BMW, Nissan [77].

The first autonomous vehicle moved on a public road in July 2013. Today, when four U.S. States have passed laws permitting autonomous cars and cities in Belgium, France, Italy and the UK are planning to operate transport systems for driverless cars, while other EU states have allowed testing robotic cars in traffic, it is clear that this revolution is in motion.

4.1 AUTONOMOUS CAR

Autonomous vehicles sense their surroundings with such techniques as radar, lidar, GPS, and computer vision. Advanced control systems interpret sensory information to identify appropriate navigation paths, as well as obstacles and relevant signage. Some autonomous vehicles update their maps based on sensory input, allowing the vehicles to keep track of their position even when conditions change or when they enter uncharted environments.

Fig. 4.1 - Automobile Automated Driving

Autonomous cars look like the vehicles we drive today. All the devices are 'retro-fitted' to the current conventional design. They have classic forward facing seats and a steering wheel. These cars take over from the driver under certain circumstances. Specific features of autonomy have been already successfully implemented. Self-parking, adaptive cruise control—which adjusts speed to keep a safe distance from cars ahead—and automatic braking are available on quite modest machines. In the near future, autonomous vehicles might take over driving entirely in heavy traffic or on motorways.

Self-driving cars are another step further on. There will not be a need for a steering wheel. It will disappear entirely, and the vehicle will do all the driving using the same system of sensors, radar and GPS mapping that autonomous vehicles employ. Call up a car with a mobile device, key in the destination and the vehicle will do all the work. [50] Self-driving cars will, therefore, allow people of all ages and abilities to use the vehicles and would thus eliminate the need for a driver's licence because it basically removes all constraints on the occupants' physical and mental state. This increases accessibility and mobility, improves the quality of social life and crucially – independence. Figure 4.2 explains the levels of automation into detail.

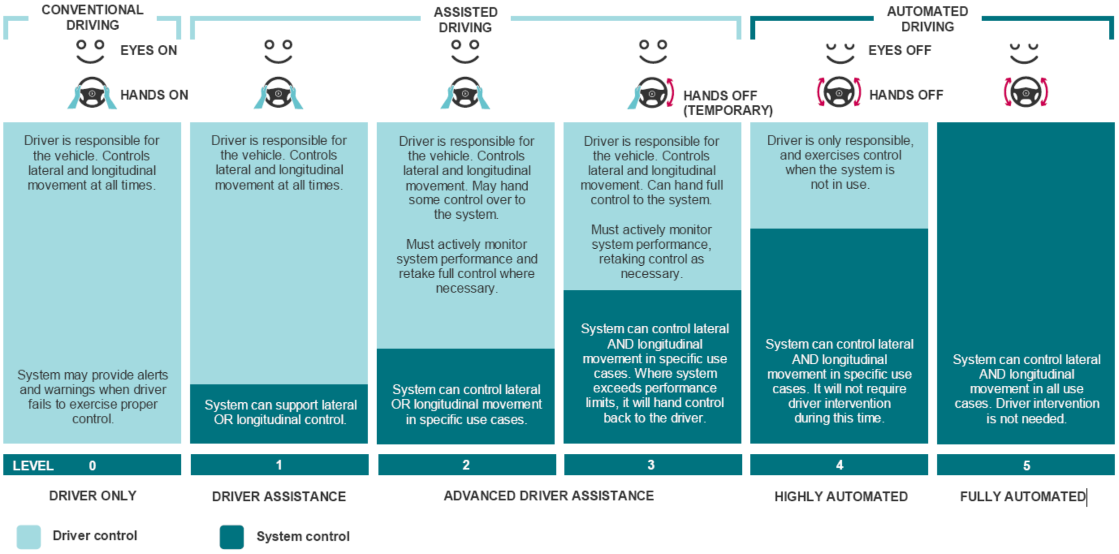


Fig. 4.2 - Summary of SAE International's Levels of Driving Automation for On-Road Vehicle (Mike Lemanski) [78]

The utilization of 'autopilot' cars will lead to a wide range of economic, productivity and time efficiency benefits. It opens a fresh market for a variety of Car-Sharing business models and brings trade expansion opportunities (mail & food delivery). Car-sharing programs would become more prevalent as autonomous vehicles could arrive at destinations and then be used by other passengers.

Driverless cars would allow people of all ages and abilities to use the vehicles and would thus eliminate the need for a driver's licence because it basically removes all constraints on the occupants' physical and mental state. This increases accessibility and mobility, improves the quality of social life and crucially - independence.

Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication would let traffic flow more freely and without the use of traffic lights. Ability to control, automate and optimize traffic will lead to a balanced distribution of traffic during peak times and therefore less wasted commuting time and fewer traffic accidents. Consequentially road capacity will increase, while demand for parking spaces will fall. Most importantly, the energy efficiency of autonomous vehicles will reduce carbon emissions and the global environmental impact of the entire automotive industry.

There are also many adjacent sectors which will be impacted by autonomous vehicles including insurance, telecommunications, electronics, technology, IT, transportation, logistics, advertising, digital and retail [79]. Autonomous vehicles will provide substantial social, industrial and economic benefits to the countries which will adopt and implement this technology into their infrastructure.

The main principle is in the digital connection between individual vehicles. Vehicles are becoming connected through mobile data networks and other dedicated communications protocols that facilitate connections with vehicles (V2V), other devices or machines (V2D) or with infrastructure (V2I) [79].

The following chapters provide a brief overview of today's available technology related to autonomous driving (AGV, UAV, obstacle detection, collision avoidance, intersection safety, etc.) and supplier resource. This desktop research should offer efficient, fast and affordable product selection for any autonomous driving application. The goal of this research is to make a pure source of all perception, computing, GPS, and interface components necessary for autonomous mobility projects.

4.2 AUTOMOTIVE RADAR

Automotive radar is a cost-effective object-detection system that uses electromagnetic (radio) waves to identify range, altitude direction, the speed of moving and fixed objects. The radar sensor transmits pulses of radio waves or microwaves which bounce off any object in their path. The object returns a tiny part of the wave's energy to the antenna which is usually located at the same site as the transmitter. Detection and tracking algorithms are typically included in a one-box design.

4.2.1 SMARTMICRO - SMART MICROWAVE SENSORS (SMS)

SmartMicro design and develop automotive-focused 24GHz radar sensors. Their Smart Microwaves Sensors includes object tracking in their standard packages. Classification algorithms can be added as an optional offer embedded onto the radar. The flexibility of their systems allows them to provide a wide range of solutions for various markets: Automotive (Passenger cars, Buses, Trucks), Autonomous Driving, Unmanned Ground Vehicles (UGV), Unmanned Aerial Vehicles (UAV).

Smart Microwave Sensors can be used for:

- Forward and Rear collision warning (FCW & RCW)
- Front and rear Pre-Crash / Pre-Safe applications
- Adaptive cruise control (ACC) with Stop&Go handling
- Traffic jam assist

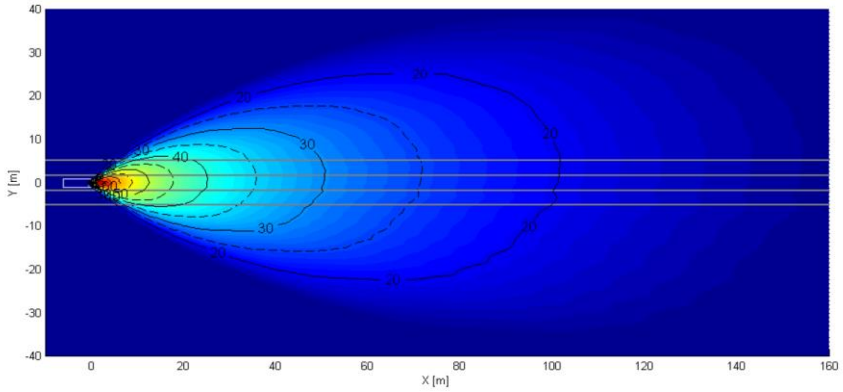


Fig. 4.3 - SMS UMRR - Antenna Field of View
Single Type 30 sensor collision warning configuration [80]

4.2.1.1 SMS UMRR Automotive Radar (Universal Medium Range Radar)

SMS Medium Range Radar sensor is able to measure range, speed and angle of multiple objects simultaneously (Fig. 4.3). It provides a combination of hardware (antenna) and software selectable field of view, real object separation capability in range and operation from a stationary position or from a vehicle [81].

4.2.1.2 SMS Multi-Sensor Systems

A network of multiple sensors can be established by connecting to a sensor data fusion and tracking controller or using two sensors in a master-slave setup. Up to 8 SMS devices can be connected to one CAN network. For the control of such a network, a multi-sensor system processing hardware can be used. This small box hosts the sensor data fusion and tracking algorithms. Sophisticated data association, synchronization and object tracking algorithms are performed. They can even generate a 360-degree picture of the traffic around a vehicle [81].

SMS Multi-Sensor System can be used for

- Mobile Enforcing / VSDS (Vehicle Spacing Determination System)
- Lane Change Assist
- Blind Spot Detection

4.2.1.3 Automotive Sensor System Architectures

In vehicle applications, usually, the sensor output is a list of detected targets (reflectors) on the sensor CAN bus with the parameters: Range, Angle (Position), Radial Speed, Reflectivity level, Type of Target (Reliability Figure).

The result of the tracking is an object list with the following parameters

- X, Y position and X, Y component of the velocity
- Type and Size of the reflector
- Visualization both targets and the objects are possible using the Drive Recorder software in any PC equipped with a CAN card.
- In vehicle applications, specific data have to be transmitted to the sensor(s) and the fusion / tracking / central ECU. Every sensor requires the information: actual ego velocity of the host vehicle and yaw rate of the host vehicle.
- The sensor system may consist of a number of individual sensors (Slaves) while one of them works as a central processing unit (Master). The latter controls the whole system interprets the sensor data and communicates with the vehicle.

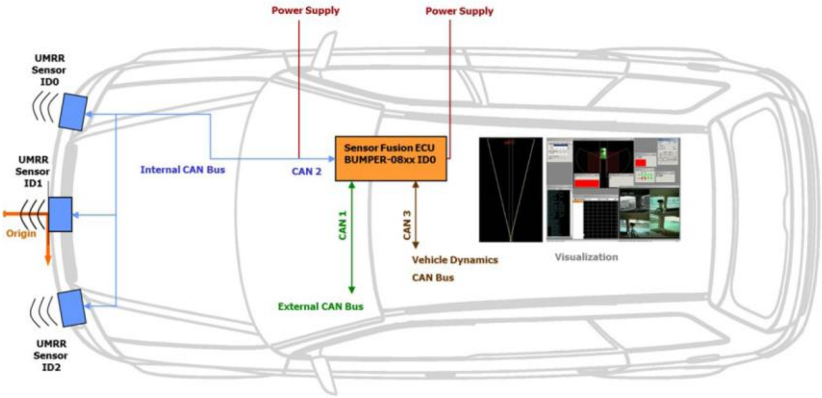


Fig. 4.4 - Example of Multi-Sensor Setup with Central ECU

4.2.2 DELPHI RADARS

Delphi is a leading global supplier of efficient electronic devices and technologies for automotive and other market segments.

4.2.2.1 Delphi ESR (Electronically Scanning Radar)

Delphi's multimode ESR combines a wide field of view at mid-range with high-resolution long-range coverage to provide two measurement modes simultaneously using a single radar. Wide, mid-range coverage not only allows vehicle cutting in from adjacent lanes to be detected but also identifies vehicles and pedestrians across the width of the equipped vehicle. Long-range coverage provides accurate range and speed data with powerful object discrimination that can identify up to 64 targets in the vehicle's path [82].

Delphi ESR can be used for:

- Adaptive cruise control (ACC) with Stop & Go
- Forward collision warning (FCW)
- Brake support
- Headway alert

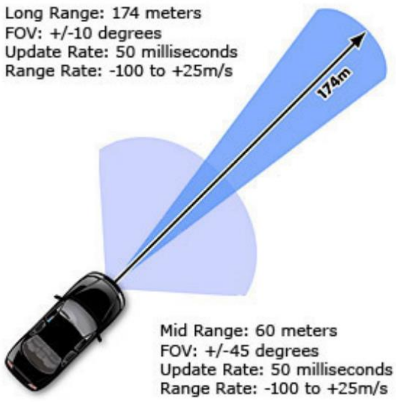


Fig. 4.5 - Delphi ESR - Long and Mid-Range [83]

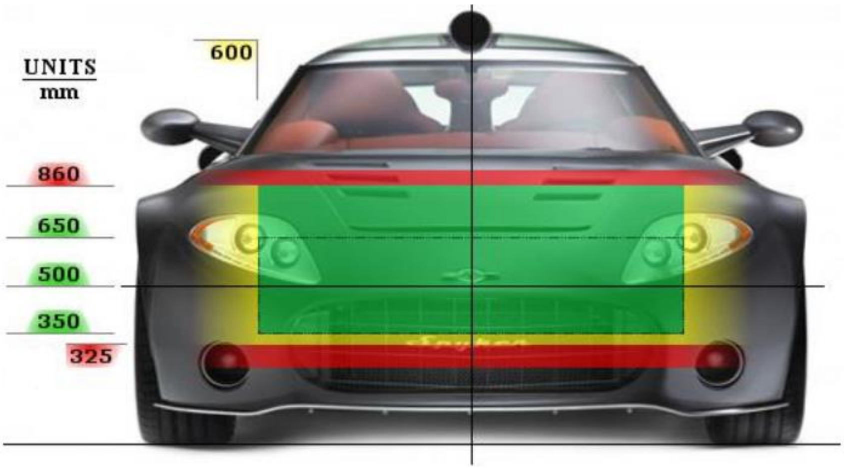


Fig. 4.6 - Delphi ESR - Mounting Guide [82]

The figure 4.6 illustrates an example of the ACC Stop-and-Go applications, the mounting height of the centre of the ESR on the vehicle should be mm to 860mm from the road surface. The illustration below shows the allowable mounting zones in green. The zones in yellow indicate potential zones with great radar and vehicle testing required. The zones in red indicate zones that are not allowed.

4.2.2.2 Delphi RSDS (Rear and Side Detection System)

By providing an alert when a vehicle has entered a blind spot to the rear or side of the vehicle, RSDS gives the vehicle more time to react to obstacles that may be difficult for the driver to see in the side mirror. This is also very useful for autonomous driving and other robotic applications. Targets of interest for these applications include on-road moving vehicles, including passenger cars, trucks, motorcycles, and vulnerable road users (VRUs) such as cyclists, pedestrians pushing shopping carts, etc.; providing they satisfy the minimum target speed requirement [84].

Accurate target data is provided in a range, range rate and angle. Furthermore, multi-target discrimination is provided in range and range rate robust performance in dense traffic and roadside clutter situations.

RSDS Key Features

- Blind Spot Information System (BLIS) - detects the presence of objects in the blind side spots
- Lane Change Merge Assist - monitors passing vehicles in adjacent lanes
- Rear Cross Traffic Alert (RCTA) - detects objects on either side of the equipped vehicle
- Rear Pre-crash Sensing - detects the potential for a rear-end collision from an approaching vehicle and works with other vehicle safety features to enhance occupant protection
- Must mount two of them at the back of a car due to its functionality and object recognition logic

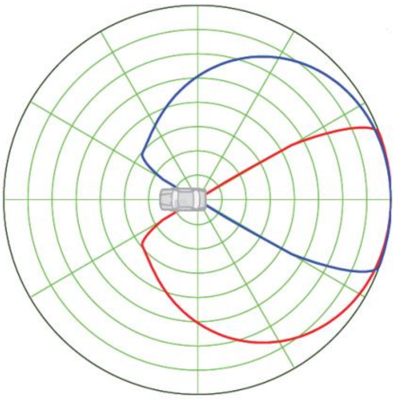


Fig. 4.7 - Delphi RSDS - Field-of-View [84]
(Range - 10m per division; Angle - 30deg per division)

4.3 LASER SCANNERS

LIDAR images the world in a true 3D manner by measuring the distance from a stationary or moving position at a million points per second. The image is recreated by the control software in a similar way as modern video gaming operates. LIDAR systems fire lasers and detect returning photons, using the timing of those return trips to measure distance and thus make 3D images.

LIDAR sensors are employed in virtually all autonomous research vehicles, the technology has already featured in cars with adaptive cruise control systems (ACC). These sensors are commercially available in these days but very expensive. A top-of-the-line Velodyne sensor which you can see spinning on the top of Google's, Lexus and Audi's research vehicles [85].

LIDAR systems that spin horizontally spread the laser distribution points evenly in the area surrounding the vehicle. As the vehicle moves forward, the laser refreshes the view of the entire area at even intervals much like a radar scan. The vehicle gets an updated, 360-degree view of all obstacles surrounding the car, but only occasionally gets a look at the most critical direction: forward.

Point Density - Each time a 3D laser passes over an area, the beam reflects off obstacles whether it be the edge of the road, a building, another vehicle, or other potentially dangerous obstacles. As the laser receiver reads the reflection, it creates data points. The 3D laser collects thousands of data points as it spins which are related to the vehicle's onboard control computer. The onboard computer creates a "drivability map", or an operational area for the vehicle that highlights all potential obstacles.

Dead Areas - Like the blind spot to a regular driver, dead areas are dangerous to autonomous vehicles because there are areas where the vehicle's obstacle detection system is literally blind. Each laser is designed differently, but most have a blind spot of some size and require the integration of additional lasers for complete coverage.

4.3.1 IBEO Laser Scanners

Ibeo Automotive Systems GmbH is the German specialist for automotive LIDAR sensor technology located in Hamburg. In addition, Ibeo develops software for environmental detection, referencing tools for Highly Automated Driving and Autonomous Driving (HAD/AD) systems as well as Highly Automated Driving and Mapping & Localization applications.

4.3.1.1 IBEO LUX

The Ibeo LUX laser scanner is the perfect basis for sophisticated and reliable automotive ADAS applications. They offer all the benefits of scanning LIDAR systems, are multi-application, weatherproof and compact [58]. The Ibeo LUX is an all-rounder for use in urban traffic and on the motorway. Ibeo LUX laser scanners work accurately and reliably even at high speeds, in poor weather conditions and heavy traffic.

IBEO LUX key features:

- Long range up to 200m
- All weather capability based on Ibeo multi-echo-technology
- Embedded object tracking
- Wide horizontal field of view

4.3.1.2 IBEO miniLUX

Ibeo miniLUX is a concept of the next generation mini laser scanners. It has amazingly compact housing and covers up to 180 degrees horizontal field of view. Vehicles can be measured in the distance up to 40m, pedestrians up to 15m [86]. This laser scanner can be used for various applications (depending on the mounting position) like protection of tailgate, drivers gesture detection (e.g. for tailgate opening) or clearance height detection. The miniLUX mounted on the sides in combination with the long-range Ibeo LUX laser scanner provides a 360 degrees field of view.

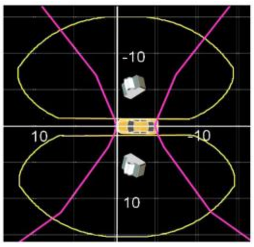


Fig. 4.8 - Based on the kidney-shaped range profile, the Ibeo miniLUX covers the entire environment on the sides.

4.3.1.3 IBEO Object Tracking by a contour matching

Ibeo scan data is associated with a filtered contour description of an object. Objects movements over time are calculated by the contour translation and rotation based on an interactive closest point algorithm. The contour contains stable geometric features like corners and lines, which are geometrically fixed on the object. Stationary objects (background objects) are covered by a dedicated static object map.

4.3.1.4 IBEO Fusion System

Ibeo laser scanners offer a very wide horizontal aperture angle. Some application areas, however, require an even higher field of vision. The LUX fusion system can combine up to six sensors in one unit. The data of the individual sensors are intelligently synchronized and combined using control software developed by Ibeo. Figure 4.9 illustrates the way of achieving a seamless 360deg recording of the vehicle’s environment.

Fig. 4.9 - Ibeo - Fusion System [87]

4.3.2 VELODYNE Laser Scanners

Velodyne LiDAR is a LiDAR technology company that focuses on applications of LiDAR technology for use in autonomous vehicles, vehicle safety systems, 3D mobile mapping, 3D aerial mapping and security. Its products range from the high-performance, surround view Ultra-Puck™ VLP-32, classic HDL-32/64 and cost-effective VLP-16. Velodyne's opulent suite of perception software and algorithms are the key enablers of its perception systems.

4.3.2.1 VELODYNE VLS-128

High-resolution LiDAR is critical to navigate autonomous cars and provide vehicle safety. A Velodyne sensor provides real-time 3D images all around the vehicle, far into the distance, producing billions of data points understood and consumed by a computer. LiDAR is more reliable, based on measurements, and therefore more accurate than a camera-based safety system. High-resolution LiDAR is essential for object detection and collision avoidance at all speeds, with the highest resolution needed when travelling at speeds higher than 30 miles per hour. The faster a vehicle goes, the more data is needed at a faster pace for safety evaluation [88].

Fig. 4.10 - Velodyne HDL-64 (Left) and Velodye VLS-128 (Right) [88]

The VLS-128™ is a 70 percent size reduction from the HDL-64, with double the range and four times the resolution. Due to its 905nm technology, it operates in dry climates and wet environments and is based on mass-produced CMOS semiconductor technologies.

4.3.2.2 VELODYNE VELARRAY

The Velarray LiDAR sensor uses Velodyne's proprietary ASICs (Application Specific Integrated Circuits) to achieve superior performance metrics in a small package size of 125mm x 50mm x 55mm that can be embedded into the front, sides, and corners of vehicles. It provides up to a 120-degree horizontal and 35-degree vertical field-of-view, with a 200-meter range even for low-reflectivity objects. With an automotive integrity safety level rating of ASIL B, Velarray will ensure not only safe operation in L4 and L5 autonomous vehicles but also in ADAS-enabled cars. It has a target price in the hundreds of dollars when produced in mass volumes [89].

Fig. 4.11 - Velodyne Velarray [89]

4.3.2.3 VELODYNE - HDL - 32E

The HDL-32E LiDAR sensor is small, lightweight, ruggedly built and features up to 32 lasers across a 40° vertical field of view. The HDL-32E measures 145 mm high x 87mm in diameter, weighs less than two kilograms. The HDL-32E's 32 lasers are aligned from +10° to -30° to provide an unmatched vertical field of view, and its patent-pending rotating head design delivers a 360° horizontal field of view natively. The HDL-32E generates a point cloud of 700,000 points per second with a range of 70 meters and typical accuracy of +/- 2cm [90].

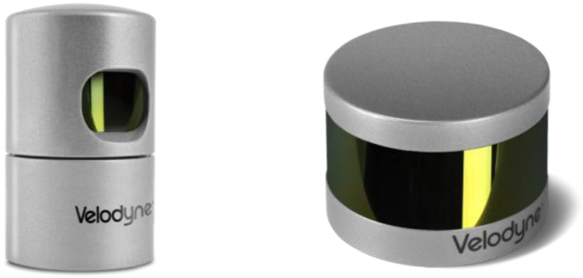


Fig. 4.12 - Velodyne HDL - 32E (left), Velodyne VLP-16 Puck (right) [90]

4.3.2.4 VELODYNE LiDAR PUCK

Velodyne's new VLP-16 PUCK sensor is the smallest product in Velodyne's 3D LiDAR product range. The VLP-16 has a range of 100m, and the sensor's low power consumption (8W), lightweight (830 grams), compact footprint (Ø103mm x 72mm), and dual return capability make it ideal for UAVs and other mobile applications. Velodyne's LiDAR Puck supports 16 channels, 300,000 points/sec, a 360° horizontal field of view and a 30° vertical field of view, with +/- 15° up and down. The Velodyne LiDAR Puck does not have visible rotating parts, making it highly resilient in challenging environments (Rated IP67) [91].

4.4 AUTOMOTIVE VISION

Stereo Vision is a crucial technology for modern Driver Assistance Systems aiming at increased traffic and driving comfort. The opportunity to directly measure the depth of pixels and objects is crucial for understanding the traffic situation and detecting risky situations.

Key Features:

- Vehicle detection and Free parking detection
- Active braking assistant reacting to crossing traffic of any type
- Pedestrians, animals or obstacles collision avoidance up to 50km/h by autonomous braking
- Lane keeping up to 200km/h even under adverse weather conditions
- Low-speed autonomous driving in traffic jams (Object tracking)
- Traffic sign recognition and Automatic Headlight Control

Stereo vision consists of mainly two tasks: Calibrating two or more cameras in the first step and finding corresponding points within different cameras in the second step. Applications in close-range photogrammetry prefer convergent camera setups that converge at the region of interest using photogrammetric markers. This camera setup changes for natural environments when the views of corresponding points should be as similar as possible, leading to parallel stereo setups with moderate baselines. This aligned stereo geometry is also used for stereo-based driver assistance [92]. However, there are several requirements in stereo vision that are to a certain extent unique to the intelligent vehicles field:

- The range of measurement covers a large area, currently typical from 2m to 50m
- Precise sub-pixel interpolation is required since the stereo baseline is constrained by design and packaging issues. Unfortunately, camera resolution and image size are limited too due to night-time performance requirements and cost.
- High accuracy demands the calibration process while the cameras are being exposed to intense temperature changes and vibrations.
- The system must operate under adverse weather conditions such as snow, rain, fog and any combination thereof.
- Processing should be done in the camera box for cost reasons.
- Cooling is not permitted (the camera is mounted behind the windshield where heating by the sun is maximal).
- The goal is to detect relevant objects (e.g. the height of curb) and their orientation

The dream of autonomous driving implies a higher resolution of the devices, even higher computational power at a given thermal dissipation loss. Above all, those applications demand a zero-error sensing system [92].

4.4.1 CONTINENTAL – ContiGuard Safety System & Stereo Vision

Continental, the international automotive supplier, incorporates a stereo camera to the comprehensive ContiGuard safety system as an integral element of its forward-looking systems. This helps to prevent or at least to reduce the seriousness of the frequent accidents involving pedestrians or with vehicles at intersections; to date, accidents like these makeup almost half (46.6%) of those traffic accidents in Germany that result in significant personal injury [93].

Fig. 4.13 - Continental - Stereo Vision

The stereo camera consists of two high-resolution CMOS mono-cameras, housed approximately 20 centimetres apart behind the windshield. Whereas a mono-camera only estimates distances, the stereo camera measures the distance to an object and its height from the road surface. At medium distances of 20 to 30 meters, the stereo camera can determine the range to the object with an accuracy of between 20 and 30 centimetres.

4.4.2 BOSCH – Stereo Video Camera

The Bosch video camera supplies data for many different tasks. The information it provides can significantly reduce both the risk and the consequences of collisions with vehicles, pedestrians, and cyclists at speeds of up to 80 km/h. It thus offers the ideal basis for improving safety in urban traffic.

The stereo camera's two CMOS (complementary metal oxide semiconductor) colour images have a resolution of 1280 x 960 pixels (1.2megapixels). Using a robust lens system, the camera records a horizontal field of view of 45 degrees, the vertical field of view of 25 degrees and offers a 3D measurement range of more than 50 meters. The image sensors, which are highly sensitive in terms of lighting technology, can process huge contrasts and cover the wavelength range that is visible to humans [94].

By integrating the control unit for image processing and function control directly in the camera housing, the Bosch engineers have created a system that is impressively compact. With a 12-centimetre distance between the optical axes of the lenses, the Bosch stereo camera may well be the smallest system of its kind currently available in the field of automotive solutions. As a result, it is particularly simple for automobile manufacturers to integrate into their vehicles.

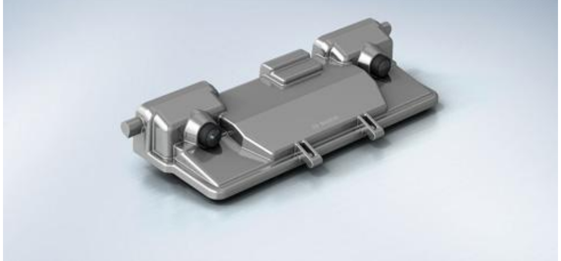


Fig. 4.14 - Bosch - Stereo Video Camera

4.4.3 MOBILEYE - 630 System

The Mobileye Camera Development Kit is ideally suited for sensor fusion systems and automated driving research. The Mobileye 630 system uses a smart digital camera located on the front windshield of the vehicle. Inside the camera, Mobileye's powerful EyeQ2® Image Processing Chip provides high-performance real-time image processing, by utilizing the Mobileye vehicle, lane and pedestrian detection technologies to efficiently measure and calculate dynamic distances between the vehicle and road objects [95].

Fig. 4.15 - Mobileye 360 System

4.4.4 FLIR SYSTEMS - THERMAL IMAGING

FLIR Systems is the world's largest commercial company specializing in the design and production of thermal imaging and infrared cameras, components and imaging sensors.

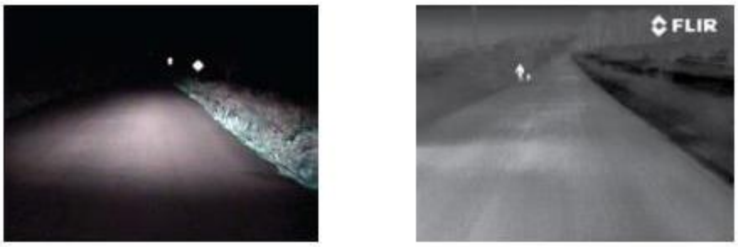


Fig. 4.16 - Thermal Sensing (Left - Without, Right - With Camera)

4.4.4.1 FLIR - PathFindIR 30-Hertz, NTSC - Camera

PathFindIR 30-Hertz Thermal Imager helps the autonomous vehicle to recognize pedestrians, animals or objects in total darkness or smoke, rain or snow. Infrared Camera not only dramatically increases vehicle's ability to see in a night or a day to spot animals, parked vehicles or pedestrians near the road in fog, dust and snow, with our camera wash system the lens remains clear regardless of conditions.

Fig. 4.17 - Flir - PathFindIR 30-Hertz, NTSC - Camera

4.5 ELECTRIC POWER STEERING

In the future, every car control will be by-wire; today's EPS looks like a step in that direction. Electric systems have an advantage in fuel efficiency because there is no belt-driven hydraulic pump always running, whether assistance is required or not, and this is a significant reason for their introduction. Another significant advantage is the elimination of a belt-driven engine accessory, and several high-pressure hydraulic hoses between the hydraulic pump, mounted on the engine, and the steering gear, mounted on the chassis. This greatly simplifies manufacturing and maintenance.

To provide steering assistance, an electric motor mounted to the side of the rack housing drives a ball-screw mechanism via a toothed rubber belt. The screw engages a spiral cut in the outside of the steering rack. A torque sensor attached to the pinion shaft signals a control computer when to help.

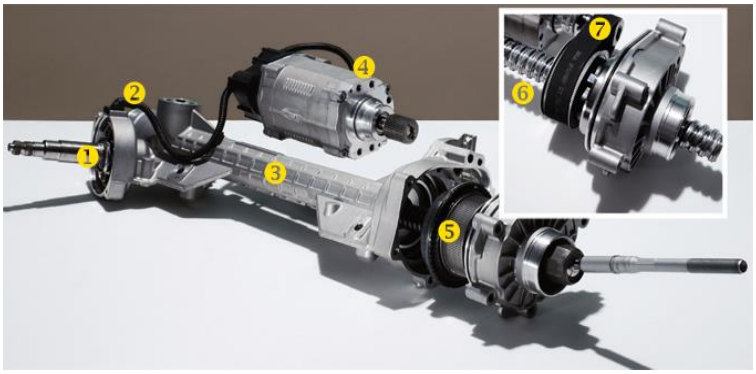


Fig. 4.18 - Electric Steering System
(1-Pinion, 2-Shaft Steering Torque Sensor, 3-Rack-and-Pinion Housing,
4-Electric Motor, 5-Ball-screw Mechanism, 6-Steering Rack, 7-Drive Belt)

4.5.1 GLOBE MOTORS – Globe Pow-R Steer

Motor-driven steering systems are also much lighter, often less than half the weight of traditional hydraulic power steering systems. The Globe Motors DC brushless motor operates independently of the engine, it provides steering assistance, even when the engine is not running.

Fig. 4.19 - Globe Motors - Pow-R Steer (PS-1265)

The POW-R STEER® unit is a permanent magnet BLDC, low cogging torque motor with an embedded controller connected to a gearbox with electronics to measure and interpret torque, vehicle speed, engine RPM, motor rotor position and speed. The unit transfers electrical power into mechanical power to assist the operator by reducing steering effort, shock and fatigue. In addition, this product can be entirely controlled by CAN-based communication. Therefore it is ideal for autonomous research applications [96].

4.6 AUTOMOTIVE GPS & IMU

An inertial measurement unit (IMU) is an electronic device that measures and reports on a vehicle's velocity, orientation, and gravitational forces, using a combination of accelerometers and gyroscopes, sometimes also magnetometers. In the automotive industry, IMUs are typically used to manoeuvre autonomous vehicles. An inertial measurement unit works by detecting the current rate of acceleration using one or more accelerometers and detects changes in rotational attributes like pitch, roll and yaw using one or more gyroscopes [97].

Recent developments allow producing IMU-enabled GPS devices. An IMU allows a GPS receiver to work when GPS-signals are unavailable, such as in tunnels, inside buildings, or when electronic interference is present. Inertial guidance systems are now usually combined with satellite navigation systems through a digital filtering system. The inertial system provides short-term data, while the satellite system corrects accumulated errors of the inertial system.

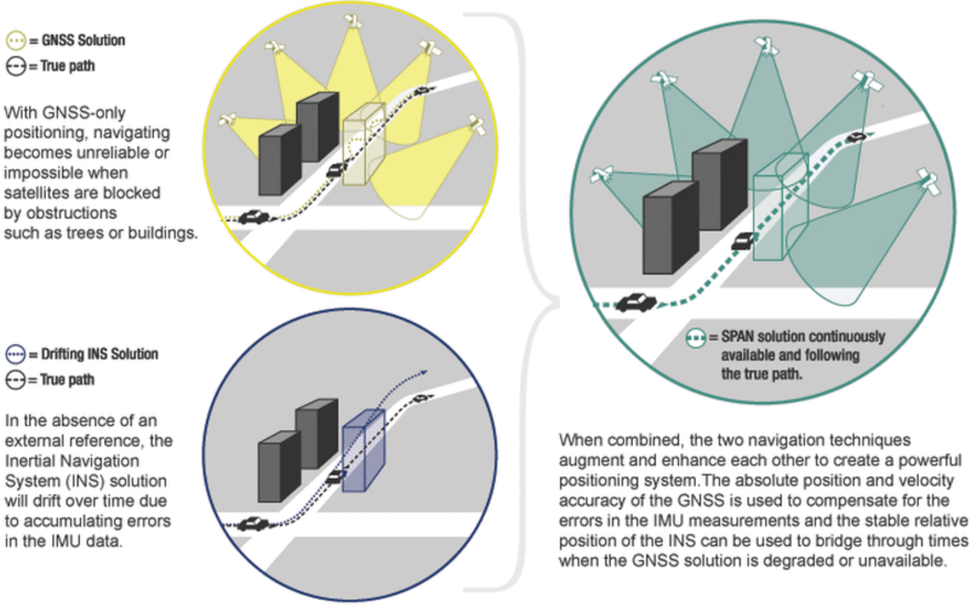


Fig.4.20 - How SPAN works [71]

IMU Construction Features

- 3 accelerometers (orthogonal to each other)
- 3 gyroscopes (orthogonal to each other)
- 3 magnetometers (orthogonal to each other)

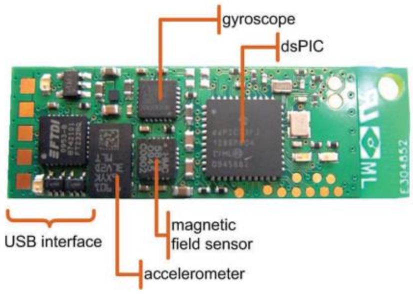


Fig. 4.21 - ETH Orientation Sensor - the components of the miniaturized IMU

4.6.1 NOVATEL GPS & IMU

4.6.1.1 NovAtel SPAN - GNSS/Inertial System

SPAN (Synchronous Position, Attitude and Navigation) technology brings together two different, but complementary technologies: GNSS positioning and inertial navigation. The absolute accuracy of GNSS positioning and the stability of inertial measurement unit (IMU) gyro and accelerometer measurements are coupled to provide a 3D navigation solution that is stable and continuously available, even when satellite signals are blocked [98].

Fig. 4.22 - SPAN - CPT Unit

SPAN-CPT is a compact receiver, capable of delivering up to centimetre-level accuracy. The IMU components within the SPAN-CPT enclosure are comprised of Fiber Optic Gyros (FOG) and Micro Electrical Mechanical System (MEMS) accelerometers, maximizing price/performance value.

4.6.2 KVH IMU - FOG

KVH Industries produces digital compass & fibre optic gyroscope (FOG) - based systems that meet the requirements commercial customers for precision guidance, stabilization, and navigation. KVH FOGs are used in commercial applications like industrial robotics, optical stabilization, autonomous vehicles, and remotely operated submersibles [99].

4.6.2.1 KVH 1750 IMU

The 1750 IMU is an ultra-compact, inertial sensor system ideal for unmanned applications where size, weight and power consumption must be minimized. The 1750 IMU incorporates three very small precision fibre optic gyro and three low noise MEMS accelerometers [100].

4.6.2.2 KVH CNS-5000 INS

The versatile, commercial CNS-5000 combines two complementary technologies – KVH's fibre optic gyro-based inertial measurement unit (IMU) with NovAtel's OEM6 GNSS precision receiver technology – within a single enclosure. The deep coupling of these technologies within the CNS-5000 optimizes the raw GPS and IMU data, delivering a superior position, velocity and attitude solution.

Through its seamless integration of these two highly reliable navigation systems, the CNS-5000 provides the solution to these needs in a low-cost, small form factor solution designed for 3D positioning, velocity, and attitude measurement [101].

4.7 SAFE STOP

The SafeStop provides an independent, wireless safety link for unmanned system operators and capable of remotely pausing or disabling unmanned ground and surface vehicles from a safe location. This ensures that people and expensive equipment are protected from the inherent dangers of unmanned vehicle system operation.

4.7.1 TORC - SafeStop - Wireless Emergency Stop System

The SafeStop receiver unit is integrated into the unmanned vehicle and is capable of disabling the unmanned vehicle with hardware contacts or pausing vehicle operation with software messages passed over Ethernet or serial interfaces.

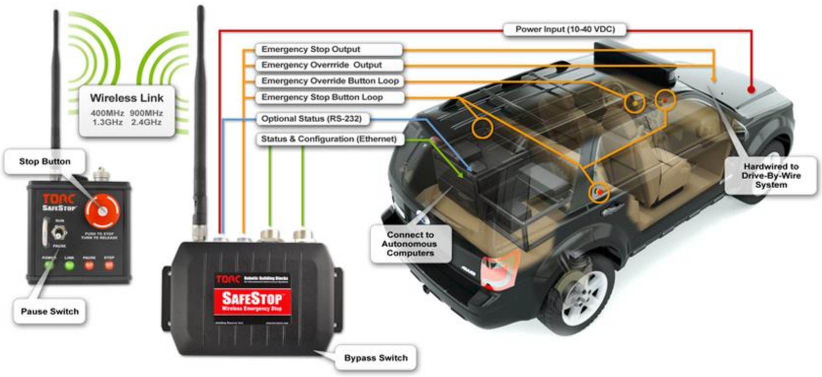


Fig. 4.23 - How RF Safe-Stop works installed in a family-size SUV

4.8 EXAMPLES OF APPLICATION

The aim of this chapter to provide the most advanced examples of application, ideally for SAE Level 5. But SAE Level 5 sensor modalities have not really been yet established. According to Samuel Rustan from AutonomouStuff, there really isn't even a “de facto” standard at this time. Since level 5 automation explicitly states that the human is out-of-the-loop, this area is undefined.

Radar-vision, radar-lidar, as well as GPS/IMU-mapping strategies, are actively being investigated. The approach at the moment for some companies is to purchase and equip a vehicle with the sensors and devices listed below:

- Radar - (e.g. Delphi ESR)
- Lidar - (e.g. Velodyne, IBEO)
- Vision - (e.g. Allied Mako, Flir)
  - Intelligent Forward View Camera (e.g. Mobileye)
- GPS-IMU (e.g. NovAtel PowerPack 7)
- Compute Platform
  - R&D ruggedized high-performance processor + GPU (e.g. AS Spectra w/ GTX-1080i)
  - High-Performance Embedded (e.g. Nvidia Drive PX, Xavier, Pegasus)
- Vehicle Control System (e.g. PACMod)

4.8.1 EXAMPLE - GOOGLE CAR

The Google driverless car is a project by Google that involves developing technology for autonomous cars. The heart of the system is a laser range finder mounted on the roof of the car - Velodyne 64-beam laser. The car then combines the laser measurements with high-resolution maps of the world, producing diverse types of data models that allow it to drive itself while avoiding obstacles and respecting traffic laws.

The vehicle also carries other sensors, which include: four radars, mounted on the front and rear bumpers, that allow the car to see far enough to be able to deal with fast traffic on freeways; a camera, positioned near the rear-view mirror, that detects traffic lights; and a GPS, inertial measurement unit, and wheel encoder, that determine the vehicle's location and keep track of its movements.

The system drives at the speed limit it has stored on its maps and maintains its distance from other vehicles using its system of sensors. The system provides an override that allows a human driver to take control of the car by stepping on the brake or turning the wheel, like cruise control systems already found in many cars today.

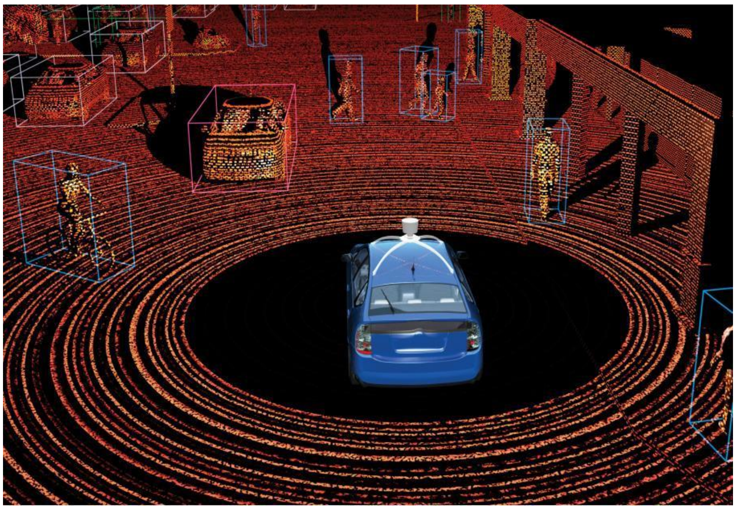


Fig. 4.24 - How a self-driving car sees the world [77]

While various companies are developing self-driving-car technology, Google's is the most advanced. Once a driver activates the autonomous mode, the vehicle's drive-by-wire system transfers control of the brake, gas, and steering to an onboard computer. The vehicle's roof-mounted lidar (or light detection and ranging) unit probes 360 degrees with 64 laser beams, taking more than a million measurements per second. This data forms a high-resolution map (accurate to about 11 cm) of the car's surroundings. Prebuilt navigation maps indicate static infrastructures, such as telephone poles, crosswalks, and traffic lights, which enables software to identify moving objects, like pedestrians and cyclists quickly. These targets are clustered together and tracked so that algorithms can process the traffic situation and plot a path safely through it [77].

4.8.2 EXAMPLE - VisLab 3DV Stereo System

The VisLab 3DV Stereo System is a result of extensive testing in extreme conditions. It has been employed during the VIAC project, a unique autonomous driving test from Italy to China: 13,000 km, 3 months of the trip, and no one driving.

PROUD Car Test 2013 (Public Road Urban Driverless-Car Test 2013)

For the first time in history, during the PROUD-Car Test 2013 event (July 12, 2013, in Parma) a vehicle moved autonomously and in total safety on a mixed traffic route (rural, freeway, and urban) open to public traffic, with nobody on the driver seat. The vehicle was not remotely controlled, but on the contrary, it was full of sensors to perceive the surrounding environment; the onboard systems interpret the traffic situation to react accordingly, acting on steering and changing speed in autonomous mode (with no human intervention) [102].

Sensors used during the test

- Two frontal cameras to locate obstacles (pedestrians, bicycles, other vehicles) on the path, locate and interpret traffic lights, determine the position of lane markings, and reconstruct the terrain profile
- Lateral cameras together with lateral laser scanners to handle merging and roundabouts
- Frontal laser scanner together with two lateral laser scanners to locate lateral objects (like nearby vehicles, barriers, tunnel sides)
- Two backward looking cameras to locate vehicles in adjacent lanes

4.8.3 EXAMPLE - AStuff Perception Kit

AStuff (AutonomouStuff) offers various flexible custom vehicle kits for advanced safety and robotic research vehicles. The option below (Fig. 4.25, Fig. 4.26) provide benefits for those developing advanced solutions. This option includes a standard set of sensors along with a pre-configured ECU enabling plug-n-play startup.

Fig. 4.25 - AutonomouStuff - Perception Kit - Example Five [78]

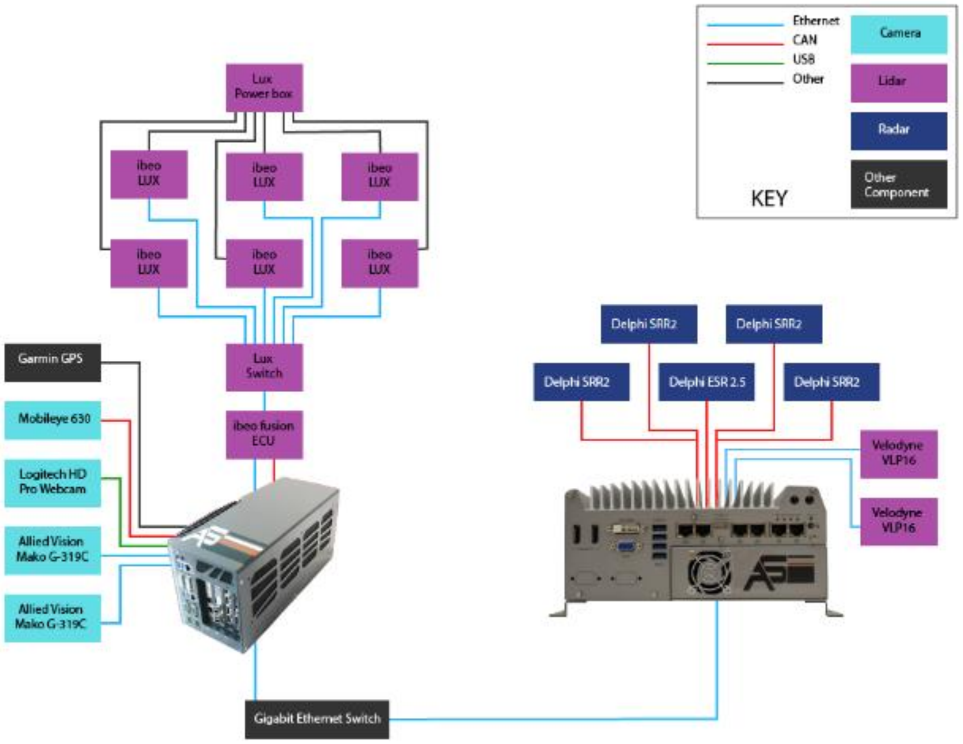
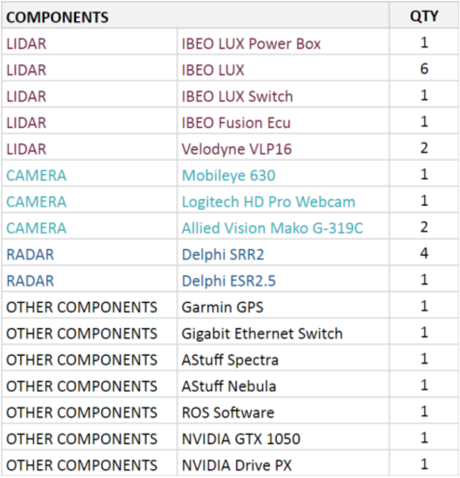


Fig. 4.26 - AutonomouStuff - Perception Kit - Example Five [78]



COMPONENTS		QTY
LIDAR	IBEO LUX Power Box	1
LIDAR	IBEO LUX	6
LIDAR	IBEO LUX Switch	1
LIDAR	IBEO Fusion Ecu	1
LIDAR	Velodyne VLP16	2
CAMERA	Mobileye 630	1
CAMERA	Logitech HD Pro Webcam	1
CAMERA	Allied Vision Mako G-319C	2
RADAR	Delphi SRR2	4
RADAR	Delphi ESR2.5	1
OTHER COMPONENTS	Garmin GPS	1
OTHER COMPONENTS	Gigabit Ethernet Switch	1
OTHER COMPONENTS	AStuff Spectra	1
OTHER COMPONENTS	AStuff Nebula	1
OTHER COMPONENTS	ROS Software	1
OTHER COMPONENTS	NVIDIA GTX 1050	1
OTHER COMPONENTS	NVIDIA Drive PX	1

Tab. 4.1 - AutonomouStuff - Perception Kit
Example Five - List of Components [78]

For specific research and development needs, AutonomouStuff can configure a custom kit for any vehicle. This provides flexibility with placement and choice of sensors. From the advanced kit to the basic kit, there is a broad spectrum of possible sensor configurations for a development vehicle.

In terms of time, effort, and money, AutonomouStuff estimates at least a 5-man-year effort, and, at the low end, about US$250,000. There are many algorithms that need to be developed for perception, object detection and classification, decision making, deep learning, and the underlying algorithms to pilot the vehicle in a smooth and comfortable manner electronically. If we are looking for rough estimations for serious work in vehicle autonomy the range could be from $250-500k USD [103].

4.9 LEGAL ASPECTS RELATED TO CONVENTIONAL AND AUTONOMOUS DRIVING

There will be a transitional period - where we will have a mixture of conventional cars, cars with increasingly sophisticated ADAS and ultimately, fully automated vehicles - the solutions for the distant future might not work now [104]. In response to the autonomous vehicle technologies, it is crucial to amend specific aspects of the current regulatory framework for driving. Mainly:

REGULATION - Clarifying provisions for the construction and use of near to market technologies (mostly remote-control parking) through changes to regulations.
INSURANCE - Making amendments to primary legislation to ensure insurance products will be available for automated vehicles.
HIGHWAY CODE - Providing guidance for drivers about the safe and appropriate use of new ADAS technologies, as well as specific advice about separation distances for vehicles driving as platoons.

To clarify the meaning of terms conventional driving, assisted driving and fully automated driving, the figure 4.2 details the diverse levels of assistance and automation with respect to the role of the driver in each of them.

By taking a step-by-step approach, and regulating in waves of reform, we will be able to learn important lessons from real-life experiences of driving of increasingly automated vehicles. We can then apply these lessons when considering what further changes will be required and are appropriate to allow the safe use of technology that is yet to be developed. This will complement the lessons learnt from testing fully automated vehicles both on test tracks and public roads, providing the government with the evidence on which to support future policy decisions [104].

This rolling program of regulatory reform enables each country to plan and act accordingly by removing barriers to the introduction of ADAS and AVT where these can be foreseen. It is also necessary to work closely with industry to identify near to market ADAS so that citizens and businesses can take advantage of innovative vehicle systems as soon as they reach the market.

4.9.1 REGULATIONS

Regulation of the automobile industry takes place primarily at international level. Generally, cars sold in Europe must comply with many regulations set globally by the World Forum for Harmonisation of Vehicle Standards. These regulations are continually being developed to enhance safety and permit the introduction of modern technology in a carefully controlled manner.

Several of these regulations form the baseline performance criteria for a vehicle type approval process. Once a manufacturer successfully receives type-approval for a new vehicle, they are free to sell it on the basis that it has been certified to have met the minimum safety and environmental criteria.

Society of Motor Manufacturers and Traders [UK] noted that ‘Step-by-step adjustments to the regulatory framework which draws upon an accurate understanding of public acceptance and use of new technologies will help ensure that regulation remains relevant and practical.

4.9.2 INSURANCE

Unlike ADAS, where the driver must monitor and remain ready to take control of the vehicle always, it is envisaged that in an AV, the driver will be able to hand full control and responsibility to the vehicle when the Automated Driving Function (ADF) is active, without the need for the driver to intervene or monitor, for some, or all, of the journey. Whilst the ADF is active, the driver would, in effect, be a passenger [104].

For every country, which aims to adopt these technologies the government policy objective remains to ensure that the use of automated vehicles (AVs) is insured so that the innocent victim of a collision involving an automated vehicle receives compensation quickly in line with longstanding practice in their insurance system. This step forward will require a new insurance framework for AVs to facilitate the arrival of new automated vehicle technology.

A precise route must be defined to secure compensation, so the victims may have to take the vehicle maker to court, which could be time-consuming and costly. The third-party victims might not be covered for collisions because of the automated vehicle and/or software failure. Drivers might also not be covered in the event of the automated vehicle and/or software failure, so might not be insured when the AV is in control.

PRODUCT LIABILITY

One of the major concerns is that the terms of product liability insurance policies are not controlled in the same way as for road traffic policies. The law underpinning product liability does not cover damage to the product which is caused by the product [104].

LEGAL FRAMEWORK ON EU-LEVEL

The ADAS functions are affected by the existing legal framework on EU-level mainly regarding the product liability [05]. Product liability claims arising from damages caused by a defective product may be based on three distinct liability systems:

- **Product liability** (based on the Product Liability Directive 85/374/EEC),
- **Contract** (contractual liability),
- and/or **Tort** (extracontractual liability) in the EU Member States [105].

From a product liability point of view, it is appropriate to design the ADAS functions in a way allowing the driver to override automated braking and/or steering interventions any time the driver wishes to do so. Non-override-ability of automated braking and/or steering interventions increases the product liability risk since the driver cannot counteract [105].

The government of each country that wants to adopt AVs should clarify which vehicle manufacturers are willing to offer full liability in case an accident occurs while a vehicle is in fully autonomous mode, i.e. the driver, or user, is entirely out of the loop'.

4.9.3 DATA

The importance of a data sharing framework that is associated with the insurance issues for automated vehicles is stressed by many law firms and insurers. Data will clearly be required to determine whether the driver or the vehicle was responsible for any collision, such as establishing who was in control at the time of the incident. This is likely to come from in-vehicle data recorders.

I expect that the out-of-the-loop motorway driving vehicles that are coming to market soon will have an event data recorder fitted. There are inevitably different views as to what data is essential, and of course, data protection and privacy considerations are necessary. It seems likely that data recorders would be regulated on an international basis, like most vehicle technologies.

4.9.4 HIGHWAY CODE

One of the two major issues in relation to the highway code here is the prohibiting drivers to view TV/display screens displaying information that is not related to the driving task while driving. The second one is one on separation distances to cater for the arrival of platooning technologies.

According to the research done by Department for Transport [UK], a broad group of respondents from the automotive industry and road safety groups did not think these regulations should be amended before the arrival of AVT [106].

4.9.5 TYPE APPROVAL FOR CARS

Vehicles of any kind have to be approved for roadworthiness. This process usually incorporates the assignment of a registration number and requires the vehicle to conform to specific requirements, e.g. for vehicle safety or environmental aspects. Within Europe, the following systems of type approval have been in existence for over 20 years:

World Forum for the Harmonization of Vehicle Regulations - UNECE (WP.29) - is based on United Nations (UN) Regulations (formerly known as UNECE Regulations) and provides for approval of vehicle systems and separate components, but not whole vehicles. Also, known as the 1998 agreement [107] which requires the vehicle manufacturers to certify their vehicles themselves It is followed by most countries (USA, China, most of the 1958 states) but it is usually the government of each individual country who is responsible for the authorization process to accept vehicles for traffic.

EC Whole Vehicle Type Approval (ECWVTA) is based on EC Directives and provides for the approval of whole vehicles, in addition to vehicle systems and separate components - The 1958 agreement system [108] which requires vehicles to be certified by an independent technical service (Europe, Japan, ROW., excluding USA, China).

Low Volume /Small Series Manufacturers - Full EC whole vehicle type approval (ECWVTA) won't suit everyone, particularly those manufacturing vehicles in low numbers. In recognition of this fact, there are a number of other approval routes available, including:

- European Community Small Series Type Approval (EC SSTA)
- National Small Series Type Approval (NSSTA)
- Individual Vehicle Approval (IVA)

The following regulations are of relevance to autonomous driving, concerning the type-approval of the added functionality.

13	Uniform provisions concerning the approval of vehicles of categories M, N and O with regards to braking
13-H	Uniform provisions concerning the approval of passenger cars with with regards to braking
79	Uniform provisions concerning the approval of vehicles with with regards to steering equipment

Tab. 4.2 – Relevant ECE regulations concerning the type-approval of added functionality [105]

4.9.6 REQUIREMENTS FOR BRAKE SYSTEMS FOR PASSENGER CARS

Autonomous brake intervention is not explicitly addressed in the regulation ECE-R13-H. If the additional functions are declared, they are permitted if they conform to the specifications in the regulation. *“The action of the service brake system shall be distributed between the wheels of one and the same axle symmetrically in relation to the longitudinal median plane of the vehicle. Compensation and functions, such as anti-lock, which may cause deviations from the symmetrical distribution, shall be declared.”* [108]

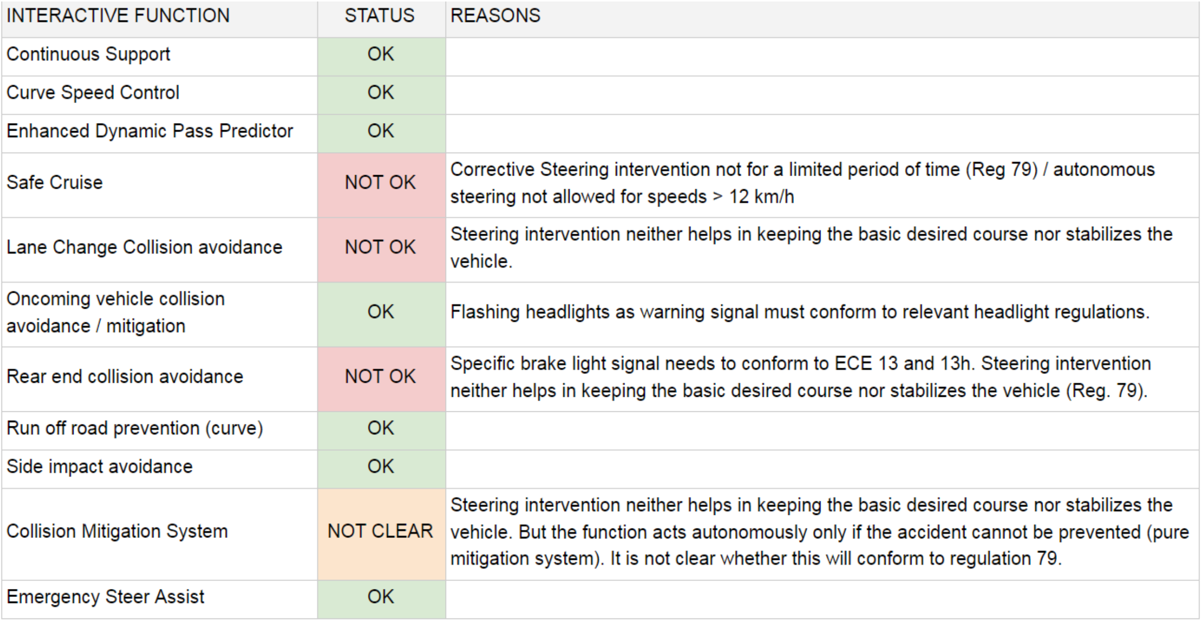
As declared in ECE-R13-H (5.2.22), braking signal must be generated by the driver or the system. Illumination of stop lamps lights must signalise deceleration. *“Activation of the service braking system by "automatically commanded braking" shall generate the signal mentioned above. However, when the retardation generated is less than 0.7* m/s^2*, the signal may be suppressed. Activation of part of the service braking system by "selective braking" shall not generate the signal mentioned above.”* [109]

It is necessary to declare the function of automatically commanded braking for vehicles, where these functions are added to the pre-approved systems and their architecture. Otherwise, this function will not be permitted. Criteria for signalization of braking or emergency braking needs to be defined.

4.9.7 REQUIREMENTS FOR STEERING SYSTEMS

Regulation ECE-R79 is applicable to vehicles of category M, N and O. It does not permit the approval of autonomous steering systems, defined as “*a system that incorporates a function within a complex electronic control system that causes the vehicle to follow a defined path or to alter its path in response to signals initiated and transmitted from off-board the vehicle. The driver will not necessarily be in primary control of the vehicle*” (ECE-79, p.6)

According to ECE-R79 (5.1.6) “*advanced driver assistance steering systems shall only be approved in accordance with this Regulation where the function does not cause any deterioration in the performance of the basic steering system. In addition, they shall be designed such that the driver may, at any time and by deliberate action, override the function*”. (ECE-R79, p.13) [105]



INTERACTIVE FUNCTION	STATUS	REASONS
Continuous Support	OK	
Curve Speed Control	OK	
Enhanced Dynamic Pass Predictor	OK	
Safe Cruise	NOT OK	Corrective Steering intervention not for a limited period of time (Reg 79) / autonomous steering not allowed for speeds > 12 km/h
Lane Change Collision avoidance	NOT OK	Steering intervention neither helps in keeping the basic desired course nor stabilizes the vehicle.
Oncoming vehicle collision avoidance / mitigation	OK	Flashing headlights as warning signal must conform to relevant headlight regulations.
Rear end collision avoidance	NOT OK	Specific brake light signal needs to conform to ECE 13 and 13h. Steering intervention neither helps in keeping the basic desired course nor stabilizes the vehicle (Reg. 79).
Run off road prevention (curve)	OK	
Side impact avoidance	OK	
Collision Mitigation System	NOT CLEAR	Steering intervention neither helps in keeping the basic desired course nor stabilizes the vehicle. But the function acts autonomously only if the accident cannot be prevented (pure mitigation system). It is not clear whether this will conform to regulation 79.
Emergency Steer Assist	OK	

Tab. 4.3 – Summary of possibilities for type-approval of interactive functions according to the current regulations

4.9.8 CLOSE TO THE MARKET TECHNOLOGIES

The automotive sector is continually evolving and innovating, and modern technologies are regularly coming to market. Driver Assistance systems and ADAS have been developing for decades and, more recently, collision avoidance technologies such as Electronic Stability Control (ESC) and Autonomous Emergency Braking Systems (AEBS) have shown a more than 20% benefit in collision reduction. The most recent advancements allow a vehicle to benefit from both longitudinal (speed and separation distances) and lateral (steering, i.e. side-to-side) control.

For the first round of the regulatory reform, it is crucial to identify the following new ADAS technologies that are being likely to come to market within the next two to four years. The ADAS technologies that are being considered, and their implication on current regulatory frameworks, are detailed below.

MOTORWAY ASSIST SYSTEMS FOR TRAVEL ON HIGH-SPEED ROADS

This technology builds on existing systems such as ACC, AEBS, and Lane Keeping Assist System (LKAS) to maintain a vehicle's position in its lane when clear lane markings are present and maintain a constant speed or constant headway to the vehicle in front. Currently, this technology is being designed to work only on high-speed dual carriageways where pedestrians and cyclists are prohibited (i.e. motorways), and drivers are required to maintain alertness, stay-in-the-loop and to remain responsible for the driving task.

This technology is seen as an incremental step on the road to highly automated vehicles. It is expected that the next stage of technological development will result in systems which are sufficiently advanced to enable the driver to come out-of-the-loop and delegate responsibility for part of the journey to the vehicle. At that stage, there will be aiming to amend road traffic legislation to retain or relax driver prohibitions and responsibilities as appropriate.

REMOTE CONTROL PARKING

This system enables the driver to get out of the vehicle and, using a mobile device (e.g. a smartphone), command it to drive itself into automatically, or out of a parking space. While the control button on the device is activated, the vehicle will manoeuvre automatically at very low speed while monitoring its surroundings for pedestrians, other road users or any other hazards [104].

The regulatory framework in the UK, probably as in many other EU countries, is unclear with regards to remote controlled parking manoeuvres, mainly when using a smartphone as the controlling device; driving when using a hand-held mobile phone is illegal. This raises a need for amending regulations and guidance to provide greater clarity in this area. Subsequent iterations of this regulatory program will likely consider future remote control systems, where it is expected that the vehicle could be out of the driver's sight while the parking manoeuvre is completed [104].

HGV PLATOONING

Platooning involves two or more vehicles connected with Vehicle-to-Vehicle (V2V) communication, allowing them to operate efficiently as a single unit - accelerating and braking simultaneously. While operating in this mode, because there is no delay between vehicles when braking, the headway between each vehicle can be reduced to a few meters, allowing the vehicles to benefit from reduced aerodynamic drag and therefore increased fuel efficiency. Platooning could also free more road space and improve traffic flow [104].

While in a platoon, the vehicle's position and speed are controlled using AEB, LKAS, and ACC that is linked to the lead vehicle (likely operated by a driver). This allows the driver of any trailing vehicle to delegate control to the driver of the lead vehicle temporarily. Initial tests around the world have proven the functionality and safety of these systems as well as the fuel saving potential [104].

4.9.9 INTERNATIONAL SITUATION

The growth in interest in automated vehicle technologies and driverless vehicles, in general, has led many countries around the world to review their regulatory requirements with a view to amending them where necessary. It is essential to ensure that existing legislative frameworks do not prevent the development of automated technologies. The automotive industry needs certainty regarding the legislation, regulations and clarity of responsibilities to make significant investment decisions. Some countries have already taken steps to review and amend their regulatory requirements, and a few have passed new legislation [106].

VIENNA CONVENTION

Many countries are signatories to the Vienna Convention on Road Traffic. Where is stated that:

- *"Every moving vehicle or combination of vehicles shall have a driver."* [Art.8(1)]
- *"Every driver shall at all times be able to control his vehicle or to guide his animals."* [Art. 8(5)]
- *"Every driver of a vehicle shall in all circumstances have his vehicle under control so as to be able to exercise due and proper care and to be at all times in a position to perform all manoeuvres required of him [...]."* [Art. 13 (1)]

This undoubtedly seems to be a barrier to the introduction of automated vehicles. This convention, therefore, needs to be amended to allow a car to drive itself.

In March 2014, the United Nations Working Party on Road Traffic Safety discussed a proposed amendment to the convention submitted by the Governments of Austria, Belgium, France, Germany and Italy. The amendment would allow vehicle systems to influence the way in which vehicles are driven (i.e. control acceleration, braking and steering) when they are: "*in conformity with the conditions of construction, fitting and utilisation according to international legal instruments concerning wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles", or "can be overridden or switched off by the driver*" [110].

INTERNATIONAL SITUATION OVERVIEW

North America has been the first country to introduce legislation to permit testing of automated vehicles, but only four states have done this. Fifteen are reported to have rejected bills related to automated driving [111].

Elsewhere in Europe and globally, legislators are considering how to accommodate the development and testing of their roads of automated technologies. Although many research projects have taken place all over Europe, many locations such as Gothenburg, have restricted boundaries or roads where testing is permitted or require a permit [104]. Asian countries are keen for the International and European regulations to be updated to allow further development of automated vehicle technologies. Testing of automated vehicles on the road has been possible, with some countries restricting testing areas and having particular requirements for license plates and driving licences [104].

USA

America is generally considered to be leading the way in terms of legislating for driverless vehicles. To date, four states in America including Nevada, Florida, California and Michigan have already passed laws concerning driverless cars (2016).

In May 2013 NHTSA (National Highway Traffic Safety Administration) issued a 'preliminary statement of policy concerning automated vehicles'. Aimed at level 3 and 4 automation for testing purposes only it recommended for example:

- License drivers to operate self-driving vehicles for testing
- Require proof of safe operation of self-driving vehicles
- Limit tests to locations suitable for self-driving vehicles
- Establish reporting requirements to monitor self-driving technology performance
- Ensure that the transitioning process from auto-mode to driver control is safe & simple
- The automated systems should not in interfere with any other required safety functions

The act in Florida and Nevada establishes additional conditions for testing of automated vehicles:

- Safety mechanisms for engaging and disengaging the technology.
- Indicators inside the vehicle that show when the vehicle is in automated mode.
- A means of alerting the operator to a technology failure

Anyone wishing to apply for a license to test automated vehicles in Nevada is required to provide proof “that one or more of your autonomous vehicles have been driven for a combined minimum of at least 10,000 miles, a complete description of your autonomous technology, a detailed safety plan, and your plan for hiring and training your test drivers.” The Department issues special red license plates which feature an ‘infinity’ symbol to indicate the vehicle is capable of automated operation.

In 2014 Google introduced their own design for a self-driving vehicle – a small, two-seat, low-speed device with no steering wheel or other controls other than a stop button. However, due to California’s requirement for an individual to be able to “immediately take control of the vehicle’s movements”, Google has been forced to redesign the vehicle to include driver controls prior to public road testing in California.

4.9.10 SUMMARY & RECOMMENDATIONS

Many countries have already responded to the commercial availability of personal electric vehicles and other innovative personal transport vehicles by defining construction and use requirements in their national laws. Innovative personal transport and personal electric vehicles offer the potential to address issues such as increasing congestion in urban areas and the need to improve air quality and reduce carbon emissions. As a result, there is likely to be increasing pressure to provide solutions to facilitate their use.

According to the Swedish Ministry of Transport, the automation of transport involves both technological and social development and will therefore take time, but certain types of vehicles may perhaps be automated faster than others [112]. New drivers’ licences may also be introduced for those with impairments to license the use of fully automated vehicles only. But before that, there must be a lot of testing conducted on public roads. The National Highway Traffic Safety Administration (NHTSA) [USA] recommends that states and countries should require proof from companies of experience operating these vehicles safely [107]:

- Certifying a minimum number of kilometres /miles have been achieved without incident.
- Submission of data from the previous testing.
- Submission of a plan detailing how risks will be minimised.

Testing should be limited to locations suitable for AVT and vehicle manufacturers should specify the type and operating conditions they wish to test and ideally submit specified previous test data to demonstrate that their self-driving vehicles are capable of operating in such conditions.

NHTSA also highlight the requirement of submitting certain information and reports monitoring the self-driving technology performance. Another critical importance is the driver’s ability retaking quickly and easily control of the vehicle from the automated system. This can be sorted for example by [107]:

- Providing a button located within the driver’s reach.
- Requiring the self-driving vehicle to alert the driver when the driver must take control.
- Ensuring that the automated functions automatically defer to the driver’s input to brakes, accelerator pedal or steering wheel

5 DRIVERLESS VEHICLE

The final objective of this work is to develop an innovative conceptual vehicle package for a new type and class of driverless transportation vehicle for the urban environment which applies the approach to inclusive design principles.

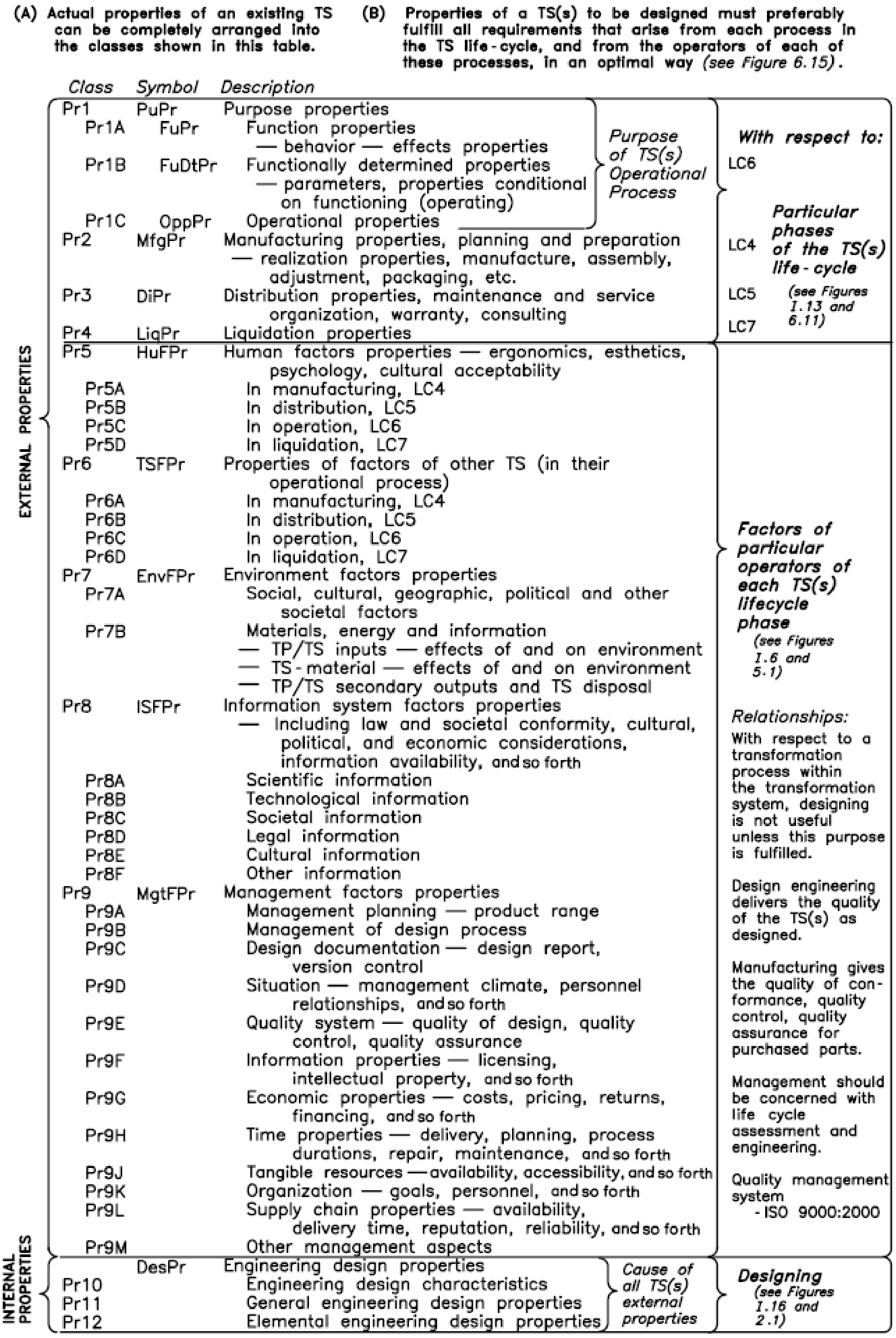
5.1 CONCEPTUAL DESIGN - BASIC ASSUMPTIONS

The conceptual vehicle package represents the design intent based on findings from previous chapters, including style and main systems functionality. Detailed specifications for implementation of technical systems and processes are given in the following sections, but in general terms, the assumptions are described as follows:

- **LIGHTWEIGHT STRUCTURE** - The conceptual vehicle demonstrates lightweight features; iStream structure and composite exterior panels. Major design intent is to keep the weight at a minimum due to the operational process involved.
- **POWERTRAIN -** The packaging concept has a production representative powertrain system, representing the intended levels of battery capacity described in the previous chapter and rear mounted traction motor.
- **ELECTRONIC SYSTEMS -** Major autonomous electronic and sensing systems described in the previous chapters are integrated into the virtual packaging concept to demonstrate their range and field of view.
- **STYLE -** Representative style developed based on previous findings related to the inclusive design topic, urban environment, legislation and components required for driverless s driving.
- **KERB WEIGHT** – Due to a limited amount the data, it is not possible to estimate the kerb weight correctly at this stage. The maximum target for further design and development is set to 1000kg.
- **SEATING -** The conceptual vehicle to have two seat configurations. The seat to be considered as a fold-down seat to allow wheelchair access.
- **ACCESSIBILITY -** The conceptual vehicle to have forward facing wheelchair capability with the possibility of access ramp integration.
- **MARKET SPECIFICATION** - As has been specified in the previous chapters, the main market is global with the aim of serve urban mobility. The conceptual platform should comply with London Conditions of Fitness (COF) requirements to meet London turning circle requirements (manoeuvrability) [113].
- **DOOR** - Single sliding door to be considered for the package study. The door must have a minimum width of 900mm allowing boarding for a wheelchair passenger.
- **INTERIOR TRIM** - The interior trim design is described briefly as it has not been fully considered for the study.

5.2 PROPERTIES OF TECHNICAL SYSTEMS

P*roperty* is anything that is possessed (owned) by an object (a TS). Each *constructional structure* (or TS) is the *carrier* of properties or classes of properties (Fig. 5.1 and Fig. 5.2).



(A) Actual properties of an existing TS can be completely arranged into the classes shown in this table.

(B) Properties of a TS(s) to be designed must preferably fulfill all requirements that arise from each process in the TS life-cycle, and from the operators of each of these processes, in an optimal way *(see Figure 6.15)*.

EXTERNAL PROPERTIES

Class	Symbol	Description
Pr1	PuPr	Purpose properties
Pr1A	FuPr	Function properties — behavior — effects properties
Pr1B	FuDtPr	Functionally determined properties — parameters, properties conditional on functioning (operating)
Pr1C	OppPr	Operational properties
Pr2	MfgPr	Manufacturing properties, planning and preparation — realization properties, manufacture, assembly, adjustment, packaging, etc.
Pr3	DiPr	Distribution properties, maintenance and service organization, warranty, consulting
Pr4	LiqPr	Liquidation properties
Pr5	HuFPr	Human factors properties — ergonomics, esthetics, psychology, cultural acceptability
Pr5A		In manufacturing, LC4
Pr5B		In distribution, LC5
Pr5C		In operation, LC6
Pr5D		In liquidation, LC7
Pr6	TSFPr	Properties of factors of other TS (in their operational process)
Pr6A		In manufacturing, LC4
Pr6B		In distribution, LC5
Pr6C		In operation, LC6
Pr6D		In liquidation, LC7
Pr7	EnvFPr	Environment factors properties
Pr7A		Social, cultural, geographic, political and other societal factors
Pr7B		Materials, energy and information — TP/TS inputs — effects of and on environment — TS-material — effects of and on environment — TP/TS secondary outputs and TS disposal
Pr8	ISFPr	Information system factors properties — Including law and societal conformity, cultural, political, and economic considerations, information availability, and so forth
Pr8A		Scientific information
Pr8B		Technological information
Pr8C		Societal information
Pr8D		Legal information
Pr8E		Cultural information
Pr8F		Other information
Pr9	MgtFPr	Management factors properties
Pr9A		Management planning — product range
Pr9B		Management of design process
Pr9C		Design documentation — design report, version control
Pr9D		Situation — management climate, personnel relationships, and so forth
Pr9E		Quality system — quality of design, quality control, quality assurance
Pr9F		Information properties — licensing, intellectual property, and so forth
Pr9G		Economic properties — costs, pricing, returns, financing, and so forth
Pr9H		Time properties — delivery, planning, process durations, repair, maintenance, and so forth
Pr9J		Tangible resources — availability, accessibility, and so forth
Pr9K		Organization — goals, personnel, and so forth
Pr9L		Supply chain properties — availability, delivery time, reputation, reliability, and so forth
Pr9M		Other management aspects

INTERNAL PROPERTIES

Class	Symbol	Description
	DesPr	Engineering design properties
Pr10		Engineering design characteristics
Pr11		General engineering design properties
Pr12		Elemental engineering design properties

Purpose of TS(s) Operational Process

With respect to:

LC6

LC4 ***Particular phases of the TS(s) life-cycle***

LC5 ***(see Figures I.13 and 6.11)***

LC7

***Factors of particular operators of each TS(s) lifecycle phase** (see Figures I.6 and 5.1)*

Relationships:

With respect to a transformation process within the transformation system, designing is not useful unless this purpose is fulfilled.

Design engineering delivers the quality of the TS(s) as designed.

Manufacturing gives the quality of conformance, quality control, quality assurance for purchased parts.

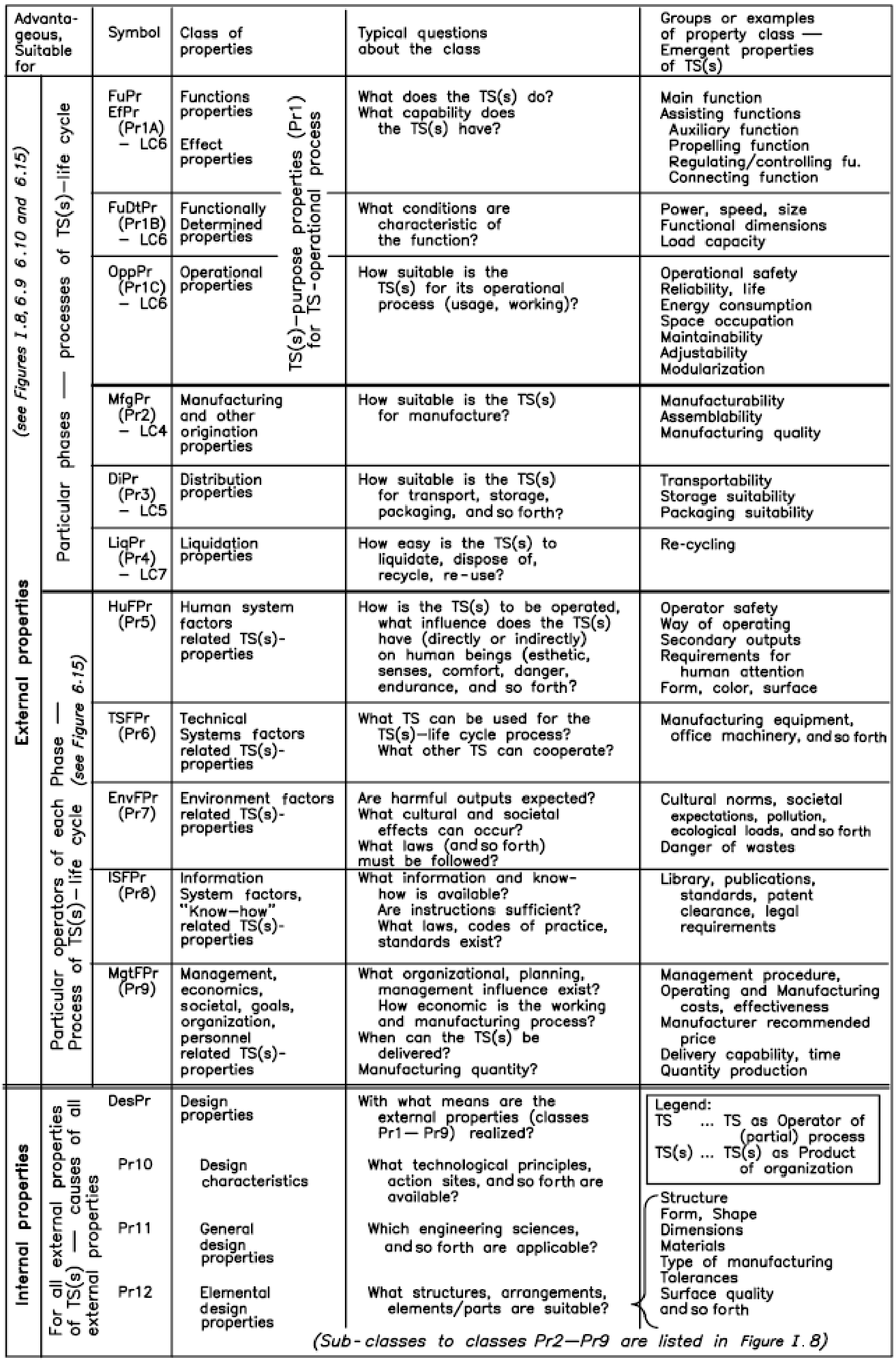
Management should be concerned with life cycle assessment and engineering.

Quality management system - ISO 9000:2000

Cause of all TS(s) external properties

***Designing** (see Figures I.16 and 2.1)*

Fig. 5.1 - Classes of properties of technical system [114]



Advantageous, Suitable for		Symbol	Class of properties		Typical questions about the class	Groups or examples of property class — Emergent properties of TS(s)
External properties (see Figures I.8, 6.9 6.10 and 6.15)	Particular phases — processes of TS(s)–life cycle	FuPr EfPr (Pr1A) – LC6	Functions properties Effect properties	TS(s)–purpose properties (Pr1) for TS-operational process	What does the TS(s) do? What capability does the TS(s) have?	Main function Assisting functions Auxiliary function Propelling function Regulating/controlling fu. Connecting function
		FuDtPr (Pr1B) – LC6	Functionally Determined properties		What conditions are characteristic of the function?	Power, speed, size Functional dimensions Load capacity
		OppPr (Pr1C) – LC6	Operational properties		How suitable is the TS(s) for its operational process (usage, working)?	Operational safety Reliability, life Energy consumption Space occupation Maintainability Adjustability Modularization
		MfgPr (Pr2) – LC4	Manufacturing and other origination properties		How suitable is the TS(s) for manufacture?	Manufacturability Assemblability Manufacturing quality
		DiPr (Pr3) – LC5	Distribution properties		How suitable is the TS(s) for transport, storage, packaging, and so forth?	Transportability Storage suitability Packaging suitability
		LiqPr (Pr4) – LC7	Liquidation properties		How easy is the TS(s) to liquidate, dispose of, recycle, re-use?	Re-cycling
	Particular operators of each Phase — Process of TS(s)–life cycle (see Figure 6.15)	HuFPr (Pr5)	Human system factors related TS(s)-properties		How is the TS(s) to be operated, what influence does the TS(s) have (directly or indirectly) on human beings (esthetic, senses, comfort, danger, endurance, and so forth?	Operator safety Way of operating Secondary outputs Requirements for human attention Form, color, surface
		TSFPr (Pr6)	Technical Systems factors related TS(s)-properties		What TS can be used for the TS(s)–life cycle process? What other TS can cooperate?	Manufacturing equipment, office machinery, and so forth
		EnvFPr (Pr7)	Environment factors related TS(s)-properties		Are harmful outputs expected? What cultural and societal effects can occur? What laws (and so forth) must be followed?	Cultural norms, societal expectations, pollution, ecological loads, and so forth Danger of wastes
		ISFPr (Pr8)	Information System factors, "Know–how" related TS(s)-properties		What information and know-how is available? Are instructions sufficient? What laws, codes of practice, standards exist?	Library, publications, standards, patent clearance, legal requirements
		MgtFPr (Pr9)	Management, economics, societal, goals, organization, personnel related TS(s)-properties		What organizational, planning, management influence exist? How economic is the working and manufacturing process? When can the TS(s) be delivered? Manufacturing quantity?	Management procedure, Operating and Manufacturing costs, effectiveness Manufacturer recommended price Delivery capability, time Quantity production
Internal properties	For all external properties of TS(s) — causes of all external properties	DesPr	Design properties		With what means are the external properties (classes Pr1 — Pr9) realized?	Legend: TS ... TS as Operator of (partial) process TS(s) ... TS(s) as Product of organization
		Pr10	Design characteristics		What technological principles, action sites, and so forth are available?	Structure Form, Shape Dimensions Materials Type of manufacturing Tolerances Surface quality and so forth
		Pr11	General design properties		Which engineering sciences, and so forth are applicable?	
		Pr12	Elemental design properties		What structures, arrangements, elements/parts are suitable?	

(Sub-classes to classes Pr2—Pr9 are listed in Figure I.8)

Fig. 5.2 - Classes of properties of technical system [114]

5.2.1 EXTERNAL PROPERTIES - CLASSES PR1 to PR9

External properties are derived directly from the tangible parts of the TS-life cycle (LC4 manufacture, LC5 distribution, LC6 operation, and LC7 liquidation), and the five operators of each of these lifecycle stages (HuS, TS, IS, and MgtS), which deliver the primary classes Pr1 to Pr9. The Purpose Properties (for LC6) are chosen as the first class(es)—if these are not sufficiently fulfilled, the TS is not really useful [114].

The ability to exert effects is not the only significant property of TS. Primarily, these effects must be exerted by TS with the necessary operating parameters, for example, power, speed, travel distance, voltage, current, flow rate. TS (autonomous vehicle) must exhibit other properties or groups of properties, for example, being able to operate or be operated with ergonomically acceptable facilities, satisfactory maintainability, durability, reliability, appearance, transportability, and so forth, within an envisaged environment, and these are to some extent established by an industrial designer [114].

Figure 5.2, contains the classes of properties, a set of typical questions that ask about the specific properties within each class, and examples to illustrate each of these classes of properties. For instance, the question: "How suitable is the TS for the TS-operational process?" should bring answers that characterize the quality of the TS with respect to its operational life, behaviour, operational safety, reliability, durability (lifespan, life expectancy), energy consumption, space requirements, maintainability, and so forth. Property class Pr1 and its subclasses are related to the purpose of the TS; classes Pr2 to Pr4 are derived from the TS-life cycle, classes Pr5 to Pr9 relate to the operators of each of the TS-life cycle processes and therefore (directly and indirectly) to humans and their society [114].

As classified in Appendix IX, all the properties for class Pr1 have been identified and fulfilled. There are divided into Function Properties, Functionally Determined and Operational Properties. Function Properties included properties related to the Autonomous Passenger Road Transportation, Transportation of goods, TS behaviour and Effect Properties and valued against their priority importance. Functionally Determined Properties introduce Performance Parameters, requirements for Engine and Transmission, Battery, parameters of Vehicle Body, Tires, Dashboard Controls, etc. Operational Properties are mostly associated with autonomous driving controls and intelligent transportation technologies and their application.

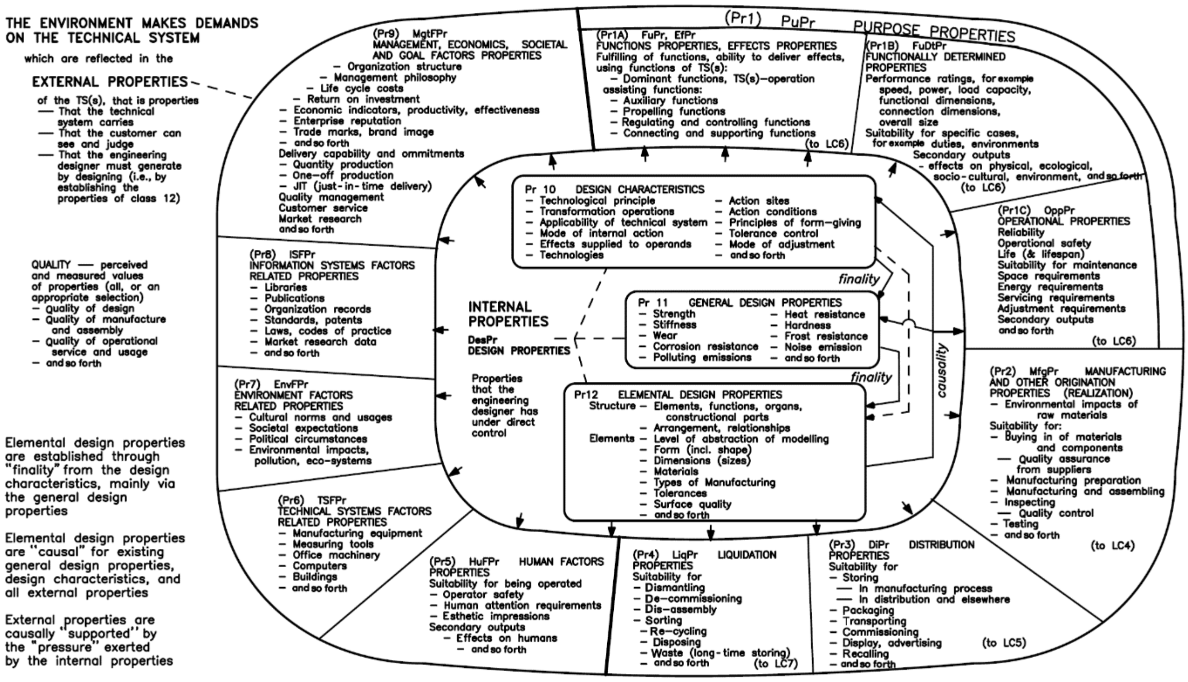


Fig. 5.3 - Relationship among external and internal properties of technical system [114]

5.2.2 INTERNAL PROPERTIES - CLASSES PR10, PR11 and PR12

The inside area in Figure 5.3 contains the three classes of internal properties. They are the core properties of TS. Internal properties can be axiomatically defined, in three classes, Pr10 to Pr12. These properties are usually not readily visible, interesting, assessable, or measurable by a nontechnical person. Most users of a TS will regard them as a “black box” and will not make contact with the internal properties [114].

The internal properties are created by the engineering designer using design characteristics (Pr10), general design properties (Pr11), and elemental design properties (Pr12). Engineering designers have the task of establishing the individual properties in these classes during their design work.

Class Pr10 of internal properties consists of design characteristics, those aspects of the TS-structures that are invariant with respect to any external and internal influences—structural, functional, and technological principles. They deliver knowledge (including heuristic values and principles) based on experience. These are established directly by the engineering designer during design work, their selection is a useful level for generating alternative solution proposals. Appendix IX contains a list of the design characteristics of TS (TS-characteristics).

Design characteristics influence most other properties. Proposed solutions to fulfil the same task (list of requirements, design specification), for which unique design characteristics were chosen (e.g., mode of action, or constructional structure), can have large technical and economic differences (e.g., a vehicle driven by an internal combustion engine or an electric motor).

The recommended methodical and systematic design procedure uses the information

about TS-structures. They help designers to establish the design characteristics and determine the levels at which designers can find alternative solution proposals and principles of operation. The process of establishing the design characteristics is treated in the design operations [114].

Class Pr11, general design properties, characterizes the TS-internal reactions to applied (internal and external) influences and consists of the applications of the engineering sciences, of heuristic knowledge about a particular system, of experience information as recorded in the technical literature, of tacit experience knowledge possessed by the individual designer [114].

Class Pr12, elemental design properties, directly describe and define the TS-structures, their elements and arrangement (mutual relationships). The constructional parts are described by their elemental design properties, typically their form (including shape), dimensions, materials, sorts of manufacturing [114].

5.3 THE DESIGN PROCESS

Creating a concept from a blank sheet of paper can be very daunting for many designers. However, even though every project will vary, the basic principles are relatively simple, and the key elements of the design process remain the same. Designing with a focused purpose and developing the architecture with a logical process ensures that every objective is accomplished [2].

The bulk of a vehicle’s proportions are established by only a few elements, namely: the occupants, powertrain, tires, cargo storage, ground clearance and crash protection systems. These can be put together in a logical order.

PACKAGE & DESIGN IDEATION - Figure 5.4 represents a basic sketch of the package concept based on the functional objectives. The sketch includes layouts of the occupants, cargo, powertrain, wheels and battery pack.

SETTING UP THE PASSENGER’S HEIGHT AND POSTURE - The second step is to position the occupant using the SAE 95th percentile manikin, establishing the heel height from the ground and then the seating posture. It is also critical considering the ground clearance and underbody structure when positioning the heel points. Probably the best way to get the driver location close is to take the findings from the previous chapter about Inclusive Design.

SET UP THE OCCUPANTS’ LATERAL LOCATION - After the passenger’s height and posture setup, it is crucial to set up the lateral position of the occupants and to consider the requirement for wheelchair access, which is one of the packaging requirements. This has a considerable effect on the overall width and the interior environment expectations.

SELECTION AND INSTALLATION OF THE POWERTRAIN - The vehicle to be designed as a rear wheel drive with an electric motor mounted between rear wheels directly on a rear subframe. This solution provides a compact packaging and simple power transmission between the motor and wheels.

CREATING SPACE FOR THE CARGO - The cargo space is design around two pieces of luggage placed at the back of the car. The option of taking the luggage into the vehicle and placing it in front of the occupant is also worth investigating as it may reduce boarding times.

SIZE & POSITION THE DRIVEN WHEELS - For simplicity, the size of the wheel and tire package was determined based on the London Taxi TX4 specification (the closest available vehicle on the market).

ESTABLISHING THE WHEELBASE - The location of the other wheel/axle will depend on weight distribution or package efficiency. For the conceptual taxis, the wheels will be as close to the door as possible. The door width of 900mm is driven by the access requirements for the wheelchair occupants.

SETTING UP THE FRONT & REAR TRACKS - Although designers usually prefer the wheels to be as far outboard as possible, the track will be limited by the vehicle width target. In this case, it is also driven by the requirement for the wheelchair users to allow them to turn the wheelchair by 180 degrees inside of the car.

SETTING UP DEVICES FOR DRIVERLESS DRIVING - The requirements for lidars, radars and cameras need to be explored at this stage as these sensors sense the vehicle surroundings. Their location may play a critical role in the future styling studies. This scenario is not usually investigated in the conventional design process but must be taken into consideration when designing driverless vehicles.

5.4 PACKAGE IDEATION

The package ideation process provides an opportunity to study as many system configurations as possible in a short period of time, allowing the designer to explore all of the possible proportion and basic form options. The main focus is on the systems layout, not the exterior design [2].

Some production projects may not require much package innovation, but packaging a driverless vehicle is open to fresh ideas. Due to the removal of a steering wheel, the vehicle concepts are open to a wide scope of interesting seating configurations, cargo storage and powertrain layouts.

It is important to think about the three entities involved in the product development: the customer, the manufacturer and the market environment. Other factors like manufacturing strategies and international legislation are more complex subjects, but it has been already considered in one of the previous chapters.

Other less influential features like lighting, instruments and trim may be ignored at this time unless there is a specific focus in the design brief for these systems. As a driverless taxi, it will probably be small, easy to park, carry only one or two people, and have limited cargo capacity. It may be distributed all over the world and therefore be manufactured in high volumes. To be aspirational, the styling will be important, and performance may need to be stepped up.

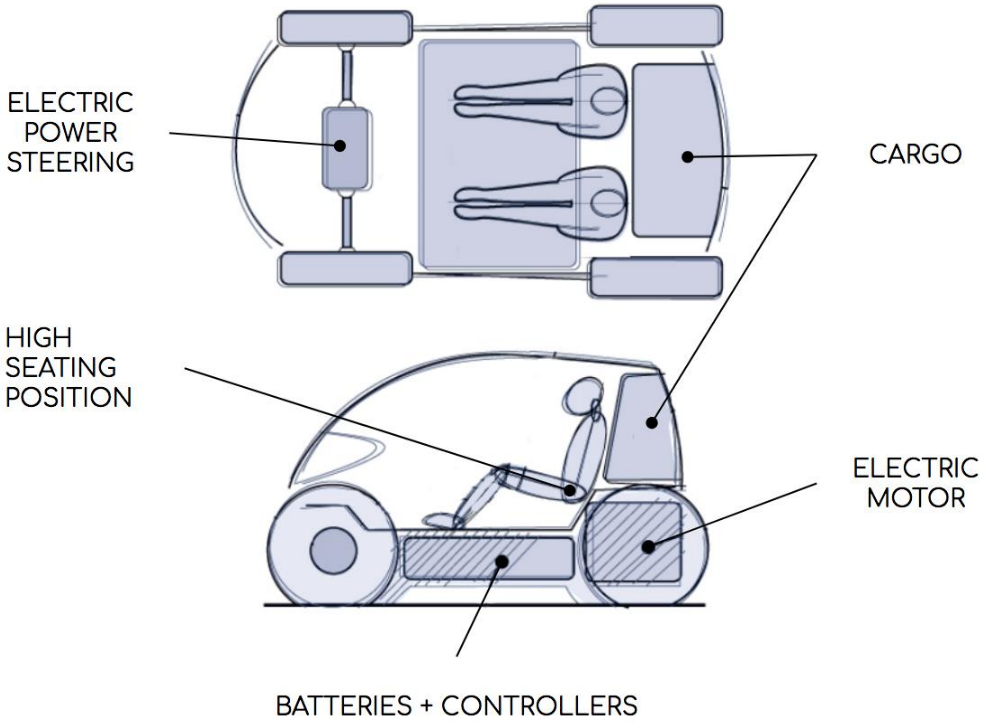


Fig. 5.4 - Package & Design Ideation

5.5 SETTING UP THE OCCUPANT HEIGHT & POSTURE

Without question, the most critical elements in every vehicle package are the occupants. If the occupant positions and postures are set up wrong, the entire architecture may need to be redesigned. Because the manikin geometries are constant and represent the customers, the vehicle bodies are scaled around them [2].

The occupants directly or indirectly influence every aspect of the vehicle's design. The main objective is to set up the occupant to be comfortable and safe, then create an envelope around them and use key reference data within their geometries to set up the rest of the vehicle package. The most important reference point in the package is the driver's hip or H point. This may be shown in several locations in the package drawings (because of seat adjustment), but the primary location is referred to as the Seating Reference Point or SgRP.

One of the most popular occupant packaging tools is the SAE 95th percentile male manikin, which is ideal for setting up the initial interior space, ensuring that the vast majority of the global population will fit into the occupant package envelope.

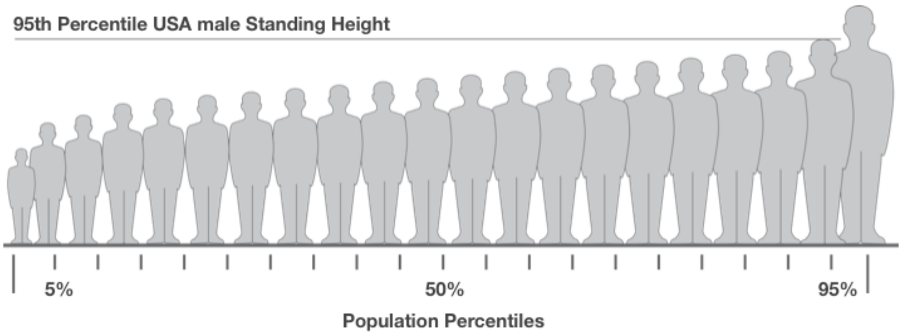


Fig. 5.5 - The 95th percentile male [2]

The driver's height and posture are governed by several factors, namely: centre of gravity, aerodynamics, ingress/egress, comfort and visibility. The vehicle height is established by a combination of these factors [2]. Below is an illustration of the basic dimensions that set up the interior environment around the occupant package. These are part of the SAE J1100 measurement index. Using the same measurement system for every project ensures that there is no confusion and the package database remains consistent.

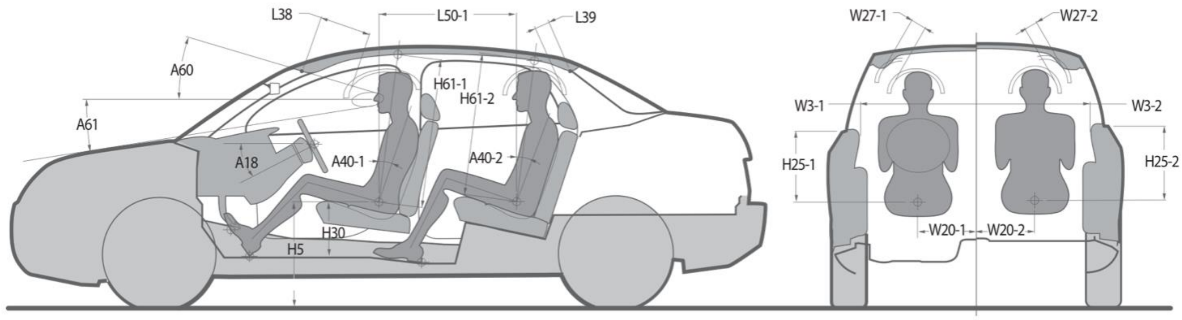


Fig. 5.6 - Occupant Environment Dimensions - SAE J1100 [2]

The table 5.1 below contains some examples of dimensions taken from current production cars. These dimensions can be used as a benchmarking reference to set up an initial package.

	HEEL TO GROUND	CHAIR HEIGHT	H-POINT TO GROUND	BACK ANGLE	EFFECTIVE HEAD ROOM	UPWARD VISION ANGLE	DOWNWARD VISION ANGLE	SHOULDER ROOM	HIP ROOM	LATERAL LOCATION
SAE J1100	**(REF)**	**H30**	**H5**	**A40**	**H61**	**A60**	**A61**	**W3**	**W5**	**W20**
NEV	325	400	725	15	1075	11	10	-	-	275
SPORTS CAR	175	150	325	28	950	8	5	1350	1275	325/400
MICRO CAR	350	275	625	21	1000	14	11	1200	1150	300
SMALL CAR	225	250	475	24	975	15	7	1350	1325	350
MEDIUM CAR	250	250	500	24	975	14	7	1475	1400	350
MEDIUM COUPE	250	175	425	24	950	13	5	1375	1325	350
LARGE CAR	275	250	525	24	975	14	6	1500	1450	375
LARGE LUXURY CAR	275	275	550	22	975	15	7	1550	1500	400
MINNIVAN	425	350	775	20	1010	9	11	1575	1525	425
SMALL SUV	400	350	750	22	1010	15	9	1425	1400	400
MEDIUM SUV	450	300	750	22	1010	14	6	1500	1450	400
LARGE SUV	450	325	775	22	1025	14	7	1650	1600	375
SMALL TRUCK	400	300	700	22	1010	14	7	1475	1450	375
LARGE 4x4 TRUCK	600	350	950	22	1025	15	8	1700	1650	475
COMMERCIAL VAN	725	350	1075	22	1010	10	10	1675	1625	525
AUTONOMOUS TAXI	330	405	735	22	1050	5	14	1542	1446	350

Tab. 5.1 - Approximate Reference Dimensions [2]

Some of the criteria that drive the driverless taxi has been discussed in previous chapters. Using the findings, the position and posture of the passenger placed in the conceptual package can be seen in figure 5.7 below. Location of 95th percentile wheelchair occupant is illustrated in figure 5.8.

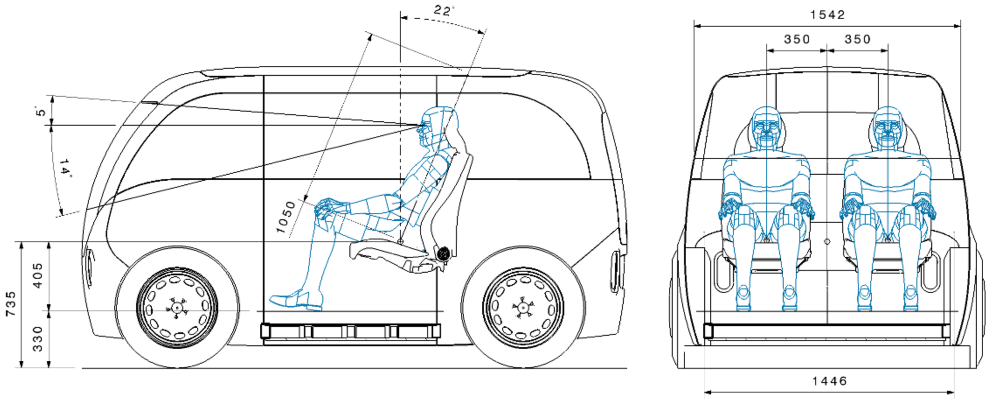


Fig. 5.7 - Setting up Occupant Height & Posture

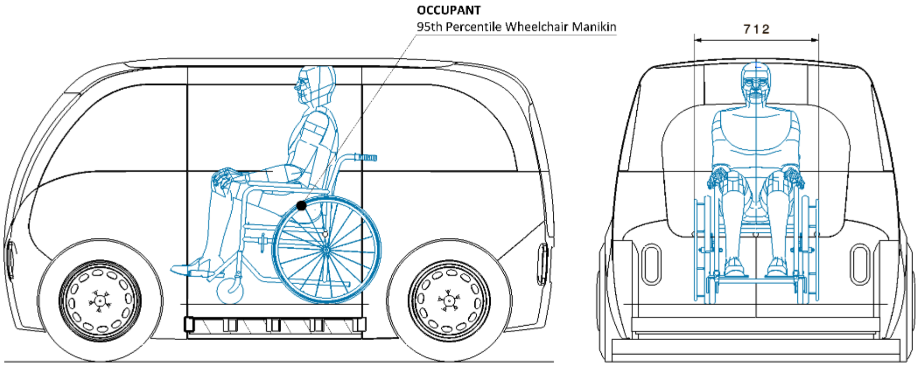
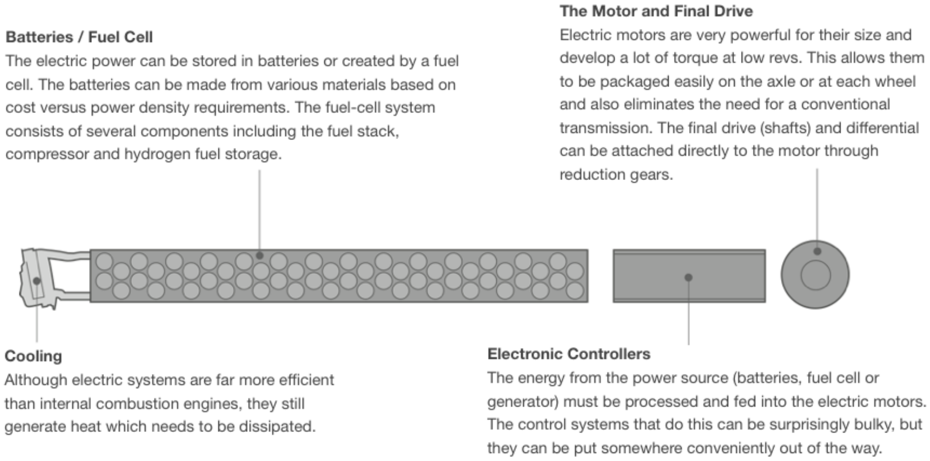


Fig. 5.8 - Setting up Wheelchair Manikin

5.6 POWERTRAIN PACKAGING

Packaging an electric system requires a different attitude to a conventional powertrain. The electric motor is relatively small, but the energy or fuel-storage systems are quite large in comparison to those of internal combustion systems. The main thing to take advantage of is the low-profile potential for these components. The battery system is packaged under the floor and offers the opportunity to reduce the overall length of the vehicle and changes the exterior proportions. On the other hand, this results in a high occupant package which is in this case desirable.



Batteries / Fuel Cell
The electric power can be stored in batteries or created by a fuel cell. The batteries can be made from various materials based on cost versus power density requirements. The fuel-cell system consists of several components including the fuel stack, compressor and hydrogen fuel storage.

The Motor and Final Drive
Electric motors are very powerful for their size and develop a lot of torque at low revs. This allows them to be packaged easily on the axle or at each wheel and also eliminates the need for a conventional transmission. The final drive (shafts) and differential can be attached directly to the motor through reduction gears.

Cooling
Although electric systems are far more efficient than internal combustion engines, they still generate heat which needs to be dissipated.

Electronic Controllers
The energy from the power source (batteries, fuel cell or generator) must be processed and fed into the electric motors. The control systems that do this can be surprisingly bulky, but they can be put somewhere conveniently out of the way.

Fig.5.9 - Electric Powertrain - Main Components [2]

To support various powertrain layout and battery pack configuration, the CAD model embodies a structural battery 'configurator' to provide a designer with an instant battery package that is driven by the battery cell size. This parametric feature offers the ability to quickly generate various cell patterns based on specific requirements, constraints and targets (e.g. size, package, capacity, weight, CG position, cooling, maintenance). The image below illustrates a structural battery pack that is packaged into the conceptual taxi's floor (figure 5.10).

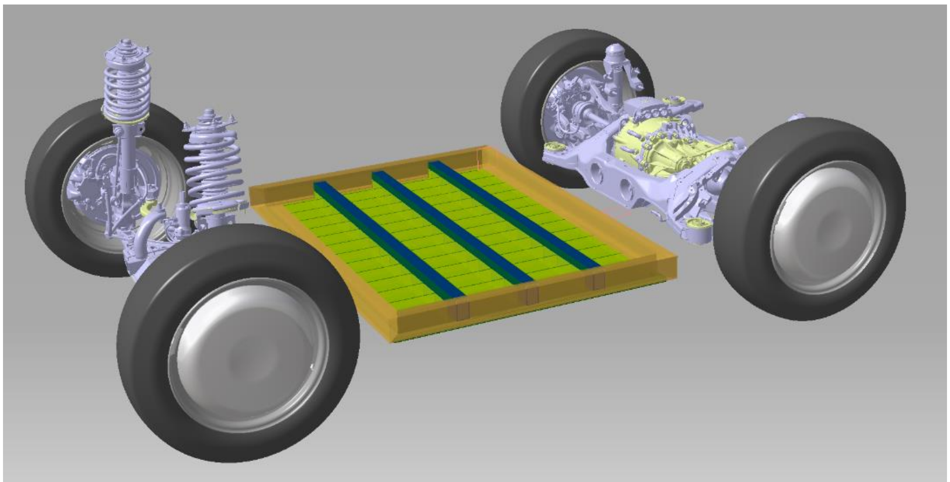


Fig. 5.10 – Structural Battery, Powertrain and Suspension Package

5.7 WHEELS, TIRES, STEERING & TURNING CIRCLE

Wheel and tire sizes should be established quite early on in the design process, usually after the preliminary occupant package has been set up. Additionally, the suspension travel and steering angles should be predicted to determine the tire envelopes, which identify the total volumes occupied by the tires during extreme use. For cars that require a comfortable ride, which is our case, average sidewall height is advisable, providing a balance between comfort and handling. For the evaluation of this study were selected identical commonly used front and rear tires (175R16C).

The steering mechanism is located just behind the front spindle. The steering wheel is directly linked to the mechanism through the input shafts, which is divided into several segments and angled to reduce steering-column movement in a frontal impact.

To follow manoeuvrability requirement defined in Condition of Fitness for London Taxis [113], the vehicle must be capable of being turned on either lock so as to proceed in the opposite direction without reversing between two vertical parallel planes not more than 8.535 metres apart. The wheel turning circle kerb to kerb on either lock must be not less than 7.62 metres in diameter. Such specific turn-circle requirements will have a considerable influence on the package. The diagrams below show the elements that control the turning circle. The two factors that control the turning circle are the wheelbase and the turn angle.

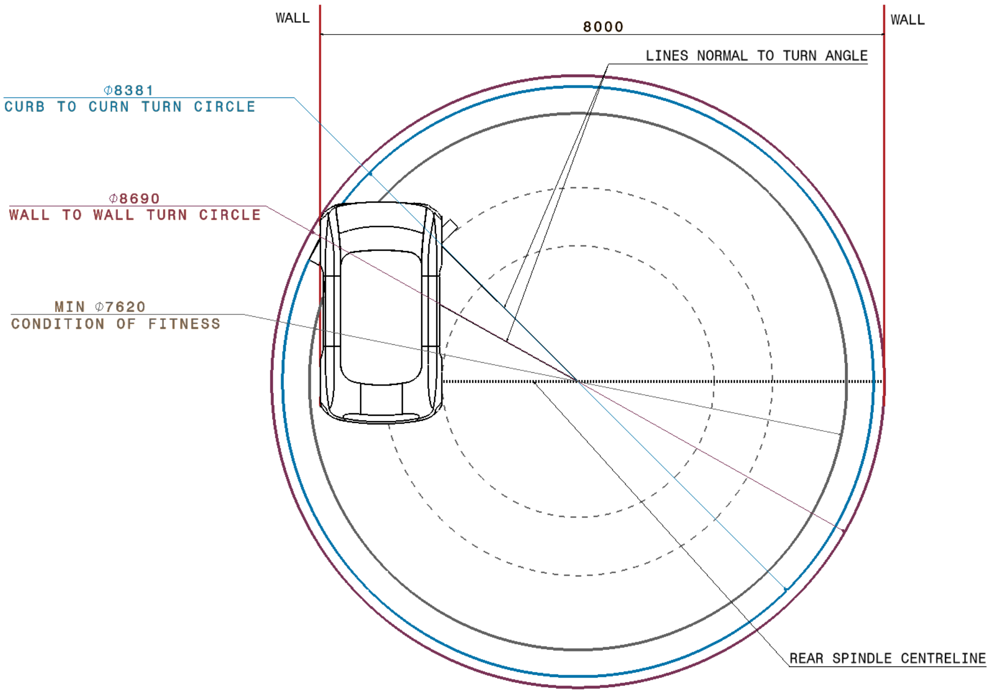


Fig. 5.11 - Conceptual Driverless Taxi - Turning Circle

With the wheelbase set to 2000mm and track width of 1571mm (both front and rear), the figure 5.11 above clearly shows that the conceptual vehicle fits within the Condition of Fitness defined. The concept can turn between two vertical walls that are 8 metres apart with a wall to wall turn circle of 8381mm.

5.8 SIZE AND PROPORTION

After the ideation process, the overall dimensions and proportions of the concept should be established. Getting the size right is critical to ensure that the vehicle is as efficient as possible and makes the right statement about its purpose - to include as many people as possible in terms of their physical capabilities.

The methodology is to start only with the specified functional objectives. This involved previous research activities into advanced and autonomous technology in developing an innovative solution before building the package around the occupants and new kinds of componentry. The exterior proportions can define the forms around this new architecture.

Often the size of a vehicle will put it into a category or market segment. This can be seen in the vehicle segmentation matrix (Fig. 5.12). To follow the functional objectives in terms of providing an exceptional driving comfort and access for the wheelchair passengers, the ‘boxed’ conceptual vehicle is wider than the benchmarked vehicles with an approximately similar vehicle length (Fiat 500, BMC Mini, Suzuki Wagon, Daihatsu Move).

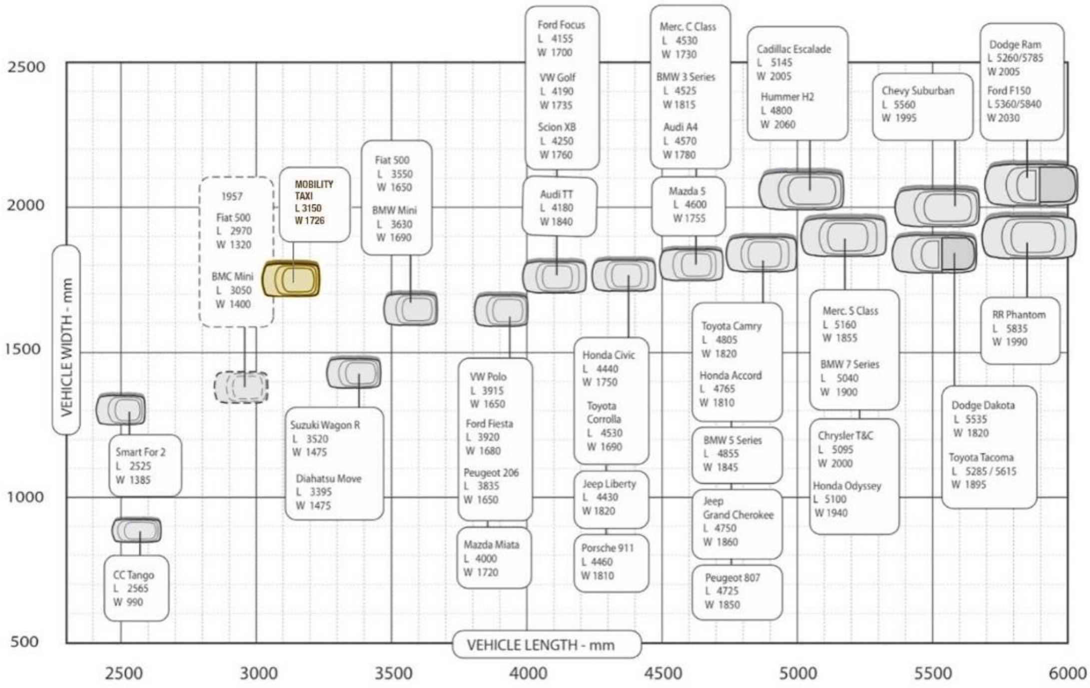


Fig. 5.12 - Vehicle Segmentation Matrix - Driverless Taxi (Yellow)

5.9 STYLING

The conceptual driverless vehicle to be representative of the style as a subject to build feasibility issues which might affect door openings, integration of major system components and development of conceptual BIW structure. Simple exterior surfaces are generated directly using CAD (Catia V5) based on packaging, hardpoint data and ergonomic constraints. The instrument panel, door trims and other interior trim styling is not considered for this demonstrative study, but it is worth to note that the instrument panel will not have a steering column as the conceptual vehicle is considered as fully driverless.

5.10 BASIC PACKAGE DRAWINGS

The initial package is usually developed accurately in a 3D CAD system (e.g. Catia V5). The drawing on the following image represents typical package logic board. It contains details about the package and the functional objectives that are driving the design. The goal is to describe the logic behind the concept's architecture.

The main views are graphic representations of the architecture with all of the major systems illustrated and described in detail. The vehicle dimensions are also included to help put the concept into benchmarking context.

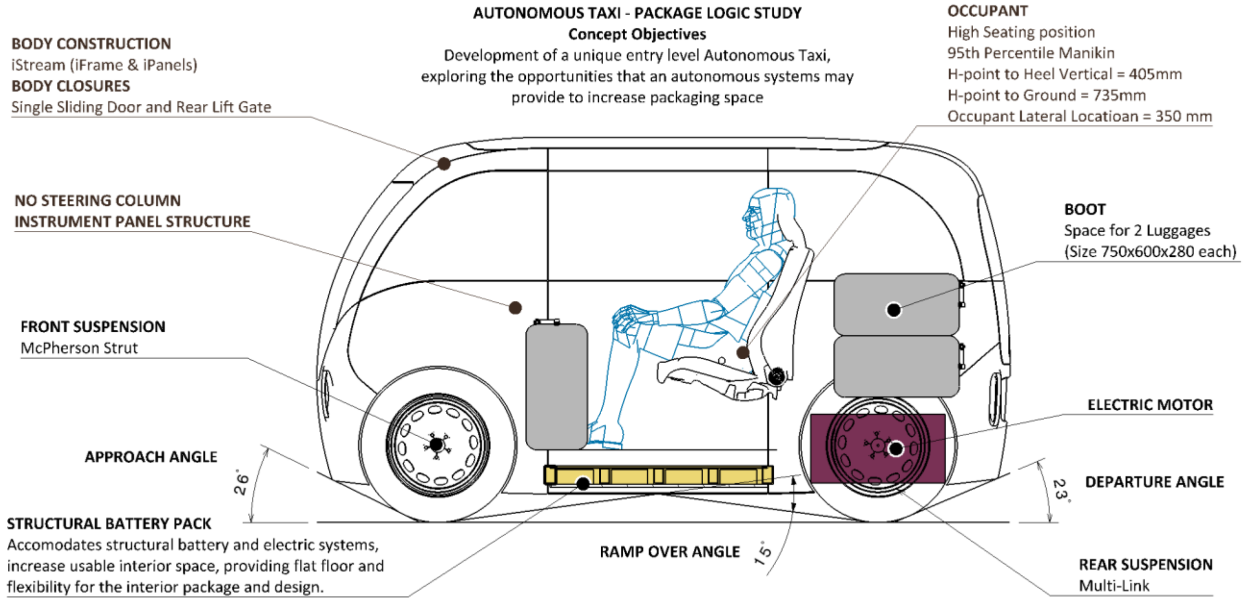


Fig. 5.13 - Conceptual Driverless Taxi - Package Logic Study

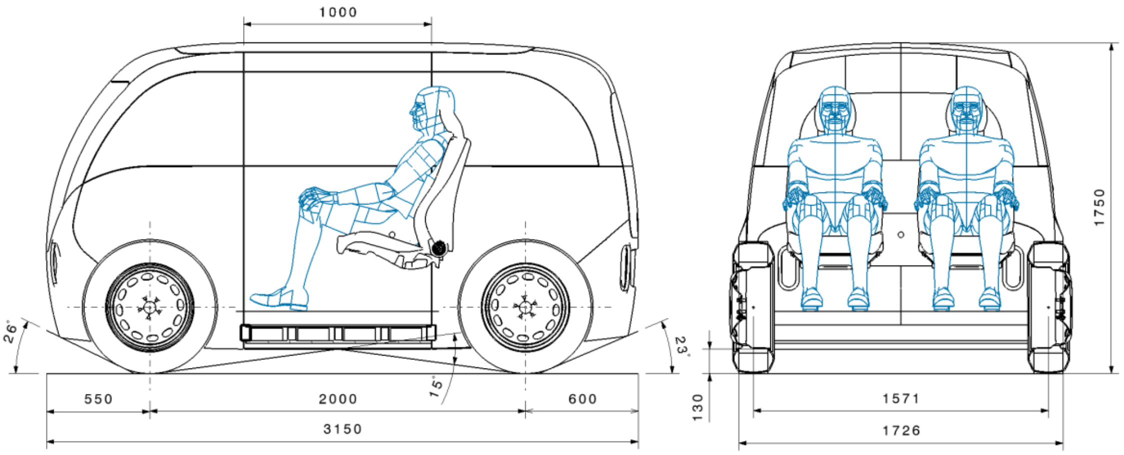


Fig. 5.14 - Conceptual Driverless Taxi - Key Dimensions

5.11 DEVICES FOR AUTONOMOUS DRIVING

All devices listed in table 4.1 are integrated into the conceptual package using simplified CAD models and their specification sheets to examine their field of range and overall coverage (Fig. 5.15).

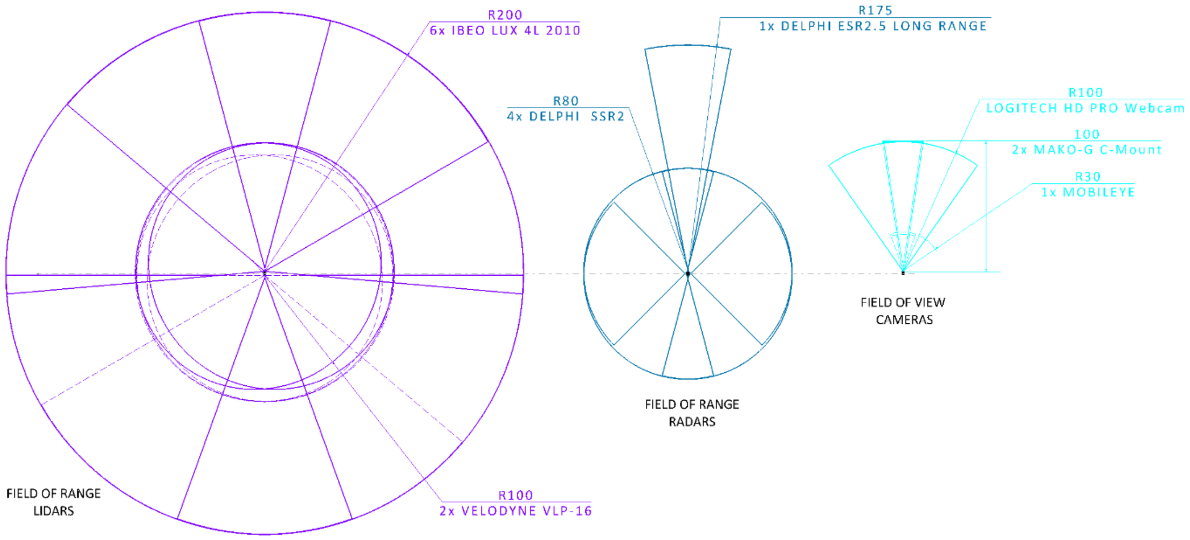


Fig. 5.15 - Field of Views - Lidars, Radars & Cameras (range shown in metres)

Front facing cameras are located at the bottom behind the windshield (Mobileye 630) and just behind front header panel (Logitech HD Pro Webcam, Mako-G C-Mount) that needs to be made from transparent material to allow clear visibility.

The long-range Delphi radar is mounted centre behind the bottom of the windshield, short-range Delphi radars are positioned behind the front and rear side panels (all in the same height). This setup of radar application provides coverage 360 degrees allowing the conceptual vehicle to sense the entire surroundings.

To provide easy access in case of upgrade requirements, the set of three Ibeo lidars (Ibeo Lux 4L 2010) is positioned behind the front bumper and three behind the rear bumper. As shown in the figure 5.16, this configuration should provide 360-degree coverage within a radius up to 200m with slightly limited coverage on vehicle sides. As illustrated in the figure 5.16, the Velodyne lidars are placed exposed on top sides of the front header panel. These two-spinning high-res pucks provide a full-frontal coverage with limited rearward visibility. They allow the vehicle to sense the frontal environment as visualized in the figure 5.17.

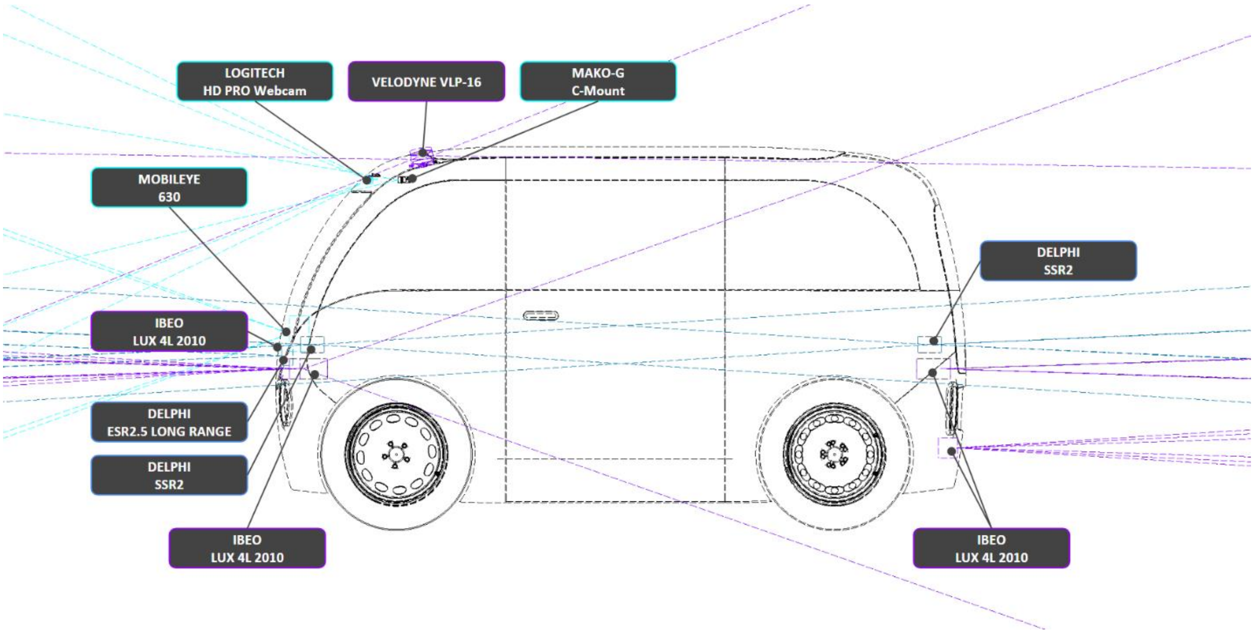


Fig. 5.16 - Conceptual Driverless Vehicle - Packaging of autonomous sensors (Side View)

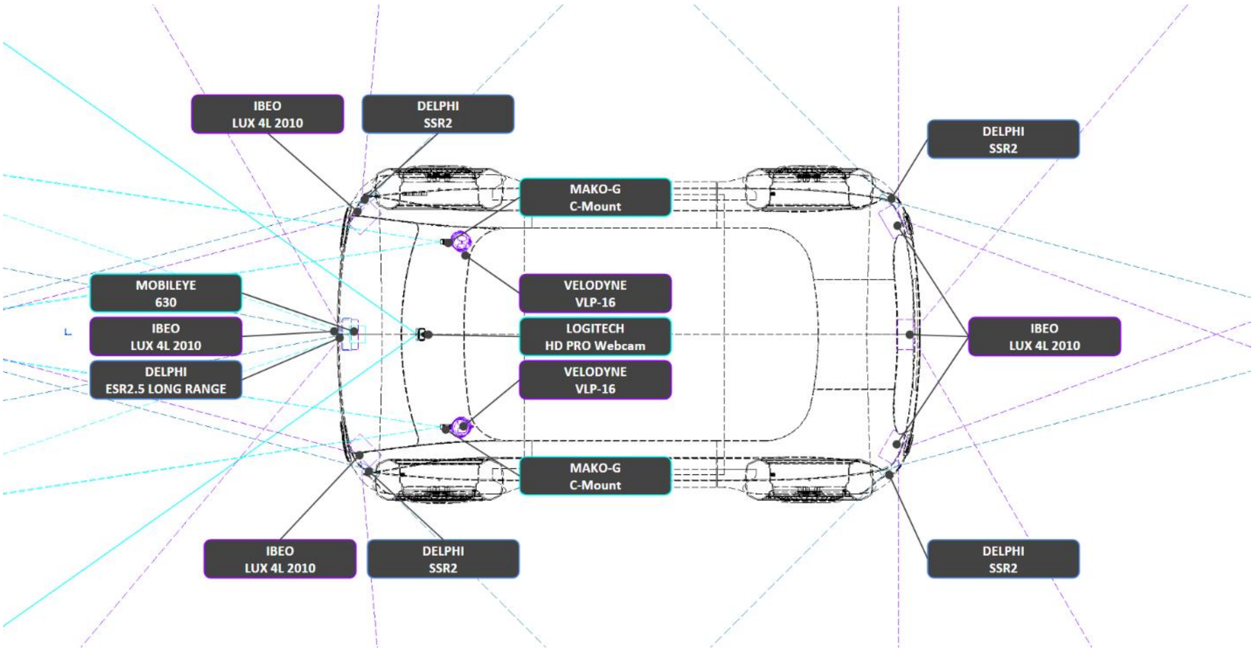


Fig. 5.17 – Conceptual Driverless Vehicle - Packaging of autonomous sensors (Top View)

5.12 INTERIORS AND CARGO

The interior components can be divided into about seven systems (Controls and Instrumentation, Trim Panels, Carpet and Sound Insulation, Seats, Heating, Ventilation and Air Conditioning (HVAC), Telematics, Instrument Panel (IP) and Consoles). The interior design on most projects follows the exterior. This drives the initial package together with the occupants, creating hard points to work around [2]. Due to the limited amount of time for this thesis, the design consideration of these components is described just briefly, and their consideration during the initial package ideation was minimized.

INSTRUMENT PANELS AND CONSOLES - Generally, the I.P. will not influence the exterior proportions of the car, so its design can follow the exterior. However, many of the key components are conventionally directly related to the driver location and posture to provide reach, visibility and safety. If the occupant package changes, it may tear up the I.P. and console design. This is one reason why the interior design is not developed to a high degree until the exterior development is advanced [2].

DOOR & PILLAR TRIM PANELS - Although these may appear to be of lesser importance to other interior components, many of the upper trim panels feature extensively in early package studies because they are designed to reduce head trauma if the occupants strike the upper body structure during an impact or rollover. As the roof rail, pillar and header sections are developed, they always include the trim [2].

CONTROLS, INSTRUMENTS & SWITCHES - These are the main elements in the vehicle’s HMI or Human Machine Interface. The steering wheel, shifter, handbrake and turn-signal stalks all are conventionally located where the driver can use them efficiently and also allow easy ingress/egress [2]. For the interior design of the conceptual vehicle, these components are omitted.

DISPLAYS - The telematics may affect the layout of the vehicle package. For some cars, it may just be a navigation screen and a smartphone dock, but other vehicles may have a 50” flat screen TV with a full home theatre system. Telematics systems and their interfaces are causing a revolution in automotive design and are a high consideration for customers. As the technology continues to develop the interior design will follow to take advantage of elements that simplify driver tasks and improve customer satisfaction [2]. Again, integration and initial conceptual design of these is omitted for the package ideation phase.

HVAC & AIR DISTRIBUTION - The main visible elements of the heating, ventilation and air conditioning systems are the air distribution vents and controls. Getting these in the correct location should be a high priority at the start of the interior design. Additionally, the modules that heat and cool the air and blow it through the cabin are quite large and are usually located between the bulkhead and centre stack between the footwells [2].

SEATS - The seats are designed around the occupants’ location and posture. They occupy a large volume, and adjustment ranges have to be factored into the location of adjacent components. Establishing a relationship between the H-point and the seat is essential but can be difficult to control. The seat cushion foam and occupant flesh combined will compress about 50mm, so the seat should be drawn intruding into the occupant [2]. About 55mm of vertical seat travel is typical for classic vehicles in terms of accommodating 95% of all drivers. Therefore this travel can be considered for driverless vehicles as well.

5.13 SUSPENSIONS, CHASSIS & ELECTRIC DRIVE

Suspension systems are complex. Choosing the type of suspension system that works with the functional objectives of the vehicle should be done in the ideation phase of the package. The effect of the turning radius of 8 metres that the front suspension system has on the tire envelopes ("Jounce and Turn") and adjacent package components should be understood so that the initial package study can be set up with these in mind. These envelopes define the swept area of the tire profile, as the suspension articulates, and the steering angles change. Due to the complexity of this initial package study, simple plan view envelopes were created to assess their effect on the front structure, mainly on the package design of the front longitudinal beams. Selected suspension types can be seen in the figure 5.10 (battery packaging).

The front suspension is a popular McPherson type, that incorporates the steering axis into the strut centerline, reducing cost. This system packages well with conventional transverse engines but usually requires a high fender to fit the spring above the tire. The missing engine brings additional space that can be used for packaging HVAC system that is conventionally positioned between engine and dashboard. The HVAC system can, therefore, use engine's space within the package ideation and provides additional space for the main cabin interior. This extra space is highly beneficial in terms of the package assessment for wheelchair accessibility and manoeuvrability inside of the vehicle interior.

The rear multi-link independent suspension system includes a compact GKN electric engine that powers the rear wheels of the LEVC (London EV Company, formerly known as London Taxi Company)'s electrified TX model. It was designed to minimise packaging and maximise performance. In the LEVC TX, GKN's eAxle is the primary drive unit, and so uses a 120kW e-motor. The lightweight unit weighs less than 17 kg and has a mechanical efficiency of up to 97.5%. Components are tightly packaged, with the reduction gearbox, open differential, drive shaft section and e-motor sharing a connected housing. This level of integration has significant benefits when it comes to packaging the eDrive unit within the new taxi's chassis [115].

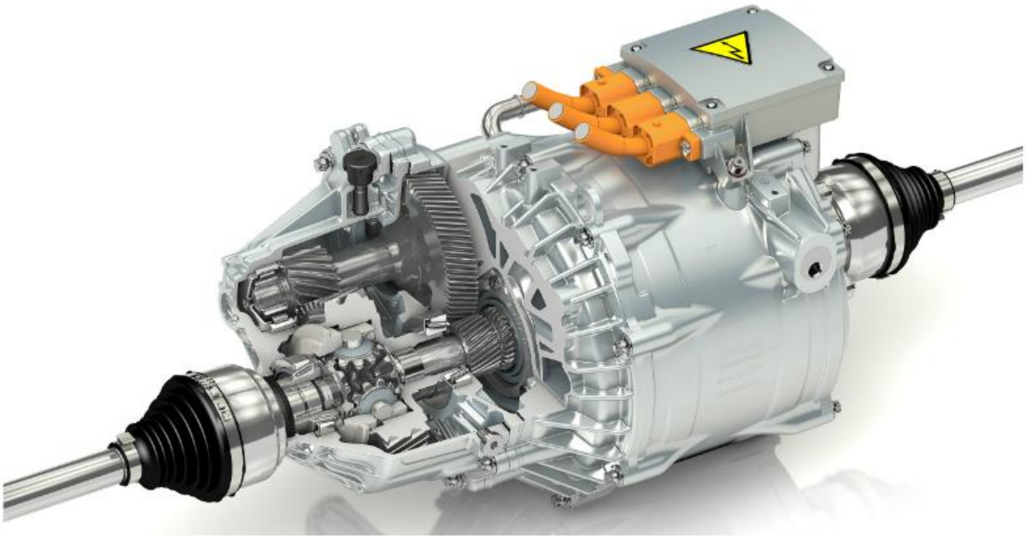


Fig. 5.18 - GKN eAxle for the electric London Taxi [115]

5.14 BODY & EXTERIOR TRIM

The body is a very complex system, which threads throughout the architecture, holding all the elements together. The body is one of the most complex assemblies of a passenger vehicle, consuming a large portion of a project's resources, both manpower and investment. Besides being a complex piece of engineering, it is also the element most tied to the vehicle's overall architecture and its appearance [2].

The body structure and outer skin have four primary functions:

- Protect the occupants and cargo
- Provide attachment points for all other major components and manage the stress between them
- Provide an appealing appearance and image of the product
- Provide an aerodynamic form to improve performance and reduce wind noise

5.14.1BODY IN WHITE STRUCTURE (BIW) - iSTREAM SYSTEM

After extensive research and consideration of all possible aspect, iStream technology designed and developed by Gordon Murray Design Limited has been selected as the best possible keystone for the conceptual design investigation for the body structure (BIW). iStream combines lightweight technology, low-energy consumption and flexible small-footprint production sites where the market is located to deliver an all-new production process, capable of producing equally innovative and forward-thinking vehicles. The end result is a vehicle that benefits from a virtuous cycle of low-weight production and delivers a 40% reduction in greenhouse emissions over its lifecycle [116].

The parametric design method used in the CAD modelling process allows the structure (chassis) to be scaled in size for different products, with each new design requiring only low-cost tooling and software changes. This flexibility means that the chassis can be used as a standard 'platform' to deliver different vehicle types and model variants, e.g. driverless taxis, driverless delivery vans, driverless emergency vehicles, etc.

iFRAME - At the core of the iStream is the technology to build a lightweight and low-cost vehicle architecture using a combination of mostly large-diameter, thin-walled steel tubes that are formed, laser cut and profiled under computer control, and then welded together [117]. This structure picks up and joins together all the structural hardpoints - suspension mounts, seat anchorages, powertrain mounts, battery mounts, interior restraints and door rails – which is cost-prohibitive in a composite structure. The tubes used in the iFrame are then coated internally and externally with an organic autophoretic material to provide exceptional corrosion resistance.

iPANELS -Low-cost composite panels are constructed from thin external skins of low-cost woven, unidirectional, random matt glass fibres or natural fibres. Sprayed with a low-cost and fast-curing matrix and then compressed, the external skins and honeycomb core of these panels deliver exceptionally high levels of bending strength and stiffness. These composite sandwich materials are bonded to the frame sections, to form an incredibly stiff impact-resistant structure. According to Gordon Murray Design, this bonded structure displays no signs of degradation even after 100,000 torsional rigidity bench tests, compared to stamped steel structures, which tend to show a loss of strength after less than 2,000 tests [117].

The overall section sizes used in this study demonstrate production intent but needs to be further optimized in terms of structural integrity, bending and torsional stiffness targets and to achieve minimal kerb weight. The iFrame design work generated on the vehicle structure represents just an initial starting point for further engineering work and does not include iPanels, therefore, may not adequately represent the design status of the prototype or production vehicle.

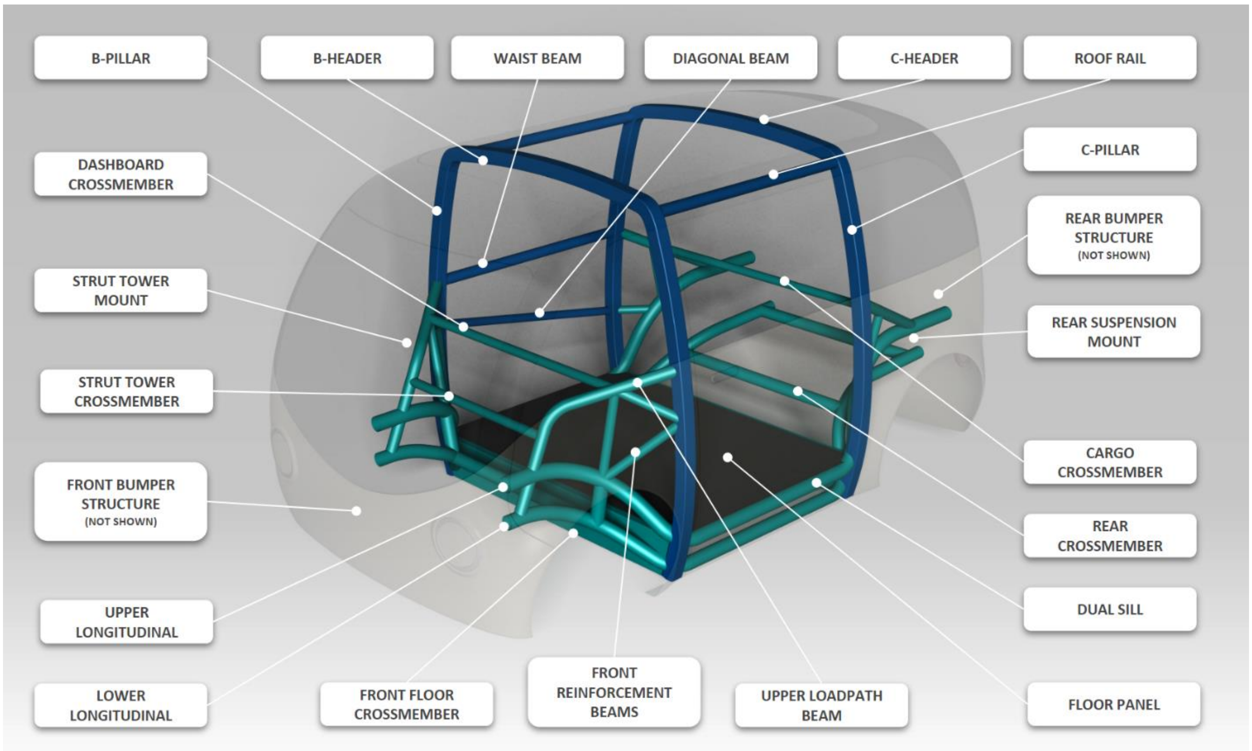
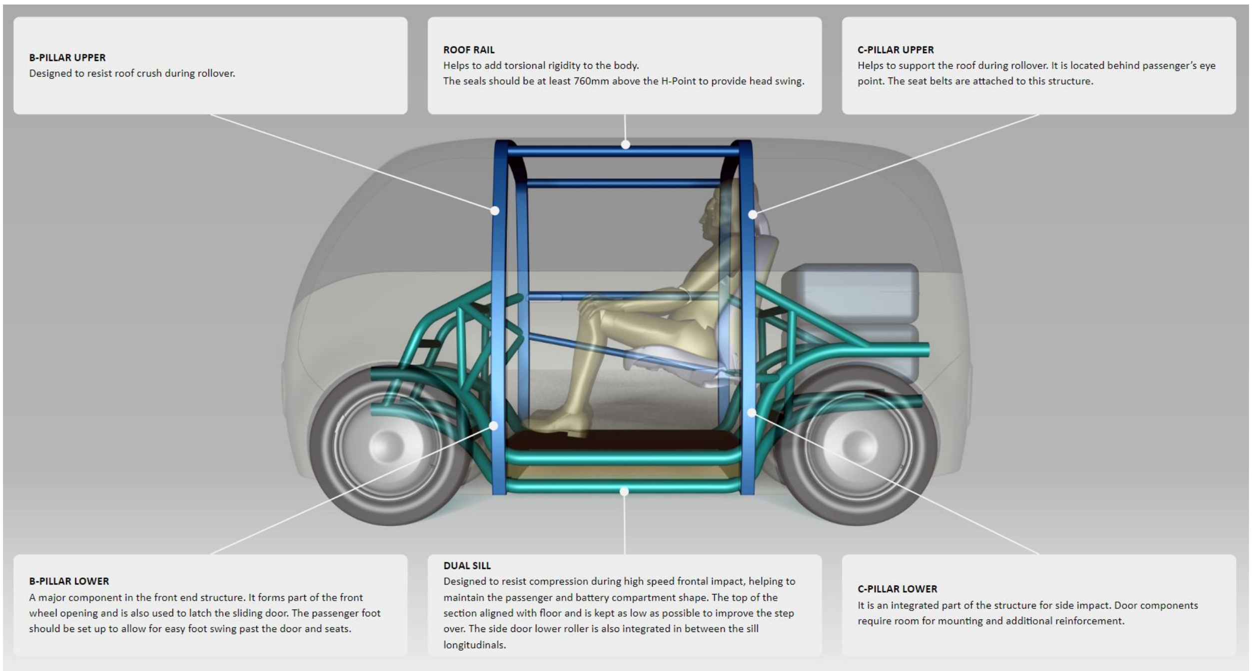


Fig. 5.19 - Anatomy of the Body Structure (iFrame)



B-PILLAR UPPER
Designed to resist roof crush during rollover.

ROOF RAIL
Helps to add torsional rigidity to the body.
The seals should be at least 760mm above the H-Point to provide head swing.

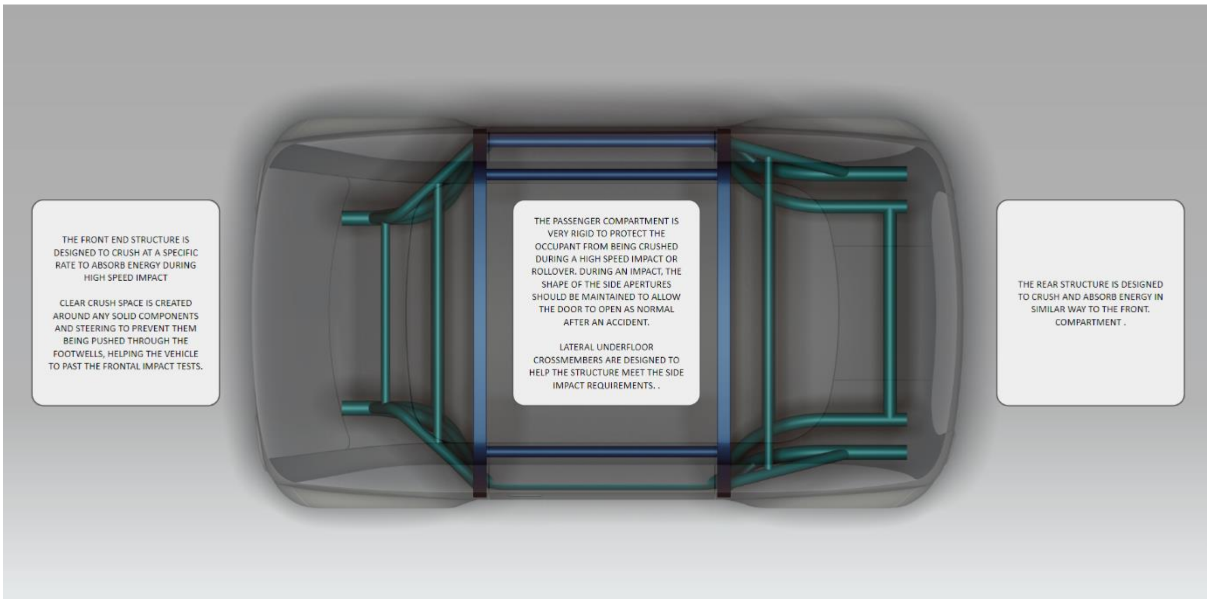
C-PILLAR UPPER
Helps to support the roof during rollover. It is located behind passenger's eye point. The seat belts are attached to this structure.

B-PILLAR LOWER
A major component in the front end structure. It forms part of the front wheel opening and is also used to latch the sliding door. The passenger foot should be set up to allow for easy foot swing past the door and seats.

DUAL SILL
Designed to resist compression during high speed frontal impact, helping to maintain the passenger and battery compartment shape. The top of the section aligned with floor and is kept as low as possible to improve the step over. The side door lower roller is also integrated in between the sill longitudinals.

C-PILLAR LOWER
It is an integrated part of the structure for side impact. Door components require room for mounting and additional reinforcement.

Fig. 5.20 - Conceptual Body Structure Design (iFrame)



THE FRONT END STRUCTURE IS DESIGNED TO CRUSH AT A SPECIFIC RATE TO ABSORB ENERGY DURING HIGH SPEED IMPACT

CLEAR CRUSH SPACE IS CREATED AROUND ANY SOLID COMPONENTS AND STEERING TO PREVENT THEM BEING PUSHED THROUGH THE FOOTWELLS, HELPING THE VEHICLE TO PAST THE FRONTAL IMPACT TESTS.

THE PASSENGER COMPARTMENT IS VERY RIGID TO PROTECT THE OCCUPANT FROM BEING CRUSHED DURING A HIGH SPEED IMPACT OR ROLLOVER. DURING AN IMPACT, THE SHAPE OF THE SIDE APERTURES SHOULD BE MAINTAINED TO ALLOW THE DOOR TO OPEN AS NORMAL AFTER AN ACCIDENT.

LATERAL UNDERFLOOR CROSSMEMBERS ARE DESIGNED TO HELP THE STRUCTURE MEET THE SIDE IMPACT REQUIREMENTS. .

THE REAR STRUCTURE IS DESIGNED TO CRUSH AND ABSORB ENERGY IN SIMILAR WAY TO THE FRONT. COMPARTMENT .

Fig.5.21 - Description of the Front, Mid and Rear Structure

5.14.2 EXTERIOR PANELS & BUMPERS

The exterior panels and bumpers together with their split lines are broadly representative of the vehicle concept. The production-intent would be to deliver the exterior panels to the assembly line pre-painted and bolt them to the completed chassis near the end of the assembly process, helping to reduce paint damage generally associated with a standard assembly line. Pre-painted body panels mean that there is no need for a paint shop in the assembly plant. Mechanical fixing of body panels is quick and low-energy. It also makes future repairs relatively simple as replacement panels are quicker and easier to fix [118].

5.14.3 GLAZING

The primary objectives for the glass panels are to protect the occupants and allow them to see out. In many cases, they also articulate to provide ventilation or access. Glass is one of the oldest materials used in vehicle design and is still manufactured using traditional processes, which can limit the design of each panel. The main reason it is still used extensively is that of its optical qualities and hardness (scratch resistance), unlike some plastics. This makes it ideal for applications where it contacts other abrasive components, such as windshield wipers and belt mouldings [2].

Two types of glass are used, laminated (for windshields) and toughened (for side glass and backlights). The laminated glass is thicker. Usually, 5–6mm, and is therefore quite substantial but will not shatter when struck, unlike the tempered glass which is usually about 3mm thick and designed to shatter into small pieces on impact [2].

PANORAMIC ROOF - Panoramic glass roof is ideal for city commuting and city cruising, therefore ideal for driverless taxis. London Taxi Company (LECV) noted that panoramic roof is one of the significant marketing attributes as there is a high demand for this feature.

5.15 CLOSURES

The closures and their apertures are designed to provide access to the passenger compartment, engine bay and cargo area. Their outlines are a design element, so breaking up the exterior panels and closures was considered early in the process. Details can be seen in the final rendered images (Fig. 5.32)

SLIDING DOOR - Ideal for situations where an out swinging door is dangerous or impractical. Sliding door systems require enough room behind the door to build in a straight, horizontal track which will carry the door to the fully opened position. They are attached to the body structure by rollers and latched into position. This separation allows them to be made of different materials from the structure, such as aluminium and plastics, creating the opportunity to make them lighter or dent resistant. This system can be electrically operated [2].

Vehicle concept has a single sliding door only. Single door solution reflects the commuting behaviour in all three analysed cities (many commuters drive alone). Therefore two-door concept seems to be unnecessary, the high weights and excessive cost related to the integration of this type door. This type of door is perfect design solution for 'box-style' cars and is highly beneficial in tight parking situation in an urban environment. Accessibility to the driverless vehicle is not compromised due to the missing steering column and compact instrument panel. The size of door aperture is limited by the body architecture but respects the minimum width requirement for accommodating wheelchair ramp. The overall door opening dimensions respects the findings from previous inclusive design chapter. Specification details for door hardware (hinges, regulators, locks and latches), door trim and door seals are not considered for this initial design stage.

LIFTGATE - The most common rear aperture closure for minivans, hatchbacks and SUVs. Providing excellent access from all angles and cover from the rain. The electric operation can help shorter people close the gate on vehicles with a tall roof [2]. Tailgate rear doors pivot about a rear header hinge line parallel to the ground line and latch onto the body via a sill mounted locking device, powered typically by gas damped struts. The primary attributes are Simple tailgate construction, low cost, low weight.

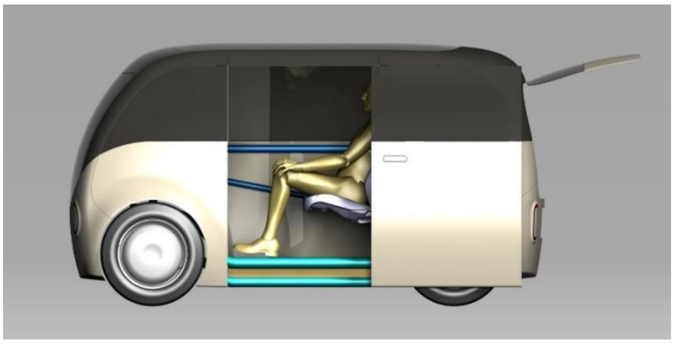


Fig. 5.22 - Sliding Door and Liftgate - Open Position

BODYSIDE APERTURE DESIGN CRITERIA - The door aperture has a significant influence on the exterior design. Some necessary parameters need to be addressed before the design concept moves forward too far. The door feasibility should be very advanced before the full-size clay model is started.

5.16 DRIVERLESS VEHICLE - CONCEPTUAL CAD DESIGN

The early conceptual design is an essential stage in vehicle product development. At this stage, various iterations of design, analysis, validation and confirmation are typically carried out with limited and continuously changing vehicle design information, thereby complicating engineering decisions. To overcome these complications, CAD tools have been developed to aid in conceptual vehicle design. Many CAD tools include functionality to create various parametric concept models rapidly. Coarse vehicle geometry can be generated, allowing for an increased number of design iterations at an early stage in the development process, thereby reducing the time per design iteration [119].

The objective of this activity is to build a conceptual parametric platform that can be easily modified and structurally pre-optimized by the improved approach of simultaneous CAD and CAE analysis to understand structural behaviour in the initial phase of the body design. Understanding of the structural behaviour through virtual validation of the conceptual parametric platform can help to reduce the cycle time respecting the architecture modularity.

Basic wireframe platform architecture is developed referencing SAE J1100 dimensions. As a starting point, all structural members are designed in a non-optimized way to fit within styling surfaces and packaging.

5.17 PARAMETRIC PLATFORM ARCHITECTURE

Parametric modelling is a method for generating a conceptual vehicle design that is easily modulable for a wide range of design changes, including vehicle configuration changes, vehicle and component changes, and even styling changes. Another aspect of the parametric modelling is the ability to generate and manipulate the conceptual platform of a vehicle for use in the initial stages of a vehicle design process. The figure 5.23 below briefly describes the main CAD platform assembly and its hierarchy.

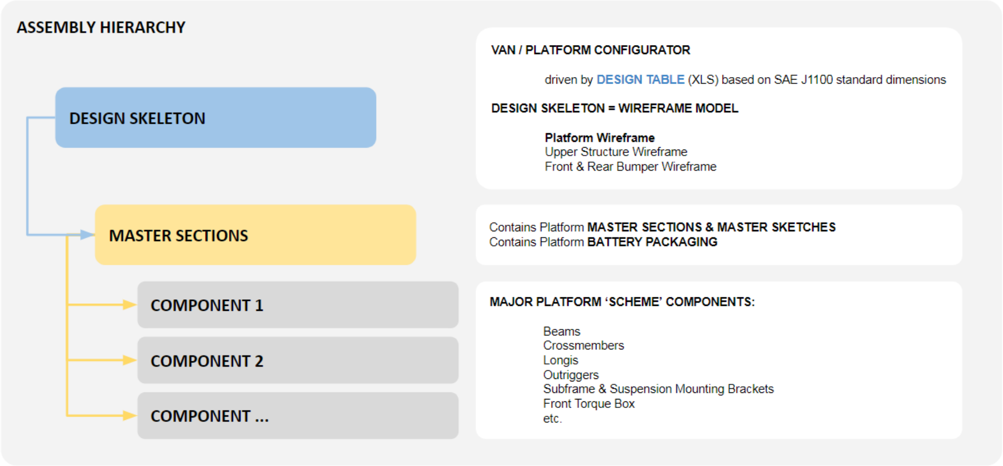


Fig. 5.23 – Parametric Concept Modelling Architecture

To maintain modularity, flexibility and updatability of the high-level conceptual CAD platform, the figure 5.24 briefly describes the linking (referencing) cascade between the significant architectural members. Lower layers in the hierarchy must reference only the upper layers to avoid the referencing loop. For example, changes made on the Design Skeleton layer (e.g. by modifying hardpoints, wireframe or Design Table configuration) will undoubtedly affect all the layers below, but all these are updated automatically without the need for manual intervention.

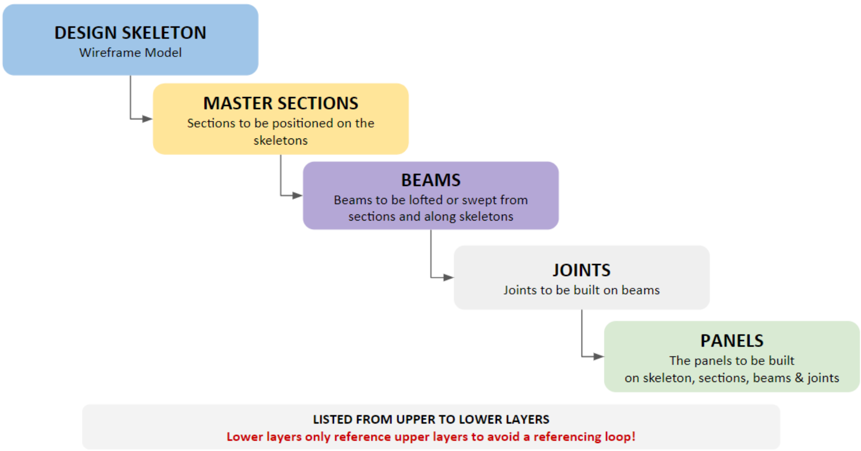


Fig. 5.24 – Model Architecture Layers – Cascade of Design Changes

5.17.1 SAE J1100 DESIGN TABLE

In CATIA V5 design tables are used to create multiple variations of a part or an assembly. The part or assembly is generic, but the design table is checked in as multi-primary content. Design tables are created using a Microsoft Excel spreadsheet. Each column represents various parameters (e.g. wheelbase, track width, ground clearance), and columns represent an instance (e.g. various vehicle models).

Design table is designed to drive the parameters of a CATIA document from pre-existing external values. When using a design table, the trick is to associate the right CAD parameters with the right table parameters. By creating associations, you declare what document parameters you want to link with what table rows.

The developed SAE Configurator is based on SAE J1100 [120] and contains a list of more than 400 codes / dimensions. This SAE Recommended Practice defines a set of measurements for motor vehicle dimensions. Evidently, most of the cells are empty at the early conceptual stage. Only the ones related to the platform and wireframe design have been defined. This configuration sheet can also contain benchmarking data from various competitor's vehicles to allow comparison of their dimensions with the driverless conceptual platform. The essential SAE J1100 reference data that were used for the conceptual CAD model can be found in Appendix X.

Unless otherwise specified, all dimensions are measured normal to the three-dimensional reference system (see SAE J182), except ground-related dimensions, which are defined normal to ground. All dimensions are taken with the vehicle at curb weight unless otherwise specified.

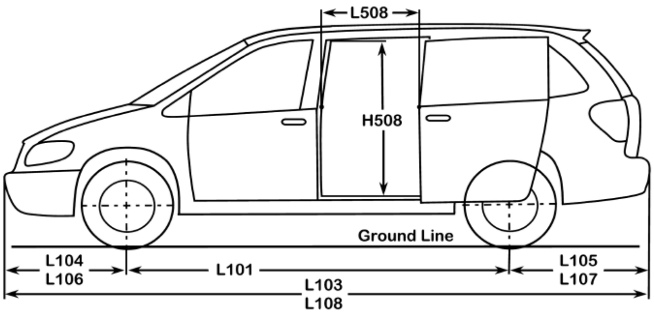


Fig. 5.25 – Example of SAE J1100 Figure and Codes

5.17.2 DESIGN SKELETON

The CAD skeleton is a collection of specifications, which keeps functional characteristic of the entire model.

The specification can be:

- Wireframe geometry (Points, lines, planes)
- Parameters and formulas
- Axis systems
- Surface geometry

Where to use skeleton method:

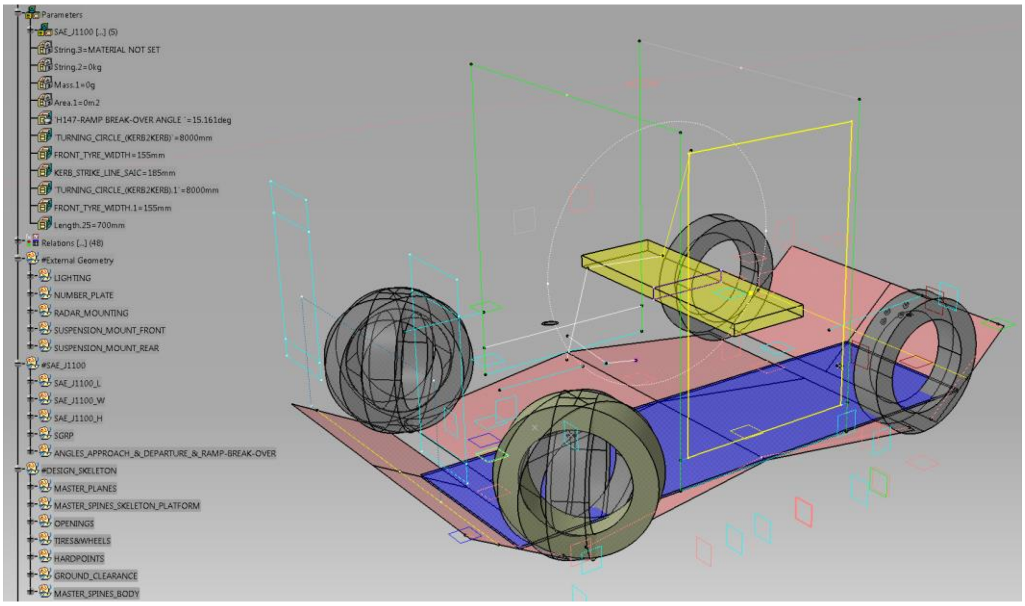
- Wireframe models with different variations of dimensions but same structural function
- For structural models with size and shape variations.

Advantages of using skeleton modelling:

- Use of Skeleton method dramatically reduces design iteration time.
- All information in assembly is stored in one part and streamlined down through the product structure.
- Every part or subassembly is constrained only to skeleton part and master section part.
- Main platform assembly does not contain unnecessary constraints. Easy replacing of components.
- Designers Engineers involved in the design process can work individually, all necessary information is stored in shared skeleton part.
- Ability to quickly evaluate and review design alternatives.
- Delivers flexible simulation, analysis and validation capabilities to improve product quality

Disadvantages of skeleton modelling:

- Skeleton modelling should be used from the beginning of design process.
- Making skeleton for a one-time project is time-consuming.



- Parameters
  - SAE_J1100 [..] (5)
  - String.3=MATERIAL NOT SET
  - String.2=0kg
  - Mass.1=0g
  - Area.1=0m2
  - `H147-RAMP BREAK-OVER ANGLE `=15.161deg
  - `TURNING_CIRCLE_(KERB2KERB)`=8000mm
  - FRONT_TYRE_WIDTH=155mm
  - KERB_STRIKE_LINE_SAIC=185mm
  - `TURNING_CIRCLE_(KERB2KERB).1`=8000mm
  - FRONT_TYRE_WIDTH.1=155mm
  - Length.25=700mm
- Relations [..] (48)
- #External Geometry
  - LIGHTING
  - NUMBER_PLATE
  - RADAR_MOUNTING
  - SUSPENSION_MOUNT_FRONT
  - SUSPENSION_MOUNT_REAR
- #SAE_J1100
  - SAE_J1100_L
  - SAE_J1100_W
  - SAE_J1100_H
  - SGRP
  - ANGLES_APPROACH_&_DEPARTURE_&_RAMP-BREAK-OVER
- #DESIGN_SKELETON
  - MASTER_PLANES
  - MASTER_SPINES_SKELETON_PLATFORM
  - OPENINGS
  - TIRES&WHEELS
  - HARDPOINTS
  - GROUND_CLEARANCE
  - MASTER_SPINES_BODY

Fig. 5.26 – CAD model of the Design Skeleton

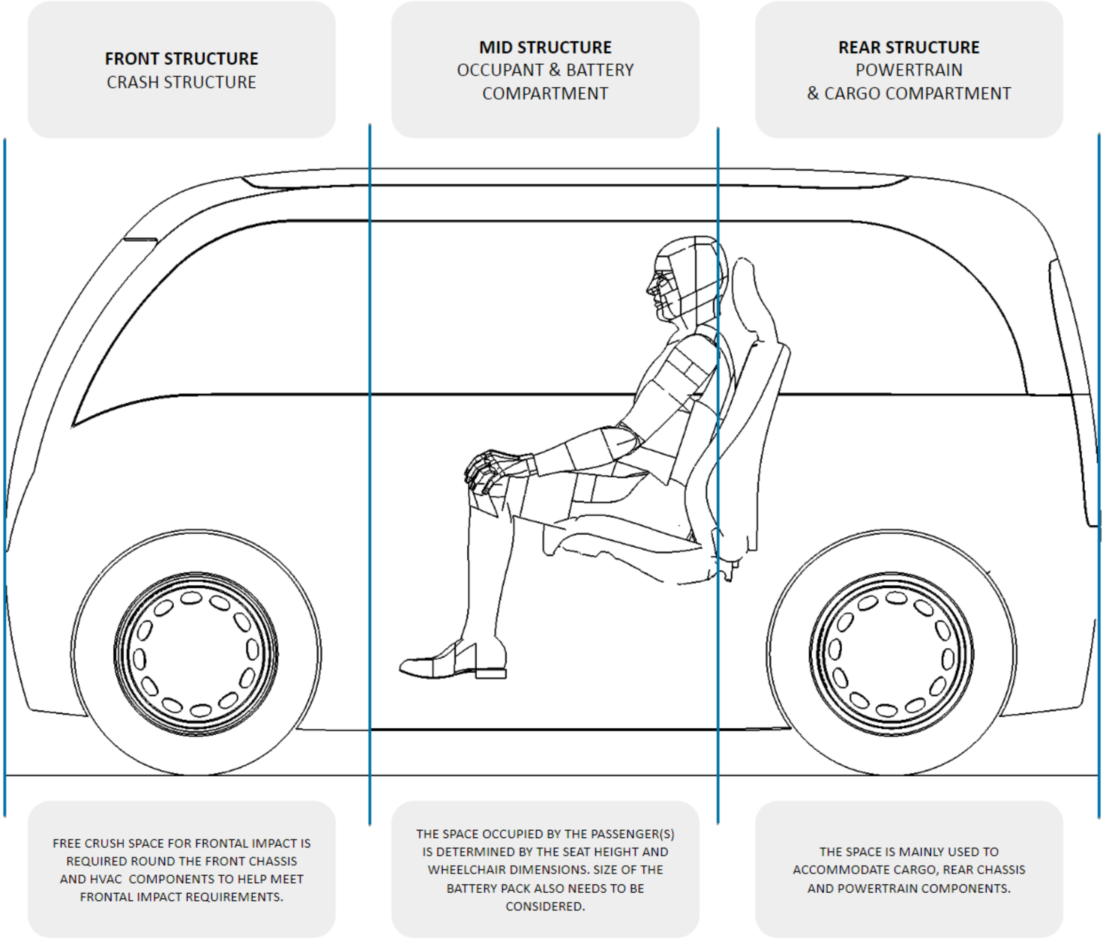
The Design Skeleton CAD part contains various sets of parametric control curves, planes and hardpoints (e.g. Master Planes associated with SAE J1100, Openings, Tire & Wheels, Master Spines, Ground Clearance Geometry).

These wireframe sets (Fig. 5.26) represent the geometric inputs for the creation of parametric Master Sketches and Sections and all the major conceptual components. Design Skeleton can be modified by dimensional or geometric input for given vehicle size, proportion, and/ or configuration using a Design Table based on SAE J1100 standard codes and dimensions. Varying the information in the Design Table results in updating or regenerating of parametric master sketches governed by the design skeleton and reposition of components assembled to the generic skeleton.

Openings (Fig. 5.26 – Yellow Lines) can be a set of 3D lines representing the vehicle body opening. Openings are grouped in an individual set within the Design Skeleton. These openings provide visual guides for users to adjust generic panels matching geometric packaging input mostly related to the upper structure.

5.17.3 SLICING UP THE PACKAGE

Every CAD package model should be developed in zones. The package drawing of the conceptual driverless vehicle shown below illustrates the main compartments of the architecture divided longitudinally (Fig. 5.27).



FRONT STRUCTURE
CRASH STRUCTURE

MID STRUCTURE
OCCUPANT & BATTERY COMPARTMENT

REAR STRUCTURE
POWERTRAIN
& CARGO COMPARTMENT

FREE CRUSH SPACE FOR FRONTAL IMPACT IS REQUIRED ROUND THE FRONT CHASSIS AND HVAC COMPONENTS TO HELP MEET FRONTAL IMPACT REQUIREMENTS.

THE SPACE OCCUPIED BY THE PASSENGER(S) IS DETERMINED BY THE SEAT HEIGHT AND WHEELCHAIR DIMENSIONS. SIZE OF THE BATTERY PACK ALSO NEEDS TO BE CONSIDERED.

THE SPACE IS MAINLY USED TO ACCOMMODATE CARGO, REAR CHASSIS AND POWERTRAIN COMPONENTS.

Fig. 5.27 - Conceptual Driverless Vehicle - Package Drawing

5.17.4 DESIGNING WITH SECTIONS

Building the vehicle architecture with sections is fundamental to the process for both construction and communication. As a concept develops these will become more and more complex. Each section is usually developed by several specialists [2].

A significant portion of the advanced package and the body is developed in four “Sectional Views” (multiple sections in one view) which are cut through the major elements of the package, i.e., the hip points (H-points), spindles, powertrain, battery pack and the cargo compartment. As the package progresses, more sections are created around the vehicle, but to get the initial concept started, it is essential to keep the initial study simple. The primary objective here is to establish some of the leading hardpoints, so that the exterior design can be modelled over the critical elements of the package, developing the body structure as each section is constructed [2].

The four main sectional views are cut through the major elements of the package. Because most vehicles have a lot of curvature on their surfaces, multiple sections are put in each view to form a clear picture of each zone of the package.

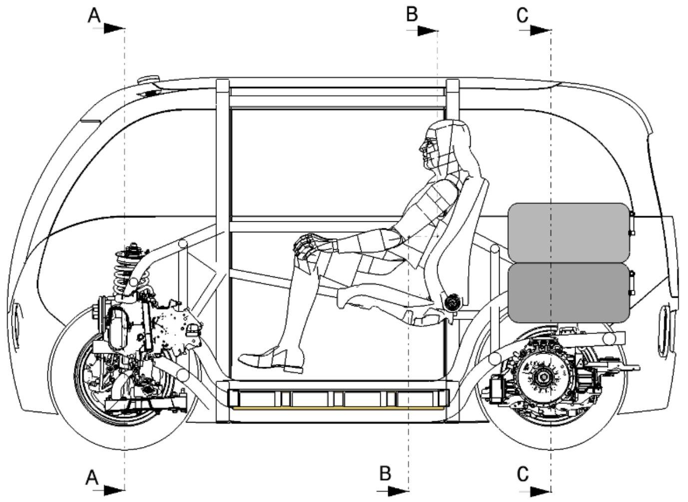
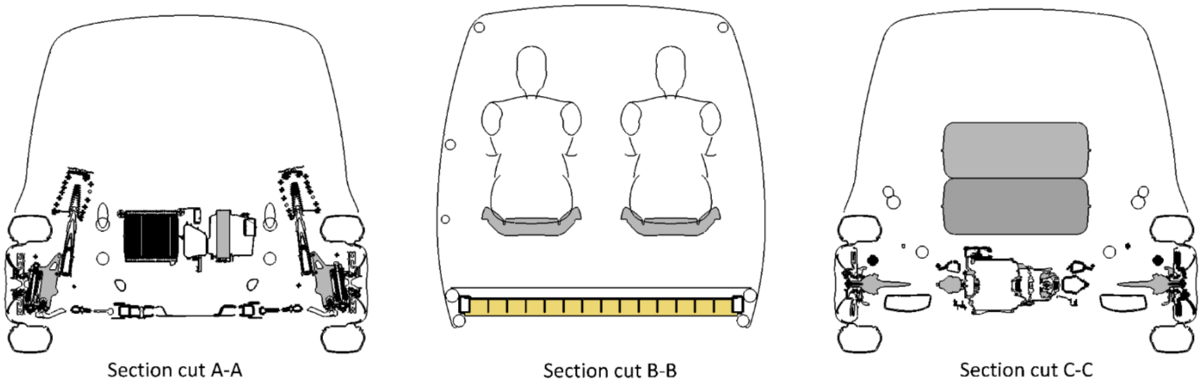


Fig. 5.28 - Sectional View Y0
This sectional side view is cut through the centreline of the body and the occupants.


Section cut A-A

Section cut B-B

Section cut C-C

Cut through the front spindles and HVAC unit. This section is used to help prove out the HVAC and front suspensions package under the fenders and their attachment to the iFrame.

Cut through the occupants’ H-point and head contours. This key section is created to set up the door panels, side glass and roof-rail sections. Other elements like roof over the head environment, sills, floor and battery structure are included here.

Cut through the rear spindles. This shows the cargo bay, rear suspension and eAxle motor.

Fig. 5.29 - Sectional Views - Front Spindle, Occupants, Rear Spindle

5.17.5 HARDPOINTS DEFINITION

The images below illustrate the main CAD hardpoints.

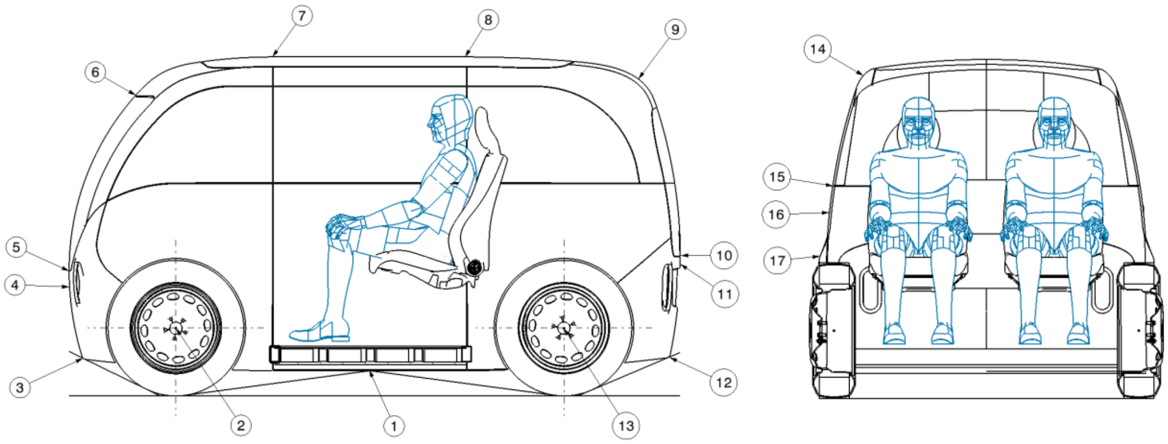


Fig. 5.30 - Conceptual Driverless Vehicle - Hardpoints

(1) SILL & FLOOR HEIGHT - Determined by the ground clearance, the ramp-over requirements of the vehicle and the underbody structure depth. The lowest point of the vehicle is often a chassis or powertrain component [2]. The significant role also plays the integration of structural battery into the floor compartment.

(2) FRONT WHEEL AND TIRE - The front spindle height is determined by the static load radius of the tire. The track is determined by a combination of the distance between the front structure frame rails and the tire turn envelope. Tire size is limited by body size, suspension components and the vehicle's turning circle.

(3) CHIN HEIGHT - The chin should clear a 162mm high parking block. A minimum 10° approach-angle line (when the vehicle is fully loaded) is recommended for passenger cars.

(4) FRONT BUMPER LOCATION - For passenger cars, the bumper system height must cover the "bumper band" which is generally mandated to be from 406mm to 508mm above the ground. The longitudinal location must provide enough crush space in front of the occupant's feet to meet high speed (40mph) frontal impact requirements [2].

(5) COWL / WINDSHIELD TOUCHDOWN - The cowl height is limited by hardpoints generated from the visibility requirements for cameras mounted behind the windshield and driver visibility. For a conventional vehicle, a downward vision angle of less than 5° may be a problem for shorter drivers. If the windshield is too far from the driver's eye point, the A-pillar may affect forward vision, but these issues will become obsolete for driverless cars.

(6) WINDSHIELD OPENING & HEADER - Determined by the head to headliner relationship, header structure and head impact foam thickness. The upward vision angle will help to set up the header location. An upward vision angle less than 11° is considered a compromise for conventional vehicles. Again, this requirement won't be necessary for driverless taxis.

(7) FRONT ROOF - Should provide appropriate room over the manikin's head form for ingress/egress clearance, trim and a sunroof if required. The roof should be as low as possible to reduce weight, lower the centre of gravity and minimize frontal area to reduce aerodynamic drag [2]. On the other hand, the design package must consider the ease of ingress/egress requirements for older passengers and their reduced mobility.

(8) REAR ROOF - A similar condition to the front headroom is desirable.

(9) REAR HEADER - Similar to the front header

(10) REAR CARGO - Most driverless vehicles will have some cargo storage. The height of the cargo area is governed by the size of the objects that are intended to be carried and the target storage volumes. When considering various derivatives of the 'boxed' driverless concept (e.g. delivery van), the rear cargo height plays an important role here.

(11) REAR BUMPER LOCATION - Similar height requirements to the front bumper but with additional consideration for load height variation which is greater at the rear. Rear impact requirements influence the rearward location of the bumper beam. The height of the fascia panel (bumper skin moulding) will affect the lift over height for loading cargo [2][2]. Again, capabilities of elderly passengers need to be considered during the design process.

(12) BODY REAR LOWER (Departure angle) - Can be less than the approach angle.

(13) REAR SPINDLE - The track and height are set up in a similar way to the front. The longitudinal location usually is as close to the rear occupant as the tire envelope will allow.

(14) ROOF RAIL SECTION - The outer skin of the roof rail is established by a stack up of several internally positioned components while providing adequate clearance to the occupant head form. The section through the rail will comprise the body-in-white (BIW) structure, the door frame, head impact protection, and trim. Additionally, side curtain airbags may be packaged.

(15) BELT-LINE LOCATION - The height and width can be driven by the exterior design. Adequate shoulder room should be provided to the door inner panel.

(16) BODY SIDE PROFILE - Is usually do designed to allow the glass surface to drop inside the sliding door section, missing all of the hardware and obstructions within the door assembly. Side impact requirements will also play a part in setting up the outer door surface.

(17) WHEEL COVERAGE - Most vehicles are designed to meet European wheel coverage requirements. This standard requires that the bodywork covers the outboard edge of the tires in a zone between a line 30° (from vertical) forward of the spindle and 50° rearward [2].

5.17.6 MASTER SKETCHES

2D master sketches are traditionally cut at specific vehicle locations. Non-limiting examples include cross member sections, outrigger sections, longitudinal sections, sill sections, bumper sections, etc. The 2D master sections are typically used to specify the design and engineering requirements for the vehicle structure. Master sections are represented by a set of parametric sections that are created based on the generic master sections and positioned in the design skeleton at corresponding locations as defined in the vehicle.

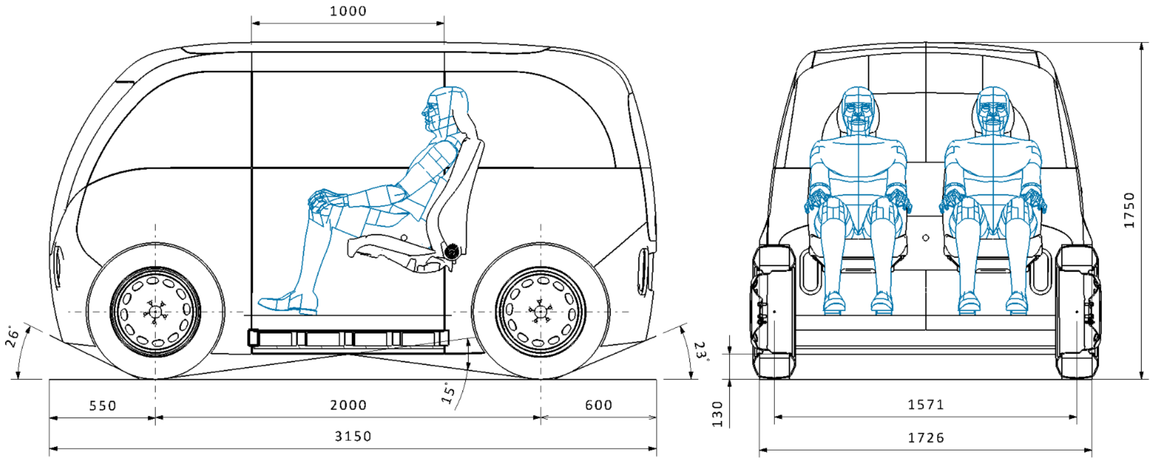
5.17.7 GENERIC SKELETON ASSEMBLY

The introduction of the Generic Skeleton assembly enables easy reuse of legacy or carry over components (e.g. from previous vehicle programs, donors, benchmarking studies, etc.). As the Design Skeleton assembly, the Generic Design assembly also uses the original Design Skeleton as a driving unit for placing the legacy components (not the new conceptual ones). The coexistence of both Generic and Design skeleton assemblies makes it possible to mix and match the innovative design with the old (or carry over, or benchmark) for creating an optimal design. This is accomplished by creating new components using the surfaces generated in the design skeleton and assembling them together with the legacy components in the generic skeleton.

5.18 DRIVERLESS TAXI

KEY SPECIFICATIONS, DIMENSIONS & RENDERS

The basic dimensions are used to set up and communicate the size and attributes of the package.



EXTERIOR	
Length	3150
Width	1726
Height	1750
Wheelbase	2000
Track	1571
Tire OD	700
Tire Size	175R16

INTERIOR	
Head Room	1050
H-point to Ground	735
Couple	700
Floor Height	330
Door Width	1000
Shoulder Room	1542
Hip Room	1446

TARGET SPECIFICATION	
Range	140 miles / 225 km
Top Speed	80 mph / 130 kmh
Weight	max 1000kg
Cost	$25-$30,000
Production Volume	10,000
Battery Capacity	40kWh
Turning Circle	8m

CONCEPT OUTLINE

A fully Autonomous Taxi for urban commuters, elderly and disabled people designed and developed on inclusive design approach.

Fig. 5.31 - Conceptual Driverless Vehicle - Key Dimensions

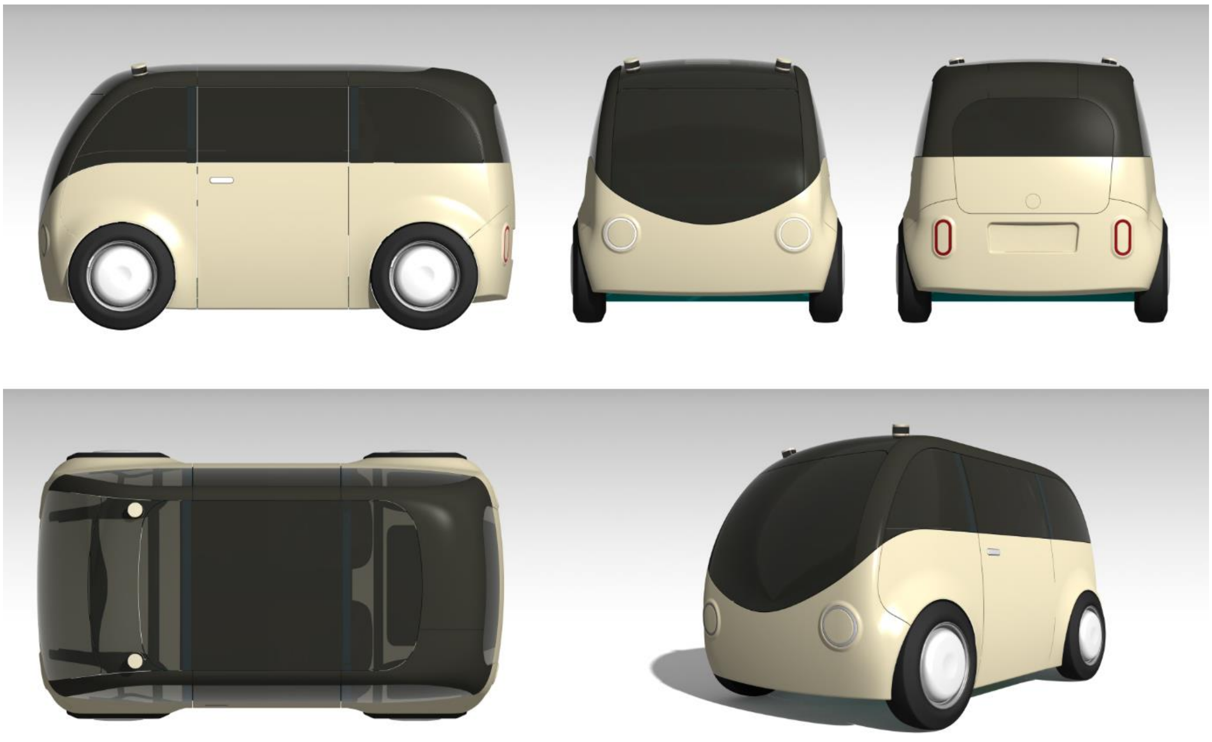


Fig. 5.32 - Final Conceptual Renders

Fig. 5.33 - Final Conceptual Renders - Front and Rear View

5.19 CHAPTER SUMMARY

The innovative approach of the parametric platform development drastically reduces the development time, cost, modularity and improves first-time right quotient. This approach also enhances the platform structural performance with minimum iterations.

The conceptual parametric platform design still requires some additional design work. Optional further work can be assessed followingly: Integration of the Front and Rear Bumper; Integration of the iPanels to further improve ongoing CAE analysis and to predict the overall CAE performance of the entire vehicle; Precise evaluation and integration of the Battery Packaging to analyse its weight in relation to the platform bending and torsional performance.

6 CONCLUSION

There is a definite global opportunity to develop a concept of a driverless car for high volume production to catalyse systemic change in urban transit networks, enabling a prosperous future for hundreds of million people in metropolitan cities. Safety, mobility and quality of life improvement by designing driverless vehicles will help to overcome common urban commuting issues and age-related deficits. With distracted driving accounting for hundreds of fatal accidents each year, there is more need for driverless vehicles than ever. The comprehensive research presented that the technology to manufacture these cars is already in existence, but before the public has a chance to get in the passenger seat of a driverless car, our legislation needs to be improved to allow driverless vehicles.

Legal obstacles, consumer trust, and infrastructure hurdles will be barriers to widespread adoption, but the Institute of Electrical and Electronics Engineers predicts that driverless vehicles will account for 75% of cars on the road by 2040 [121]. Vehicles must become more flexible in terms of size and operation. Standard bus services, which only operate between bus stops, have to be complemented or substituted with more flexible services.

This work was just a starting point for a much more extensive investigation into personal urban mobility taking account the challenges we currently face with an ageing driving population, slower city speeds and an increasing information flow. It is a very vast and complex task which offers many directions to be further explored.

From the all the gathered findings, one can already imagine how the body structure and exterior of the future car may possibly look like. There are many already established car concepts such as VW Sedric. Currently, there are 44 corporations working on autonomous vehicles (2017), most importantly Google, Uber, Tesla, Honda, Mercedes-Benz, BMW, Audi and Apple [29]. It is essential that these manufacturers of autonomous vehicles and future taxi companies use autonomous cars that, as far as possible, meet the requirements stated in this thesis as being in the comfortable range whenever possible. Car designers and engineers can use these data and information from this study when developing new cars suitable for elderly and disabled people.

Even though the focus of this paper was not on re-designing the physical aspect of the car, it is about to have a general understanding of the issues related to the inclusive design approach and how the elderly passengers may benefit from integrating the process into design and development of the vehicle.

Transport and mobility systems should be designed for a multi-generational context rather than catering for isolated consumer types. Everyone will appreciate the benefits of having a unit which can be called remotely to pick up and deliver people ‘door-to-door’ and interface with digital services from home, website or mobile devices. One can argue that the internet can supply most of the mobility and transportations issues, but it does not offer a complete answer to digital integration; many people are still digitally excluded. Digital or remote connection does not replace physical contact.

Driverless vehicles will provide substantial social, industrial and economic benefits to the countries which will adopt and implement this technology into their infrastructure. It is a unique opportunity and challenges for the Czech Republic and Slovakia as they have the highest direct automotive manufacturing employment to working population ratio in the world (CZ 2.7%; SK 2.3%) [122].

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APPENDIX A

(P2)	**PLAN FOR THE DESIGN WORK**
P2.1	**Analyze and categorize the technical process and technical system from viewpoints which influence design work and planning**
	Automotive Industry Analysis to be made at the start of the project
	Transportation Statistic Evaluation (Traffic Volume, Energy Consumption, Operating Fleet, Infrastructures, Social Impact)
	Involvement of a skilled professional with autonomous driving experience is considered as essential
	Automotive Market Research & Analysis (Motorshow visit, Automotive conference visit)
	Evaluation of European Adult Data and Disability Surveys (Motion, Dexterity, Reach & Strech, Vision, Hearing, etc.)
	Companies & Organization relevant to the project to be contacted / visited
P2.2	**Select overall strategy, partial strategies and operations for important partial systems**
	Systematic procedure of Inclusive Design principles to be followed at the first stage of the project
	- Demographic changes in population to be evaluated
	- Physical and Cognitive aspects that affect eldery drivers to be defined
	- Social aspects that affect elderly to be examined
	- Disablity statistics and Disability surveys to be assessed
	- Inclusive Design approach to be integrated into the design process
	- Types of User Capabilities (Disabilities) to be defined
	- Mapping of human factor design of the autonomous vehicles (Ingress, Egress, Driving comfort, Human machine interface)
	- Demand and Exclusions to be assessed using Inclusive Design Toolkit
	- Case study (Visionary Scenario) for the autonomous vehicle to speficied
	- Design exclusions to be quantified and assessed
	Design issues for urban environment to be elaborated
	- Global population, vehicle fleet and commuting reviewed
	- Commuting stastistics in specified metropolitan cities to be analysed
	- Mobility and vehicle-sharing to be characterized together with vehicle design in urban context
	- Mobility business plan to be developed based on recent findings
	- Case study for a specified city to be assessed
	- Benchmarking of recent electric vehicles and their relation to the business model to be evaluated
	Design of autonomous vehicles to be analysed and individual devices to be assessed
	- Automotive radar sensors to be reviewed
	- Automotive lidars to be reviewed
	- Cameras suitable for autonomous vehicle to be reviewed
	- Other related components and devices required for autonomous driving to be specified
	- Examples of application to be characterized
	A list of requirements for a conceptual design of an autonomous vehicle to be established
	A detailed list of all relevant system properties to be established
	Vehicle form and basic exterior styling for a new lightweight vehicle type to be generated based on the gathered information
	- Pre-Concept Development (Form Generation, Body Styling Development, Preliminary Renders)
	- Plan for a optimized body structure to be developed
	- Conceptual parametric platform to be designed using advanced CAD modeling techniques
	- Integration of devices required for autonomous driving to be proposed
P2.3	**Establish degree of difficulty of the design work**
	Large amount of statistic data to be evaluated
	Design difficulties could arise in terms of tranferring the findings into the vehicle design form
	Complex input data required for the mobility business plan may affect the estimated financial projections
	Limited access to autonomous technology and lack of experience may cause issues during the research process
P2.4	**Establish task for operators and individual staff members**
	Not applicable
P2.5	**Plan the anticipated work, under time pressure**
	3years as target, intermediate target dates need to be set for individual stages.
P2.6	**Estimate the design cost**
	Not available / Not applicable at the start of the project
P2.7	**Establish further goals, for example masters, forms, catalogs and so forth**
	Virtual concept can be further development and optimized
	Mobility business plan can be assessed for futher metropolitan cities
P2.8	**Improve, Optimize ← Substantiate, Evaluate, Select, Decide → Verify, Check, Reflect**

APPENDIX I

MOBILITY'S OPERATING EXPENSES

Financial projections for an industry that does not yet exist will of necessity include some assumptions. It is useful to know what these assumptions are and the justifications on which they are based.

VEHICLE DEPRECIATION

Depreciation is based on eight years at 75,000 miles per year, 600,000 miles total. By 2025, the average cost of these autonomous vehicles, including a 40 kW-hour heated and cooled battery pack with a range of 140 miles, is estimated to be $ 26,760. Note that cooling a battery improves its useful life. Based on performance monitoring, Autos will have their battery packs replaced after an average of 3.3 years for $ 5,120. The replacement battery, which will likely be better than the original, will be expected to last through the remainder of the Auto's 4.7 years of life [52] [66].

After four years, every driverless taxi will have its interior furnishings replaced ($ 2,500) and all of its electronics and some of its sensors updated ($ 2,800). The total vehicle cost over eight years would average $ 37,180, for an annual depreciation expense of $ 4,648 (see Appendix II, Cost of a 2025 driverless taxi, for details) [52].

FINANCING COSTS

A significant variable is the cost of money for Google and its partners. In 2014, Apple raised a total of $ 10 billion. Its 10-year maturity bonds had an interest rate of 3.46%. Assuming Google provides the initial financing, we will use 3.46% since 10 years is close to the eight-year taxi life. Based on an average driverless taxi price of $26,500 over eight years, and total upgrades and component replacements of $ 10,420 over four years, the average cost of money would be [52]:

$$0.0346 \times ((8 \times 26{,}500 + 4 \times 10{,}420) / 8) = 1{,}097.16 = \$\ 1{,}097 \text{ per year.}$$

INSURANCE COSTS

This is a significant unknown in estimating costs. Without a clear casualty history, insurance companies are inclined to expect the worst and charge the most. Assuming driverless cars continue to maintain an exemplary safety record, combined with their ability to document accidents since they continuously record a 3D image of the surrounding 100 + meters/ yards, Google/ Mobility could elect to self-insure [52]. Nonetheless, for a fleet of 10,000 vehicles, there will always be some accidents and casualty costs. An annual set-aside of $ 1,000 per year per taxi seems reasonable. This represents a $10 million annual reserve for the entire fleet of 10,000 driverless taxis. A surety bond for a self-insurance certificate will likely also be required before operations begin [52].

FUEL (ELECTRICITY)

According to the GreenCar calculator [123], the Nissan Leaf costs about $0.0764/mile to operate based on a $0.2524/kW-h national grid average for electricity [UK][124].

We will assume for now that carbon fibre is not used for the driverless taxi’s body and estimate that the average taxi will weigh approximately 920 kg, about the same as the rear-wheel-drive 920kg Smart ForTwo Electric Drive. Assuming the mileage to be approximately proportional to weight, based on the 1500kg Nissan Leaf, we would predict the driverless taxi cost per mile to be:

$$\$0.0764/\text{mile} \times (920\text{kg} / 1500\text{kg}) = \$0.0469/\text{mile}$$

Given that the rapid chargers are rated at 90% efficiency, adjusting for this factor raises the $0.0469 to $0.0521/mile. Assuming 75,000 miles per year, $0.0521/mile equates to an annual cost of $3,906/year.

TAXES AND REGISTRATION FEES

Based on the analysis conducted by The Earth Institute at Columbia University, Transforming Personal Mobility [71], we will estimate $600 a year.

MAINTENANCE AND REPAIRS

Since electric vehicles have so few moving parts compared to conventional cars, their maintenance and repair costs are much lower. Routine services would likely be limited to visual inspections, chassis lubrication, changing brake fluid, changing cabin air filters, rotating and occasionally changing tires, and changing battery pack coolant [52].

Nissan's Leaf, which is somewhat comparable, recommends a 15,000-mile interval for “severe use,” and a 30,000-mile service interval for “less severe” operating conditions. Based on the gentle driving style of the control software and the fact that it takes only five months to reach this mileage, 30,000 miles seems reasonable.

According to Repair Pal, the estimated fee for a brake fluid flush and change at $94. Since these are the only labour-intensive services, allocating $ 100 for each visit should provide some padding. Actual service costs will be lower since all vehicles drivetrains are identical. We'll allocate $250 for 2.5 service visits per year plus $450 per year for tires for a total of $700 per year for maintenance and repairs [52].

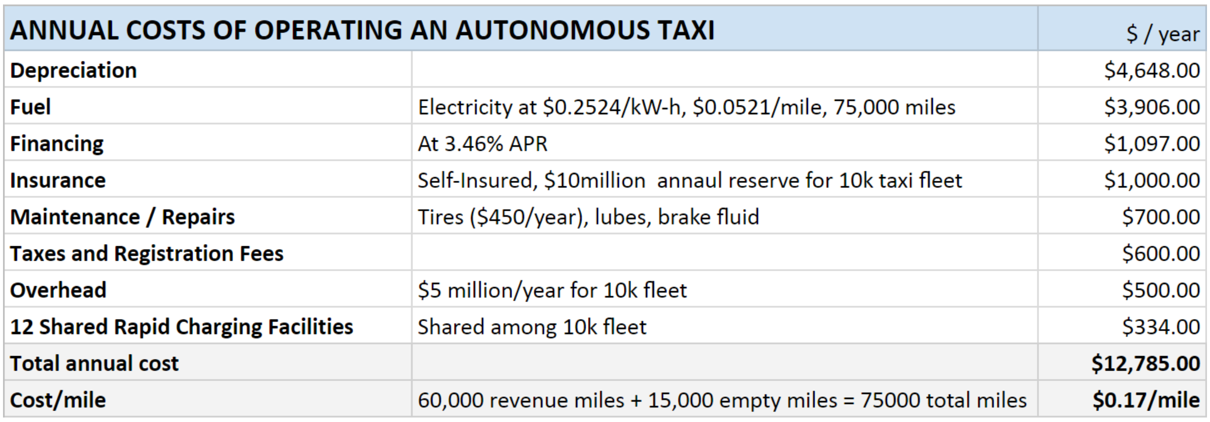
OVERHEAD

The Mobility dispatch system is highly automated as are the fee collections and basic accounting. Taxis monitor their own schedules, automatically driving to the maintenance facility when it is time for service. The primary function of management is to ensure that everything runs smoothly and to interface with the software developers and local officials as needed. A remote call centre would also be required for those occasional customer issues that require a human touch. But compared to conventional taxi services, the overhead cost would be quite low. The leverage of additional sites needed to minimize overhead should be achieved relatively quickly as Mobility expands. Even so, we'll allocate $500/year/vehicle for overhead. Based on 10,000 Autos, this funds overhead at $5 million per year [52].

12 RAPID CHARGING FACILITIES

Each of the 12 Rapid Charging Facilities provides access to 70 units of 480V fast-recharge "docking stations." The vehicles would automatically manoeuvre themselves to dock with the charging stations, each of which could recharge a taxi’s battery to 85% capacity in 25 minutes. Rapid Charging

Facilities would be geographically distributed to minimize empty mile travel. These facilities would be inside a secure fence with an automated gate and automated security. Two daytime staff members would handle all car washes and interior cleaning. Some vehicles would park there overnight while others would be scattered throughout the suburban customer neighbourhoods, ready for their morning fares. The estimated annual cost per Auto for this shared service is $334/year. Details are provided in Appendix III, Rapid Charging Facilities [52].



ANNUAL COSTS OF OPERATING AN AUTONOMOUS TAXI		$ / year
Depreciation		$4,648.00
Fuel	Electricity at $0.2524/kW-h, $0.0521/mile, 75,000 miles	$3,906.00
Financing	At 3.46% APR	$1,097.00
Insurance	Self-Insured, $10million annaul reserve for 10k taxi fleet	$1,000.00
Maintenance / Repairs	Tires ($450/year), lubes, brake fluid	$700.00
Taxes and Registration Fees		$600.00
Overhead	$5 million/year for 10k fleet	$500.00
12 Shared Rapid Charging Facilities	Shared among 10k fleet	$334.00
Total annual cost		**$12,785.00**
Cost/mile	60,000 revenue miles + 15,000 empty miles = 75000 total miles	**$0.17/mile**

Tab I. - Driverless Taxi - Annual Operating Cost

APPENDIX II

DRIVERLESS TAXI LIFE

With high-quality computer-monitored and managed maintenance and relatively rare collisions, it is reasonable to expect to operate a driverless electric taxi for eight years (see appendix I). There might be some additional repairs for individual taxis, but for the most part, barring crashes the basic chassis and body should easily last 10 to 15 years. Brushless electric motors also have a very long useful life, and those that might fail can be replaced or rebuilt if problems occur.

A new replacement motor is estimated to cost about $3,000 [52]. Specific components, including the batteries, passenger interior furnishings plus some of the sensors and electronics, will be appropriately scheduled for replacement. Battery life will be monitored to determine when a battery pack needs to be replaced. But for the purpose of financial modelling, we will assume the 2025 batteries will be replaced at 250,000 miles with batteries that will last 350,000 miles [52]. The cabin refurbishing and electronics and sensor upgrades will happen halfway through the eight-year service life.

In September 2014, Velodyne announced its LiDAR Puck, a 16-laser device that provides 300,000 points a second for real-time 3D imaging with an accuracy of about a centimetre and a 100-meter range. It sells for $8,000. Since it is designed to be mass-produced, Velodyne hopes it can get the quantity price down to a much lower level, which would attract a far more significant market [52].

Inexpensive stereo cameras can provide accurate distance ranging at up to about 30 meters/ 90 feet. Radar is needed for shorter-range (5 meters/ 15 feet or less) applications, such as automatic parking and monitoring vehicles in what is for most cars their blind spot. Germany's Bosch, Silicon Radar and Karlsruhe Institute of Technology recently announced a 5-meter-range chip-based radar sensor that costs only a few dollars. We can expect to see the variety and capabilities of these devices improve over the next five years. Given Moore's Law plus production versus prototype costs, it seems reasonable to estimate that by 2020 the cost of the driverless taxi’s computer plus sensors will fall to $5,000 or less.

Lithium batteries have historically been the most expensive single component for electric vehicles. But with the new Nevada Tesla/ Panasonic battery Gigafactory, Tesla CEO Elon Musk predicts a drop of 30% by 2017. He also noted that Tesla's current cost for battery packs, including power management and cooling systems, was $300/kWh, so that translates to $210/kWh by 2017. Based on historical price declines, we will estimate that by 2025 batteries will be available for $160 kWh [52].

The London Mobility Model also assumes that by 2025 Tesla's battery packs will have an average life of 250,000 miles or 3.33 years with recharging twice a day. Assuming a twice-daily charge under regular use, this equates to about five years. So a 3.33-year life estimate seems quite conservative [52].

To maintain a 140-mile range, we estimate that the relatively lightweight two-passenger Autos would require 40 kW-hour batteries, in part due to the deterioration of lithium batteries over time. This battery pack is estimated to provide a 140-mile range initially, but the range could be greater based on the relatively gentle driving style of Autos and the software's maximization of regenerative braking. Thus, based on Tesla's expectations, the original batteries would cost $ 5,760, and the mid-2025 replacement batteries would cost $5,120. Also, assuming battery lifespan increases and energy density improves in the next five years, it would be possible to downsize the batteries or increase the range [52].

Of course, remember that the driverless taxis would not require a steering wheel, dashboard electronics, or brake/ gas pedals and related linkages, or any of the following:

- Internal combustion engine
- Exhaust system
- Transmission
- Starter
- Catalytic converter
- Gas tank
- Alternator
- Oil, Lines & Filter
- Fuel pump
- Timing belts
- Air intake filter
- Spark plugs

However, to be conservative and also provide a cushion for some disabled-access Autos, we will assume a $16,000 average cost for this basic body and chassis. That includes comfortable leather-like seats, 4K monitors (or possibly virtual or augmented reality glasses), a flat fold-out work surface, and fast Internet, plus a storage area for shopping bags and a child seat. The electronics, sensors, and LiDAR would add $5,000, and the 40 kW-hour battery $5,760, for a total of **$26,760** [52].

APPENDIX III

RAPID CHARGING FACILITIES

The overriding consideration for Rapid Charging Facility design is the need to recharge 10,000 driverless taxis between the morning and evening rush hours. Rush hour is when most of the Mobility's revenues are generated. After the evening rush hour, there will be plenty of time to recharge, but there is a much smaller window between the morning and evening rush [52].

Morning rush hour usually lasts from 6am to 10am and evening rush hour from 4-8pm. There are tapers on the edges of these rush-hour periods, with traffic cresting at about 8am and 5pm. From 10am to 4pm there is a window of 6 hours for charging, though considering the edge tapers not all of the driverless taxis will need to be charged by 4pm due to the edge tapers [52] .

CHARGING OF BATTERIES

The useful life of most batteries produced today is maximized when batteries are charged to less than full. Some manufacturers recommend as low as 80 percent rather than a full charge. However, this isn't necessarily the most cost-effective solution for Mobility since it requires more driving time to charging stations and creates more empty miles than when batteries get more fully charged.

Profits are maximized when the number of visits to Rapid Charging Facilities is minimized, and taxis are on the street taking care of customers, assuming the battery packs' lives aren't excessively shortened. In planned studies, approximately 1,000 taxis can each be charged to 80%, 85%, 90%, and 95% to provide data for battery life analytics on cost/ revenue optimization. Within a year, Mobility should have the data needed to optimize this business strategy. Until then, most taxis will be charged to 85 percent. Also, battery life and chargers will improve by 2025. Research in advance of an initial rollout will better inform this strategy as well as the sizing of the battery pack [52].

The jointly-developed Sumitomo/ Nissan Leaf 480-volt charger ($15,500 plus installation, higher than 90 percent efficiency) can bring Leaf's 24 kW-hour battery from near empty to 80 percent in 30 minutes. Mobility will develop or support the development of a similar but more industrial system, stripped of most of the bells and whistles featured on this public-use Nissan unit, and capable of charging three to five vehicles simultaneously [52].

It is estimated that by 2025 the cost of this system will be about $10,000 per charger, including installation, concrete base, and docking ports, in initial quantities over 800 (12 facilities with 70 chargers each). Most taxis won't come in empty, so charging to 85% should take less than 30 minutes.

This should provide at least a 140-mile range for the 40 kW-hour. Mobility's docking port would be entirely different from conventional EV charging systems. The taxis would feature a concealed port on the rear of the vehicle. The vehicle would automatically steer itself into the charger's docking port and then separate when fully charged. In fact, the Google prototype is already able to charge itself when needed [52].

ON-SITE CLEANING CREW

A two-person cleaning crew is needed eight hours a day, seven days a week to ensure that the inside of the taxis is wiped down after they automatically wash. Two automatic car wash units at $90,000 each would service the 835 taxis at each Rapid Charging Facility [125].

SOLAR ELECTRICITY

With the installed cost of solar electricity generation continuing to decline by double digits annually, solar power generation has a likely future in the London Mobility Model. A recent utility solar electricity cost study from Lawrence Berkeley Labs reported a 70% decline in the price over the past five to six years. Long-term contract solar electricity prices have recently hit $0.05/kW-hour [126].

By covering the Rapid Charging Facilities with solar panels, Mobility will gain cheap electricity while sending a green message to the community. By supplementing the mid-day and late-afternoon recharging power demand, Mobility can shift some recharging to midnight to 6am to help utilities manage peak loads [52].

The newest solar power facilities can generate about 0.2 megawatts per acre. For our 2025 estimates, we will assume that at their current pace of development, in five years they will be able to generate at least 0.3 megawatts per acre. The 12 Rapid Charging Facilities occupy a total of 3.6 acres, of which perhaps three acres could be covered with solar panels to provide a total of about 0.9 megawatts of capacity [52].

USING RETIRED BATTERIES TO STORE POWER

Auto batteries lose their capacity over time and will be replaced when they fall below about 75% of their original rating. However, they still have a substantial amount of energy capacity when they are retired. By designing power storage into Rapid Charging Facilities, the used batteries can collect excess solar electricity to be used at peak demand times. This is an example of efficient reuse rather than merely recycling batteries for their chemical components.

Each time the fleet's 10,000 taxis replace their 25% depleted 40 kW-hour batteries, 240 megawatt-hours of storage can be added to the power storage farm. And as Mobility grows, so grows the farm. These batteries can also be used to store off-peak energy at 3am, which can be partially credited to recharging taxis from 9am to 3pm for the afternoon rush hour. Assuming the local utility offers off-peak electricity rates, this could be a major cost saving since it mitigates peak demand, a win-win for both Mobility and the utility [52].

ESTIMATING REQUIRED FACILITY CONFIGURATION AND CAPACITY

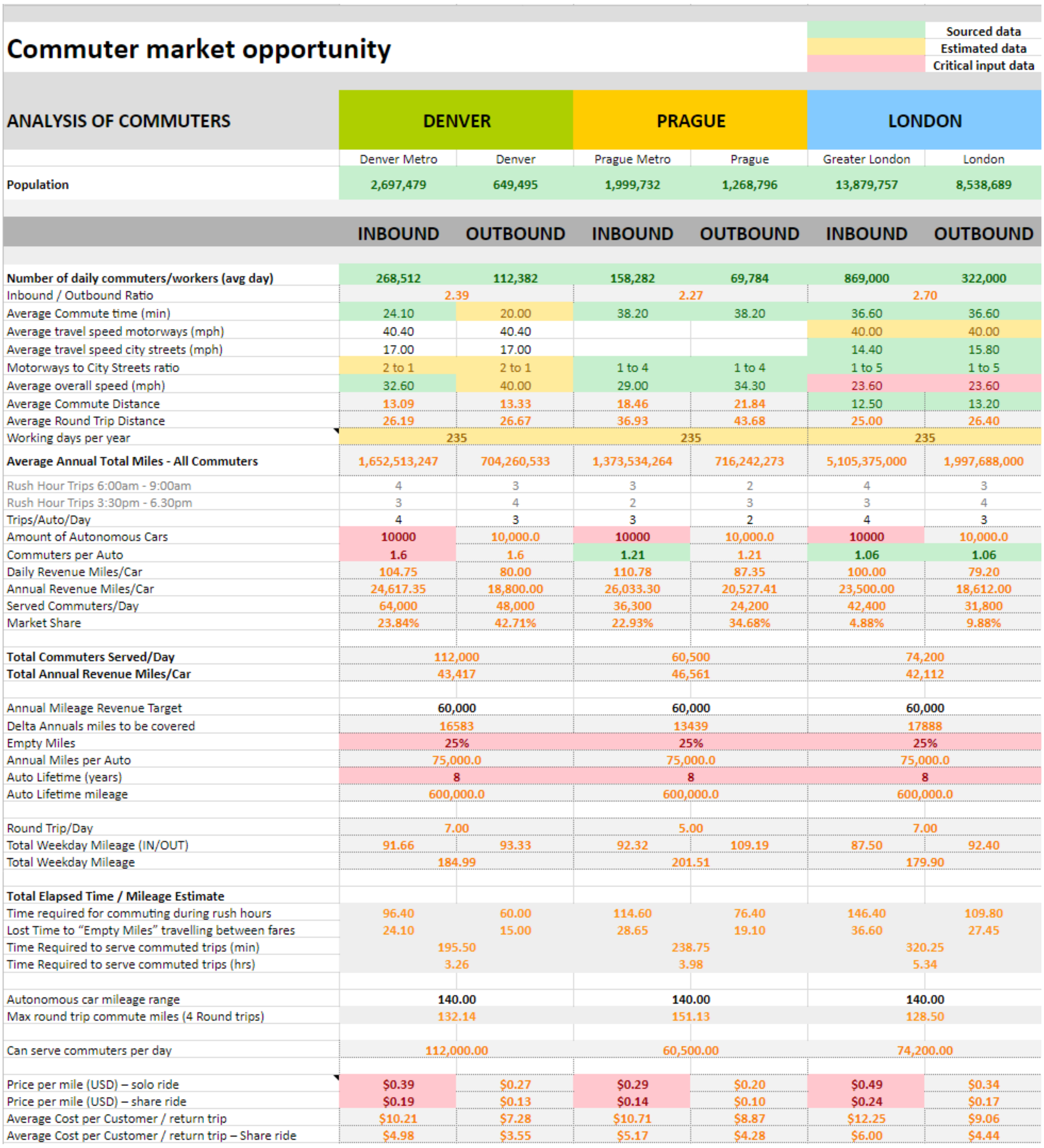
So, how many chargers are needed to service 10,000 Autos? With some modest improvements over the next five years, we estimate 25 minutes charging time plus five minutes to disengage one taxi and "port" the next, or 30 minutes per vehicle, two vehicles per hour. In the 6.5hour window between 10am and 4pm, each charger could support 13 taxis. Therefore, to handle 10,000 taxis, we'd need about 770 chargers, but to provide some scheduling and maintenance cushion we'll budget for 840 chargers. At $10,000 each, that is a capital outlay of $ 8.4 million, plus the cost of the facilities. Depreciated over seven years, the annual cost of the chargers is $1.2 million a year, or about $ 120 a year per taxi. The total costs including facilities would be about $ 3,341,700 a year, or $ 334 a year per taxi [52].

Item	Capital Cost	Depreciation (years)	Cost/year
Automatic gate	$5,000	10	$500
Security fencing	$52,800	10	$5,280
2 automatic car wash units	$180,000	7	$25,715
Cleaning crew, 2 people, 8 hours, 7 days, $20/hour net	$116,800	1	$116,800
Cleaning crew building with toilet	$35,000	10	$3,500
100x120 concrete pad	$42,000	10	$4,200
Industrial land cost (0.3 acres)	$200,000	10	$20,000
70 docks@$10,000	$700,000	7	$100,000
Security lights	$10,800	10	$1,080
Security system	$7,000	5	$1,400
Totals per facility	$1,349,400		$278,475
Total, 12 facilities	$16,192,800		$3,341,700
Cost per *Auto*	$1,619		$334.17

Tab. III - Rapid Charging Facility capital costs and annual costs [52]

APPENDIX IV

COMMUTER MARKET OPPORTUNITY FOR DENVER, PRAGUE, LONDON



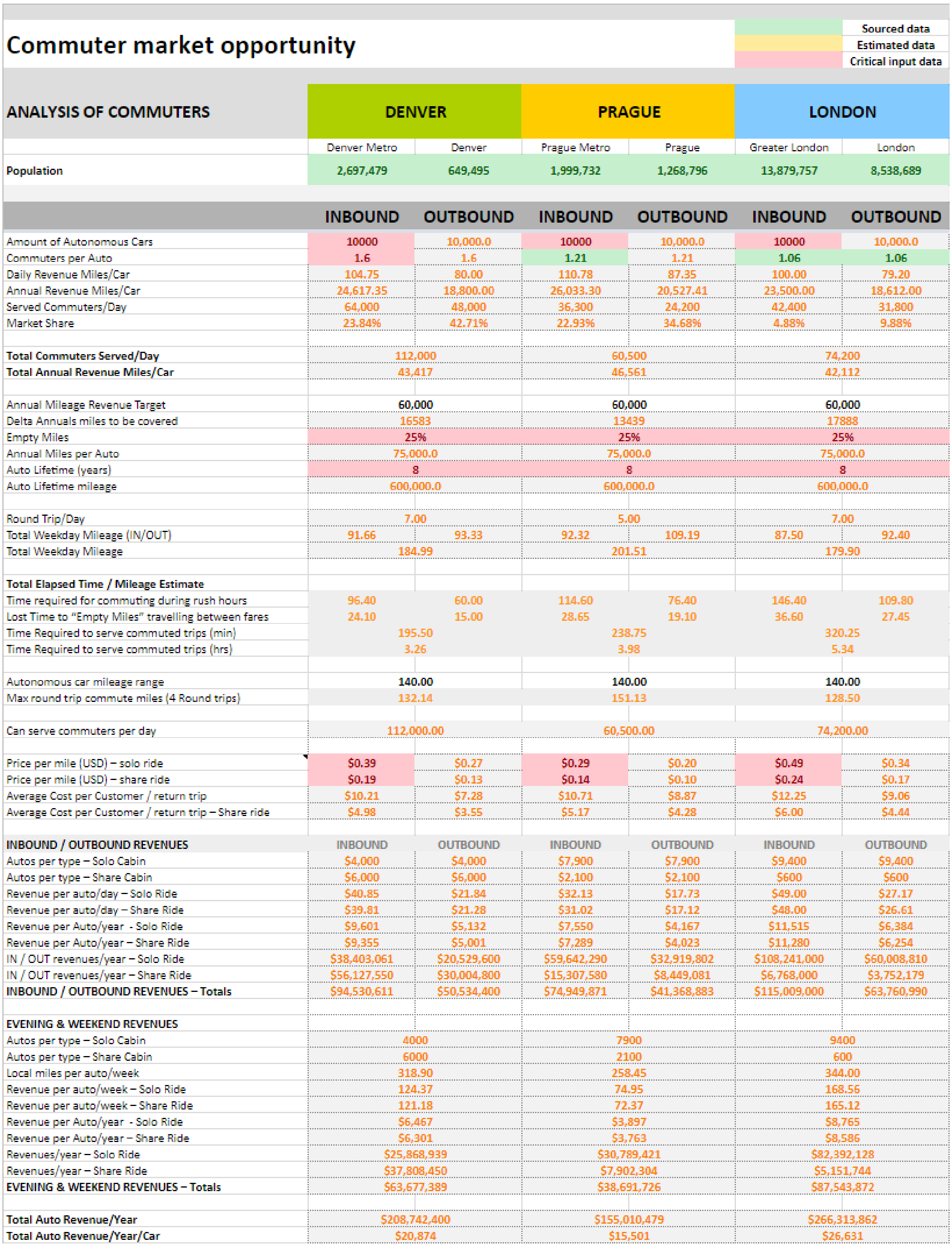
Commuter market opportunity

🟩 Sourced data
🟨 Estimated data
🟥 Critical input data

ANALYSIS OF COMMUTERS	**DENVER**		**PRAGUE**		**LONDON**	
	Denver Metro	Denver	Prague Metro	Prague	Greater London	London
Population	2,697,479	649,495	1,999,732	1,268,796	13,879,757	8,538,689
	INBOUND	**OUTBOUND**	**INBOUND**	**OUTBOUND**	**INBOUND**	**OUTBOUND**
Number of daily commuters/workers (avg day)	268,512	112,382	158,282	69,784	869,000	322,000
Inbound / Outbound Ratio	2.39		2.27		2.70	
Average Commute time (min)	24.10	20.00	38.20	38.20	36.60	36.60
Average travel speed motorways (mph)	40.40	40.40			40.00	40.00
Average travel speed city streets (mph)	17.00	17.00			14.40	15.80
Motorways to City Streets ratio	2 to 1	2 to 1	1 to 4	1 to 4	1 to 5	1 to 5
Average overall speed (mph)	32.60	40.00	29.00	34.30	23.60	23.60
Average Commute Distance	13.09	13.33	18.46	21.84	12.50	13.20
Average Round Trip Distance	26.19	26.67	36.93	43.68	25.00	26.40
Working days per year	235		235		235	
Average Annual Total Miles - All Commuters	1,652,513,247	704,260,533	1,373,534,264	716,242,273	5,105,375,000	1,997,688,000
Rush Hour Trips 6:00am - 9:00am	4	3	3	2	4	3
Rush Hour Trips 3:30pm - 6.30pm	3	4	2	3	3	4
Trips/Auto/Day	4	3	3	2	4	3
Amount of Autonomous Cars	10000	10,000.0	10000	10,000.0	10000	10,000.0
Commuters per Auto	1.6	1.6	1.21	1.21	1.06	1.06
Daily Revenue Miles/Car	104.75	80.00	110.78	87.35	100.00	79.20
Annual Revenue Miles/Car	24,617.35	18,800.00	26,033.30	20,527.41	23,500.00	18,612.00
Served Commuters/Day	64,000	48,000	36,300	24,200	42,400	31,800
Market Share	23.84%	42.71%	22.93%	34.68%	4.88%	9.88%
Total Commuters Served/Day	112,000		60,500		74,200	
Total Annual Revenue Miles/Car	43,417		46,561		42,112	
Annual Mileage Revenue Target	60,000		60,000		60,000	
Delta Annuals miles to be covered	16583		13439		17888	
Empty Miles	25%		25%		25%	
Annual Miles per Auto	75,000.0		75,000.0		75,000.0	
Auto Lifetime (years)	8		8		8	
Auto Lifetime mileage	600,000.0		600,000.0		600,000.0	
Round Trip/Day	7.00		5.00		7.00	
Total Weekday Mileage (IN/OUT)	91.66	93.33	92.32	109.19	87.50	92.40
Total Weekday Mileage	184.99		201.51		179.90	
Total Elapsed Time / Mileage Estimate						
Time required for commuting during rush hours	96.40	60.00	114.60	76.40	146.40	109.80
Lost Time to "Empty Miles" travelling between fares	24.10	15.00	28.65	19.10	36.60	27.45
Time Required to serve commuted trips (min)	195.50		238.75		320.25	
Time Required to serve commuted trips (hrs)	3.26		3.98		5.34	
Autonomous car mileage range	140.00		140.00		140.00	
Max round trip commute miles (4 Round trips)	132.14		151.13		128.50	
Can serve commuters per day	112,000.00		60,500.00		74,200.00	
Price per mile (USD) – solo ride	$0.39	$0.27	$0.29	$0.20	$0.49	$0.34
Price per mile (USD) – share ride	$0.19	$0.13	$0.14	$0.10	$0.24	$0.17
Average Cost per Customer / return trip	$10.21	$7.28	$10.71	$8.87	$12.25	$9.06
Average Cost per Customer / return trip – Share ride	$4.98	$3.55	$5.17	$4.28	$6.00	$4.44

Tab. IV (1 of 2) - Commuter Market Opportunity - Denver, Prague, London

Source: U.S Census Bureau, IPR Praha, GLA Intelligence, Waze.com, CZSO, Googlemaps, Travel In London Report 2014, Commuting and Business Travel Factsheet, ONS – Census Analysis - Distance Travelled to Work



Commuter market opportunity

🟩 Sourced data
🟨 Estimated data
🟥 Critical input data

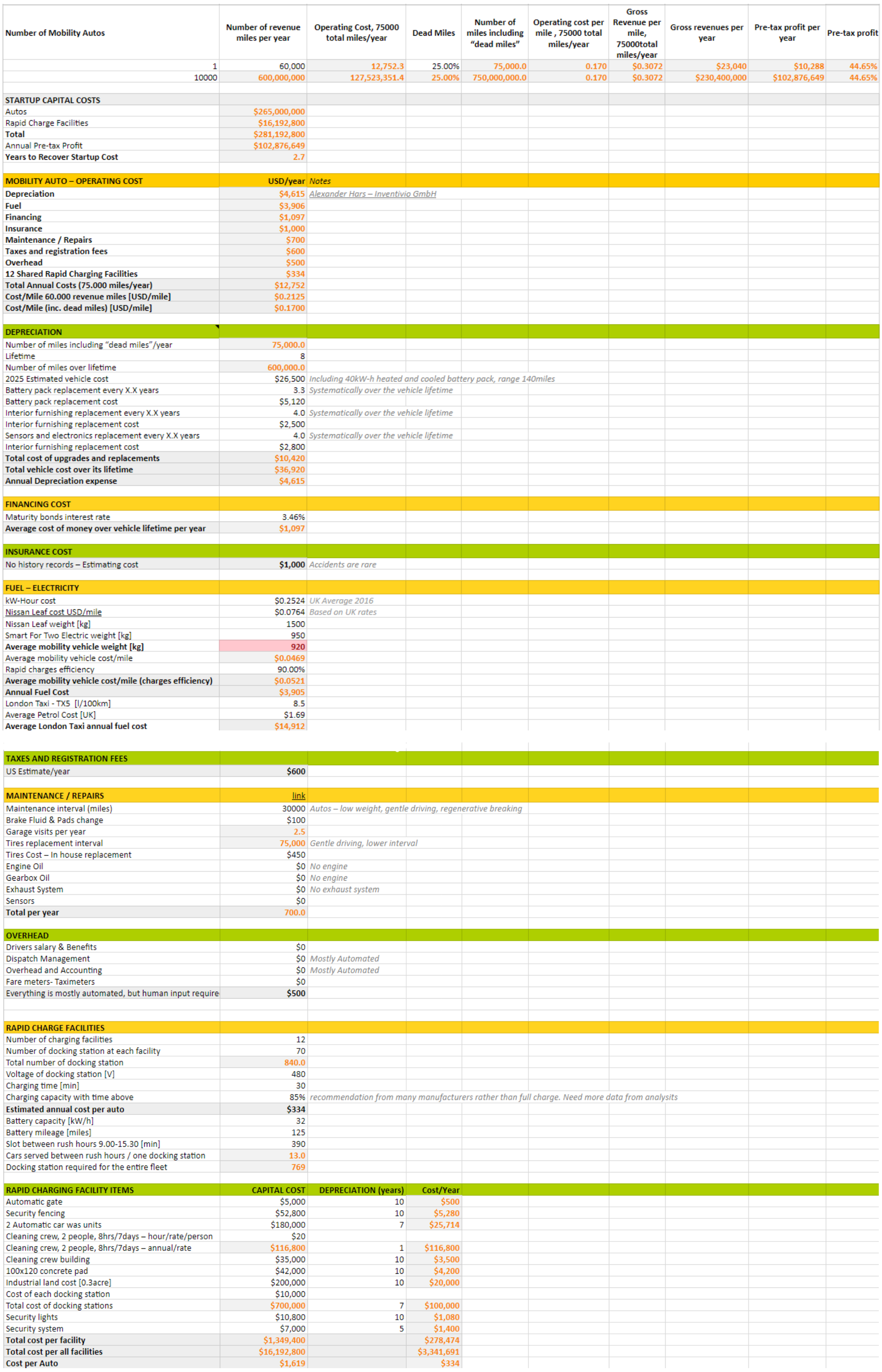
ANALYSIS OF COMMUTERS	DENVER		PRAGUE		LONDON	
	Denver Metro	Denver	Prague Metro	Prague	Greater London	London
Population	2,697,479	649,495	1,999,732	1,268,796	13,879,757	8,538,689
	INBOUND	**OUTBOUND**	**INBOUND**	**OUTBOUND**	**INBOUND**	**OUTBOUND**
Amount of Autonomous Cars	10000	10,000.0	10000	10,000.0	10000	10,000.0
Commuters per Auto	1.6	1.6	1.21	1.21	1.06	1.06
Daily Revenue Miles/Car	104.75	80.00	110.78	87.35	100.00	79.20
Annual Revenue Miles/Car	24,617.35	18,800.00	26,033.30	20,527.41	23,500.00	18,612.00
Served Commuters/Day	64,000	48,000	36,300	24,200	42,400	31,800
Market Share	23.84%	42.71%	22.93%	34.68%	4.88%	9.88%
Total Commuters Served/Day	112,000		60,500		74,200	
Total Annual Revenue Miles/Car	43,417		46,561		42,112	
Annual Mileage Revenue Target	60,000		60,000		60,000	
Delta Annuals miles to be covered	16583		13439		17888	
Empty Miles	25%		25%		25%	
Annual Miles per Auto	75,000.0		75,000.0		75,000.0	
Auto Lifetime (years)	8		8		8	
Auto Lifetime mileage	600,000.0		600,000.0		600,000.0	
Round Trip/Day	7.00		5.00		7.00	
Total Weekday Mileage (IN/OUT)	91.66	93.33	92.32	109.19	87.50	92.40
Total Weekday Mileage	184.99		201.51		179.90	
Total Elapsed Time / Mileage Estimate						
Time required for commuting during rush hours	96.40	60.00	114.60	76.40	146.40	109.80
Lost Time to "Empty Miles" travelling between fares	24.10	15.00	28.65	19.10	36.60	27.45
Time Required to serve commuted trips (min)	195.50		238.75		320.25	
Time Required to serve commuted trips (hrs)	3.26		3.98		5.34	
Autonomous car mileage range	140.00		140.00		140.00	
Max round trip commute miles (4 Round trips)	132.14		151.13		128.50	
Can serve commuters per day	112,000.00		60,500.00		74,200.00	
Price per mile (USD) – solo ride	$0.39	$0.27	$0.29	$0.20	$0.49	$0.34
Price per mile (USD) – share ride	$0.19	$0.13	$0.14	$0.10	$0.24	$0.17
Average Cost per Customer / return trip	$10.21	$7.28	$10.71	$8.87	$12.25	$9.06
Average Cost per Customer / return trip – Share ride	$4.98	$3.55	$5.17	$4.28	$6.00	$4.44
INBOUND / OUTBOUND REVENUES	INBOUND	OUTBOUND	INBOUND	OUTBOUND	INBOUND	OUTBOUND
Autos per type – Solo Cabin	$4,000	$4,000	$7,900	$7,900	$9,400	$9,400
Autos per type – Share Cabin	$6,000	$6,000	$2,100	$2,100	$600	$600
Revenue per auto/day – Solo Ride	$40.85	$21.84	$32.13	$17.73	$49.00	$27.17
Revenue per auto/day – Share Ride	$39.81	$21.28	$31.02	$17.12	$48.00	$26.61
Revenue per Auto/year - Solo Ride	$9,601	$5,132	$7,550	$4,167	$11,515	$6,384
Revenue per Auto/year – Share Ride	$9,355	$5,001	$7,289	$4,023	$11,280	$6,254
IN / OUT revenues/year – Solo Ride	$38,403,061	$20,529,600	$59,642,290	$32,919,802	$108,241,000	$60,008,810
IN / OUT revenues/year – Share Ride	$56,127,550	$30,004,800	$15,307,580	$8,449,081	$6,768,000	$3,752,179
INBOUND / OUTBOUND REVENUES – Totals	$94,530,611	$50,534,400	$74,949,871	$41,368,883	$115,009,000	$63,760,990
EVENING & WEEKEND REVENUES						
Autos per type – Solo Cabin	4000		7900		9400	
Autos per type – Share Cabin	6000		2100		600	
Local miles per auto/week	318.90		258.45		344.00	
Revenue per auto/week – Solo Ride	124.37		74.95		168.56	
Revenue per auto/week – Share Ride	121.18		72.37		165.12	
Revenue per Auto/year - Solo Ride	$6,467		$3,897		$8,765	
Revenue per Auto/year – Share Ride	$6,301		$3,763		$8,586	
Revenues/year – Solo Ride	$25,868,939		$30,789,421		$82,392,128	
Revenues/year – Share Ride	$37,808,450		$7,902,304		$5,151,744	
EVENING & WEEKEND REVENUES – Totals	$63,677,389		$38,691,726		$87,543,872	
Total Auto Revenue/Year	$208,742,400		$155,010,479		$266,313,862	
Total Auto Revenue/Year/Car	$20,874		$15,501		$26,631	

Tab. IV (2 of 2) - Commuter Market Opportunity - Denver, Prague, London

Source: U.S Census Bureau, IPR Praha, GLA Intelligence, Waze.com, CZSO, Google maps, Travel In London Report 2014, Commuting and Business Travel Factsheet, ONS – Census Analysis - Distance Travelled to Work

APPENDIX V

THE LONDON MOBILITY MODEL



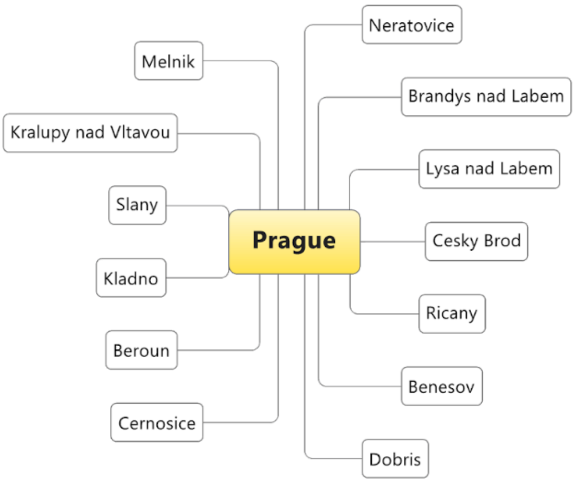
Number of Mobility Autos	Number of revenue miles per year	Operating Cost, 75000 total miles/year	Dead Miles	Number of miles including "dead miles"	Operating cost per mile , 75000 total miles/year	Gross Revenue per mile, 75000total miles/year	Gross revenues per year	Pre-tax profit per year	Pre-tax profit
1	60,000	12,752.3	25.00%	75,000.0	0.170	$0.3072	$23,040	$10,288	44.65%
10000	600,000,000	127,523,351.4	25.00%	750,000,000.0	0.170	$0.3072	$230,400,000	$102,876,649	44.65%

STARTUP CAPITAL COSTS			
Autos	$265,000,000		
Rapid Charge Facilities	$16,192,800		
Total	$281,192,800		
Annual Pre-tax Profit	$102,876,649		
Years to Recover Startup Cost	2.7		
MOBILITY AUTO – OPERATING COST	**USD/year**	*Notes*	
Depreciation	$4,615	*Alexander Hars – Inventivio GmbH*	
Fuel	$3,906		
Financing	$1,097		
Insurance	$1,000		
Maintenance / Repairs	$700		
Taxes and registration fees	$600		
Overhead	$500		
12 Shared Rapid Charging Facilities	$334		
Total Annual Costs (75.000 miles/year)	$12,752		
Cost/Mile 60.000 revenue miles [USD/mile]	$0.2125		
Cost/Mile (inc. dead miles) [USD/mile]	$0.1700		
DEPRECIATION			
Number of miles including "dead miles"/year	75,000.0		
Lifetime	8		
Number of miles over lifetime	600,000.0		
2025 Estimated vehicle cost	$26,500	*Including 40kW-h heated and cooled battery pack, range 140miles*	
Battery pack replacement every X.X years	3.3	*Systematically over the vehicle lifetime*	
Battery pack replacement cost	$5,120		
Interior furnishing replacement every X.X years	4.0	*Systematically over the vehicle lifetime*	
Interior furnishing replacement cost	$2,500		
Sensors and electronics replacement every X.X years	4.0	*Systematically over the vehicle lifetime*	
Interior furnishing replacement cost	$2,800		
Total cost of upgrades and replacements	$10,420		
Total vehicle cost over its lifetime	$36,920		
Annual Depreciation expense	$4,615		
FINANCING COST			
Maturity bonds interest rate	3.46%		
Average cost of money over vehicle lifetime per year	$1,097		
INSURANCE COST			
No history records – Estimating cost	**$1,000**	*Accidents are rare*	
FUEL – ELECTRICITY			
kW-Hour cost	$0.2524	*UK Average 2016*	
Nissan Leaf cost USD/mile	$0.0764	*Based on UK rates*	
Nissan Leaf weight [kg]	1500		
Smart For Two Electric weight [kg]	950		
Average mobility vehicle weight [kg]	920		
Average mobility vehicle cost/mile	$0.0469		
Rapid charges efficiency	90.00%		
Average mobility vehicle cost/mile (charges efficiency)	$0.0521		
Annual Fuel Cost	$3,905		
London Taxi - TX5 [l/100km]	8.5		
Average Petrol Cost [UK]	$1.69		
Average London Taxi annual fuel cost	$14,912		
TAXES AND REGISTRATION FEES			
US Estimate/year	**$600**		
MAINTENANCE / REPAIRS	link		
Maintenance interval (miles)	30000	*Autos – low weight, gentle driving, regenerative breaking*	
Brake Fluid & Pads change	$100		
Garage visits per year	2.5		
Tires replacement interval	75,000	*Gentle driving, lower interval*	
Tires Cost – In house replacement	$450		
Engine Oil	$0	*No engine*	
Gearbox Oil	$0	*No engine*	
Exhaust System	$0	*No exhaust system*	
Sensors	$0		
Total per year	700.0		
OVERHEAD			
Drivers salary & Benefits	$0		
Dispatch Management	$0	*Mostly Automated*	
Overhead and Accounting	$0	*Mostly Automated*	
Fare meters- Taximeters	$0		
Everything is mostly automated, but human input require	**$500**		
RAPID CHARGE FACILITIES			
Number of charging facilities	12		
Number of docking station at each facility	70		
Total number of docking station	840.0		
Voltage of docking station [V]	480		
Charging time [min]	30		
Charging capacity with time above	85%	*recommendation from many manufacturers rather than full charge. Need more data from analysits*	
Estimated annual cost per auto	**$334**		
Battery capacity [kW/h]	32		
Battery mileage [miles]	125		
Slot between rush hours 9.00-15.30 [min]	390		
Cars served between rush hours / one docking station	13.0		
Docking station required for the entire fleet	769		
RAPID CHARGING FACILITY ITEMS	**CAPITAL COST**	**DEPRECIATION (years)**	**Cost/Year**
Automatic gate	$5,000	10	$500
Security fencing	$52,800	10	$5,280
2 Automatic car was units	$180,000	7	$25,714
Cleaning crew, 2 people, 8hrs/7days – hour/rate/person	$20		
Cleaning crew, 2 people, 8hrs/7days – annual/rate	$116,800	1	$116,800
Cleaning crew building	$35,000	10	$3,500
100x120 concrete pad	$42,000	10	$4,200
Industrial land cost [0.3acre]	$200,000	10	$20,000
Cost of each docking station	$10,000		
Total cost of docking stations	$700,000	7	$100,000
Security lights	$10,800	10	$1,080
Security system	$7,000	5	$1,400
Total cost per facility	$1,349,400		$278,474
Total cost per all facilities	$16,192,800		$3,341,691
Cost per Auto	$1,619		$334

APPENDIX VI

COMMUTER ANALYSIS DATA – PRAGUE

Table VI was generated using google maps. The thirteen biggest cities around Prague were picked, and basic commuting data was analysed. Due to the lack of statistical data related to the average commuting distances, average speed and time spend travelling, google maps is a quick source of relevant and accurate information. The data gathered is associated with the morning and afternoon rush hours, therefore reflects lower travelling speed and longer commuting time.



MORNING TRIPS

3 INBOUND
2 OUTBOUND

100 revenue miles

RUSH HOURS

06 – 10 AM
02 – 06 PM

200 revenue miles/per day in total

EVENING TRIPS

3 OUTBOUND
2 INBOUND

100 revenue miles

GOOGLE MAPS ANALYSIS FOR PRAGUE

	km	miles	INBOUND [min]	OUTBOUND [min]	Average Speed IN [kmh]	Average Speed OUT [kmh]	Average Speed IN [mph]	Average Speed OUT [mph]
Praha – Melnik	48	29.8	49	40	58.8	72.0	36.5	44.7
Praha – Kralupy nad Vltavou	34	21.1	45	35	45.3	58.3	28.2	36.2
Praha – Neratovice	28	17.4	45	33	37.3	50.9	23.2	31.6
Praha – Brandys nad Labem	32	19.9	42	33	45.7	58.2	28.4	36.2
Praha – Lysa nad Labem	44	27.3	40	55	66.0	48.0	41.0	29.8
Praha – Cesky Brod	46	28.6	50	45	55.2	61.3	34.3	38.1
Praha – Ricany	24	14.9	33	30	43.6	48.0	27.1	29.8
Praha – Benesov	45	28.0	50	37	54.0	73.0	33.6	45.3
Praha – Dobris	47	29.2	55	43	51.3	65.6	31.9	40.8
Praha – Cernosice	20	12.4	42	30	28.6	40.0	17.8	24.9
Praha – Beroun	33	20.5	47	37	42.1	53.5	26.2	33.3
Praha – Kladno	30	18.6	50	45	36.0	40.0	22.4	24.9
Praha – Slany	38	23.6	55	47	41.5	48.5	25.8	30.1
Average	**36.1**	**22.4**	**46.4**	**39.2**	**46.7**	**55.2**	**29.0**	**34.3**

Tab. VI - Commuter Analysis Data – Prague

APPENDIX VII

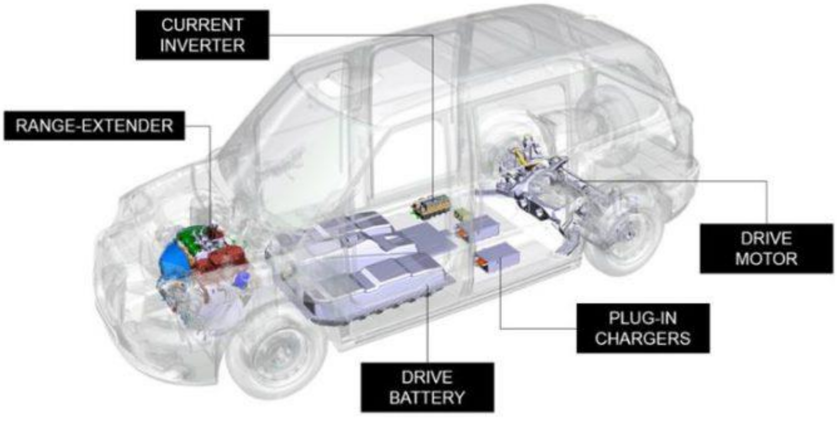
RESEARCH OF RECENT ELECTRIC CARS DESIGNED FOR URBAN ENVIRONMENT

LONDON TAXI - LEVC - TX (2018)

The LEVC TX (previously known as the TX5) is a purpose-built hackney carriage manufactured by the London EV Company (LEVC), a subsidiary of the Chinese automaker Geely. It is the latest in a succession of purpose-built hackney carriages produced by LEVC and various predecessor entities. The LEVC TX is a plug-in hybrid range-extender electric vehicle [127]. The vehicle is designed to comply with Transport for London's Taxi Private Hire regulations [128], which, from January 1, 2018, ban new diesel-powered taxis and require zero-emissions capability.

Fig. VII.1 - X - LEVC TX [127]

The LEVC TX is built on a unique platform, underpinned by a bonded aluminium chassis built in the UK. The LEVC TX is powered by a full-electric hybrid drivetrain. It drives in full-electric mode all the time but is recharged by an 81hp Volvo sourced 1.5-litre turbocharged three-cylinder petrol engine. The LEVC TX is fitted with a 33 kWh pack supplied by LG Chem, and powers a 110 kW Siemens-built electric motor for traction [127].



Fix. VII.2 - LECV TX - Powertrain layout [129]

GORDON MURRAY DESIGN - T25

The T25 & T27 represents a significant breakthrough in city car design and is a vehicle that has been optimised through design for strength, performance, weight, cost, safety, usability, tooling, quality, energy efficiency, recyclable and ease of assembly. The T25 is a micro city car powered by a modified three-cylinder 660c Smart engine, and T27 an electric variant. These vehicles are designed to demonstrate a new efficient manufacturing method, called iStream.

Fig. VII.3 - Gordon Murray Design - T25

The process centres on a separate body chassis assembly process. The assembly process is separate. During the first part, the powertrain, wiring harnesses, brakes, suspension and all major components can be fitted directly onto the chassis prior to the body panels being fitted. At the heart of the iStream system is a cheap, recycled lightweight composite material, which is used to make the chassis, onto which components and plastic body panels are installed. Therefore, all three following steps are completely eliminated: stamping the steel frame, welding the body together and rustproofing.

The body panels are delivered to the line pre-painted and bolted to (rather than welded or glued) the completed chassis near the end of the assembly process, helping to reduce paint damage generally associated with a standard assembly line.

Pre-painted body panels mean that there is no need for a paint shop in the assembly plant. Mechanical fixing of body panels is quick and low-energy. It also makes future repairs relatively simple as replacement panels are quicker and easier to fix.

The construction method allows the chassis to be scaled in size for different products, with each new design requiring only low-cost tooling and software changes. This flexibility means that the chassis can be used as a standard 'platform' to deliver different vehicle types and model variants, e.g. car, urban delivery van, taxi, emergency support vehicle. This process also makes cosmetic repairs cheaper and more manageable, and also potential future updates to external panels to suit customer preferences.

Murray has estimated that a manufacturer could build an iStream plant to make 100,000 cars annually for 85% less capital than a conventional one.

The T25 and T27 each seat three people instead of two, with driver placed in the middle ahead of the two passengers. The cars weigh only 550kg, half that of other city cars, but have passed the European Union crash-test requirements. The T25 is powered by a frugal 3-cylinder petrol engine and the T27 by a 25KW motor and lithium-ion battery [130].

VW SEDRIC - CONCEPT (2017)

Sedric is the given name for the prototype of a self-driving car by Volkswagen, presented at Geneva Motor Show on 6 March 2017. The fully electrically powered car should roll without steering wheel, without pedals and without circuit on the roads. The group announced that it would invest several billion euros in further development in the coming years.

Fig. VII.4 - Sedric – Concept [87]

Volkswagen sees Sedric as either a shared mobility system operating worldwide or a vehicle from one of the group's brands that might be owned by an individual. The benefits offered by Sedric—the name is a portmanteau of "self-driving car"—are legion. It could drive children to school, drop their parents at the office, and then look independently for a parking space. It could collect pre-ordered shopping or meet you at the station or airport [87].

The seats are trimmed in birch leather, said to be a "haptic, natural material pleasant to the touch." The front seats fold up to provide more floor area so the rear passengers can stretch out or to house luggage. Air quality is maintained using large bamboo charcoal air filters and a collection of air-purifying plants that sit in front of the rear windscreen.

Once inside, the operation is based on voice commands: you just tell Sedric where you want to go and the route you would prefer to take. Sedric responds with information on the journey time and the current traffic situation. Passengers can sit back and relax or can engage more fully with the journey through a windscreen that is, in fact, a transparent, high-resolution OLED display. This can provide augmented reality data or can be used as an entertainment centre [87].

Sedric is a battery-powered electric vehicle with a flat battery pack mounted under the floor between the front and rear axles. There is a single drive motor, which is between the rear wheels. The heating, ventilation, and climate-control systems and the sensing and control systems that drive the car are mounted in the short overhangs front and rear [87].

KARSAN – CONCEPT V1 (2011)

Concept V1 creates a new class of vehicle. It aims to offer a new dimension of transportation freedom to those with impaired mobility offering pleasure and comfort both to passengers and drivers. Comfort is ensured via the high ceiling, entirely even floor and automated access ramp, while plenty of space is guaranteed by a large passenger compartment, thanks to a flexible and easily adjustable seat configuration [131].

Fig. VII.5 - Karsan - Concept V1

The V1 platform, initially developed in response to New York's Taxi of Tomorrow tender (2011), was also attempting to satisfy a global social demand. After being hailed as New Yorkers' favourite "Taxi of Tomorrow" at its launch, Concept V1 was promoted as a highly accessible vehicle designed to facilitate and enhance transportation for society's mobility impaired members.

Concept V1 was designed for the convenient use of all taxi commuters, operators and drivers, including people with reduced mobility, especially ones who travel in wheelchairs, the elderly, those with strollers and prams and passengers carrying lots or cumbersome packages [131].

Karsan – Concept V1 - Special Unique Features

- Wide and tall doors are opening to 90 degrees for easy ingress and egress, especially useful when carrying packages, loading strollers, etc.
- Equipped with a patented, factory-installed, automated and illuminated wheelchair ramp extending to the curb on either side, specially designed wide doors opening at 90° allowing easy access, a low floor structure and a security latch for wheelchair stability as well as keyboard and braille communication for the hearing and visually impaired.
- With flexible seat options and seating arrangements that allow 3-5 passengers or a passenger in a wheelchair to travel comfortably.
- Low step up the flat floor with no driveshaft tunnel or hump for the exhaust system.
- Concept V1 has been designed to be exceptionally durable against the war and tear of rough streets and rough surroundings. Specifically, crafted body panels can be effortlessly and economically replaced in case of any damage, for considerably lower expense and quicker than ordinary vehicle bodywork, reducing out-of-work repair time and associated costs.

BMW i3 (2013)

The BMW i3 is a B-class, high-roof hatchback manufactured and marketed by BMW with an electric powertrain using rear wheel drive via a single-speed transmission. Its underfloor Li-ion battery pack is offered in two capacities as well as with an optional range-extending gasoline engine. The i3 was BMW's first zero emissions mass-produced vehicle and was launched as part of BMW's electric vehicle sub-brand, BMW i [132].

As of December 2016, the i3 ranked as the world's third bestselling all-electric car in history with more than 65,000 units sold since its inception [133].

Fig. VII.6 - BMW i3

The i3 was the first mass production car with most of its internal structure and body made of carbon-fibre-reinforced plastic (CFRP). The i3 includes four doors and seating for four occupants with rear suicide doors. The i3 uses a newly developed powertrain consisting of a 130-kilowatt (170 hp) electric motor running on lithium-ion batteries and driving the rear axle [134]. BMW aimed to achieve a range of 160 km (100 mi), the same range that was expected for the BMW ActiveE, but in order to reduce weight with a battery capacity of 16 kWh instead of the ActiveE's 30 kWh [135].

NISSAN LEAF (2010)

First electric vehicle to win the 'Car of the Year' title in 2011. The Nissan Leaf is a five-door hatchback electric car introduced in Japan and the United States in December 2010. The US Environmental Protection Agency official range is 117 kilometres, with an energy consumption of 765 kJ/km and rated the Leaf's combined fuel economy at 2.4l/100km. The Leaf has a range of 175 km. The price in the European countries is around €35,000. This price includes the price of the battery pack. Most countries have appropriate tax incentives or subsidies for eligible buyers that reduce the effective cost of purchase below the retail prices listed by Nissan.

Fig. VII.7 - Nissan Leaf (2010)

RENAULT ZOE (2012)

Renault has decided to present the production version of this oft-exhibited concept: the first car conceived to be 100% electric, accessible to all and ideal for daily use. It stands at just 4.10 metres in length and is powered by a 60kW (80hp) motor with a torque of 222Nm that enables it to zip silently through city traffic. ZOE is also ideal for out-of-town journeys thanks to its 19-inch wheels and reassuring, profiled flanks. Renault ZOE’s battery can be charged in one of three ways: standard charge (between 6 and 8 hours depending on the available electric power), quick charge (37 miles range in less than 10 minutes or 80% battery capacity in 30 minutes) or "quick drop" (a 3-minute battery exchange). Renault ZOE's equipment package ensures the wellbeing of its occupant's thanks to a triple-effect system (Skin Hydration, Detox Effect, Stimulating or relaxing scent diffuser) developed in association with Biotherm®, the skin biology brand of L'Oréal's Luxury Products Division.

Fig. VII.8 - Renault Zoe

RENAULT TWIZY (2012)

The ultra-compact footprint of Renault Twizy (length 2,338mm; width 1,237mm; height 1,454 mm) is ideally suited to city motoring. It went on sale in Europe early 2012 with a price tag beginning at €6,990 inclusive of taxes, depending on the fiscal measures available in each country. Like for other Renault Zero Emission vehicles, Twizy customers will lease the battery. The monthly subscription starts at €45 inclusive of taxes for an annual distance travelled of 7,500km, a figure which covers the vast majority of ordinary motorists' requirements. Renault Twizy's running costs – insurance, maintenance and energy (battery lease and electricity for recharging) – are just as modest, working out at 15% lower than those of a three-wheeled scooter.

Fig. VII.9 - Renault Twizy

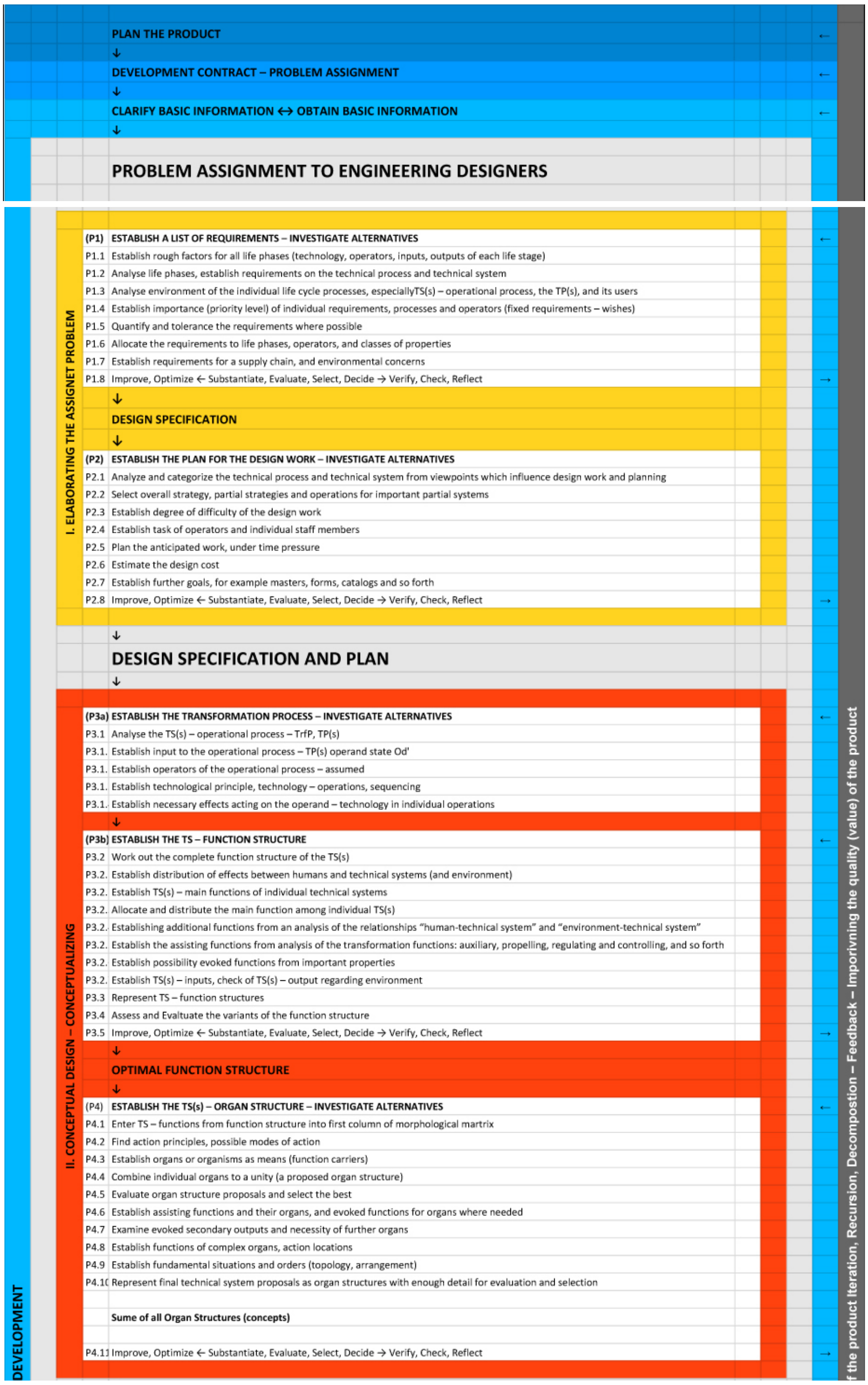
Vehicle	Model year	Wheelbase	Length	Width	Height	Weight	Electric Motor		Range		Battery Capacity	Turning Radius	Seats	Battery Weight	Batter Weight / Vehicle Weight	Battery Energy Capacity Coeficient	Mileage Range / Battery Capacity Coeficient
EV CARS		mm	mm	mm	mm	kg	kW	bhp	km	miles	kWh	m		kg		Wh/kg	
BMW i3	2014/15	2570	3999	1775	1578	1195	125	168	130	81	22.0	4.9	4	230	19.25%	95.7	3.7
Scion iQ EV	2013	2000	3051	1680	1500	985	47	63	80	50	12.0	4.1	2	166	16.85%	72.3	4.1
Chevrolet Spark EV	2014/15/16	2375	3720	1627	1590	1356	97	130	132	82	21.3	5.2	4	254	18.73%	83.9	3.9
Honda Fit EV	2013/14	2499	4114	1720	1580	1170	92	123	132	82	20.0	5.3	4	317	27.09%	63.1	4.1
Fiat 500e	2013/14/15	2300	3617	1627	1527	1355	83	111	170	106	24.0	4.8	4	272	20.07%	88.2	4.4
Volkswagen e-Golf	2015/16	2631	4270	1798	1450	1605	85	114	134	83	34.2	5.6	4	330	20.56%	103.6	2.4
Nissan Leaf (24 kW-hr)	2013/14/15/16	2700	4445	1770	1550	1493	80	107	135	84	24.0	5.2	4	275	18.42%	87.3	3.5
Mitsubishi i	2012/13/14/16	2550	3395	1475	1600	1080	47	63	100	62	16.0	4.5	4	165	15.28%	97.0	3.9
Smart Electric Drive	2013/14/15/16	1867	2695	1559	1566	900	55	74	145	90	17.6	4.4	2	180	20.00%	97.8	5.1
Tesla Model S AWD - 70D	2015/16	2960	4976	1964	1435	2090	568	762	390	242	70.0	5.6	4	540	25.84%	129.6	3.5
Tesla Model S AWD - 85D	2015/16	2960	4976	1964	1435	2188	568	762	426	265	85.0	5.6	4	540	24.68%	157.4	3.1
Tesla Model S (60 kWh)	2014/15/16	2960	4976	1964	1435	1961	568	762	335	208	60.0	5.6	4	540	27.54%	111.1	3.5
Tesla Model S AWD - P85D	2015/16	2960	4976	1964	1435	2239	568	762	426	265	85.0	5.6	4	540	24.12%	157.4	3.1
Ford Fusion AWD A-S6 2.0L (Average new vehicle US)	2016	2844	4869	1850	1475	1670	Combustion Engine								N/A	N/A	N/A
London Taxi TX5 (Hybrid)	2017	2986	4857	1874	1888	2230	120	161	129	80	31.0	4.2	7	X	X	X	2.6
EV CONCEPT CARS / LOW PRODUCTION VOLUME						kg	kW	bhp	km	miles	kWh	m		kg			
MEV Hummer HX	2010	2128	3000	1480	1450	803	X	X	100	62	X	X	2	X	X	X	X
Renault Twizy	2009	1686	2320	1190	1460	450	13	17	100	62	6.1	3.4	2	100	22.22%	61.0	10.2
VW Nils	2011	2150	3035	1391	1200	460	25	34	65	40	5.3	X	1	X	X	X	7.6
Audi Urban Concept	2011	X	X	X	X	480	15	20	72	45	7.1	X	1	X	X	X	6.3
Opel Rak	2011	X	3000	X	1190	380	36.5	49	100	62	5.0	X	2	X	X	X	12.4
KTM E3W	2011	X	X	X	X	500	15	20	100	62	6.5	X	2	X	X	X	9.6
Daihatsu Pico	2011	X	X	X	X	400	X	X	50	31	X	X	2	X	X	X	X
GMD T27	2011	1780	2400	1300	1600	680	25	34	160	99	12.1	3	2	X	X	X	8.2
Hiriko Fold	2003	X	2500	X	X	500	15	20	120	75	X		2	X	X	X	X
Lumeneo Smera	2010	X	2500	960	1480	550	30	40	100	62	9.3	X	2	80	14.55%	116.3	6.7
Lumeneo Neoma	2010	870	2690	1600	1480	850	34	46	140	87	14.2	X	4	X	X	X	6.1

Table VII - Vehicle Benchmarking

APPENDIX VIII

GENERAL PROCEDURAL MODEL OF ENGINEERING DESIGN PROCESS

General Procedural Model of ED Process [114]



DEVELOPMENT

I. ELABORATING THE ASSIGNET PROBLEM

II. CONCEPTUAL DESIGN – CONCEPTUALIZING

f the product Iteration, Recursion, Decompostion – Feedback – Imporivning the quality (value) of the product

	PLAN THE PRODUCT	←
	↓	
	DEVELOPMENT CONTRACT – PROBLEM ASSIGNMENT	←
	↓	
	CLARIFY BASIC INFORMATION ↔ OBTAIN BASIC INFORMATION	←
	↓	
	PROBLEM ASSIGNMENT TO ENGINEERING DESIGNERS	
(P1)	**ESTABLISH A LIST OF REQUIREMENTS – INVESTIGATE ALTERNATIVES**	←
P1.1	Establish rough factors for all life phases (technology, operators, inputs, outputs of each life stage)	
P1.2	Analyse life phases, establish requirements on the technical process and technical system	
P1.3	Analyse environment of the individual life cycle processes, especiallyTS(s) – operational process, the TP(s), and its users	
P1.4	Establish importance (priority level) of individual requirements, processes and operators (fixed requirements – wishes)	
P1.5	Quantify and tolerance the requirements where possible	
P1.6	Allocate the requirements to life phases, operators, and classes of properties	
P1.7	Establish requirements for a supply chain, and environmental concerns	
P1.8	Improve, Optimize ← Substantiate, Evaluate, Select, Decide → Verify, Check, Reflect	→
	↓	
	DESIGN SPECIFICATION	
	↓	
(P2)	**ESTABLISH THE PLAN FOR THE DESIGN WORK – INVESTIGATE ALTERNATIVES**	
P2.1	Analyze and categorize the technical process and technical system from viewpoints which influence design work and planning	
P2.2	Select overall strategy, partial strategies and operations for important partial systems	
P2.3	Establish degree of difficulty of the design work	
P2.4	Establish task of operators and individual staff members	
P2.5	Plan the anticipated work, under time pressure	
P2.6	Estimate the design cost	
P2.7	Establish further goals, for example masters, forms, catalogs and so forth	
P2.8	Improve, Optimize ← Substantiate, Evaluate, Select, Decide → Verify, Check, Reflect	→
	↓	
	DESIGN SPECIFICATION AND PLAN	
	↓	
(P3a)	**ESTABLISH THE TRANSFORMATION PROCESS – INVESTIGATE ALTERNATIVES**	←
P3.1	Analyse the TS(s) – operational process – TrfP, TP(s)	
P3.1.	Establish input to the operational process – TP(s) operand state Od'	
P3.1.	Establish operators of the operational process – assumed	
P3.1.	Establish technological principle, technology – operations, sequencing	
P3.1.	Establish necessary effects acting on the operand – technology in individual operations	
	↓	
(P3b)	**ESTABLISH THE TS – FUNCTION STRUCTURE**	←
P3.2	Work out the complete function structure of the TS(s)	
P3.2.	Establish distribution of effects between humans and technical systems (and environment)	
P3.2.	Establish TS(s) – main functions of individual technical systems	
P3.2.	Allocate and distribute the main function among individual TS(s)	
P3.2.	Establishing additional functions from an analysis of the relationships “human-technical system” and “environment-technical system”	
P3.2.	Establish the assisting functions from analysis of the transformation functions: auxiliary, propelling, regulating and controlling, and so forth	
P3.2.	Establish possibility evoked functions from important properties	
P3.2.	Establish TS(s) – inputs, check of TS(s) – output regarding environment	
P3.3	Represent TS – function structures	
P3.4	Assess and Evaltuate the variants of the function structure	
P3.5	Improve, Optimize ← Substantiate, Evaluate, Select, Decide → Verify, Check, Reflect	→
	↓	
	OPTIMAL FUNCTION STRUCTURE	
	↓	
(P4)	**ESTABLISH THE TS(s) – ORGAN STRUCTURE – INVESTIGATE ALTERNATIVES**	←
P4.1	Enter TS – functions from function structure into first column of morphological martrix	
P4.2	Find action principles, possible modes of action	
P4.3	Establish organs or organisms as means (function carriers)	
P4.4	Combine individual organs to a unity (a proposed organ structure)	
P4.5	Evaluate organ structure proposals and select the best	
P4.6	Establish assisting functions and their organs, and evoked functions for organs where needed	
P4.7	Examine evoked secondary outputs and necessity of further organs	
P4.8	Establish functions of complex organs, action locations	
P4.9	Establish fundamental situations and orders (topology, arrangement)	
P4.1(	Represent final technical system proposals as organ structures with enough detail for evaluation and selection	
	Sume of all Organ Structures (concepts)	
P4.11	Improve, Optimize ← Substantiate, Evaluate, Select, Decide → Verify, Check, Reflect	→

PRODUCT PLANNING AND DEVELOPMENT PROCESS / INTERGRATED PRODUCT

ENGINEERING DESIGN PROCESS – DESIGNING

III. LAYING OUT – EMBODYING

IV. DETAILING – ELABORATING

Iteration, Recursion, Decompostion – Feedback – Imporivning the quality (value) of the product Iteration, Recursion, Decompostion – Feedback – Imporivning the quality (value) o

	↓	
	OPTIMAL ORGAN STRUCTURE	
	↓	
	↓	
(P5a)	**ESTABLISH THE CONSTRUCTIONAL STRUCUTRE (1) – INVESTIGATE ALTERNATIVES**	←
P5.1	Establish and analyze the requirements for the constructional structure and constructional parts	
	Charakterize the design situation	
	Analyse the conceptualized organ structure for potenatial constructructional problems	
	Extract from the design specification for each group:	
	-- The external requirements	
	-- The internal requirements for General Design Properties	
	-- The requirements for evoked functions	
	Order, categorize, classify, establish importance and tolerances of requirements – transfer to constructional parts of groups	
	↓	
	List of Requirements for constructional structure and parts	↔
	↓	
P5.2	Establish leading sizes (dimensions) of action locations	
	Establish mode of construction, and basic arrangement	
	Establish constructional groups (assembly groups, sub-assemblies)	
	Establish basic form – refine the arrangement	
	↓	
	Conception of constructional structure	↔
	↓	
P5.3	Establish rough constructional structure as preliminary layout	
P5.3.	Define constructional design groups	
	Select masters	
P5.3.	Establish rough form- giving of each constructional design group	
	-- Consdider requiremetns	
	-- Concretize the evoked functions	
	-- Consider re-use of existing or purchasable organs, assembly groups, modules or constructional design groups	
	-- For construcional parts to be designed, establish	
	-- -- Rough Arangement	
	-- -- Form	
	-- -- Dimensioning (establish leading size)	
	-- -- Kind of manufacturing / production	
P5.3.	Elaborate the rough constructional structure – integrate into the delveoping total constructional structure (synthesis)	
P5.3.	Represent preliminary layout(s)	
	↓	
	Sume of preliminary layouts	↔
	↓	
P5.3.	Choose optimal variants	
	Improve, Optimize ← Substantiate, Evaluate, Select, Decide → Verify, Check, Reflect	
	↓	
	OPTIMAL CONSTRUCTIONAL STRUCTURE (1) – Preliminary layout	
	↓	
(P5b)	**ESTABLISH CONSTRUCTIONAL STRUCTURE (2) – INVESTIGATE ALTERNATIVES**	←
P5.4	Establish the definite constructional structure	
P5.4.	Review the requirements, clear up, complete, perfect, optimize	
P5.4.	Definitevly estbalish the arrangement for each construction zone and for each constructional part:	
	-- Establish local arrangement	
	-- Establish form - giving	
	-- Establish dimensions	
	-- Select materials and treatment	
	-- Select classes of manufacturing processes	
	-- Establish tolerances (dimensional and geometric)	
	-- Establish surface quantities	
	-- Establish state of assembly	
P5.4.	Represent the definite dimensional layout	
	↓	
	Sume of constructional structure – dimensional layout	
	↓	
P5.4.	Select the optimal variants:	
	Improve, Optimize ← Substantiate, Evaluate, Select, Decide → Verify, Check, Reflect	→
	↓	
	OPTIMAL CONSTRUCTIONAL STRUCTURE (2) – DIMENSIONAL LAYOUT	
	↓	
	<Release for Detailing>	
	↓	
(P6)	**ESTABLISH THE CONSTRUCTIONAL STRUCUTRE (3) – INVESTIGATE ALTERNATIVES**	←
P6.1	Prepare detail drawings for each constructional part	
	Complete the form – giving of all constructional parts	
	Represent all constructional parts	
	Establish all design properties	
P6.2	Prepare a control of assembly drawing and parts list	
P6.3	Consider constructional parts for evoked functions, add details	
	↓	
	Constructional parts and structure -- assembly (and contro)	↔
	↓	
P6.4	Prepade any additional documentation: drafts of design report, special instructions for manufacture, instructions for any assembly and adjustemen, user manuals, and so forth	
	↓	
	Sume of Manufacturing documents	
	↓	
	Sume of Additional documentations	
	↓	
P6.5	**Control, correct, coordinate, check, audit**	
	Improve, Optimize ← Substantiate, Evaluate, Select, Decide → Verify, Check, Reflect	→
	↓	
	OPTIMAL CONSTRUCTIONAL STRUCTURE (3) – REPRESENTATION and DESCRIOPTION of COMPLETE TECHNICAL SYSTEM	
	↓	
	Manufacture, Test, Delevelop prototype	→
	↓	
	Correct for changes, Release for manufacture and distribution	→

I., II., III.,	…	**Design Phases**
(P1), (P2), (P3)	…	**Design Stages**
P1.1, P1.2,	…	**Design Steps**

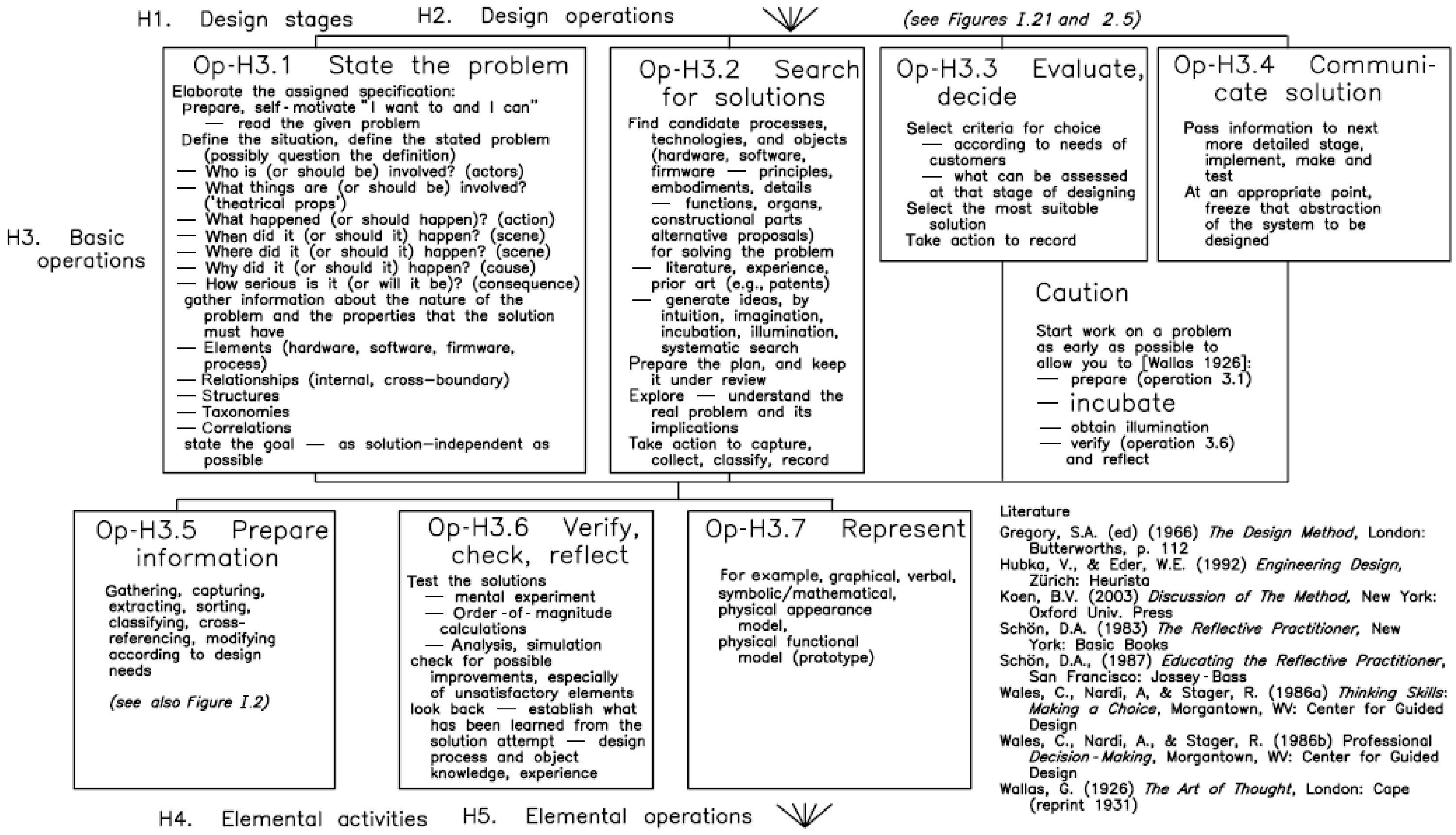
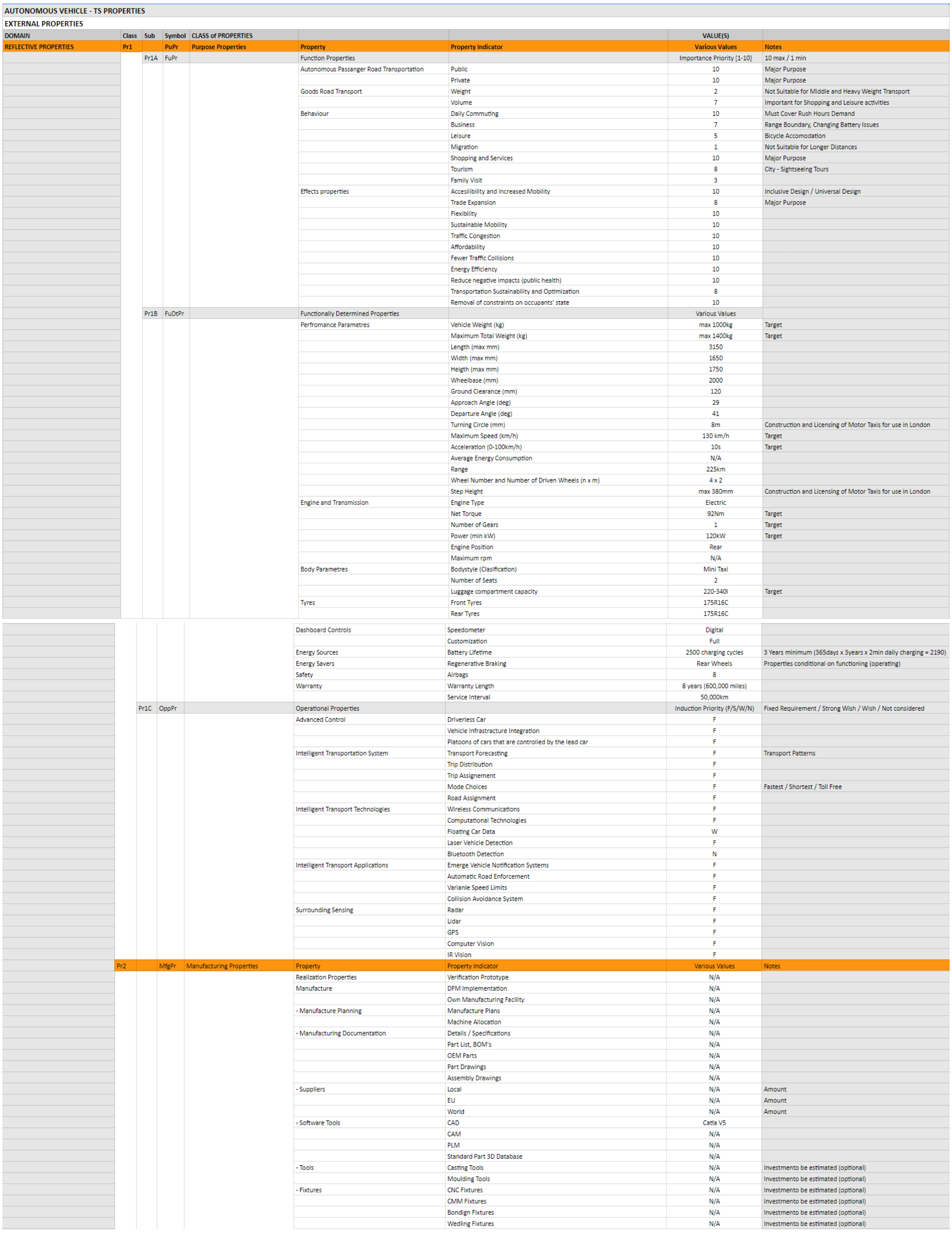


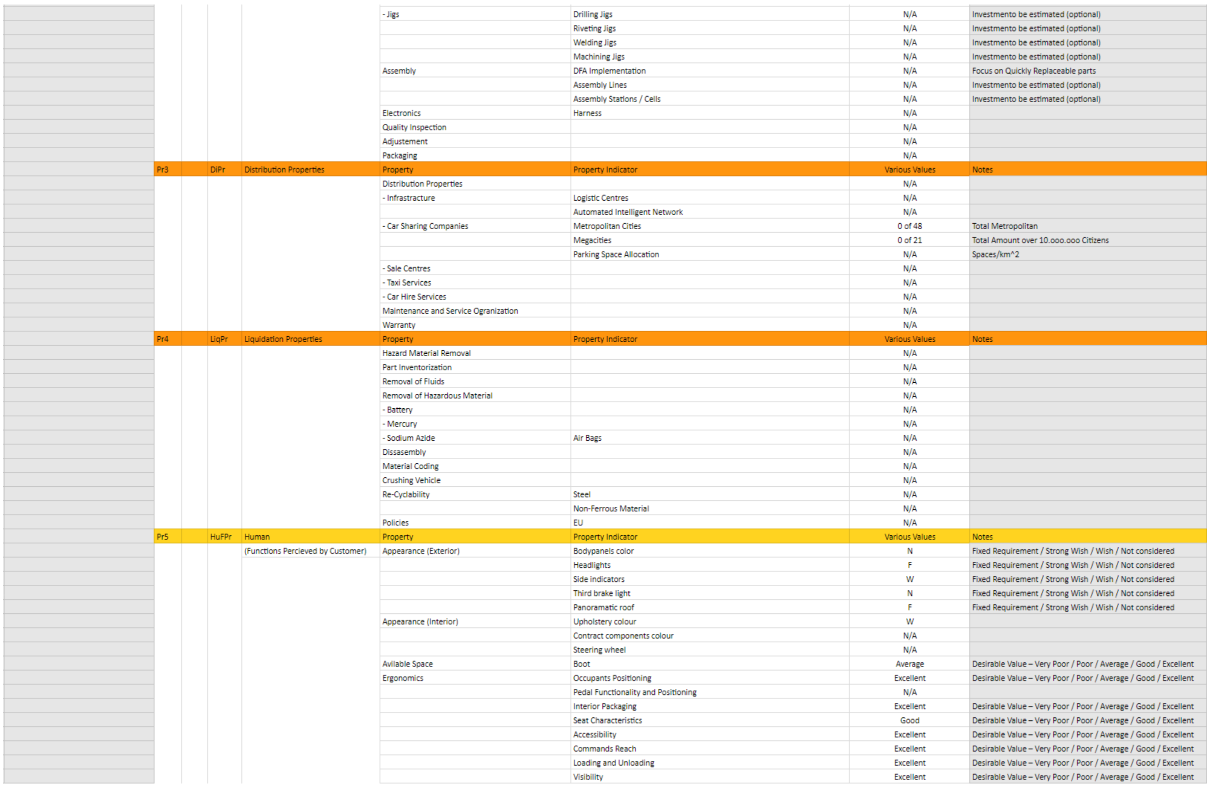
Fig. VIII.1 - Basic operations - Problem-solving in the design process [114]

APPENDIX IX

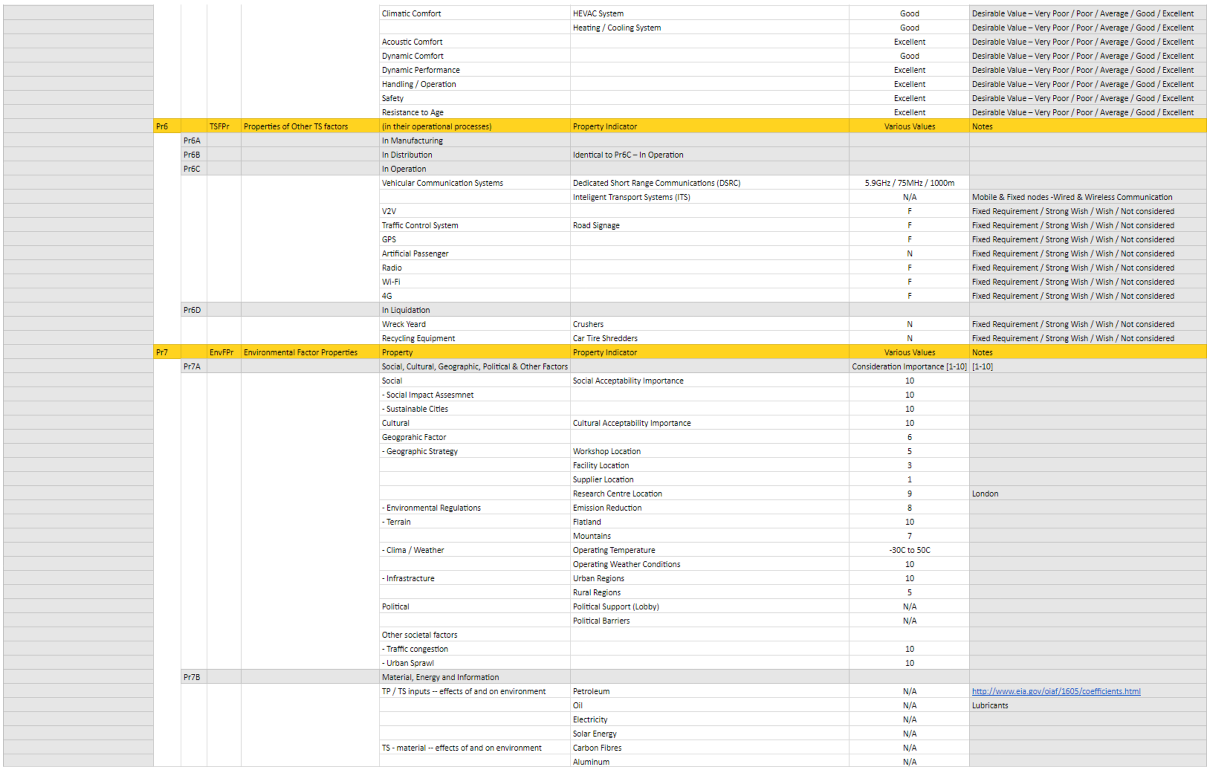
DRIVERLESS VEHICLE – TS PROPERTIES



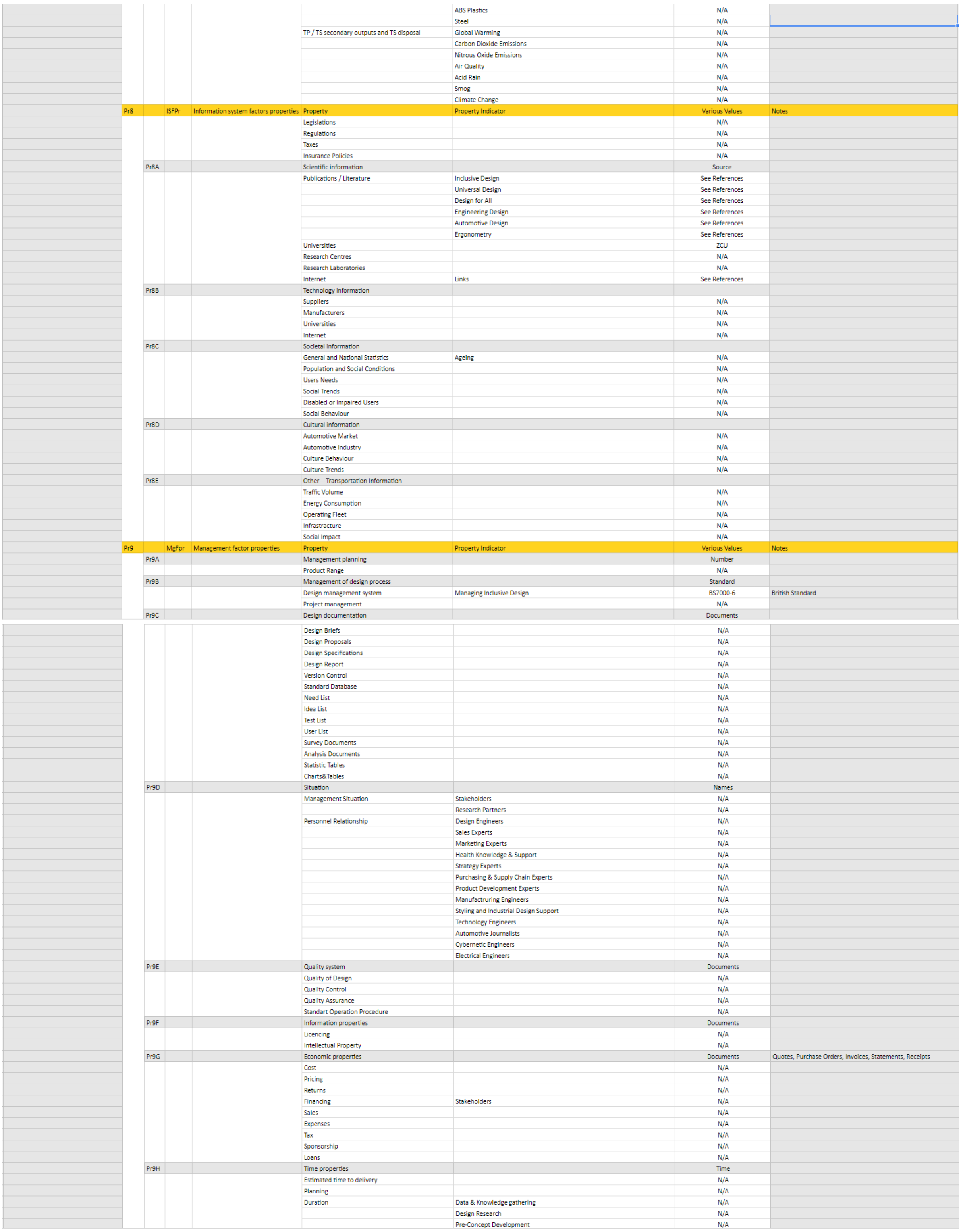
AUTONOMOUS VEHICLE - TS PROPERTIES								
EXTERNAL PROPERTIES								
DOMAIN	Class	Sub	Symbol	CLASS of PROPERTIES			VALUE(S)	
REFLECTIVE PROPERTIES	Pr1		PuPr	Purpose Properties	Property	Property Indicator	Various Values	Notes
		Pr1A	FuPr		Function Properties		Importance Priority [1-10]	10 max / 1 min
					Autonomous Passanger Road Transportation	Public	10	Major Purpose
						Private	10	Major Purpose
					Goods Road Transport	Weight	2	Not Suitable for Middle and Heavy Weight Transport
						Volume	7	Important for Shopping and Leisure activities
					Behaviour	Daily Commuting	10	Must Cover Rush Hours Demand
						Business	7	Range Boundary, Changing Battery Issues
						Leisure	5	Bicycle Accomodation
						Migration	1	Not Suitable for Longer Distances
						Shopping and Services	10	Major Purpose
						Tourism	8	City - Sightseeing Tours
						Family Visit	3	
					Effects properties	Accesilibility and Increased Mobility	10	Inclusive Design / Universal Design
						Trade Expansion	8	Major Purpose
						Flexibility	10	
						Sustainable Mobility	10	
						Traffic Congestion	10	
						Affordability	10	
						Fewer Traffic Collisions	10	
						Energy Efficiency	10	
						Reduce negative impacts (public health)	10	
						Transportation Sustainability and Optimization	8	
						Removal of constraints on occupants' state	10	
		Pr1B	FuDtPr		Functionally Determined Properties		Various Values	
					Perfromance Parametres	Vehicle Weight (kg)	max 1000kg	Target
						Maximum Total Weight (kg)	max 1400kg	Target
						Length (max mm)	3150	
						Width (max mm)	1650	
						Heigth (max mm)	1750	
						Wheelbase (mm)	2000	
						Ground Clearance (mm)	120	
						Approach Angle (deg)	29	
						Departure Angle (deg)	41	
						Turning Circle (mm)	8m	Construction and Licensing of Motor Taxis for use in London
						Maximum Speed (km/h)	130 km/h	Target
						Acceleration (0-100km/h)	10s	Target
						Average Energy Consumption	N/A	
						Range	225km	
						Wheel Number and Number of Driven Wheels (n x m)	4 x 2	
						Step Height	max 380mm	Construction and Licensing of Motor Taxis for use in London
					Engine and Transmission	Engine Type	Electric	
						Net Torque	92Nm	Target
						Number of Gears	1	Target
						Power (min kW)	120kW	Target
						Engine Position	Rear	
						Maximum rpm	N/A	
					Body Parametres	Bodystyle (Clasification)	Mini Taxi	
						Number of Seats	2	
						Luggage compartment capacity	220-340l	Target
					Tyres	Front Tyres	175R16C	
						Rear Tyres	175R16C	
					Dashboard Controls	Speedometer	Digital	
						Customization	Full	
					Energy Sources	Battery Lifetime	2500 charging cycles	3 Years minimum (365days x 3years x 2min daily charging = 2190)
					Energy Savers	Regenerative Braking	Rear Wheels	Properties conditional on functioning (operating)
					Safety	Airbags	8	
					Warranty	Warranty Length	8 years (600,000 miles)	
						Service Interval	50,000km	
		Pr1C	OppPr		Operational Properties		Induction Priority (F/S/W/N)	Fixed Requirement / Strong Wish / Wish / Not considered
					Advanced Control	Driverless Car	F	
						Vehicle Infrastracture Integration	F	
						Platoons of cars that are controlled by the lead car	F	
					Intelligent Transportation System	Transport Forecasting	F	Transport Patterns
						Trip Distribution	F	
						Trip Assignement	F	
						Mode Choices	F	Fastest / Shortest / Toll Free
						Road Assignment	F	
					Intelligent Transport Technologies	Wireless Communications	F	
						Computational Technologies	F	
						Floating Car Data	W	
						Laser Vehicle Detection	F	
						Bluetooth Detection	N	
					Intelligent Transport Applications	Emerge Vehicle Notification Systems	F	
						Automatic Road Enforcement	F	
						Varianle Speed Limits	F	
						Collision Avoidance System	F	
					Surrounding Sensing	Radar	F	
						Lidar	F	
						GPS	F	
						Computer Vision	F	
						IR Vision	F	
	Pr2		MfgPr	Manufacturing Properties	Property	Property Indicator	Various Values	Notes
					Realization Properties	Verification Prototype	N/A	
					Manufacture	DFM Implementation	N/A	
						Own Manufacturing Facility	N/A	
					- Manufacture Planning	Manufacture Plans	N/A	
						Machine Allocation	N/A	
					- Manufacturing Documentation	Details / Specifications	N/A	
						Part List, BOM's	N/A	
						OEM Parts	N/A	
						Part Drawings	N/A	
						Assembly Drawings	N/A	
					- Suppliers	Local	N/A	Amount
						EU	N/A	Amount
						World	N/A	Amount
					- Software Tools	CAD	Catia V5	
						CAM	N/A	
						PLM	N/A	
						Standard Part 3D Database	N/A	
					- Tools	Casting Tools	N/A	Investmento be estimated (optional)
						Moulding Tools	N/A	Investmento be estimated (optional)
					- Fixtures	CNC Fixtures	N/A	Investmento be estimated (optional)
						CMM Fixtures	N/A	Investmento be estimated (optional)
						Bondign Fixtures	N/A	Investmento be estimated (optional)
						Wedling Fixtures	N/A	Investmento be estimated (optional)



					- Jigs	Drilling Jigs	N/A	Investmento be estimated (optional)
						Riveting Jigs	N/A	Investmento be estimated (optional)
						Welding Jigs	N/A	Investmento be estimated (optional)
						Machining Jigs	N/A	Investmento be estimated (optional)
					Assembly	DFA Implementation	N/A	Focus on Quickly Replaceable parts
						Assembly Lines	N/A	Investmento be estimated (optional)
						Assembly Stations / Cells	N/A	Investmento be estimated (optional)
					Electronics	Harness	N/A	
					Quality Inspection		N/A	
					Adjustement		N/A	
					Packaging		N/A	
	Pr3		DiPr	Distribution Properties	Property	Property Indicator	Various Values	Notes
					Distribution Properties		N/A	
					- Infrastructure	Logistic Centres	N/A	
						Automated Intelligent Network	N/A	
					- Car Sharing Companies	Metropolitan Cities	0 of 48	Total Metropolitan
						Megacities	0 of 21	Total Amount over 10.000.000 Citizens
						Parking Space Allocation	N/A	Spaces/km^2
					- Sale Centres		N/A	
					- Taxi Services		N/A	
					- Car Hire Services		N/A	
					Maintenance and Service Ogranization		N/A	
					Warranty		N/A	
	Pr4		LiqPr	Liquidation Properties	Property	Property Indicator	Various Values	Notes
					Hazard Material Removal		N/A	
					Part Inventorization		N/A	
					Removal of Fluids		N/A	
					Removal of Hazardous Material		N/A	
					- Battery		N/A	
					- Mercury		N/A	
					- Sodium Azide	Air Bags	N/A	
					Dissasembly		N/A	
					Material Coding		N/A	
					Crushing Vehicle		N/A	
					Re-Cyclability	Steel	N/A	
						Non-Ferrous Material	N/A	
					Policies	EU	N/A	
	Pr5		HuFPr	Human	Property	Property Indicator	Various Values	Notes
				(Functions Percieved by Customer)	Appearance (Exterior)	Bodypanels color	N	Fixed Requirement / Strong Wish / Wish / Not considered
						Headlights	F	Fixed Requirement / Strong Wish / Wish / Not considered
						Side indicators	W	Fixed Requirement / Strong Wish / Wish / Not considered
						Third brake light	N	Fixed Requirement / Strong Wish / Wish / Not considered
						Panoramatic roof	F	Fixed Requirement / Strong Wish / Wish / Not considered
					Appearance (Interior)	Upholstery colour	W	
						Contract components colour	N/A	
						Steering wheel	N/A	
					Avilable Space	Boot	Average	Desirable Value – Very Poor / Poor / Average / Good / Excellent
					Ergonomics	Occupants Positioning	Excellent	Desirable Value – Very Poor / Poor / Average / Good / Excellent
						Pedal Functionality and Positioning	N/A	
						Interior Packaging	Excellent	Desirable Value – Very Poor / Poor / Average / Good / Excellent
						Seat Characteristics	Good	Desirable Value – Very Poor / Poor / Average / Good / Excellent
						Accessibility	Excellent	Desirable Value – Very Poor / Poor / Average / Good / Excellent
						Commands Reach	Excellent	Desirable Value – Very Poor / Poor / Average / Good / Excellent
						Loading and Unloading	Excellent	Desirable Value – Very Poor / Poor / Average / Good / Excellent
						Visibility	Excellent	Desirable Value – Very Poor / Poor / Average / Good / Excellent



					Climatic Comfort	HEVAC System	Good	Desirable Value – Very Poor / Poor / Average / Good / Excellent
						Heating / Cooling System	Good	Desirable Value – Very Poor / Poor / Average / Good / Excellent
					Acoustic Comfort		Excellent	Desirable Value – Very Poor / Poor / Average / Good / Excellent
					Dynamic Comfort		Good	Desirable Value – Very Poor / Poor / Average / Good / Excellent
					Dynamic Performance		Excellent	Desirable Value – Very Poor / Poor / Average / Good / Excellent
					Handling / Operation		Excellent	Desirable Value – Very Poor / Poor / Average / Good / Excellent
					Safety		Excellent	Desirable Value – Very Poor / Poor / Average / Good / Excellent
					Resistance to Age		Excellent	Desirable Value – Very Poor / Poor / Average / Good / Excellent
	Pr6		TSFPr	Properties of Other TS factors	(in their operational processes)	Property Indicator	Various Values	Notes
		Pr6A			In Manufacturing			
		Pr6B			In Distribution	Identical to Pr6C – In Operation		
		Pr6C			In Operation			
					Vehicular Communication Systems	Dedicated Short Range Communications (DSRC)	5.9GHz / 75MHz / 1000m	
						Inteligent Transport Systems (ITS)	N/A	Mobile & Fixed nodes -Wired & Wireless Communication
					V2V		F	Fixed Requirement / Strong Wish / Wish / Not considered
					Traffic Control System	Road Signage	F	Fixed Requirement / Strong Wish / Wish / Not considered
					GPS		F	Fixed Requirement / Strong Wish / Wish / Not considered
					Artificial Passenger		N	Fixed Requirement / Strong Wish / Wish / Not considered
					Radio		F	Fixed Requirement / Strong Wish / Wish / Not considered
					Wi-Fi		F	Fixed Requirement / Strong Wish / Wish / Not considered
					4G		F	Fixed Requirement / Strong Wish / Wish / Not considered
		Pr6D			In Liquidation			
					Wreck Yeard	Crushers	N	Fixed Requirement / Strong Wish / Wish / Not considered
					Recycling Equipment	Car Tire Shredders	N	Fixed Requirement / Strong Wish / Wish / Not considered
	Pr7		EnvFPr	Environmental Factor Properties	Property	Property Indicator	Various Values	Notes
		Pr7A			Social, Cultural, Geographic, Political & Other Factors		Consideration Importance [1-10]	[1-10]
					Social	Social Acceptability Importance	10	
					- Social Impact Assesmnet		10	
					- Sustainable Cities		10	
					Cultural	Cultural Acceptability Importance	10	
					Geogprahic Factor		6	
					- Geographic Strategy	Workshop Location	5	
						Facility Location	3	
						Supplier Location	1	
						Research Centre Location	9	London
					- Environmental Regulations	Emission Reduction	8	
					- Terrain	Flatland	10	
						Mountains	7	
					- Clima / Weather	Operating Temperature	-30C to 50C	
						Operating Weather Conditions	10	
					- Infrastructure	Urban Regions	10	
						Rural Regions	5	
					Political	Political Support (Lobby)	N/A	
						Political Barriers	N/A	
					Other societal factors			
					- Traffic congestion		10	
					- Urban Sprawl		10	
		Pr7B			Material, Energy and Information			
					TP / TS inputs -- effects of and on environment	Petroleum	N/A	http://www.eia.gov/oiaf/1605/coefficients.html
						Oil	N/A	Lubricants
						Electricity	N/A	
						Solar Energy	N/A	
					TS - material -- effects of and on environment	Carbon Fibres	N/A	
						Aluminum	N/A	



					ABS Plastics	N/A	
					Steel	N/A	
				TP / TS secondary outputs and TS disposal	Global Warming	N/A	
					Carbon Dioxide Emissions	N/A	
					Nitrous Oxide Emissions	N/A	
					Air Quality	N/A	
					Acid Rain	N/A	
					Smog	N/A	
					Climate Change	N/A	
Pr8		ISFPr	Information system factors properties	Property	Property Indicator	Various Values	Notes
				Legislations		N/A	
				Regulations		N/A	
				Taxes		N/A	
				Insurance Policies		N/A	
	Pr8A			Scientific information		Source	
				Publications / Literature	Inclusive Design	See References	
					Universal Design	See References	
					Design for All	See References	
					Engineering Design	See References	
					Automotive Design	See References	
					Ergonometry	See References	
				Universities		ZCU	
				Research Centres		N/A	
				Research Laboratories		N/A	
				Internet	Links	See References	
	Pr8B			Technology information			
				Suppliers		N/A	
				Manufacturers		N/A	
				Universities		N/A	
				Internet		N/A	
	Pr8C			Societal information			
				General and National Statistics	Ageing	N/A	
				Population and Social Conditions		N/A	
				Users Needs		N/A	
				Social Trends		N/A	
				Disabled or Impaired Users		N/A	
				Social Behaviour		N/A	
	Pr8D			Cultural information			
				Automotive Market		N/A	
				Automotive Industry		N/A	
				Culture Behaviour		N/A	
				Culture Trends		N/A	
	Pr8E			Other – Transportation Information			
				Traffic Volume		N/A	
				Energy Consumption		N/A	
				Operating Fleet		N/A	
				Infrastructure		N/A	
				Social Impact		N/A	
Pr9		MgFpr	Management factor properties	Property	Property Indicator	Various Values	Notes
	Pr9A			Management planning		Number	
				Product Range		N/A	
	Pr9B			Management of design process		Standard	
				Design management system	Managing Inclusive Design	BS7000-6	British Standard
				Project management		N/A	
	Pr9C			Design documentation		Documents	
				Design Briefs		N/A	
				Design Proposals		N/A	
				Design Specifications		N/A	
				Design Report		N/A	
				Version Control		N/A	
				Standard Database		N/A	
				Need List		N/A	
				Idea List		N/A	
				Test List		N/A	
				User List		N/A	
				Survey Documents		N/A	
				Analysis Documents		N/A	
				Statistic Tables		N/A	
				Charts&Tables		N/A	
	Pr9D			Situation		Names	
				Management Situation	Stakeholders	N/A	
					Research Partners	N/A	
				Personnel Relationship	Design Engineers	N/A	
					Sales Experts	N/A	
					Marketing Experts	N/A	
					Health Knowledge & Support	N/A	
					Strategy Experts	N/A	
					Purchasing & Supply Chain Experts	N/A	
					Product Development Experts	N/A	
					Manufactruring Engineers	N/A	
					Styling and Industrial Design Support	N/A	
					Technology Engineers	N/A	
					Automotive Journalists	N/A	
					Cybernetic Engineers	N/A	
					Electrical Engineers	N/A	
	Pr9E			Quality system		Documents	
				Quality of Design		N/A	
				Quality Control		N/A	
				Quality Assurance		N/A	
				Standart Operation Procedure		N/A	
	Pr9F			Information properties		Documents	
				Licencing		N/A	
				Intellectual Property		N/A	
	Pr9G			Economic properties		Documents	Quotes, Purchase Orders, Invoices, Statements, Receipts
				Cost		N/A	
				Pricing		N/A	
				Returns		N/A	
				Financing	Stakeholders	N/A	
				Sales		N/A	
				Expenses		N/A	
				Tax		N/A	
				Sponsorship		N/A	
				Loans		N/A	
	Pr9H			Time properties		Time	
				Estimated time to delivery		N/A	
				Planning		N/A	
				Duration	Data & Knowledge gathering	N/A	
					Design Research	N/A	
					Pre-Concept Development	N/A	

						Pre-Concept Development	N/A	
						Discovery Needs Low Contact	N/A	
						Discovery Needs Medium Contact	N/A	
						Discovery NeedsHigh Contact	N/A	
						Discovery Needs Simulation	N/A	
						Mapping Insight	N/A	
						Brief Translation	N/A	
						Scenario Built	N/A	
						Concept Development	N/A	
						Resource Building	N/A	
						Quantifying Design Exclusions	N/A	
						Countering Design Exclusions	N/A	
						Testing	N/A	
		Pr9J			Tangible resource		Companies / Universities	
					Availability		N/A	
					Accesibility	3D Printer	SPSS Tabor	
						5axis CNC	N/A	
		Pr9K			Organization		Notes	
					Goals	Prototype Realization	N/A	
					Personnel		N/A	
		Pr9L			Supply chain properties		Benchmark	
					Lead Times		N/A	
					Reputation		N/A	
					Reliability		N/A	
					Valuability		N/A	
		Pr9M			Other management aspects			

INTERNAL PROPERTIES

DOMAIN	Class	Sub	Symbol	CLASS of PROPERTIES			VALUE(S)	
REACTIVE PROPERTIES	**Pr10**			**Design Characteristics**	**Property**	**Property Indicator**	**Various Values**	**Notes**
					General construction	Accessibility	Wheelchair Accessibility	Taxis offered for type approval must be so constructed as to facilitate the carriage of disabled persons and must be capable as a minimum of accommodating a disabled person in a DfT reference wheelchair in the passenger compartment
					Manoeuvrability requirement	Turning Circle	7.62-8.535m	The vehicle must be capable of being turned on either lock so as to proceed in the opposite direction without reversing between two vertical parallel planes not more than 8.535 metres apart; The wheel turning circle kerb to kerb on either lock must be not less than 7.62 metres in diameter.
					Tyres	Legislation	BS AU 144E	All tyres must comply with the relevant legislation. Specifically, retread tyres must comply with BS AU 144E as amended and be marked accordingly
					Brakes	Anti-lock braking system	YES	
					Interior Lightning		N/A	Adequate lighting must be provided for the driver and passengers
					Electrical equipment	EMC	N/A	Any additional electrical installation and/or after-market components to be used within the taxi must meet the requirements of the relevant Automotive Electro Magnetic Compatibility (EMC) Directive, as amended, and be marked accordingly.
					Powertrain System	Electric Vehicle	YES	
					Exhaust emissions standards	Zero Emission Capability	N/A	From 1 January 2018 new taxi models must be Zero-emission Capable ("ZEC") vehicles; It must emit no more than 50g CO2/km (at tailpipe) determined in accordance with the relevant European Drive Cycle and relevant EU and UN ECE Regulations; It must be capable of being operated with no (zero) tailpipe exhaust emissions for a minimum range of 48.28 kilometres or 30 miles (determined as above);
					Steering	Autonomous Steering		Level 5 Autonomy
					Body	Length	5m	The overall length must not exceed 5 metres. This is essential for determining the size of taxi ranks, other pick-up points and for the free access and flow of other vehicles in London's congested streets
					Facilities for the disabled	Wheelchair ramp	1	Every taxi must be equipped to approved standards in order that wheelchair passengers may be carried. Approved anchorages must be provided for wheelchair tiedowns and the wheelchair passenger restraint. These anchorages must be either chassis or floor linked and capable of withstanding approved dynamic or static tests. Restraints for wheelchair and occupant must be independent of each other. Anchorages must also be provided for the safe stowage of a wheelchair when not in use, whether folded or otherwise, if carried within the passenger compartment. All anchorages and restraints must be so designed that they do not cause any danger to other passengers.
					Facilities for the disabled	Door Accessibility	75cm / 90deg	The door and doorway must be so constructed as to permit an unrestricted opening across the doorway of at least 75cm. The minimum angle of a hinged door when opened must be 90 degrees
					Facilities for the disabled	Door Height	1.2m	The clear height of the doorway must be not less than 1.2 metres.
					Facilities for the disabled	Grab Handles	Colour	Grab handles must be placed at door entrances to assist the elderly and disabled. All grab handles must be in a contrasting colour
					Facilities for the disabled	Floor Height	380mm max	The top of the tread for any entrance should normally be at floor level of the passenger compartment and comply with the following requirements: a) be not more than 380 mm from the ground, (measured at the centre of the tread width); b) the surface shall be covered in a slip-resistant material; c) have a band of colour across the entire width of the edge which shall contrast with the remainder of the tread and floor covering
					Facilities for the disabled	Roof Height	1.3m	The vertical distance between the highest part of the floor and the roof in the passenger compartment must not be less than 1.3 metres
					Seats	Clear Space	66cm	Where all seats are placed facing to the front of the vehicle, there must be clear space of at least 66cm in front of every part of each seat squab, measured along a horizontal plane at the centre of the cushion
					Wheelchair ramp	Width	70cm	15.10 A ramp for the loading of a wheelchair and occupant must be available at all times for use, as a minimum, at the nearside passenger door on all new vehicles presented for licensing. The ramp must have a safety lip, be 70cm wide, as a minimum, and comprise a single non-slip surface. It is desirable for this facility to be available at the offside passenger door also. An adequate locking device must be fitted to ensure that the ramp does not slip or tilt when in use. Provision must be made for the ramp to be stowed safely when not in use
					Seats	Width	40cm min	The rear seat dimensions must be adequate to carry the appropriate number of adult passengers comfortably
					Seats	Colour	Yellow	Colour contrasting sight patches are required on all passenger seats.
					Seats	Headrest		Head restraints must be fitted for all (forward and rear facing) seats. The design of headrests should maximise rear sightlines for the driver when any of the passenger seats are not occupied
					Visibility	Windows	Maximise	The windows should maximise passenger visibility into and out of the vehicle. The top of the window line for front and side windows, when measured vertically to the top of the visible portion of the glass, must not be less than 780mm on any glass panel forward of or beside the seated passenger. The vertical distance is to be measured through the E point as defined in Directive 77/649/EEC, from the top of the uncompressed rear forward-facing passenger seat cushion to the first point of totally obscured glass. Manufacturers are to declare conformity to this condition in drawing format
					Visibility	Windows Tint Value	25%	Windows must permit maximum visibility into, and out of, the vehicle. They must have no more than 25% tint value

					Visibility	Windows Opening	Yes	Passenger windows must be capable of being opened easily by passengers, including those in wheelchairs, when seated. The control for opening a window must be clearly identified to prevent it being mistaken for any other control
					Heating and ventilation	Heating and Ventilation Controlling	Reach Distance	An adequate heating and ventilation system must be provided for the passengers. All switches must be within easy reach of seated passengers, including those in wheelchairs
					Door fitings	Automatic Securing Device	Approved	An approved type of automatic door securing device must be fitted to passenger doors to prevent them being opened when the vehicle is in motion. When the vehicle is stationary, the passenger doors must be capable of being readily opened from the inside and outside of the vehicle by one operation of the latch mechanism. The door must not open from the inside if the driver has the foot brake depressed. The interior door handle must be clearly identified to prevent it being mistaken for any other control.
					Floor Covering	Slip Resistancy	N/A	The flooring of the passenger compartment must be covered with a slip resistant material, which can be easily cleaned
					Lugagge	Luggage securing	N/A	Suitable dedicated provision for the secure carriage of luggage must be made, separated from the passenger compartment and proportionate in size to the number of passengers carried
					Taxi Sign	Roof Fitted	N/A	A "Taxi" sign approved by LTPH, clearly visible both by day and night when the taxi is available for hire, must be fitted.
					Maintanence		N/A	Vehicles, including all fittings, advertisements, etc., must be maintained to approved standards. The vehicles should always be kept clean and in good working order. Vehicles will at all times be subject to test and inspection and should it be found that a vehicle is not being properly maintained or kept in good working order, a notice will be served on the owner prohibiting him/her using the vehicle until the defect has been rectified
				Lighting	Headlights	US	SAE and FMVSS 108	Consisting of a high and low beam to illuminate the environment in front of the vehicle. Lens minimum sizes are determined by photometric requirements and lamp technology. Two or four lamps set symmetrically about centerline as far apart as practical.
				Lighting	Headlights	EU	ECE-R112, R98/99, R48, R45	Consisting of a high and low beam to illuminate the environment in front of the vehicle. Lens minimum sizes are determined by photometric requirements and lamp technology. Two or four lamps set symmetrically about centerline as far apart as practical.
				Lighting	Daytime Running Lights	US	FMVSS 108	Two dedicated lamps or the low beam headlamps to help make oncoming vehicles more conspicuous in day light. Lens minimum sizes are determined by photometric requirements and lamp technology. Two or four lamps set symmetrically about centerline as far apart as practical.
				Lighting	Daytime Running Lights	EU	ECE-R91, R48	Two dedicated lamps or the low beam headlamps to help make oncoming vehicles more conspicuous in day light. Lens minimum sizes are determined by photometric requirements and lamp technology. Two or four lamps set symmetrically about centerline as far apart as practical.
				Lighting	Park and Turn	US	SAE, IIHS and FMVSS 108	Park - Indicates the vehicle's position when parked or during headlight failure. Turn - Flashes to indicate the driver's intent to turn, and can be used together for hazard warning. Mounted symmetrically about centerline.
				Lighting	Park and Turn	EU	ECE-R19, R48	Park - Indicates the vehicle's position when parked or during headlight failure. Turn - Flashes to indicate the driver's intent to turn, and can be used together for hazard warning. Mounted symmetrically about centerline.
				Lighting	Front Fog	EU	ECE-R6, R48	Two forward-facing lights mounted symmetrically about centerline. Fog-light function is separate from headlight
				Lighting	Side Marker	US	SAE and FMVSS 108	Side markers indicate the overall length of the vehicle
				Lighting	Side Marker	EU	ECE-R6, R7, R77, R48	Side markers indicate the overall length of the vehicle
				Lighting	Side Repeater Lamps	EU	ECE-R87, R48	Work with turn signals to show intent to turn or change lanes to vehicles traveling alongside
				Lighting	Center High-Mounted Stop Lamp (CHMSL)			One red light mounted on the vehicle centerline facing rearward, activated with brake lights.
				Lighting	Tail, Stop, Park & Turn-Singal Lamps	Tail Lights	RED	Mark the presence of a vehicle and work with the headlights or park
				Lighting	Tail, Stop, Park & Turn-Singal Lamps	Brake Lights	RED	Indicate the vehicle is slowing down/stopping
				Lighting	Tail, Stop, Park & Turn-Singal Lamps	Turn Signal	US - Red or Amber, EU - Amber	Flash to indicate driver's intent to turn, or for hazard warning. All mounted symmetrically about centerline and a portion, meeting legal requirements, must be mounted on the fixed body.May be clustered into a single light assembly.
				Lighting	Back-Up / Reversing Lamps	Colour	WHITE - 1	For illumination behind the vehicle, and they provide a warning signal when in reverse. Only one required, two optional (must be symmetrical)
				Lighting	Rear Fog Lamps	EU	ECE-R19, R48	Red in color - For making the vehicle more visible in fog. Only one required, mounted on centerline or driver's side. Two optional (must be symmetrical).
				Lighting	Rear Fog Lamps	US	Not Permited	
				Lighting	License Plate Lamps	EU	ECE-R4, R48	To Illuminate the rear licence plate to be legible at night
				Lighting	License Plate Lamps	US	SAE	To Illuminate the rear licence plate to be legible at night
DOMAIN	**Class**	**Sub**	**Symbol**	**CLASS of PROPERTIES**			**VALUE(S)**	
DESCRIPTIVE PROPERTIES	**Pr11**			**General Design Properties**	Property	Property Indicator	Various Values	Notes
					CAS (Computer Aided Styling)	Form Generation	Catia V5 / ICEM Surf	
						Mathematical Model Generation	N/A	
					CAD (Computer Aided Design)	Body Modeling	Catia V5	
						Rules & Common-Practice in CAD Modelling	Catia V5	
						Reference Points	Catia V5	
						Part Detailed Drawing	Catia V5	
					DMU (Digital Mockup)	DMU Application	Catia V5	
						Virtual Reality and Body Engineering	N/A	
					Ergonomics&Packaging	Manikin Placement	95%	
						- Backbone	N/A	
						- Joints	N/A	
						- Effect of the Vibrations on the Comfort	N/A	
						Manikins for Interior Packaging	Catia V5	
						- Anthropometry Analysis	N/A	
						- 2D Manikins	Catia V5	
						- Head Contour	N/A	
						- 3D Manikins	Catia V5	
						- SAE Quotation System	N/A	
					Inclusive Design Principles		N/A	
					Autonomous Engineering	Aplication of Autonomous sensors and devices	N/A	
	Pr12			**Elemental Design Properties**	**Property**	**Property Indicator**	**Various Values**	**Notes**
					Assembly Structure of TS		N/A	
					Body Work		N/A	
					- Body in White	Body Setting	iStream	
					- Body Side	Body Side Setting	N/A	
					- Fenders		N/A	
					- Roof Assembly		N/A	
					- Front Frame		N/A	
					- Rear Frame		N/A	
					- Compartment Floor		N/A	
					- Closed Bodies		N/A	
					Body Components		N/A	
					- Outer Body Components	Bumpers	N/A	
						Grilles	N/A	
						Sill Covers	N/A	
						Side Airdams	N/A	
						Outer Moldings	N/A	
						Spoilers	N/A	
					- Weather Strips	Door Weather Strips	N/A	
						Liftgate and Trunk Lid Weather Strips	N/A	

	Hood Seals	N/A
	Opening Roof Seals	N/A
	Glass Seals	N/A
- Glass and Mirrors	Windshield	1
	Door Windows	1
	Quarter Glass	4
	Back Window	1
	External Mirrors	0
	Inside Mirrors	0
- Movable Parts	Side Doors	0
	Sliding Doors	One side only
	Trunk Lid, Liftgate, Tailgate	1
	Twin Rear Doors	0
	Hood	0
	Sunroofs	0
	Window Glass Regulators	0
- Windshield Wiper		N/A
- Vehicle Lightning and Signaling		N/A
Body Interiors		N/A
- Restrain Systems	Safety Belts	N/A
	Air Bags	N/A
- Cockpit		N/A
- Dashboard		N/A
- Console		N/A
- Interior Trims	Pillars and Interior Valence Panels	N/A
	Door Panels	N/A
	Parcel Trays	N/A
	Headliners	N/A
- Seats	Front Seats	2
	Rear Seats	N/A
	Child Seats	N/A
- Airconditioning System	Air Conditioning	N/A
Parts of Assembly Strutcure of TS	Geometry / Form / Shape	N/A
	Dimensions	N/A
	Materials	N/A
	- Material Properties(Density, Surface)	N/A
	- Mechanical Properties	N/A
	- Thermal Properties	N/A
	- Manufacturing Properties	N/A
	- Finishing Properties (Coating Properties)	N/A
	- Tolerance Properties	N/A

APPENDIX X

SAE J1100 – DESIGN TABLE used for Conceptual CAD model (CATIA V5)

DIMENSION INDEX - 2009 Code	Figure	SAE J1100	Autonomous Taxi
BOFRP X Coordinate (BOFRPx)	—	L1	1017
AHP X Coordinate (AHPx)	—	L8	835
SgRP X Coordinate – Front	—	L31-1	1290
Effective Leg Room – Accelerator	23	L34	696
Effective Leg Room – Second	24-27	L51-2	1087
SgRP to Heel – Front	22	L53-1	635
Wheelbase	47	L101	2000
Tire Size – Front	—	L102-1	699.6
Tire Size – Rear	—	L102-2	699.6
Vehicle Length	47	L103	3150
Overhang – Front	47	L104	550
Overhang – Rear	47	L105	600
Front Wheel Centreline to SgRP – Front	19	L114	1322
Wheel Centerline X Coordinate – Front	—	L128-1	2018.2
Wheel Centerline X Coordinate – Rear	—	L128-2	4018.2
Minimum Loading Length (Width) of Side Cargo Door	47	L508	985
BOFRP Y Coordinate (BOFRPy)	—	W1	215
Steering Wheel Centre – Y Coordinate	—	W7	215
AHP Y Coordinate (AHPy)	—	W8	215
Steering Wheel Diameter	30	W9	375
SgRP Y Coordinate – Front	—	W20-1	350
SgRP Y Coordinate – Second	—	W20-2	350
Tread Width – Front Tires	49A, 49B	W101-1	155
Tread Width – Rear Tires	—	W101-2	155
Track Width – Front Tires (new in 2005)	49A, 49B	W102-1	1571
Track Width – Rear Tires (new in 2005)	—	W102-2	1571
Vehicle Width, Maximum (without mirrors)	50	W103	1650
Fender Width – Front	49A	W106	1726
Fender Width – Rear	49A	W107	1726
BOFRP Z Coordinate (BOFRPz)	—	H1	330
SgRP to Ground – Front	33	H5-1	743
AHP Z Coordinate (AHPz)	—	H8	360
Seat Height – Front	34	H30-1	415
Upper-Body Opening to Ground – Front	33	H50-1	1655
Upper-Body Opening to Ground – Second	—	H50-2	1655
SgRP Z Coordinate – Front	—	H70-1	735
Vehicle Height – Body	54	H100	1750
Vehicle Height – Maximum	54	H101	1750
Static Load Radius – Front Tire	55	H108-1	350
Static Load Radius – Rear Tire	55	H108-2	350
Step Height – Running Boards – Front	56	H117-1	330
Step Height – Running Boards – Second	56	H117-2	330
Zero Z-Plane to Ground – Front	**19**	**H136-1**	813.9
Zero Z-Plane to Ground – Rear	**19**	**H136-2**	813.9
Suspension or Axle to Ground – Front	—	H148-1	145
Suspension or Axle to Ground – Rear	52	H148-2	145
Ground Clearance	49B	H156	120
Ground Clearance – GVM	—	H156-GVM	130
Lift In Height	57ABC	H196	720
Steering Wheel Angle, Y-Plane	33	A18	33.7
Torso Angle – Front	36	A40-1	19
Hip Angle – Front	36	A42-1	95
Shoe Plane Angle	36	A47	42
Thigh Angle – Front	36	A57-1	103
Angle of Approach	55	A106-1	26
Angle of Departure	55	A106-2	23
Ramp Breakover Angle	55	A147	16.6
Turn Diameter, Wall-to-Wall	70	D102	8000