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Human centred design of first and last mile mobility vehicles

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Human Centred Design

of

First and Last Mile Mobility Vehicles

by

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Project Title:

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Abstract

Enabled through the advancement of vehicle automation, driverless first and last mile mobility vehicles are emerging through public trials around the world. However, due to the focus on the complex technology, the end users have not yet received sufficient attention. The user requirements in regards to the comfort and user experience in driverless first and last mile mobility vehicles subsequently remain relatively unknown.

This thesis therefore investigated and evaluated passenger comfort and experience in the context of driverless first and last mile mobility vehicles through a novel design proposal and proposes design recommendations for such vehicles.

The 1st chapter introduces the research topic and the context for the research work as well as detailing the overall aim and objectives for the thesis.

In the 2nd chapter, a literature review is used to establish the state of the art for driverless vehicles with the focus on first and last mile mobility and the passenger comfort experience. Furthermore, likely scenarios, operators and passengers for such vehicles were also identified. This review demonstrated that the advancement in driverless vehicle technology has now reached a point that allows to critically investigate the potential benefits and issues with such vehicles.

The 3rd chapter introduces the concept of iterative and user centred design as an overall approach for the research work and details the individual methods used. Along with traditional tools such as focus groups, surveys and observations an ergonomic buck was constructed to conduct user trials. Lastly, a new methodology was developed using the ergonomic buck as a basis for a fully immersive design experience and evaluation tool.

Following on from the literature review, in the 4th chapter, a theoretical passenger comfort model for driverless first and last mile mobility vehicles was proposed.

Here eight factors were identified which influence the passenger comfort and wellbeing in driverless first and last mile mobility vehicles and ranked them based on the perceived importance.

These were subsequently used to create a benchmark of current driverless first and last mile mobility vehicles in chapter 5. Using the aforementioned comfort model to evaluate ten existing driverless first and last mile mobility concepts further shortcomings in the areas of passenger comfort and usability as well as user perception were identified.

The information gathered from the initial activities was then used in the 7th chapter to produce a design specification for a driverless first and last mile vehicle for a range of typical scenarios. A vehicle design concept which included the appearance, package and ergonomic features was then created in line with the specification and discussed in detail in chapter 8.

For an initial evaluation, described in chapter 9, the exterior appearance and user acceptability of six vehicle designs, including the proposed design, was evaluated through questionnaires and focus groups. The results indicated that the proportions, colours and face of each vehicle have a significant impact on the perception of the vehicle behaviour and stability.

In a second study, covered in chapter 10, the ergonomic aspects of the proposed vehicle concept such as the seat height and handrail placement were evaluated using a digital model with the PLM Siemens Jack software. This study highlighted initial issues with the seat height and depth as well as with the overhead handrail. A number of adjustments were undertaken to improve on the identified issues and continuously re-evaluated in the software.

Subsequently, an ergonomic buck was built, which is detailed in chapter 11, to undertake user tests, focussing on aspects of physical comfort, reach, visibility, and accessibility using a range of potential future users including elderly and visually impaired, discussed as a third study in chapter 12. These tests identified a number of requirements specific to those with visual and mobility impairments and supported further adjustments to the handrail placements and the shape of the seats.

For the following evaluation stage, suitable software and hardware were evaluated, selected and then integrated into a mixed reality simulation, a research tool which is discussed in detail in chapter 13. The mixed reality simulator was subsequently used by a test population of users to evaluate further aspects of the vehicle, design features such as natural light influx, interior lights placement and materials. The seating arrangement was also re-evaluated along with the visibility from and into the vehicle and the results written up in chapter 14.

Finally, the entire process, the overall evaluation of the design and of the approach used, were synthesised in the 15th chapter, in order to develop a list of suggestions outlining design features with the aim to enhance the passenger comfort and experience in driverless first and last mile mobility vehicles.

In summary, this thesis investigated and evaluated passenger comfort and experience in driverless first and last mile mobility vehicles and proposed a novel vehicle concept for this type of vehicle. Lastly the thesis concludes with a set of design recommendations for driverless first and last mile mobility vehicles with the aim to improve the passenger comfort and experience in this vehicle type.

1.0. Introduction

1.1. Introduction

With the steady advancement of automated vehicle technologies, various applications are being investigated and trialled. First and last mile mobility vehicles, which provide transport to and from transport hubs, are likely to be the earliest real-world applications of highly automated vehicles, also referred to as SAE level 4 vehicles (SAE, 2018). These vehicles do not require human intervention and can be used in confined areas with closely defined parameters, such as technology parks, university campuses and large public sites, due to the relatively lesser complexity of these environments. They also provide scenarios in which the general public can experience and familiarise themselves with driverless technology, often forming their first impressions of this radical technological development.

For the successful public acceptance and uptake of such mobility concepts, it is important that such vehicles are being perceived as comfortable, seamless, and intuitive (Nordhoff et al 2016, van der Laan et al 1997). This can be expected to be especially relevant during the introductory period of such vehicles in which the general public may be hypercritical. To date, the development and evaluation of such vehicles has largely focussed on the underlying technology, its performance and other road users' perceptions (Bell 2015). In contrast, the design of the passenger experience has received relatively little attention. The initial impression of the vehicle appearance, the interaction with the vehicle and the physical comfort requirements are all likely to affect the overall acceptance of these vehicles. Accessibility for passengers with mobility impairments and other disabilities is also a critical aspect of these vehicles which requires further development.

This thesis therefore argues, based on the Kano Model (Kano 1984) which describes the impact a predominant focus on technology can have, that the user experience will become the most critical requirement for such vehicles (see also Diels & Bos 2016). Subsequently, it aims to investigate what the passenger comfort and experience in the context of driverless first and last mile mobility vehicles entails and how design choices can positively impact on these aspects. This pertains to both the interior and exterior vehicle design, as well as user interactions.

For this thesis the following definitions of driverless vehicles and first and last mile are assumed:

- Driverless Vehicles

  The Society of Automotive Engineers defines vehicles in which under certain conditions all driving tasks are highly automated, as level 4 automation (SAE, 2018). The complete definition consists of five automation levels, with the last two being completely independent of a driver, without the requirement to monitor. Therefore level 4/5 SAE vehicles are the first which may not feature a vehicle to driver interface. The level 4 definition stipulates that this automation is limited to “certain conditions” which for this research is assumed to be a controlled and limited environment, such as a technology park (KPMG 2015). Some vehicles may feature level 4 automation which can be activated in a suitable scenario but will be manually controlled otherwise.

  It should be noted that in the general media the term automated (vehicle) is frequently interchanged with autonomous (vehicle) or driverless (vehicle), all with similar and subsequently confusing definitions. The term driverless was chosen for this work because it aligns with the description most frequently used in the media as “driverless pods” (UK Autodrive 2018).

- First and Last Mile

  The term last mile is commonly used in the context of goods deliveries made directly to the recipient (customer) rather than to an intermediary, i.e. shop (Macharis & Melo 2011). It describes a challenge which also exists in the context of mobility and public transport, where a traveller has to bridge the gap between their start point, their home for example and the first node in the transport system such as a train station and similarly, on the other end of the journey, between the last node and the destination. The solution to this is frequently referred to as first and last mile mobility. First and last mile mobility is believed to be of growing importance in regards to be able to access and to increase the uptake of services such as public transport (DfT 2013, KPMG 2015).

1.2. Research Context - HORIBA MIRA

The research sponsor HORIBA MIRA is a vehicle testing and engineering businesses located in central England, providing consultancy and testing services for all of the major automotive manufacturers. The company is located on a large site, featuring high speed, off-road and city circuits as well as wind tunnels and a large number of office buildings.

Due to the fact that technology parks can be self-contained environments, they are likely to be one of the first scenarios in which the general public will be able to experience automated mobility (KPMG 2015). The MIRA Technology Park features a private road network, permitting prototype vehicles to be used on the roads, ideal for trialling driverless first and last mile mobility solutions.

The technology park covers an area of 800 hectares and consists of a range of testing facilities and office buildings spread across the entire site with employees and visitors currently using private vehicles to move from one to another. An internal survey (n ≈ 300) conducted in 2017 investigating the travel behaviour of the HORIBA MIRA employees showed that on average each of the employees (580) travels eight miles a day, equating to 4800 miles a week or 220.800 miles in a year.

When considering the site speed limit and the typical routes taken, this adds up to 400 hours on average spend travelling on site. Multiplying this with the hourly pay rate of a graduate engineer, it shows that this costs HORIBA MIRA £8910 each week in travel alone, an annual total cost of £427.680. The financial cost, however, is not the only driving force for the driverless first and last mile mobility project, as measurements with emissions testing equipment showed that these journeys also produce 18t of CO_2 and 15Kg of NO_x each year, which represents a significant carbon footprint.

The lack of mobility options on site is also causing an overwhelming number of employees to not use ride share or public transport options for their daily commute; many stating that whilst the commute itself would be feasible, they would be unable to move around the site and therefore would be unable to perform their jobs.

Beyond the potential economic and ecologic benefits, there would also be a positive impact on each of the employees as well as any visitor. Many visitors would be relieved of the requirement to navigate the site by themselves and it would serve as a showcase of the core capabilities of HORIBA MIRA in the fields of vehicle engineering, automation and validation as well as testing. The employees could switch to other forms of commuting, reducing individual costs and thereby improving satisfaction as well as their environmental impact.

All these points align with the four megatrends identified by HORIBA MIRA as the driving force for the transport industry in the next 25 years; Making vehicles and journeys safer, enabling vehicles to be cleaner, making journeys more efficient and developing vehicles that are rewarding.

Therefore, in the following work, the MIRA Technology Park will be used as the main scenario to inform the research questions and vehicle design.

1.3. Aim and Objectives

1.3.1. Aim

The aim of this work is to investigate and evaluate the passenger comfort and experience in the context of driverless first and last mile mobility vehicles through a novel design proposal and thus to produce design recommendations for such vehicles.

1.3.2. Objectives

1. To undertake a literature review to establish the state of the art for driverless vehicles focussing on first and last mile mobility and on passenger comfort. To identify from the review the likely scenarios, operators and passengers for such vehicles and to speculate on other possible uses for them.
2. Based on the review to establish a theoretical passenger comfort model for such vehicles and to establish its efficacy through participant lead trials. Benchmark current driverless first and last mile mobility vehicles based on the model.
3. To synthesise the information gathered and to produce a design specification for a driverless first and last mile vehicle for a typical scenario. To produce a design concept which includes the appearance, package and ergonomic features in line with the specification.
4. To evaluate the likely user acceptability of the appearance design through questionnaires and focus groups.
5. To evaluate the design by making an ergonomic buck for the design concept and undertaking user tests to evaluate it focussing on physical comfort.
6. To select, evaluate and integrate suitable software and hardware to create a mixed reality simulation.
7. To use the mixed reality simulator with a test population of users to evaluate the vehicle design.
8. To synthesise the work to produce an overall evaluation of the design and of the approach used, to develop a list of suggestions outlining design features which will enhance the passenger comfort and experience in driverless first and last mile mobility vehicles.

Below is a list detailing in which chapter each object is addressed and which actions are required to fulfil the objectives (Fig. 1.1.)

Objective	Chapter	Action
1	2.0 6.0	• Review current academic literature in the areas of comfort, driverless technology as well as shared public transport. • Synthesise parts of this information in exemplary personas and scenarios for the context of driverless first and last mile mobility.
2	4.0 5.0	• Use an existing comfort model in combination with two key product design methodologies as a foundation to create a theoretical comfort model describing the passenger comfort and wellbeing requirements in driverless last mile mobility vehicles. • Review a number of current driverless vehicle concepts to create a benchmark.
3	7.0 8.0	• List the design and engineering requirements for a driverless first and last mile mobility vehicle on the MIRA Technology Park. • Create a vehicle design (interior & exterior) inspired by the previously gathered information.
4	9.0	• Compare and review the exterior aesthetics of six vehicle concepts, analysing the perceived effect on the onlooker.
5	10.0 11.0 12.0	• Begin the ergonomic evaluation of the design concept using the Siemens Jack PLM software. • Construct a full-scale ergonomic buck, replicating the interior of the vehicle concept. • Re-evaluate the ergonomic aspects of the vehicle concept through a user trial, involving disability consultants.

6	13.0	• Integrate different software and hardware components into a simulator which allows trial participants to evaluate the vehicle design as part of a fully immersive experience.
7	14.0	• Use the aforementioned simulator in a large scale trial, in which participants experience a journey in the concept vehicle, in order to evaluate the interior design.
8	15.2	• Generate a list of design recommendations for a driverless first and last mile mobility vehicles on the basis of the findings and results from the forgone aspects of this research.

Figure 1.1. A list detailing how and in which chapter each objective is resolved

2.0. Literature Review

2.1. Driverless Technology & Economics

Driverless vehicle technology is on the verge of becoming a mainstream technology with the potential to drastically change mobility and public transport. Whilst this change is largely driven by the rapid evolution of the technology, the comfort requirements and the user experience of the passengers still requires further investigation. The review of the current literature below, therefore discusses the advancement of the driverless technology, the potential positive impact on mobility, novel economic models and reviews the fundamental comfort theories.

2.1.1. Automated Vehicles

History

The concept of "driverless cars" was first presented in 1939, with GM exhibiting the "Futurama" concept. It suggested a vehicle that would platoon on highways, even predating the construction of interstates (Kröger 2016). Until the early 1970s, the idea of a vehicle that drives itself remained fiction but then, as part of the PROMETHEUS project, the researcher Prof. E. Dickmanns created the VaMoRs (Versuchsfahrzeug für autonome Mobilität und Rechnersehen). The vehicle, build on the base of a Daimler Benz Van, travelled along a closed-off section of the motorway at nearly 100km/h in 1992 (Welt 2017).

Through the following years the technological development then gradually introduced the concept of technology supported driving with the first demonstrations of fully automated driving taking place in the early 2000s as part of the DARPA Grand Challenge. The challenge was introduced by the American Military in order to accelerate the development of autonomous vehicles and challenged the participants to build vehicles which independently navigate a difficult desert route. None of the entries completed the full route in the inaugural year, however in the following year the Stanford Racing Team successfully navigated the entire route to claim the prize (DARPA 2019).

Since then the technological advancements were rapid and Google showcased a bespoke driverless car, without a steering wheel and foot controls, navigating the roads of California in 2015 (Waymo 2016). The advancement in driverless vehicle technology has now reached a point that allows to critically investigate the potential benefits and issues with such vehicles. This technological progression, albeit initially graduate, is now universally seen as a major disruptive force (Maunsell et al. 2014).

However, to understand and evaluate these changes it is important to be aware of the different levels of automation for vehicles which will be briefly summarised below.

SAE Levels

The Society of Automotive Engineers (SAE) separates the stages of driverless technology into six levels (Fig. 2.1); level zero is defined as no automation, the human driver is in control of all aspects of driving, even though there may be some support by pre-warning systems. Level one includes driver assistance systems such as emergency brake assist. Level two further includes partial automation in which the assistance systems control some tasks fully such as advanced motorway cruise control or automated parking. In the following level three, conditional automation, the system automation is functional for specific use cases such as high way automation.

In these scenarios, the entire driving task is automated, with the human driver supervising the system and intervening only on request (in situations which the automation is unable to resolve itself). The fourth level defines a highly automated system in which the driving task in a specific scenario is completely controlled by the systems even if the driver does not intervene when prompted with a takeover request. The fifth level is full automation, all driving tasks for all situations are controlled by the system and the driver is now only a passenger (SAE International 2014).

Summary of Levels of Driving Automation for On-Road Vehicles

This table summarizes SAE International's levels of *driving* automation for on-road vehicles. Information Report J3016 provides full definitions for these levels and for the italicized terms used therein. The levels are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level. "System" refers to the driver assistance system, combination of driver assistance systems, or *automated driving system*, as appropriate.

The table also shows how SAE's levels definitively correspond to those developed by the Germany Federal Highway Research Institute (BASt) and approximately correspond to those described by the US National Highway Traffic Safety Administration (NHTSA) in its "Preliminary Statement of Policy Concerning Automated Vehicles" of May 30, 2013.

Level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)	BASt level	NHTSA level
***Human driver* monitors the driving environment**								
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
***Automated driving system* ("system") monitors the driving environment**								
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	Highly automated	3
4	**High Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	-	

Figure 2.1. Levels of automation defined by Society of Automotive Engineers (SAE)

Currently, the terms "autonomous", "self-driving" and "driver-less" are used interchangeably and often only seen as differentiating term to a conventional self-driven vehicle. The vehicles discussed in this thesis are defined as "road vehicles capable of operating independently of real-time human control in controlled environments" according to the SAE Level4 and shall be referred to as driverless vehicles as proposed by Le Vine S. et al (2015).

The fast-evolving technology is applied in a variety of fields; from automated construction equipment, military equipment to passenger vehicles of all kinds (HORIBA 2017). However, the most likely initial application for highly automated passenger vehicles will be in contained environments due to a lack of clear legislation in regards to current vehicle standards (KPMG 2015) and due to the fact that they allow for environmental hazards, traffic flows and general operational requirements to be closely controlled.

This limits the software requirements and reduces the risks which the introduction of this technology involves. In these environments, first and last mile mobility vehicles often provide transport across parklands for those with mobility impairments for example.
If these vehicles would be used on the regular public road network, the aforementioned unclear situation in regards to legislation and the complexity of the environment would cause a number of issues.

Such as, does the vehicle having to comply with current crash test standards for current passenger vehicles despite travelling at lower speeds or does it have to comply with public transport legislation, typically covering larger capacity vehicles such as busses. Liu et al. (2016) also argue that the first and last mile mobility sector is the ideal starting point for the introduction of driverless vehicles; "With exclusive right of way (ROW), 100% market penetration, and long existing automated operators, transit has been and should have the potential to lead the pack".

This aligns with the timeline predicted by the Connected Places Catapult; shared taxis and on demand-responsive buses will provide a much denser public transport network and subsequently reducing the need to travel by private car for the medium term (2020-2025). This is predating the predictions by KPMG, who are expecting the arrival of fully autonomous transport solutions in the long-term (2025-2030). Regardless of the timeframe, the creation of a highly efficient and dense network of always available transport, ultimately eradicating the need for a private vehicle for urban travel entirely is universally expected (CATAPULT Transport Systems 2015, KPMG 2015, KPMG 2016).

As a result, the UK government, in the form of Innovate UK (UK Innovation Agency), created the Connected Places Catapult as one of ten industry-government intermediaries. The aim of this particular institution is to collaborate with the industry in the development of future mobility solutions.

The Pathfinder Pod project is the result of such a collaboration, specifically the Lutz (Low Carbon Urban Transport Zone) vehicle, which is a small two-seater driverless vehicle designed to explore technical, social and ethical questions regarding driverless first and last mile transport (Begg 2014).

Figure 2.2 Lutz Pathfinder Vehicle in Milton Keynes

With regard to the previously discussed legislative issues and the likelihood of autonomous transport systems being launched in contained environments, the focus on a single country and market will further simplify the introduction.

A particular advantage, which the UK holds over their European competitors, is the fact that the UK Government did not ratify the 'Vienna Convention for Road Traffic'. The UK government identified this as an opportunity to accelerate the testing of autonomous vehicles on public roads through the release of £100 million in funding, as Article 8 of the convention stipulates that; "Every moving vehicle or combination of vehicles shall have a driver." (United Nations 1977) (Grayling 2017). The UK government is expected to publish a code of conduct to clarify the standards that the manufacturers are expected to follow for further testing (KPMG 2015).

2.1.2. Urban mobility / Shared mobility

The UK is the eighth most densely populated and the fifth most congested country in the world, which is estimated to cost 12 billion pound every year (Institute of Mechanical Engineers 2012). This aligns with an older study conducted in 2006 which estimated that the elimination of congestion would save 7-8 billion pounds a year, whereas not resolving the issue would amount to costs of an extra 22 billion by 2025 (Eddington, Sir Rod 2006). Noting the difference between the amounts estimated in both studies in relation to the time when they were conducted, indicates that this is a growing issue which is leading to spiralling costs.

This increase in congestion is the result of the majority of travel being completed by road; 64% of all trips in the UK, which equate to 78% of the distance travelled. As key reasons are stated flexibility and convenience when using a car (CATAPULT Transport Systems 2015, Tranter et al. 2015). According to the National Travel Survey (NTS) conducted in the UK in 2014, the most common reasons to travel are shopping and personal business at 38% combined, which however only accounts for 25% of the distance. Commuting, visiting friends and other leisure journeys are very similar at 15%-16% each, however making up almost 60% of distance travelled (Tranter et al. 2015).

Focusing on the travel movements in urban areas and in particular London, it can be said that the average time spend on travelling by a Londoner per year is 402 hours, with an average commute taking 42mins. It is particularly noteworthy that in London buses and trains are used well above the national average and only 40% of trips are done by car (Tranter et al 2015).

A case study of the urban metropolises the cities London and Berlin clearly demonstrates a trend towards “zero car households”, 40% of households in Berlin rely exclusively on public transport and MaaS (Mobility as a Service) options. MaaS describes an emerging type of mobility which is based on using vehicles and transport services provided by a company through flexible membership schemes (DfT 2019).

A growing share of over half of the households in Inner-London are a “zero car” and 30% in Outer-London, which is a result of the differences in population density and the focus on upgrading public transport in Inner-London (Rode, P. et al. 2015). A key driver for this trend is the fact that the attitude towards ownership and property has fundamentally shifted; people are still willing to drive cars and bikes but do not feel the need to own them (Freese et al. 2014). A large part of the reasoning against a personally owned vehicle are the running costs such as insurance, fuel and upkeep. Whilst these have always been important factors, now the space where the car is parked must also be added, as in urban areas renting a car parking space can be the equivalent of several hundred pounds per month (Walker 2017).

A further explanation to that phenomenon is offered by “Think Act”, suggesting that the consumption culture in industrialized and highly developed countries is changing away from ownership which was seen as a representation of wealth to a more aware society that cares about waste and inefficiencies and thus is content with just using and sharing a product.

A trend also influenced by “the fundamental human need to be part of a community, share with others” (Freese et al. 2014). The concept “Shared Economy” has increased significantly in popularity in recent years; a study conducted by PWC (2016) shows that in Europe it is growing rapidly and is generating revenues of 3.6 billion euros whilst facilitating transactions worth 28 billion euros in 2015. The UK shared economy alone is expected to experience a growth of 30% over the next 10 years and generate £18 billion of revenue whilst facilitating transactions worth £140 billion each year by 2025. The companies currently dominating this space are AirBnB and Uber and whilst accommodation initially dominated, it has since been overtaken by ride-sharing (Deloitte 2016).

One popular shared economy concept is car sharing, where users can access a network of cars at their convenience and with a basic membership just pay for the time they utilize the vehicle. For many users this makes financial sense as the average car is parked at home for 80% of the time, 16% of the time parked elsewhere and only used for 4% of the time (Bates, J. Leibling D. 2012). According to “The State of European Car-Sharing” report, there are 384,749 car-sharing customers in Europe, with 11,909 vehicles available to them (Loose 2010). The car-sharing providers which who provided the information for the report also stated that 27.3% of their customers had either sold their personal car or not bought a new one as a consequence of them using the car-sharing service. The report estimates based on those numbers that each shared vehicle removed approximately seven private cars from the roads.

Part of the success, according to the report is the accessibility of the car-sharing services, the majority of customers have less than 500m walking distance to an access point. Together with the practicability and the convenience, this leads to overall high user satisfaction, yet the customer retention rate is lower than expected as the user’s situation changes and car-sharing is no longer a feasible option. In general, five key aspects lead travelers to opt for car-sharing; to reduce expenses, to travel more sustainably, convenience, to avoid maintenance and to avoid looking for parking spots (Ramos et al. 2018 & Ullah et al. 2019).

A further and related aspect of the shared economy is ride-sharing, which combines multiple journeys from a driver and several passengers through an algorithm for the most efficient use of a vehicle. The VW Group subsidiary MOIA is based on the ride-sharing principle and operates modified and electric VW transporters driven by permanent drivers. The interior of these vans is designed to provide privacy and connectivity for each passenger. The ride-sharing is organised in individual cities via an app and in Hamburg alone, the company has had 770.000 passengers within the 6 months of operation.

The success of the ride-sharing offer has prompted the company to double the vehicle number to 200 and conduct trials in London (MOIA 2019). In Germany overall car sharing grew by 350.000 to 2.41mio journeys in 2018, underlining the increasing acceptance of this type of mobility service (BCS 2018).

Whilst it is a growing phenomenon, research by Gehrke et al. (2018) shows that in the US, currently only one-fifth of users are using a pooling option for their journey and beyond that 12% of on-demand trips are replacing journeys on public transport (including also walking and cycling) even if those passengers hold a monthly pass. Sadowsky et al. (2017) further report based on their case study of ride-hailing in New York City, that initially with a single operator of ride-hailing and carsharing the usage of public transport increased, like due to the operator providing transport on the last mile of the journey, opening up the public transport network to further user groups. They do however also report that once a second operator begins to provide service in the same area, the usage of the public transport network declines below the level before ride-sharing and hailing services arriving. They suggest that at this point the price competition and oversupply lead to the services becoming an alternative to the traditional public network rather than supplementing it.

A possible conclusion from these findings is that ride-sharing and hailing can have a positive influence on the usage of traditional public transport networks if they are regulated carefully to avoid an oversupply. Ride or carsharing is an essential part in the increase of efficiency of driverless first and last mile mobility vehicles. Passengers sharing the same vehicle for a portion of the journey whilst potentially having different starting points and destinations avoid that these vehicles otherwise add to congestion by undertaking too many so-called “dead-runs”, journeys without a passenger on board. Those are for example trips to and from a parking place after dropping off a passenger or when vehicles are roaming to find another customer.

It should be noted however that the opposite trend is still prevailing in emerging economies such as China and India; here personal car use is still continuously rising (Rode et al. 2015).

Whilst the media widely reports that driverless taxis no longer just being trialled but instead now becoming a “common” sight (Bell 2019 & V. A. 2018), the advantages and challenges of the introduction of an autonomous taxi fleet still require further discussion. Schaller (2018) for example states in his report that the growth of Traffic Networking Companies (TNCs) such as Uber and Lyft within New York resulted in an overall increase of car ownership. This is likely due to vehicles being purchased for the sole purpose of providing transport to others as a business, which in turn leads to an increase in the mileage driven and ultimately causing an increase in congestion (Schaller 2018). The report suggests that instead these services should be legislated to operate in rural areas which feature fewer transport nodes. This is relevant in regards to the overall aim of this research, as the integration of driverless first and last mile mobility vehicles into existing public transport systems are likely to encounter the same issues as TNCs. This is due to the operation modus of network based on demand taxi services being akin to the current understanding of how driverless taxis will be used. Driverless first and last mile mobility vehicles are the likely to be used to close the gap between the existing traditional public mass transport services such as buses and trains and the start point or destination of the journey and subsequently may lead to a better coverage of areas with currently poor connection to the public transport system (KPMG 2015).

In principle, driverless vehicles could potentially become roving taxis, readily available to transport anyone anywhere at any time with a theoretical 100% utilization (KPMG 2015). Aarhaug et al. (2018) however argue that this would result in an increase in traffic due to the driverless vehicles roaming empty, so-called “dead runs” awaiting a new booking. They may further increase traffic by driving themselves to a parking space.

The authors also expect a driverless on-demand transport system to induce further demand and also lead to journeys being transferred away from traditional means of travelling towards these vehicles. Maciejewski and Bischoff (2018) argue that the size of the vehicle fleet within a system has a significant impact on the traffic situation; a small fleet of vehicles will increase the traffic, a large fleet they argue instead, will have a positive effect.

However, the authors believe that small fleets can be deployed efficiently in small areas to avoid dead running over long distances. Therefore, to avoid replicating the negative impact the NTCs had on the traffic situation, driverless first and last mile mobility vehicles should be deployed in areas where are not competing with existing networks such as in large parks or business parks. In these areas, the vehicles should be to function as an addition to the existing public transport network and make it more accessible rather than being a direct competitor to it in the short journey sector. Whilst Begg (2014) argues that shared driverless cars will become busses whilst driverless busses will function like trains, potentially providing efficient mass transport with very low infrastructure costs and a high degree of flexibility.

The majority consensus is however that the aim for these vehicles should not be to reduce busses and trains but instead to add a further service with the ultimate aim to create transport links that reach from the starting point to the final destination and thus are attractive enough to replace personal vehicles. As existing public transport systems are designed to service the major commuting arteries within cities, an application in the first and last mile sector would reduce the difficulties experienced by 12% of travellers in England in reaching their final destination (NTS 2019). A concept supported by Wadud (2019) who suggests that to combat the increase of inner-city congestion and to encourage a growing uptake of shared mobility options, it is necessary to provide a well-connected, convenient system in which the passengers can use their time productively, perhaps as mobile workplaces, movie theatres or even relaxation booths.

Overall current last mile transportation as it stands today, shows that legislation is required to deal with the introduction of novel technologies and mobility offers such as driverless taxis or TNC which otherwise may cause issues such as increasing congestion or miles driven. Driverless technology will also have an impact on the trains, allowing trains to run shorter distances apart, increasing the service frequency and subsequently increasing the capacity of the current public transport network. The technology is already in use in some applications, such as the fully automated Vancouver SkyTrain, therefore the expectation is that there will be a gradual transition for this type of rail system to full automation (Begg D. 2014, Railway Technology).

Aside from permitting an increase of efficiency in the public transport networks, each privately owned vehicle could also follow the same path. The average car is currently parked at home for 80% of the time, 16% of the time parked elsewhere and only used for 4% of the time (Bates, J. Leibling D. 2012).

Another significant benefit to society would be the restoration of mobility and subsequently independence for those unable to drive themselves such as the elderly or disabled. An increasingly important aspect as the demographic with traditionally low car ownership such as students and the elderly is progressively growing in numbers (Rode et al. 2015).

According to the NTS 2014, the majority of young people who do not hold a driving licence, state the costs of learning to drive, insurance, vehicle purchase and general motoring costs as the main barrier as for the elderly it is safety concerns and physical difficulties as the predominant reason (Tranter et al. 2015).

New concepts which are emerging to provide mobility for those who require it in rural areas are suggesting that the majority of the cost of rural transport is human labour. Due to the fact that an estimated 40% of the operating costs are drivers' wages (Begg 2014), concepts such as the "Rural Wheels" program run by the Cumbria Council, are operated by volunteers (Cumbria Council 2016). As the vehicles are purchased and maintained by the council and booked on demand, driverless vehicles could potentially solve this issue, despite likely higher initial purchasing costs. (Meyer & Beiker 2016). This is supported by Liu et al. (2016) who state that the reduction of the human cost will allow more travellers to use on automated demand services. Beyond a reduction of running costs, a survey further identified a business opportunity as passengers stated that they would be willing to spend an average of 3.03 pound on each journey that is currently free for them (CATAPULT Transport Systems 2015). In the paper Think Act Freese et al. (2014) argue however those rural areas will be unable to scale such shared mobility solutions and which will subsequently widen the gap between rural and urban areas. This introduces the challenge to find alternative payment systems such as urban mobility systems financing the upkeep of rural offerings.

2.1.3. Economics

The automotive industry is undergoing a multi-faceted change in which the emergence of new technologies in the areas of drivetrain, connectivity, shared mobility and automation. An area now frequently referred to as CASE (**C**onnected **A**utomated **S**hared **E**lectric) (Ehlers 2018). 82% of the industry executives are expecting a significant disruption of the industry in the coming five years according to the 2016 Automotive Executive Survey by KPMG (KPMG 2016).

The drivetrain revolution towards electrification has been on-going for the past years; 521,343 electric vehicles were sold globally in 2015, with an overall growth of 50-55% in sales.

More recently, connectivity and digitalisation have risen to the top on the list of key trends, from previously 10th ranked by the automotive industry executives (Frost & Sullivan 2016). Ranked sixth, MaaS was a new entry to the key trends for 2025 (KPMG 2016).

This is supported by the Frost & Sullivan prediction of mobility gaining increasingly more attention, as OEMs (Original Equipment Manufacturers) start to invest into mobility services in the form of CaaS (Car as a Service), like in the case of Daimler with "MyTaxi, Car2Go and moovel" (Frost & Sullivan 2016).

The Head of Automotive KPMG John Leech expects "the arrival of electric shared-use autonomous vehicles in urban settings by around 2030" (KPMG 2015). The market growth in the sectors of traditional car sharing (company owned) and P2P (peer to peer i.e. privately owned and shared vehicles), a rise of 50% within two years to 11.49 million and 2.45 million respectively in 2016, leaves no doubt for a rapidly growing demand (Frost & Sullivan 2016). Mobility is also described as having "the highest growth potential for the years ahead" by the Roland Berger Strategy Consultants in the paper "THINK ACT" (Freese et al. 2014). Shared mobility in particular is now "deemed a mass phenomenon" as in major cities across the globe shared mobility operators now handle "10% of public passenger transportation, up from less than 1% in 2014" which is expected to create 3.7-5.6 million Euro annual revenue by 2020, with a projected annual growth rate of 30% (Freese et al. 2014).

New payment and financing systems are also likely to emerge alongside the new technology as it allows for novel ideas (Kamargianni et al. 2015). Personalised marketing is already widely used in applications such as social media where "curated content" is shown and advertisement is based on the user's preferences and behaviour.
Similarly to social media platforms, connected vehicles are expected to learn a lot about the individual user in order to provide them with a tailored service in regards to their radio settings or climate preferences. This could lead to personalized marketing being placed in the vehicle with the passenger potentially opting into watching them in return for a cheaper or free transport service. As a consequence, passengers could pay for the service with their time and attention.

The improvement of the journey experience through better connectivity and greater personalisation of the vehicle itself is also financially interesting as it is valued at 37 pence per trip, a value which increases to one pound if travelling for longer than an hour. Similarly, better interconnectivity between travel modes is valued at 76 pence per trip, a value pool of 0.5 billion pound according to a study by CATAPULT Transport Systems (2015). On this basis, M. Bhaiji states that; “people will pay for a premium journey experience, not a premium driving experience” and subsequently “the car manufacturers need to radically rethink their relationship with the consumer” (KPMG 2015).

Murray Raisbeck proposes that the necessary connectivity of a driverless vehicle might also establish location-based insurances. Similar to the current black boxes offered by insurers, vehicles could now be charged according to how many metres were driven in specific locations and situations (KPMG 2015). Yet this could provide further issues by distorting the mobility costs for those who are already disadvantaged by living in problematic areas. Ultimately, John Leech argues that “the consumer should be the main beneficiary” of falling insurance costs, just as emergency brake systems already entitle owners to lower insurance rates (KPMG 2015).

However, the downsides to the expected business opportunities are likely issues regarding entire business types becoming obsolete such as taxi drivers. Independent repair shops are likely to face pressure as well, as the systems will possibly become too complex to be repaired by anyone other than the manufacturer. Insurers are likely to benefit through better data and supervision, but will ultimately lose out due to a reduction in accidents (KPMG 2015). Overall the advancement in automation will cause a reduction in the employment numbers in certain industry sectors, however other industry sectors are likely to grow such as the health care and social assistance sector, which will add around 5 million new jobs over that decade. This about one third of the projected job growth in other industries into which some of the existing jobs which will be erased through automation will have to migrate (West 2015).

2.1.3.2. Cross Industry Development

The general consensus within the industry is, that cars will change from being a stand-alone product to being a service, requiring continuous developments and updates (Spulber et al. 2016). As a conclusion, many automotive executives believe there will be a shift in the customer relationship away from the OEMs to the ICT (Information Communication Technology) companies such as Google or Apple, as they are experienced in providing continuously updated software for computers and cell phones (Gao et al. 2016). This is due to many automotive OEMs currently focusing on production and technology-led business model and subsequently not being able to cope with the demands of their connected customers (KPMG 2016).

However, some see the future more brightly; "We see Google and Apple as "frenemies", we compete and learn from each other" (Zetsche 2016). A view that is supported by M. Bahiji (Assoc. Director Strategy Group KPMG UK); "The traditional car manufacturers face disruption, but not defeat by the tech interlopers", describing the current efforts by Google as a trial platform for their software, rather than a serious competitive product challenging the established manufacturers (KPMG 2015).

As a result, the automotive industry is growing partnerships to cut costs and share technologies (Frost & Sullivan 2016). This development is likely to create a new network of companies who work together to provide mobility; the OEMs will provide the hardware, possibly sold to a service provider with the software of an ICT company which is connected through an infrastructure provider. This will then create the challenge of dividing the revenues between those involved, leading to changes to the automotive industry as a whole. Dieter Zetsche (Daimler Benz CEO 2006-2019) describes it in an interview as: "Building cars remains the core of our business. But it will become part of an overall ecosystem we are currently developing" (Zetsche 2016). Purchasing the software from an ICT for their product might even be the smarter choice for the OEMs as Raisbeck points out; consumers may be more comfortable trusting a software developed by Apple or Google as they have the experience in this field as opposed to Ford or Volvo for example and the quality of this software is the key to their safety (KPMG 2015).

2.1.4. Safety

A SWOV (2017) forecast has suggested that by 2020, developments in the field of vehicle automation could result in an annual decrease of 10 road deaths and 300 serious injuries in the Netherlands alone. The forecast for 2030 is that this decrease in road casualties will be around 10 times higher, meaning that for the Netherlands there could be a reduction of around 90 road deaths and 3300 serious injuries per year. This does not include the effects of new technology such as electronic stability control being introduced to vehicles, which is expected to reduce the number of road deaths by around 10% per year and the number of serious injuries by 100 per year for 2020 as well as 2030.

Those statistics are playing an important part in influencing public sentiment towards autonomous vehicles, however, the safety of the pedestrians who are likely to disrupt the path of the vehicle is seen as equally important. Results from initial trials conducted with the Lutz Pathfinder in Milton Keynes show that 61% of adults there would be interested in using an autonomous vehicle, well above the national average of 39% (CATAPULT Transport Systems 2016).

This suggests that the general safety perception of these vehicles nationally is still apprehensive, yet can be changed dramatically by a small-scale demonstration in which the public can experience the safe operation of these vehicles. Thus previously discussed trials in enclosed environments will likely be the correct approach to introducing these vehicles and demonstrating their safe usage and benefits. This also provides the technology with a space to develop from the infant stage to a tested and proven solution which can be deployed as part of regular traffic.

Some companies, such as Google, Volvo or Uber, are running trials with their automated vehicles (SAE Level 4/5) on public roads, where certain US states, such as Arizona, have changed their legislation to allow the testing of automated vehicles (Ducey 2015). Whilst the majority of these test went unnoticed by the general public, the incidents and accidents which involved automated vehicles did make international headlines.

In a particular case, an automated vehicle operated by UBER killed a person who attempted to cross a road late at night on March 18th 2018. The incident report provided by the NTSB (2018) indicates that the vehicle sensors did recognise the person, the automation software however did not react appropriately and lastly, the safety driver was not sufficiently alert to avoid the collision. This incident highlights the complexity of the public road space and that the automation systems are not yet capable of coping with all eventualities. It can be argued therefore that controlled environments are, at this development stage, the more suitable test environment due to the lower complexity in regards to the potential scenarios.

Prior to the technology being released into the public space, the question of liability needs to be resolved as it is safety relevant. Under current traffic laws, the vehicle driver is ultimately responsible for his vehicle; the condition of it and its movements, thus when the vehicle is no longer owned by an individual and no longer driven by a human driver there is a lack of clarity. As demonstrated by the UBER incident above, if the vehicle software for example is not kept up to date it can be a significant safety risk.
The issue is further complicated as these vehicles are likely to be made up of several essential components; the mechanical aspects and the software, which itself may rely on a map provider and a connection to a road-side infrastructure provided and sustained by the local highway agency (Hevelke 2015). This further supports the argument that a controlled environment with a single vehicle operator who is responsible for the entire system, is a safer solution to explore the initial stages of driverless technology.

2.2. User Experience

The acceptance of driverless first and last mile mobility vehicles by the general public is key for the technology to be a success. The user acceptance is shaped by a number of factors, mainly the user experience which consists amongst other areas, of the interaction with the vehicle and the physical comfort.

2.2.1. User Acceptance

Public Perception

The view of the general public in regards to driverless vehicles is very mixed and highly dependent on the level of automation. Schoettle and Sivak (2016) found that only 15.5% of people would like to engage with a fully automated vehicle, with this number increasing to 38.7% with partially automated vehicles. They further report that these numbers have not changed significantly from their first survey in 2014 to the follow up one in 2016, a result which may be a surprise considering the increased publicity and successful trials of driverless vehicles. These results, however, are likely to have been influenced by promotional material rather than experiences. Yet, if evaluating the user acceptance following an experience, the likely case is that the responses will be directly influenced by the hedonic motivation or the joy people felt due to the novelty factor (Madigan 2017). It is therefore argued by Nordhoff et al. (2016) that the developers of driverless first and last mile mobility vehicles have to find ways to carry over this enthusiasm by providing users with a comfortable experience whilst also creating opportunities to use these vehicles as social meeting or workspaces.

A number of studies have shown that cultural, gender and age differences influence the willingness to trust and use automated vehicles (Kyriakidis et al. 2015, Schaefer et al. 2014).

A point that highlights that a driverless first and last mile mobility vehicle has to cater to a range of different users which all have to be considered. In order to accomplish that, Grush et al. (2016) state that the focus in the development should be in the user requirements and preferences, to avoid a one fits all approach.

Automation

Summala (2007) further argues that four separate variables impact on the overall comfort experience in vehicles: the vehicle-road system, the rule-following, progressing well with the trip, and safety margins.

Out of the four variables, two cannot be directly altered by the passenger, a driverless vehicle hypothetically follows all rules and the user also has no influence over the traffic. The two remaining ones, however, could be influenced, the vehicle-road system, if the vehicle is equipped with a variable suspension setup (air-ride) and within a safe operating window, the safety margins. The safety margins such as merging or following distances could be influenced in a driverless scenario by the "driver" of a vehicle. This could potentially give a passenger the option to "regain" some control over the vehicle and regain some of the control they would have had as a driver, subsequently this could be interpreted as the most influential aspect over the perceived comfort.

Not giving the option to the user to alter the following distance to another car or chose to initiate an overtake manoeuvre, if it is determined to be safe by the system, could result in a lack of willingness to use a system that is entirely controlling.

An experience of discomfort could also lead to unnecessary interventions with the vehicle automation system, which may interfere with the normal functions. Users exposed to discomfort through the automation may attempt to take over control in order to make minor corrections which are not safety relevant.

Pain-Points (in current public transport)

The CATAPULT Transport Systems (2015) survey established that 75% of all journeys involving public transport in the UK involve negative experiences, so-called pain-points, which are likely to also have an impact on the consumer satisfaction in driverless first and last mile mobility vehicles. The pain-points vary depending on the transport mode; 25% of rail users stated 'poor value for money' as the greatest issue, with the lack of space due to crowding also affecting 20% of rail customers. Another important issue is the perceived inconvenience when travelling by rail, due to the dependence on onwards connections, which is particularly important as surface rail journeys are on average made up of 2.74 travel stages (DfT 2013).

This means that on average each journey includes two changes between modalities, a number likely to increase if first and last mile mobility services become part of regular journeys as well. The ease of switching between transportation modes is therefore key to a reduction of pain-points. 16% of users cited that a better connection between rail and bus services, such as directly linked stations, would be the main reason for an overall improved journey (DfT 2013). The current government strategy, as a consequence, focuses on smart ticketing to provide a more interconnected payment system which allows public transport users to change between services and networks without having to purchase several individual tickets.

Limited connectivity within the vehicles, through the lack of on-board Wi-Fi or poor network coverage, which 14% of rail users note as being affected by, is a further point that can already be addressed (CATAPULT Transport Systems 2015). A potential solution could be the integration of cell phone network access points within the vehicles as connectivity is becoming increasingly important as "72% of the UK travelling public now own smartphones", a number that is forecasted to increase to 81% by 2017 and more importantly "54% already consider them to be an essential part of their journey" (CATAPULT Transport Systems 2016). Smartphones already provide an improved and integrated service with applications such as "Trainline", the No.1 downloaded app reaching over 9.4 million users (Trainline 2016). These applications allow travellers to check train times, receive real-time information about delays and book their paperless tickets which are checked at barriers via QR codes displayed on the phone screen.

The rapid growth in smartphone connectivity could be used to not only provide the consumer with data via their smartphone but also gather data about demand, peak times and traffic flow to further improve the service. According to the IMAGINE traveller survey, 57% of travellers would not mind sharing their data for an improved service, which could provide great insight into traveller movement.

The paper “Travelling in a Changing World” discusses various way to use the data to provide a better service to the users, such as using geotags placed by the users to instantly locate problems in the network such as broken ticketing machines or full bins (Jain, J. and Glenn Lyons Eds., 2012). However, not all travellers can access those services through a smartphone and require alternatives. Most importantly, this refers to the elderly demographic which is also one of the most mobility dependant (Webber et al 2010).

Shared mobility itself has the potential to create a new pain point which could become important: the lack of personalisation in shared vehicles. Private cars typically represent an extension of the personal living space, containing personal items and are set up to individual preferences regarding the infotainment system or the climate control for example. A notion that ought to be carried over to autonomous shared vehicles, here the high degree of connectivity could provide the opportunity to store and subsequently customise every vehicle according to the passengers’ preferences. Climate control settings could be remembered as well as personal stored data such as images or documents could be available to the user via the infotainment system (KPMG 2015). Liberated from the need to control the vehicle, this would allow users to use their freed-up time to be more productive; read reports or books, watch the news or prepare the next business meeting. Overall an ‘end-to-end-user-centric’ travelling experience needs to become one of the key mobility goals in order to gain the interest and long lasting support of users (CATAPULT Transport Systems 2016).

Beyond singular pain points during a journey, it is also crucial to understand the various traveller types as they also affect how passengers experience a journey. ‘Dependant Passengers’ have particular requirements that differ greatly from ‘Progressive Metropolites’, as they are unable to drive themselves, making them dependent on public transport services and other mobility offers (CATAPULT Transport Systems 2015 p.23).
Dependent Passengers represent 21% of the population and 18% of the journeys undertaken and are an important demographic to which the technology needs to cater.

The ‘Progressive Metropolites’ are being identified as the “ideal lead users for the new Intelligent Mobility solutions” as 70% state that they are willing to be the first trying new technology (CATAPULT Transport Systems 2015 p.11). This highlights the challenge of the ethical responsibility to design a product which caters to the less affluent demographic with more challenging design requirements. This becomes apparent when comparing the ‘Progressive Metropolites’, who only represent 14% of the population but generally have high disposable incomes to the ‘Dependant Passengers’, who represent 21% of the population with generally low household income (CATAPULT Transport Systems 2015 p.14).

This only exemplifies one particular point, however further mobility groups such as ‘Default Motorists’ and ‘Urban Riders’ exist with their particular requirements. The ‘Default Motorist’ undertakes the majority of the journeys (37%) however the vast majority of those are undertaken within a private vehicle and are therefore difficult to capture within the public transport user requirements. Whereas over half (57%) of the ‘Progressive Metropolites’ can already imagine leaving their privately owned cars behind and change to shared mobility solutions such as peer to peer car sharing(CATAPULT Transport Systems 2015 p.13). The ‘Urban Riders’ are the obvious target group for last mile mobility offers as only 40% of them hold a driving licence and predominately undertake local journeys in an urban environment.

Accessibility

As a positive effect, the introduction of autonomy is also largely expected to dramatically change the interior layout of driverless last mile mobility vehicles, creating vehicle cabins without a predefined direction of travel. The problem of missing legislation in this regard is exemplified by the issue of wheelchair accessibility and restraining systems as none of the current standards cover road vehicles capable of travelling in more than one direction (BS ISO 10865, BS ISO 10542). As a consequence, all currently existing prototypes are promising solutions to those issues as they are essential to the marketing strategies of these vehicles, but none have a clear solution which would fulfil either legislation.

The importance of this issue is reaffirmed by 80% of the automotive executives who view the legislation as having a high impact on the development of their industry (KPMG 2016).

2.2.2. Comfort Experience

Le Goff (1991) demonstrated that the concept of comfort has reached the public space, including urban public transport. Loriquet et al. (2017) further argue that comfort is now key to the interior design of vehicles as it impacts on the quality of user experience and therefore, as previously discussed, also on the willingness to accept this new vehicle type. A concept which Richards (1980) already observed, stating that comfort carries a significant role in the adaptation of new vehicle types, as an improvement in the comfort experience during a journey will lead to an increase in the willingness to use this particular vehicle. Especially in the context of driverless shared mobility, the passenger comfort plays a critical role; as it should be "high to archive acceptance and usage of the automation and improve passenger safety" (Parasuraman et al. 1997).

Comfort is defined by the Oxford Dictionary (2010) as "a state of physical ease and freedom from pain or constrain". Whereas "Discomfort is seen as an unpleasant state of the human body in reaction to its physical environment" (Vink and Hallbeck 2012 p271). Various further definitions of comfort have been introduced in the current literature. Pineau (1982) included everything that "contributes to the human wellbeing and convenience of the materialistic aspects of life", whereas Slater (1985) defines comfort as a pleasant state of physiological, psychological and physical harmony between a human being and the environment. That comfort goes beyond the physical aspects and does include the psychological aspects, such as being free from mental pain, worry and disappointment is argued by Dumur et al. (2004), which aligns with the definition by Evans et al. (2010): comfort is "a general mood or emotion which is pleasant but not especially aroused, tense or activated".

Comfort definitions as seen above, are usually rather vague however a few common aspects are agreed upon within the literature and are best summarised by De Looze et al. (2003):

1. Comfort is a construct with subjective and personal elements,
2. Comfort is influenced by psychological, physiological & physical factors
3. Comfort is a reaction to the environment

Vink and Bauer (2011) add that there is a gap between the experience of discomfort and comfort where a person does not experience discomfort but also not comfort as they suggest that in order to experience comfort they have the experience more positive things than expected.

For a comfortable experience in regards to a product, Vink et al. (2005) include “a convenience experience of the user during or just after interaction with the product”. It can be argued that the general trend is now to focus on designing a pleasurable experience, with convenience and comfort in mind rather than only trying to avoiding discomfort. Hassenzahl et al. (2013) also noted that society is changing its focus from “well-fare” to actively pursuing “well-being”, defining the new challenge of designing for happiness.

A widely used model to describe comfort in regards to product comfort, and seating in particular, was developed by De Looze et al. (2003). As shown in figure 2.3., it separates discomfort and comfort into two independent outcomes which are both influenced by three main factors: the environment, the product and the human itself. The model shows at the first level the influence of the environment in which the experience is taking place, paired with the task which is conducted during the experience. The second level then includes the physical features of the product and its aesthetic impression. The two first levels are then influenced by the human itself at the third level, in the case of the discomfort it’s the physical processes which have an impact, and the comfort is influenced through the emotions and expectations of each individual.

Whilst this model was developed mainly for seating comfort, it can be used to further illustrate that there is a range of different factors influencing the user perception of comfort in driverless first and last mile mobility vehicles. The environment in which the vehicles are operating and the fact that they are moving without a driver is the base level influence on the perceived comfort.The vehicles themselves influence the perception through the physical features the user interact with, the cabin height, the handrails or the seating space. But also the aesthetic impression of the vehicles does impact on the perception, both the exterior design, which is further investigated in chapter 9.0 as well as the interior design choices.

Lastly, the passengers and their emotions and expectations, as well as their physical response to the previously mentioned physical features, also shape the comfort perception.

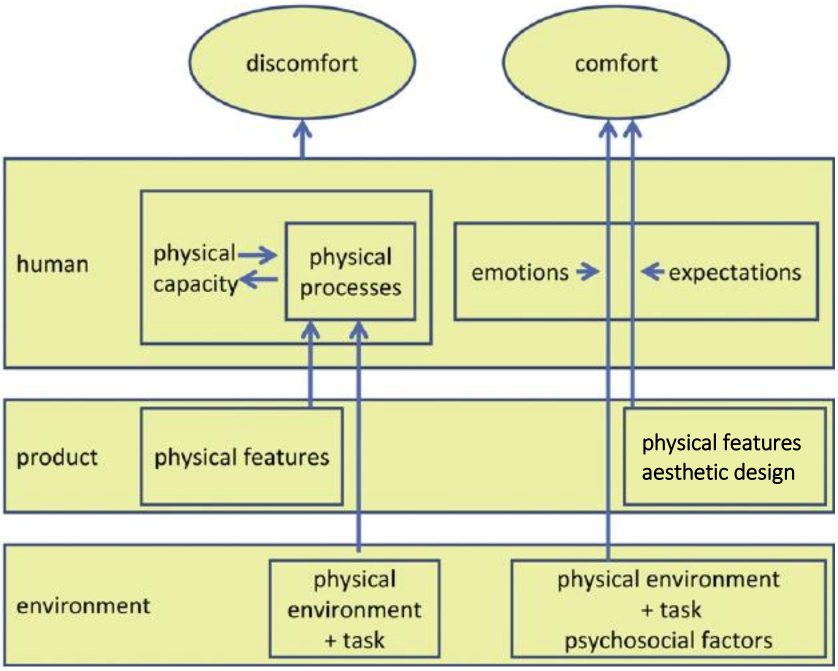


Figure 2.3. Comfort Model for sitting by De Looze et al. (2003)

Loriquet et al. (2017) argue however that the previous comfort models, whilst useful in the analysis of work-related physical complaints were too focused on discomfort.
Yet in the development of new products, as previously discussed, comfort is becoming a main factor.

Vink et al. (2011) therefore expanded on the previous models and proposed an addition, i.e. a third state in between discomfort and comfort, described as "nothing" (see figure 2.4). This further distinction is built on the assumption that comfort is more than just the absence of discomfort and requires additional delights or positive surprises.

Similar to the De Looze Model, the model also connects the expectations with comfort, stating that not only the perceived effects felt by the person but also their expectations will influence the experience of comfort. Different societies and environments will shape the expectations passengers will have for public transport vehicles. The space the interior offers, for example, passengers on the Tokyo underground are likely to have a higher crowding threshold as they experience trains on a daily basis at 164% of their capacity for over 15 years (Ryall 2017). The expectations of those passengers who do not typically rely on public transport for their mobility are likely to be more closely aligned with their privately owned vehicles.

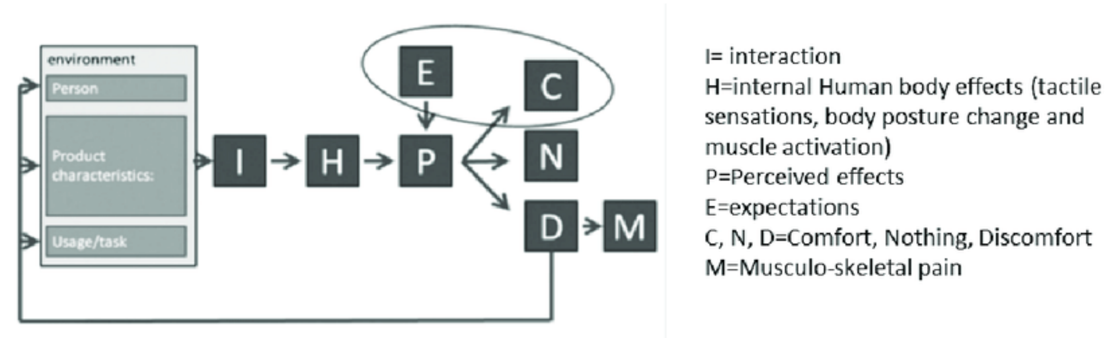


Figure 2.4. Comfort Model as proposed by Vink et al. 2011

In the field of aviation, Ahmadpour (2016) states that comfort is further influenced by several "concern categories"; control, connectedness (i.e. empathy & closeness to others), tolerance (towards the behaviour of neighbours) and privacy. Whilst noting some similarities, such as sharing the space with strangers and not controlling the vehicle, amongst clear differences such as journey time, these categories may also be applicable to driverless first and last mile mobility vehicles. In these vehicles, the passengers are not in immediate control of the vehicle itself and may only receive information about the journey progress via the vehicle HMI.

Passengers will also have to enter into a space which they may perceive as relatively small and confined with other passengers who they do not know already present. These considerations inspire the discourse about passenger comfort in driverless first and last mile mobility vehicles and the subsequent development of a comfort model for this type of vehicle in chapter 4.0.

Loriquet et al. (2017) suggest that a holistic approach of the entire journey is required to understand the comfort requirements. They call it “approche 5A” for avant - accueil - ancrage – activities – après (which translates to; before – welcoming – anchorage – activities – after) and splits the journey into five segments, each with their specific comfort requirements. The first “before” is largely based on the accessibility of the service, the cost, the crowds and the journey to the starting point. The second “welcoming” is the time period during which the passenger enters the vehicle and analyses the situation, is there sufficient seating or a large crowd. The third “anchorage” is based around the fact that travellers in moving vehicles will always seek for a place to steady themselves against, that can be the seating or handrail but also just any surface. The fourth judges if the person is, due to being sufficiently steady, able to conduct any “activity” such as reading a book or chatting with their neighbour. The last aspect, the “afterward” relates to the passenger being able to easily exit the vehicle and continue on with their journey. This model does not give insight to the particular aspects of the comfort experience and instead highlights that there is a sequence of factors throughout the journey which need to be considered.

This aligns closely with the research conducted by van Hagen et al. (2018) as part of the National Rail Netherlands effort to improve the passenger experience. The research identified three core needs for travellers; control, appreciation and freedom, which has the highest impact on the overall satisfaction. To the three core needs, a number of design principles can be related:

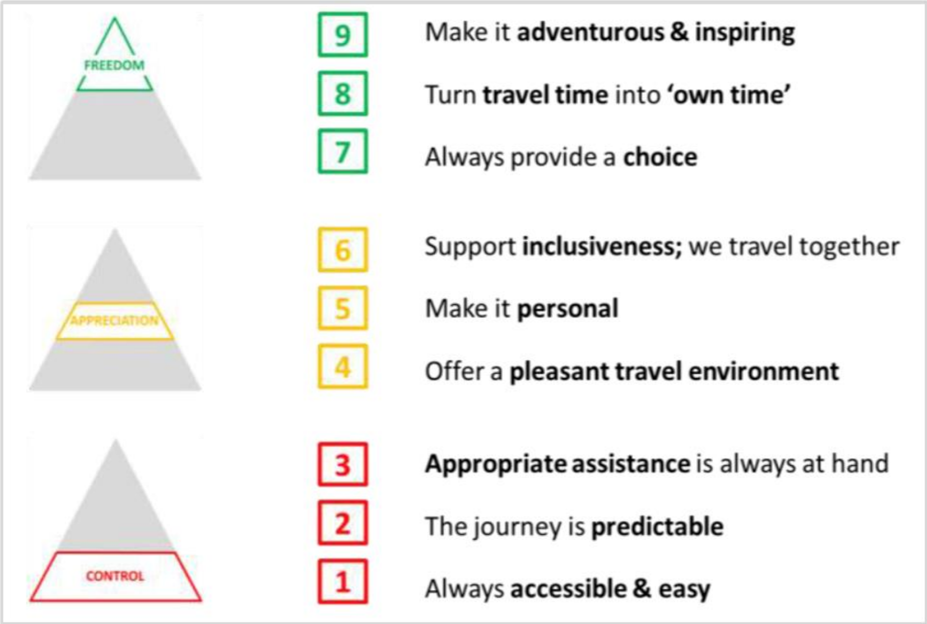


Figure 2.5. Customer Experience Design Principles (van Hagen et al., 2018)

They further suggested two further general guidelines: never leave the passenger without choice and do not aim for a "flatline" experience, instead create positive surprises and delights, leading to peaks of happiness. The overall journey experience can be described as a curve which dips and rises based on traveller satisfaction. Not every component of the journey can be a delight, however small improvements to specific parts of the journey can lift the overall satisfaction (van Hagen et al. 2018).

One of the areas for improvements can be the provision of personal space, a factor which influences all three of the identified core user needs; offering a pleasant travel environment, turning the travel time into 'own time' and making it personal. The ease of accessibility is a further area which is repeatedly established by the models above as a key component of a comfortable journey experience.

Hassenzahl et al. (2013) define "experience" as an episode or a moment of time that one went through, with sights, feelings, thoughts, motives and actions which are closely tied together and then stored in memory, labelled, relived, and communicated to others.

They further argue that the fulfilment (or frustration) of psychological needs causes an experience to become positive (or negative). Their research identified six psychological needs which they believe most important when considering what can cause an experience to be positive: autonomy, competence, relatedness, popularity, stimulation and security with relates closely with the factors identified by van Hagen et al. (2018) in figure 2.5.

Motion Sickness

It is increasingly common knowledge that differing information between what motions are perceived by the human stability organs (inner ear) and the movements observed by the eyes can lead to people experiencing nausea, generally described as motion sickness. This is the result of the human brain being confronted by contradicting information about the individual's actual and visually perceived movements.

The currently prevailing hypothesis is that the brain assumes to have been poisoned, a logical conclusion based on the confusion, which then leads to nausea and potentially to the humans' natural form of removing the "poison", vomiting (Medline Plus 2016).

In traditional manually driven vehicles the most frequent solution to combating the symptoms motion sickness is looking outside the window at the horizon. Removing this option for the passengers could lead to an increase of motion sickness which is likely to detract significantly from the benefits of driverless vehicles since the passengers would not have the ability to make use their gained time. Despite that, a lack of consideration for this issue has been demonstrated by many of the concepts currently presented by the design consultancies and OEMs (Diels et al. 2016 p.122). Many of the proposed usage concepts of driverless vehicles such as mobile workspaces (with displays), movie theatres (single large screen & windowless) or shuttles (with informative displays) incite the passengers to concentrate on a potential moving image away from the exterior.

Several key points for designing a vehicle with the issue of motion sickness in mind are noted in the chapter "Motion Sickness in Automated Vehicles – The Elephant in the room": allowing participants to anticipate the movements of the vehicle, avoiding vehicle movements around 0.16 Hz and avoiding incoherent visual and physical motion cues (Diels et al. 2016).

This presents the challenge of designing the cabin space in such a way that the full benefit of the technology can be experienced without deducting from the usability. The potential of driverless vehicles is, as previously discussed, in part defined by the ability to use the time spent in the vehicle differently and more productively.

Personal Space

Personal space, as defined by Beaulieu (2004), is attributed to the space surrounding a person in all directions, which allows a person to regulate the interactions with others without intrusion. Public transport users are frequently forced into an intimate social distance, impeding their personal space, which often causes psychological or social discomfort (Hall 1966).

The availability of personal space impacts on the perceived comfort and subsequently one of the primary reasons given for the commute with a private car is the enhanced privacy it provides (Dockendorf et al 2001, Ibrahim 2003). In shared mobility, the invasion of personal space is seen as more discomforting than an overall higher passenger density (Harris et al. 1978). However, Merat et al. (2016) point out that these factors are related, as an increase in passenger density is likely to reduce the personal space available for each passenger. Which means that those who are in the immediate surrounding seats cause more discomfort than an overall densely packed train. This is supported by Ewans and Wener (2007), who showed that a lack of personal space or perceived privacy for seated passengers in trains leads to an increase in the stress level of travellers.

To avoid these moments of discomfort, Altman (1975) argues that travellers typically regulate their private space by adjusting social interaction to desired levels with an intricate system of verbal and physical processes. The majority of the current driverless shared vehicle concepts provide space for 8-10 passengers without considering the personal space requirements and are likely to subsequently increase the feeling of discomfort (Merat et al. 2016).

However, as it is already the case in the field of furniture and interior design, designers can positively influence the experience through the space and features they provide and the authors of the "Privacy Ideasbook" provide a list of four separate aspects which impact the perception of privacy (Steelcase 2017):

Acoustical:	managing what the person can hear and others hear from that person
Visual:	controlling how much can be seen of the person and how much they see themselves, reducing visual distractions from the surrounding environment
Territorial:	providing a physical space occupied by the person alone
Informational:	keeping any analogue, digital or verbal data/information confidential

These learning may be applied to the interior design of shared spaces in the automotive area, however, it is important to bear in mind that the analysis above is based on western culture and behaviour, as people with different cultural backgrounds have differing perceptions of personal space, they not only structure spaces differently but experience it differently, because the sensorium is differently "programmed" (Hall et al. 1968).

2.3. Summary & Conclusion

The review of the current literature clearly demonstrates the positive benefit driverless vehicles can bring to society as well as the economic opportunity this technology represents.

However, the key trends identified by the automotive industry in regards to last mile mobility and driverless vehicles focus mostly on vehicle connectivity and the vehicle engineering (rated most important in a study by CATAPULT Transport Systems (2015). They further identified the improvement of existing mobility services integration and the passenger-vehicle (second most important factor in the study) (CATAPULT Transport Systems 2015). This is underlined by the Federal Transport Administration (FTA), part of the US Department of Transport (USDOT), putting “great emphasis on connectivity” (Liu R.; Fagnant D. J.; Zhang W. B. 2016).

This leaves a knowledge gap regarding the passengers in this new vehicle type, aspects such as the user experience and comfort requirements. The radical changes caused by the elimination of the drive train and controls will liberate the interior of driverless vehicles, yet based on the literature review there appears to be limited expertise and research conducted in this field. The changes provide a unique opportunity to investigate solutions to existing pain-points and introduce novel concepts for the in-ride passenger experience. Mobile workspaces, movie theatres or even relaxation booths have been suggested but normal passenger vehicles, taxi like shared mobility solutions should be considered as well.

This provides the basis for this thesis; researching passenger comfort and designing the interior space of a driverless first and last mile mobility vehicle. This will include investigating issues such as handicap previsions, seat arrangements as well as infotainment and HMI offerings.

1st Objective Part 1

This, therefore, fulfils the first part of the first objective, which aimed to review the current academic literature in the areas of comfort, driverless technology as well as shared public transport. The information gathered as part of the literature review will be used to inform the development of the comfort model in chapter 4.0, the benchmark in chapter 5.0 and the creation of the personas and scenarios for the context of driverless first and last mile mobility (chapter 6.0). It will also guide the evaluation studies (chapters 9.0-14.0) of the design created in chapter 7.0.

3.0. Methodology

3.1. Iterative & User Centred Approach

Norman (1988) states that designers knowing that a product needs to be intuitive is not enough, some design principles are needed to guide the design and the research on which it is based. The methodology for this thesis is based on a fusion of principles from the product design field in order to provide a structure to the academic research, resulting in a user centred and iterative design research approach. It is mainly based on a combination of iterative design and formative research in a real-world context and is known under a variation of names: design experiments (Brown, 1992; Collins, 1992), design research (Cobb, 2001), and development research (Richey & Nelson, 1996; van den Akker, 1999).

Cobb (2001) splits the method into four stages:

1. The development of a theory.
2. The derivation of principles for design from the theory.
3. The translation of the principles into concrete designs.
4. The assessment of the designs to test whether they work as anticipated.

This method provides a direct route from the theoretical inception of a project to a finished working design and which does, however, assume a fully developed theory which can be directly translated into a complete design (Edelson 2002). The method chosen for this research however aligns more closely with the current understanding of iterative design research, in which design plays a significant role in the whole process, not only during the evaluation (Brown, 1992; Kelly & Lesh, 2000; Richey & Nelson, 1996; van den Akker, 1999). In this approach, the initial concept is only developed loosely and refined at each of the following stages.

The basic stages of the iterative design process do not divert too far from the aforementioned developed by Cobb (2001), the main differentiation is that following each evaluation the design theory is reviewed and potentially amended based on the new learnings. This, in turn, leads to a new design iteration for each of the successive stages.

Therefore, throughout the following work, changes were made to the comfort model as well as design and their impact were documented after each of the evaluation stages.

Following the above-mentioned definition for iterative design, an initial comfort theory will be developed, through a traditional review of the current literature regarding driverless technology and comfort theory, conducted in chapter 2.0. This provides the starting point for the development of a comfort model for driverless first and last mile vehicles in the following chapter 4.0. In order to validate the comfort model and test its suitability as a design guide for this type of vehicle, a vehicle design for a driverless first and last mile mobility vehicle, the MiCar concept, will be created. This design process centres on the user and will be involving potential end-users in every step of the development.

There is a number of ways the potential end-users can be involved in the design process, but the important notion is that they *are* involved. The term "user centred design" was first used by Norman (1986) when he recognised the needs and interests of the end user. In his work, he stated the need to fully explore the needs and desires of the user and their intended uses for the product, which requires the involvement of the actual users. The involvement of the end-user is typically during the phases of requirements gathering and the evaluation and trials.

Preece et al. (2002) conclude that if done correctly, it will lead to more effective, efficient and safer products and will further contribute to the acceptance and success of the product.

The involvement of the end-user, therefore, is a key part of the research methodology used in this thesis. Consequently, in chapter 6.0 the end-users will be identified including an in-depth investigation of their needs. As a clear identification of the stakeholders, including a thorough analysis of their needs is required prior to engaging in the design process. Furthermore, these findings will not only inform the design process but will also be used to select the appropriate participants to be involved in the design evaluations (chapter 9.0-14.0). These potential end-users can be involved in the design process in a number of ways as shown in table 3.1.

Table 3.1. Involving users in the design process adapted from (Preece et al. 2002)

Research method	Purpose	Stage of Design Cycle
Background interviews and questionnaires	Collecting data related to the needs and expectation of design alternatives, prototypes and the final artefact	At the beginning of the design project
Sequence of work interviews and questionnaires	Collecting data related to the sequence of work to be performed with the artefact	Early in the design cycle
Focus group	Include a wide range of stakeholders to discuss issues and requirements	Early in the design cycle
On-site observations	Collecting information concerning the environment in which the artefact will be used	Early in the design cycle
Role-Playing, walkthroughs & simulations	Evaluation of the alternative designs and gaining additional	Early and mid-point in the design cycle

	information about user needs and expectations; prototype evaluation	
Usability testing	Collecting quantitative data related to measurable usability criteria	Final stage of the design cycle
Interviews and questionnaires	Collecting qualitative data related to user satisfaction with the artefact	Final stage of the design cycle

All these techniques will be relied upon in this research at the appropriate stages:

- The MIRA Technology Park scenario will be developed through background interviews and questionnaires conducted at HORIBA MIRA (Chapter 1.0, 6.0 & 7.0).
- Focus groups and questionnaires will be used to analyse the appearance of the current vehicles (Chapter 9.0.).
- On-site observations of a small sample of driverless vehicle examples will be conducted as part of the benchmarking.
- Following the design development, the evaluation stage included role-playing and walkthroughs using an ergonomic buck (chapter 12.0.).
- A final set of tests including interviews and questionnaires to evaluate the overall journey experience, will be undertaken with the Mixed Reality Simulator (chapter 14.0.).

3.2 Automotive Design Process

The traditional automotive design process consists of a number of steps, beginning with a concept sketch which then evolves through several models, first digital and then physical, into a refined production ready product. The initial stages of this process typically are also user centred and consist of numerous iterations to the initial concept.

The design process, therefore, is closely aligned with the research process described above.

Table 3.2. The design process: step by step (Daimler 2019)

1. Drawing/rendering
2. Package
3. Virtual model
4. 1:4 clay models
5. 1:1 model
6. Model selection
7. Interior sketches
8. Interior clay model
9. Colour & trim/control and user interface concepts
10. Equipment models
11. Final model
12. Series production data
13. Data control model

The first three phases of the process are most relevant to this research project, where the initial concept sketches are used to visualise the theoretical findings. This vehicle concept can then be used as a basis for the following evaluation stages.

At the start of any design project, the critical attributes are laid down, which in this case are the learnings from the comfort model and benchmarking exercise. Based on these, a designer can then produce the first proportional models for the new vehicle, sketching either on paper or increasingly more often digitally. In this phase, a large number of concepts are created to establish the general direction and then are slowly refined to a small number varieties of a singular design direction.

During the phase of refinement to a single direction, the vehicle package, which allocates the occupant and component space within the vehicle is developed simultaneously and evaluated in combination with the design. Digital models are then created to further inform the design process and allow designers to view their work as a three dimensional object. This allows for a more concrete and complete version of the concept to be developed.

Exacting lines and curves can now be modelled and an initial engineering package can be included, at this stage the digital modellers work closely together with the designers and human factors specialists, among other experts, to refine the concept to a finished design (BMW 2012, Nissan 2017). At this point the Mixed Reality simulator can be used as an additional method of experiencing the design, providing all involved with another evaluation tool.

3.3 MiCar Design Concept

The previously introduced MiCar scenario will be used as a platform to convert the theoretical work in regards to the comfort requirements into a vehicle concept which in turn will be used as a basis for the evaluation of the theory.

The vehicle concept will incorporate the data from the scenario and persona development in chapter 6.0, the learnings from the benchmarking (chapter 5.0) as well as responding to the guidelines developed as part of the comfort model (chapter4.0). The vehicle concept functions as a visualisation and communication tool to the non-expert audience which will be involved in the trials. The findings from each of the trials can then be implemented in the design, using the previously discussed iterative design process as guideline.

Ultimately the vehicle concept will also be used as a basis and visualisation for the proposed design guidelines for driverless first and last mile mobility vehicles (chapter 15.0).

4.0. Comfort Model

4.1. Introduction

The view of the general public in regards to driverless vehicles is very mixed and highly dependent on the level of automation. Schoettle and Sivak (2016) found that only 15.5% of people would like to engage with a fully automated vehicle, with this number increasing to 38.7% with partially automated vehicles. They further report that these numbers have not changed significantly from their first survey in 2014 to the follow up on in 2016, a result which may be a surprise considering the increased publicity and successful trials of driverless vehicles.

The successful acceptance and uptake of driverless vehicle concepts by the general public, depends on these vehicles being perceived as comfortable, seamless, and intuitive (Nordhoff et al 2016, van der Laan et al 1997). This can be expected to be especially relevant during the introductory period of such vehicles in which the general public may be hypercritical. To date, the development and evaluation of such vehicles has largely focussed on the underlying technology, its performance, and other road users' perceptions (Bell 2015). In contrast, the design of the passenger experience has received relatively little attention. The initial impression of the vehicle appearance, the interaction with the vehicle and the physical comfort requirements are all likely to affect the overall acceptance of these vehicles. Accessibility for passengers with mobility impairments and other disabilities is also a critical aspect of these vehicles which requires further development.

Based on this, the assumption for this research is therefore that a positive user experience is the most critical requirement for such vehicles (Diels & Bos 2016). Subsequently, there is a need for a theoretical framework which disseminates the different aspects which influence passenger experience and comfort in a driverless first and last mile mobility context.

The basis for this development lies within an analytical tool, which has a long history of being used in automotive design work as well as an existing comfort model:

- The Kano Model of Consumer Satisfaction will, in the context of this chapter, aid to illustrate why this chapter focuses on the interior design features and human factors as well as the HMI of driverless last mile mobility vehicles.

- The existing comfort model, as will be discussed in detail below, was developed to provide insight into the passenger comfort requirements during air travel. As discussed in section 4.3., it can be used as a suitable starting point as in both contexts the passenger experiences the journey in a shared environment with no direct influence over the vehicle movements. Furthermore, the infotainment systems are the main point of information in both contexts however the difference in journey duration does differ significantly.

4.2. Kano model

The Kano Model considers product satisfaction as a function of its attributes and customers' expectations of these attributes (Kano 1984). Applying this tool, product features are categorized into five groups based on customer satisfaction. The relation between all five categories can be seen in the form of a graph as illustrated in figure 4.1 (Verdyn 2013).

Most customers can name the performance figures of a product and subsequently are most aware of such "performance" features (see the middle function in figure 4.1). Information such as the maximum speed or the battery pack capacity of an electric vehicle is well understood. If they are executed well customer satisfaction increases and reversely, decreases satisfaction if executed poorly.

Features, which can be categorised under the “threshold” group, are essential to the product and subsequently can cause grave dissatisfaction with the product if missing (see the bottom function in figure 4.1). Appropriate seats, easy entry to the vehicle and sufficient handholds fall into this category. A product with all threshold features, however, will only meet the basic customer expectation and will not add towards an increase of satisfaction.

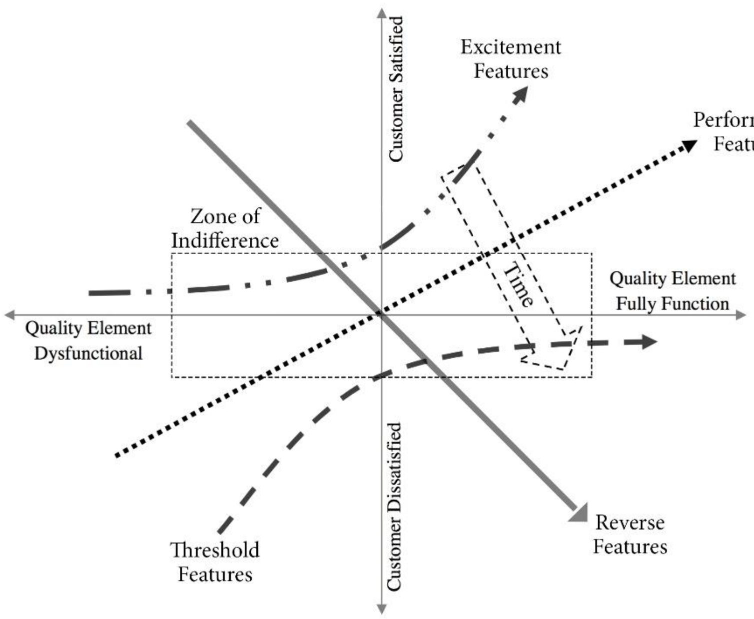


Figure 4.1. Kano Model. Indicating the relation between the five categories. (Lee 2011).

The opposite can be observed with features that delight and excite a consumer (see the top function in figure 4.1 termed “excitement”). For example, in-vehicle displays communicating contextual journey information may increase satisfaction considerably but are unlikely to have a negative impact on satisfaction if they are not there. USB charging sockets in busses are also likely to fall into this category as well, as they provide an additional service that is unrelated to the actual use, which is however of use to the user.

Two further categories can be included in the analysis, the “zone of indifference” and the “reverse features”. The first describes features which are present but only appreciated by very few consumers and thus can be excluded from the product.

A lap-timing feature or a G-Force indicator in a road going sports car can be seen as an example for this category. Only a few vehicle owners will ever make use of the feature yet it did create costs in development and implementation. “Reverse features” are not essential and cause dissatisfaction to the user due to their poor execution. An example for this could be an overly loud warning sound for closing doors on public busses.

In the context of the current paper, the Kano model illustrates why this paper focuses on the interior design, human factors aspects and the vehicle HMI. Most users who are unfamiliar with the advances in technology required for level four autonomy, the technical specification of the vehicle (sensor and software specification) will be perceived as a “given” and therefore fall into the “threshold category”. The expectation for the passenger is to be transported from A to B without any issues or disruption, lengthy delays due to sensor malfunctions or arriving at the incorrect destination will likely lead to dissatisfaction.

Subsequently, the attributes that may influence the user positively are the level of comfort provided for the journey, including the ease of use, which is mainly described by the performance and excitement categories (Turisová, 2015). However, one can argue that the basic aspects of comfort, such as providing adequate seating, extend to the threshold category, reinforcing the notion that passenger comfort is essential to a positive travelling experience. Karlsson et al. (2003) suggest that the challenge is, for those involved with the project or technology (e.g. designers, engineers), that the difficulty in achieving even the expected level of performance is so apparent that they fail to fully appreciate that the end-user will be unaware of them and will subsequently expect more from the product.

The first generation of a new vehicle type, particularly one so strongly dependent on novel technology, is naturally centred on achieving the technological breakthrough and to proof the capabilities.

Whereas now, with the first trials in the public commencing, the focus will shift, as the vehicle previously was assessed by experts, it is now the unaware end-user gaining an initial impression of the technology. Mano and Oliver (1993) already stated that the examination of utilitarian performance is not sufficient to understand customer satisfaction. Thus this comfort model review analyses the attributes required to ultimately facilitate user satisfaction.

For a user to be content with a product, several attributes have to be satisfied to some extent. With regards to first and last mile mobility vehicles, these attributes can be grouped into three categories: 1) symbolic attributes which cover the social influence of a product; 2) hedonic attributes describing the pleasure and fun derived from using the product; and 3) the functional attributes, the by far largest group covering the performance and effort expectancy as well as the related facilities and the price value (Merat et al. 2016). This demonstrates that the passenger satisfaction is dependent on more than just the performance of the vehicle, further underlining the findings from the Kano Model and Mano et al. (1993) and allows for the vehicle attributes to be categorised according to the satisfaction attributes.

Merat et al (2016) further suggest that there are also significantly related psychological criteria such as trust, which is strongly connected to the user expectations of the vehicle behaviour being met. The vehicle therefore is required to communicate its intentions to the passengers and outsiders, who can then, for example, predict the vehicle path. If the vehicle then behaves as the person predicted it would increase the trust into the vehicle abilities. A user, who is satisfied according to the previously mentioned criteria, is likely to express a growth in acceptance regarding last mile mobility vehicles.

The discussion demonstrates that a detailed understanding of comfort is required to design a vehicle, which will be accepted by the public as a viable product. Subsequently, there is a need for an appropriate comfort model to be developed.

This chapter, therefore, argues for a suitable proven model to be adapted for the specific application in last mile mobility vehicles.

Kano Model	Ahmapour Factors	Product Attributes
Threshold Features	Peace of Mind	Functional Attributes
	Physical Wellbeing	
	Proxemics	
Performance Features	Satisfaction	Hedonic Attributes
Excitement Features	Pleasure	
	Social	Symbolic Attributes
	Aesthetics	
	Association	

Figure 4.2 Relation between the three models

Figure 4.2 shows how the three underlying principles are directly related, the threshold features align with peace of mind, physical wellbeing and proxemics from the aviation comfort model and would be considered functional attributes. The Kano performance feature category only aligns with the user satisfaction and would be considered a hedonic attribute. The satisfaction factor is however also related to the excitement features, along with the pleasure, social, aesthetics and association factors from the aviation comfort model, all of which are considered symbolic attributes.

4.3. Comfort Model

Although there are several schools of thought as to what is meant by comfort and discomfort, for this work comfort is considered a bipolar phenomenon whereby comfort is positioned at the extreme positive end, and discomfort at the extreme negative end of a continuum with a neutral point in between (Vink 2005). Thus comfort will be regarded as a multifaceted experience influenced by a combination of physical, psychological, semantic, and social variables.

Therefore in this paper, the following definitions are used (Oxford Dictionary 2010, Vink and Hallbeck 2012 p271):

- Comfort: A pleasant state of well-being, ease, and physical, physiological and psychological harmony between a person and the environment

- Discomfort: A state where one experiences hardship of some sort, which could be physical, physiological or psychological

Whilst there are varying methodologies to grade comfort, research by Ahmadpour et al. (2016) demonstrated that a single graded evaluation scale is best suited to assess user perception of passenger in-flight comfort and discomfort. In the paper, the group explores the experience of flight comfort and discomfort as a combined experience and attempts to validate this theory through two studies.

Passenger comfort forms a key user requirement in the aviation industry with 35% of passengers on intercontinental flights basing their choice of the airline on comfort, placing it after flight schedules (Brauer, 2006). As a consequence, passenger comfort has been an important research area in aviation for some time. Recently, Ahmadpour et al. (2014) explored which factors, in particular, are important in determining comfort and suggested eight key factors (see figure 4.3 right).

Thus the following part explores if and to what extent these factors can be extrapolated across domains and be used to guide the design and evaluation of last mile mobility vehicles. The reason for this is that vehicle automation transforms the active driver into a passive monitor, and ultimately into a passenger. This shift from the driver to passenger experience, where the occupant is no longer in control of the vehicle, forms an essential aspect of vehicle automation (Diels & Bos, 2016). Consequently, it will no longer be appropriate to consider traditional automotive comfort factors only and comfort factors in aviation will increasingly become of interest. At the same time, however, it is also important to realise that there are a number of fundamental differences between both modes and the model cannot simply be extrapolated to first and last mile mobility solutions.

There are several commonalities between the passenger experiences across the two transport modes, in both situations, the passenger is not directly in control of the vehicle for example. Instead, a journey to a prior chosen destination is undertaken during which information about the duration and location may be provided. However, unlike aeroplanes, last mile mobility vehicles may provide the option for users to alter the destination on route based on information about possible delays or difficulties.

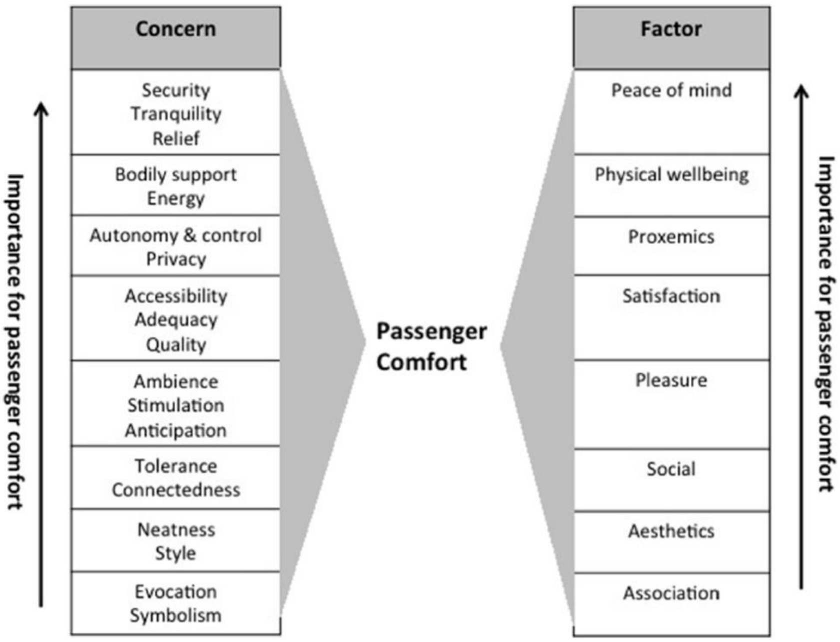


Figure 4.3. Overview of the eight factors of passenger comfort in relation to their concerns (Ahmadpour et al. 2014)

This demands for an interface that allows the passenger to interact with the vehicle and receive essential travel details such as time to arrival. Furthermore, during the transit period, both modes may offer entertainment or connectivity to the passenger in a space, which is shared with other, possibly unknown to the passengers.

Yet, a further difference is related to the fact that in contrast to an aeroplane in mid-air, last mile mobility vehicles will operate in environments containing a large number of other road users which are visible to the occupants.

While acknowledging the differences, the passenger comfort experience model appears to be a suitable starting point to explore the passenger expectations and needs in the context of driverless vehicles.

A similarity between these factors and the factors established by Karlsson et al. in their work regarding the assessment of vehicle interiors based on the semantic environment description (SMB) can be argued and further supports the theory of adopting the comfort model originating in aviation for an automotive context (figure 4.4). The SMB is a method which can be used to evaluate the overall impression of an environment and according to Laike (1999) also a vehicle environment. It is based on 36 adjectives, which were selected from over a thousand and each participant answers on a semantic scale how well the adjective fits the environment. Both research groups follow two different approaches with their aim to verbalise the factors which influence the comfort perception, the SMB offers a broader range of words whereas Ahmadpour proposed a more specific group of terms. Using the SMB method, Volvo compared the interior of their vehicle with a number of competitors and demonstrated that it can be used to organise and summarise the impression gained from a vehicle interior with the help of sample users. The authors note that the SMB does not permit to connect the findings directly to specific features as it describes the overall impression and therefore should be used in combination with quantitative techniques to identify the reaction to specific interior features (Karlsson et al. 2003).

For the proposed driverless first and last mile vehicle comfort model a number of similarities can be seen between the two sets of factors identified and can be used to further inform the development of the new model. However, a number of differentiations are required prior to defining the factors for road transport. The service (catering) can be influential on the perception of comfort during air travel but is currently unlikely to be experienced in an automotive environment.

Equally the comfort criteria that become relevant with longer travel durations can be neglected for first and last mile mobility applications. This includes, for example, the requirement for passengers to be able to adjust their seats for greater comfort whilst resting or set up workstations, as the time spent in the vehicle is likely to be less than 15 minutes at a time.

Further consideration required in regards to how the time spent during a journey is used, as a survey of commuters in the Sacramento – Francisco Bay Area transportation corridor indicates the wish to be able to work whilst commuting. As part of this survey, the ability to work was stated as a key reason for changing the travel mode, from a manually driven car to a bus or train (Malokin et al. (2015).

However, a correlation between travel time as well as the reason for travelling and in travel time use requires further investigating, as there are conflicting responses to the desire to work during commuting.

According to a survey in Germany, the demand to facilitate activities such as working is low, as only a minority undertakes work; 77% of respondents never work on busses most likely due to the constant directional changes and vibrations during the journey, 69% when travelling on trains, despite undertaking next to no directional changes and providing a much smoother ride than busses. Driverless first and last mile mobility vehicles are likely to be very similar to busses in their movement patterns and subsequently will be used in similar ways to busses.

A small number of passengers still manage to use their journey time productively and need to be considered as one user type. Instead, enjoying the landscape dominates the answers (Cyganski et al. 2014). Schoettle and Sivak (2014) add that the most frequent answer seen in their survey was “Watch the road even though I would not be driving”. Cyganski et al (2014) go on to report that the morning commute is seen as particularity unpleasant, even less popular than work itself.

This could be caused by the time spent travelling traditionally been seen as dead time, reducing the possibility to spend time more enjoyably. As previously mentioned, enjoying the landscape is the most frequent answer, however often mentioned activities are also listening to music, reading for leisure and relaxing, something that driverless vehicles have the potential to enable fully. This research contrasts with the common perception in regards to the main benefit of driverless vehicles as described in the current public opinion. However, it should be noted that the current public opinion is likely to have been shaped by the existing transport options, many of which are not designed for working. As a consequence, it is likely to change if vehicle designers consider working during the commute as a requirement and provide passengers with more adequate solutions.

In addition to the two previous comfort models, a detailed taxonomy of attributes which influence comfort in public transport created by Napper et al. (2015), can also be used to inform the driverless first and last mile mobility vehicle comfort model. The taxonomy is split into four categories; environmental, organisational, social and personal, which together consist of 203 individual attributes, many of which are directly related to the factors identified in the two previously discussed comfort models (Figure 4.4).

The environmental category includes attribute groups such as the seat characteristics, access and egress and the muscular-skeletal, which all fit into the physical wellbeing and satisfaction factors in the Ahmadpour comfort model. The organisational category matches the peace of mind factor, in particular, the requirement for information regarding the journey by the passenger. The social category matches with the factors, proxemics, looking at the amount of space available for each passenger, the peace of mind factors in regards to the feeling of safety when engaging into any activity during the journey and the social factor, highlighting the society’s perception of the user in the vehicle.

The fourth category, the psychological attributes match with the peace of mind and pleasure factors, detailing the mental experience during any the journey.

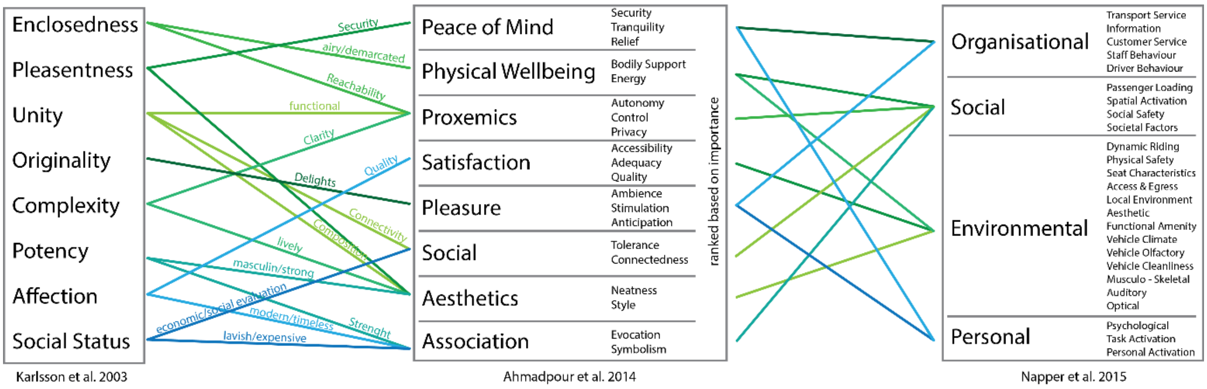


Figure 4.4. Indication of similarities between Karlsson et al. (2003), Ahmadpour et al. (2014) & Napper et al. (2015)

The taxonomy by Napper et al, the factors established by Karlsson et al and the aviation comfort model by Ahmadpour et al., each detail a number of important comfort factors which can be directly linked (Fig.4.4). The links between the different models indicate the similarities and allow connections to be drawn between the three models.

Comfort Factors

The information gathered in the review of existing comfort model can be synthesized into a comfort model for driverless first and last mile mobility vehicles (Fig. 4.5), describing in detail eight factors which influence the passenger comfort and wellbeing. However, exact definitions of all comfort factors identified by Ahmadpour et al. (2014) are not achievable due to the fact that some attributes featured in more than one comfort category.

The model shows the eight comfort factors relevant to the passenger comfort and wellbeing; Peace of Mind, Physical Wellbeing, Proxemics, Usability, Pleasure, Social, Aesthetics and Association, with the size of the circle indicating the rank of the perceived importance.

Figure 4.5 Comfort & Wellbeing Diagram (Ranking Comfort Factors based on Perceived Importance)

Peace of mind: Factor one according to the importance ranking by Ahmadpour et al. (2014) is “Peace of Mind” to which attributes such as an efficient interior layout and the adjustability of the seats contribute. On a practical level, offering a secure storage for luggage and belongings is essential as well as a contribution to a passenger’s peace of mind.

Additionally, the opportunity to rest physically and mentally contributes to the factor. Mental rest in the case of driverless vehicles in particular, is mostly related to trusting the automation and the systems and therefore being at “ease”. This can be achieved in part by being able to observe the vehicle behaviour i.e. a good view to the exterior and a HMI informing the passenger as this will help the passenger understand how the vehicle is dealing with any scenario and the vehicle can demonstrate that it is aware of the surroundings, and therefore in control of the situation.

A novel factor for this use case is the ability to regain control over the journey, allowing passengers to prematurely terminate the route or choose a different path to the proposed one. As the initial vehicles will challenge the passenger's trust into the novel technology, this first factor will further gain in importance compared to traditional self-driven vehicles, over the initial trust barrier. In this regard, providing passengers with an indication that the vehicle is remotely monitored and an option to contact the human operator could also help lower the trust barrier. The discussion on trusting a self-driven vehicle extends beyond the interior and the passengers to those who will encounter the vehicle as road user. The vehicle has to communicate its intention, its chosen path or halting at a zebra crossing for example to those who are dependent on the information in order to react to it. A pedestrian will have to judge whether the vehicle has recognised him and understood his intentions.

This understanding is critical on both sides particularly as these vehicles currently all operate in a shared space with pedestrians. Whilst the eight factors are discussed individually below, they do frequently overlap and therefore for each design feature has to satisfy a combination of comfort factors.

Physical Wellbeing: The second factor is "Physical Wellbeing" which is predominately focused on attributes providing good body support whilst giving a degree of privacy and distance from other passengers. Noted is also the amount of energy required by a passenger to utilise the vehicle, such as entering over a tall step or restraining oneself against vehicle movements. With the passengers being able to conduct non-driving tasks such as working or reading it is essential that sufficient body support is offered by the seating reducing the need to strain against uncontrolled movements caused by the vehicle changing its path. It subsequently also aids in combating the induction of motion sickness caused in part by jolting vehicle movements.

Proxemics: "Proxemics" is the third factor, describing a feeling of autonomy and control over the space such as seats and HMI. The adjustability of the seating furniture is a recurring theme throughout various factors, arguably demonstrating its importance in relation to physical comfort.

Beyond the physical aspects of the interior, Hall (1966) categorises in the Theory of Proxemics the different zones of personal space, placing a scenario where occupants of a vehicle are seated next to each other as "intimate" which is normally reserved for affectionate contact between lovers. A reason why the central seat in a set of three is the least preferred option amongst travellers using public transport. To ease this subsequently often greatly uncomfortable experience Evans and Werner (2007) propose the use of territorial furniture such as armrests. This factor does in part contribute to the following factor of user satisfaction.

Satisfaction: The fourth factor "Satisfaction" consists as previously discussed, of three aspects; symbolic, hedonic and functional. All contribute to a user's satisfaction and are individually important and therefore the first two are discussed below under different names, pleasure-hedonic and symbolic-association, in further detail as separate factors. The aspect of functionality can also be renamed for this instant as usability and is predominately based around the ease of interaction with a driverless vehicle through the HMI, easily accessible buttons and screens that can be operated without effort.

Pleasure: "Pleasure" was ranked fifth and as previously discussed, is in part related to the factor of proxemics, more specifically the individual's perception of personal space. Pleasure as a factor greatly influences the overall user satisfaction and can be positively influenced by providing the passenger with the ability to make choices, adjustments and generally performing different activities during the transit.

The haptic of the materials that the passenger comes in contact with influences the experience of pleasure as well. However, as this type of vehicle permits the occupants to focus on non-driving related tasks, the quality of the infotainment system for example, such as the ease of use and clarity are a major contributing factor to a pleasurable journey.

With the advancement of technology, driverless first and last mile mobility vehicles also provide the opportunity to create new experiences through novel entertainment features. The current trend goes towards providing a higher degree of personalisation, providing passengers with infotainment based on their stored preferences.

Noteworthy, in regards to the previous three points, is the predicted change in the cause for the occupant's pleasure and satisfaction. Initially, the passenger experience will be dominated by the novelty factor, however as the availability of the systems increases and it will become the norm to utilize these vehicles, passengers will focus on other attributes such as the way they are able to use their time and how easy the interaction with the vehicle is (Nordhoff et al. 2016).

Social: On the sixth position are "Social" factors, dominated by the circumstance that these vehicles are shared vehicles operating within a MaaS concept. This leads to a mixture of preferences such as being able to interact with others in the space or alternatively seeking personal space. The seating arrangement has a significant impact on the ability for passengers to interact and converse with each other, by providing seating space that is facing each other for example. It may also provide passengers with a personal space by shielding the passenger from others with visual or sound barriers. As these are to some extent opposing functions, they need to be considered based on the scenario in which the vehicle is to be used.

Increasingly the support of mobile network connectivity does also play a significant role as passengers want to go online, stay in touch via messenger applications or keep track on their journey (CATAPULT Transport Systems 2016).

Aesthetics: The "Aesthetics" are ranked seventh, with attributes such as a clutter-free and clean interior that is well maintained and a vehicle that conveys a sense of stability and protection. From the outside, it is important that the cabin appears inviting and that the onlooker can discern easily if there is space available to board.

Association: The eighth comfort factor is "Association", part of the symbolic satisfaction attributes, which similarly to aesthetics describes attributes such as a modern cabin, notably described as "car-like" in the aviation model survey by Ahmadpour et al. (2016) a cosy interior that does not agitate or tire a passenger is also a contributing factor to the association.

These factors were used as a basis for developing a set of criteria to analyse the mobility concepts. The criteria can be grouped in several categories; the accessibility, analysing ingress and egress to the vehicle for the different passenger groups, the interior space, investigating the amount of space given to the passengers to move within the vehicle as well as the overall impression of the cabin, the seating provided for the users, also including standing options, the interaction with the vehicle through the HMI and the Emotional experience of travelling on-board of one of these vehicles.

4.4. Analysis

The research done by Ahmadpour et al. (2016) in regards to the comfort factors "implies that comfort is greatly reduced in the presence of negative physical conditions, while an experience of joy enhances passengers' experience of comfort". Subsequently, factors with the greatest potential for negative impact are the highest-ranked factors according to importance to the passengers, thus require the greatest attention.

The eight factors which were identified as part of the proposed comfort model for driverless first and last mile mobility vehicles provide a foundation to better understand the comfort requirements for passengers in this kind of vehicle (Figure 4.4). Peace of mind being ranked first in the model is particularly important in the given context as there is a prevalent uncertainty towards the technology. The vehicles will have to provide solutions to grow the trust of the user in the technology, such as allowing passengers to see ahead in order to be able to anticipate the vehicle movements.

The second ranked physical wellbeing plays an important role in any mobility context and goes beyond a comfortable seating space. The height of the cabin and the location of handrails and armrests for example also do have an impact on the physical wellbeing. In a shared mobility environment, the third ranked proxemics, i.e. the immediate surroundings of the passenger and the personal space, are a vital aspect due to the passengers being confined to a small space with to them unknown others. In order for the journey to be a pleasurable experience, the space within the vehicle for each passenger needs to be managed carefully using features to provide sufficient separation and privacy.

All three of the highest-ranking factors, peace of mind, physical wellbeing and proxemics, are in the Kano Model considered threshold categories highlighting their significance in regards to the overall passenger comfort.

The factors usability and pleasure are closely tied together, ranked 4th and 5th respectively, and are the areas which hold the greatest potential to positively surprise and delight a user. A simple and well-designed user interface, for example, will improve the usability of the vehicle and subsequently the journey experience. The two factors are therefore in the excitement category of the Kano Model, where the user potentially does not expect a positive experience and therefore a small improvement can cause a big impact.

The sixth ranked social aspect of comfort also holds great potential in the context of shared mobility as any user may be exposed to two different scenarios, travelling with friends and family with whom they may want to interact, or unknown others from whom they may want to distance themselves. This category, therefore, is connected to the proxemics category but does consider the potential positive scenario of experiencing a journey with someone and interact with them, which the design of the vehicle has to enable.

The aesthetics and association rank lowest in the first and last mile mobility context due to the fact that time spent with the product is short and it is not owned by the end user. Nonetheless, these factors cannot be ignored as some aesthetic features such as colour and material choices, may influence other factors such as pleasure, usability and peace of mind.

It is worth noting that, for the majority of the users, particularly once the introductory phase has passed, the engineering aspects of driverless technology, such as the route finding, vehicle control and obstacle sensing will be considered to be in the threshold category based on the Kano Model. As a consequence, the complexity of achieving driverless mobility will not be able to positively influence user perception, even when working flawlessly. This further iterates the need for the manufacturers to provide users with more than just a working vehicle to avoid disappointment.

4.5. Summary & Conclusion

Comfort models which were established for other modes of transport, such as air travel, were adapted to inform the comfort research for related modes. Specifically, in this chapter, a proven comfort model from the aviation sector, in combination with known product development tools, such as the Kano Model were used as a basis for a new comfort model.

This proposed comfort model for driverless first and last mile mobility vehicle separates the passenger comfort and wellbeing into eight factors and ranks them based on the perceived importance. The detailed discussion highlights which aspects are particularly relevant in a driverless first and last mile mobility context. The proposed comfort model will, therefore, be used as a guideline to develop a set of criteria for a benchmark of current driverless last mile vehicles in regards to their passenger comfort and usability which will be conducted in the following chapter.

2nd Objective Part 1

The development of the above discussed comfort model for driverless first and last mile mobility vehicles fulfils the first part of the second objective. Here, based on the literature review and in combination with an existing theoretical model and two product design principles, a theoretical model was created to describe the passenger comfort and wellbeing requirements. It will now be used as a basis for a benchmark of current driverless first and last mile mobility vehicles conducted in chapter 5.0. In the following chapters (9.0-14.0), the validity of the comfort model will be evaluated using an exemplary design.

Disclaimer

This chapter contains passages previously published as a conference paper at the 2017 AHFE International, 8th International Conference on Applied Human Factors and Ergonomics in LA, California US. The paper can be accessed under: Wasser, J., Diels, C,. Baxendale, A., Tovey, M., (2018) Driverless Pods: From Technology Demonstrators to Desirable Mobility Solutions © Springer International Publishing AG 2018 N.A. Stanton (ed.), Advances in Human Aspects of Transportation, Advances in Intelligent Systems and Computing 597, DOI 10.1007/978-3-319-60441-1_53

5.0. Benchmark

5.1. Introduction

A benchmark is an analytical tool commonly used in any product development process in order to identify the trademarks of potential competitors and the potential areas for improvement. In the benchmarking process, a number of relevant criteria are used to rank different options for a direct comparison. For this analysis of ten different existing driverless first and last mile mobility vehicles and concepts, the criteria are based on the eight comfort factors; Peace of Mind, Physical Wellbeing, Proxemics, Usability, Pleasure, Social, Aesthetics and Association, developed previously in chapter 4.0. As discussed as part of the model development, some of these comfort factors are influenced by more than one design feature. In order for these to be used in the benchmark, were translated into the five criteria groups, which are based on separate design features. As seen in table 5.1, the groups are; Accessibility (Usability & Physical Wellbeing), Interior Space (Peace of Mind, Physical Wellbeing, Proxemics, Usability & Aesthetics), Seating (Usability, Physical Wellbeing, Proxemics & Social), Interaction (Peace of Mind, Usability & Pleasure) and Emotional Experience (Peace of Mind & Social). The emphasis of the criteria selection was on the physical features of a vehicle, combining the comfort model factors with a traditional automotive checklist.

Table 5.1: Benchmarking Criteria

Accessibility	Ingress Egress Disabled access	Step height Handholds Door aperture size Wheelchair ramp availability
Interior Space	View to the exterior Interior Light Levels Haptics Aesthetics	Size & placement of windows Transparency of the windows

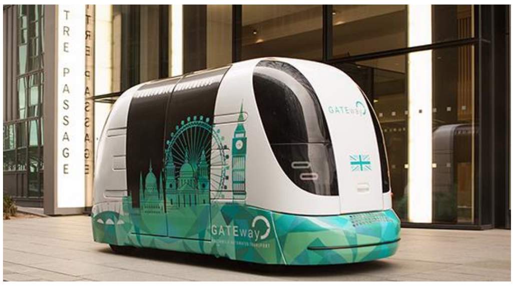
	Storage space	Material, shapes and colours of the interior surfaces
		Space for luggage, handbags
Seating	Layout Shoulder space Body support	The arrangement, type and shape of the seats Suitability for elderly and young passengers
	Wheelchair restraining systems	Availability of speciality safety equipment
Interaction	Booking system	Which systems are available
	Access system External HMI Internal HMI	Visual Quality What & how is the information presented
Emotional Experience	Sense of Control Sense of Safety & Protection Ability to observe vehicle behaviour	How can the passenger observe and understand the vehicle behaviour

Below is a benchmark of ten current driverless first and last mile mobility vehicles (state early 2018). The vehicles represent different types of driverless pods; vehicles with a large passenger capacity of 10-12 passengers (Navya Arma, Olli, EZ10, eGo Mover), smaller vehicles for up to four passengers (ULTra, GRT, NEXT, Hannah) and vehicles which are intended for a use beyond the first and last mile Navya Cab, SEDRIC). The review also includes the Hannah design concept by Teague which at the time of writing is not existing as a physical vehicle but was included based on the proposed HMI.

When this review was initially conducted, only a small number of vehicles which fit into the category of driverless first and last mile mobility vehicles existed.

With the quick progression of the technology however, the number of vehicles has increased significantly. The criteria for the selection for this benchmark was, therefore, the existence of a physical vehicle, at the minimum at the prototype stage. The only exception is the Hannah vehicle concept as it is the only vehicle aimed at younger passengers with an exterior HMI designed specifically for this use case.

Table 5.2. List of benchmarked vehicles

	Brand	Specifications	Example Image
1	ULTra ULTra Global PRT TRLpublish (2018) ULTra (2016)[1] ULTra (2016)[2]	Length: 370cm Width: 2150cm Height: 180cm Weight: 1.3t (curb weight) Drivetrain: Electric 7kW AC drive 40kph max speed Electrolyte Lead-Acid Bat. (45ah)	 https://www.digitalgreenwich.com/wp-content/uploads/2016/01/gateway-mitre-passage-700x336.png
2	GRT 2getthere.eu GRT (2016)[1] GRT (2016)[2] Serious Wheels (2016)	No specification data available Drivetrain: Lithium Phosphate Bat. 60km range on a 1.5h charge	 https://www.uts.ae/primages/articles/2gethere-apm-01.jpg
3	Olli Local Motors Financial Express (2016) Autonews (2016) IBM (2017)	Length: 392cm Width: 205cm Height: 250cm Weight: 1.5t (curb weight) Drivetrain: Electric 20kW continuous 15.5kWh Bat. ≈ 52.2km	 https://www.thelocal.de/20161215/driverless-bus-olli-undergoes-testing-in-berlin

4	Navya Arma Navya Navya (2014)	Length: 392cm Width: 205cm Height: 250cm Weight: 2.1-2.35t (curb weight) Drivetrain: Electric 15kW continuous 15.0kWh Bat. ≈ 52.2km 45kph max speed/ 25kph av.	 https://navya.tech/wp-content/uploads/2017/09/Autonom_shuttle-1.jpg
5	Navya Cab Navya Navya (2017) Navya (2019)[1]	Length: 392cm Width: 205cm Height: 250cm Weight: 2.0t (curb weight) Drivetrain: Electric 15kW (25kW peak) Lithium Ion (LiFeP04) 33kWh Bat. ≈ 10h operation 55kph max speed/ 30kph av.	 https://navya.tech/wp-content/uploads/2017/09/Autonom_cab-1.jpg
6	EZ10 EasyMile Easy Mile (2019)[2] EasyMile (2017)	Length: 392cm Width: 198cm Height: 275cm Weight: 2.8t (loaded) Drivetrain: Electric asynchronous drive Lithium-Ion (LiFeP04) 14h charge 40kph max speed/ 20kph av.	 https://newatlas.com/easymile-ez10-driverless-bus/39891/
7	NEXT future transportation Next (2018)	Length: ≈ 200cm Drivetrain: Electric	 https://www.boldbusiness.com/transportation/next-incorporates-digital-barriers-live-video/

8	eGO Mover eGO Mobile AG eGO Mobile AG (2017)[1] eGO Mobile AG (2017)[2]	Length: 4.65cm Width: 195cm Height: 250cm Weight: 2.1t (curb weight) Drivetrain: Electric 150kW up to 70kWh Bat. ≈ 10h operation Level 0-4 Autonomy	 https://www.electrive.net/wp-content/uploads/2018/03/ego-mover-rwth-aachen-e-kleinbus-autonom.png
9	Hannah TEAGUE TEAGUE (2017)	Concept render (no engineering data) Drivetrain: Electric	 http://teague.com/work/hannah
10	SEDRIC VW Group VW (2018) VW Group (2017)	Concept render (no engineering data) Drivetrain: Electric	 https://www.discover-sedric.com/de/

For each vehicle, relevant information was gathered in the form of press releases and specification sheets by the manufacturers, images and video footage. A number of the vehicles were also visited and tested in person, the Navya Arma during a demonstration at Heathrow Airport (UK), the Olli during a permanent trial at the EUREF Campus in Berlin (Germany), the eGo Mover in an exhibition space in Aachen (Germany) and the RDM Pod Zero as well as the GRT at a tradeshow in the UK. During these observations measurements and photos were taken as well as observation noted. The gathered information was then compared with the benchmarking criteria, investigating how each of the factors is met by the vehicle, to produce a detailed review of each vehicle.

Following the written review, all factors were also ranked individually for each vehicle in a table (Table 5.3), providing an overview and direct comparison of all vehicles. All aspects were ranked on a five-point scale, from Unacceptable (-2) / Poor (-1) / Average (0) / Good (+1) / Excellent (+2) in order to be able to compare the vehicles on each aspect. The aim of the benchmark is not to create an overall ranking of the vehicles but instead to provide insight into individual aspects of each vehicle in order to identify suitable solutions or issues.

5.2 Vehicles

The following section provides an individual review for each of the ten driverless first and last mile mobility vehicles selected for the benchmark. This analysis is conducted in order to identify issues with the current vehicles in regards to user experience and comfort. Using the proposed comfort model (chapter4.0) as a baseline for user requirements, the benchmark can be used to establish if these are met adequately by any of the vehicles as well as identify potential solutions.

5.2.1. ULTra – ULTra Global PRT

The ULTra system connects the Heathrow Airport business passenger car park with the Terminal 5 on a 3.9km long route, operating 21 vehicles. Launched in 2011, the system represents an early form of driverless automated transport with remote controlled vehicles operating on a pre-set track. The vehicle is now also used as part of the GATEway project, for which the vehicle has been adapted to operate without pre-set tracks as a public shuttle service in the London borough of Greenwich (TRLpublish 2018). Other than the fitment of sensors required for driverless off-track operation, such as LIDAR, no design changes were undertaken to adapt the vehicle to the new environment.

Accessibility & Seating - The ULTra vehicles are equipped with four seats in the form of two benches, which are located on either end of the cabin. The narrow vehicle shape and the rounded tumblehome, limits the available space on the bench, leading to two average sized passengers to rub shoulders as observed during a visit. Access to the with 150cm height, very low interior space is provided through two sliding doors on either side, requiring passengers to stoop when entering the vehicle and making it unsuitable for standing passengers. An even transition to the platform provides easy wheelchair access, however, there are no provisions for securing the wheelchair in the cabin, which does provide sufficient space when no other passengers are on board. As the vehicle was designed with a platform as an entry point, the trials in Greenwich will require some previsions due to a high entry step from road level.

Interior space – The ULTra Pods are designed in a style that is reminiscent of what was thought in the 60s to be the future. The very round capsule-like shape makes the vehicle look impenetrable and heavy, something that is reflected in the dark and small cabin. The interior appears utilitarian and basic, typical public transport, with everything covered in vacuum-formed grey plastic covers, which do however create a very robust impression.
Overall the cabin has a very confined feel to it, which is also caused by the limited visibility. The limited visibility is likely to negatively impact on the user experience, due to them being unable to observe the movements of the vehicle. Despite the vehicles application as an airport transfer, it does not offer a space to securely store luggage, placing the passenger's belongings into the footpath of those entering the vehicle.

HMI - Small screens, two mounted in the side pillars and two in the ceiling, inform the passenger about the route. The vehicle does also provide a two-way communication system with the operator for emergency situations. The interaction with the vehicle is limited to illuminated buttons controlling the doors and starting the journey. The passenger is guided through the process by audio commands. Prior to entering the vehicle, the destination is chosen on a column with a touch screen, offering a choice of languages and in the case of Heathrow Airport, two destinations.

5.2.2. GRT - 2getthere.eu

The GRT is very similar in its application to the ULTra vehicle; it functions as a driverless shuttle on pre-set tracks and routes, providing transport between an airport terminal and a technology park. The vehicle has been running as a permanent installation in Masdar City providing a shuttle service.

Aesthetics - The design of the GRT is based on traditional automotive design, featuring a front grill and a suggested beltline. Overall it creates a rounded and capsule like look.

Seating - It provides space for four adult occupants on a combination of individual seats and benches on either side. The bench-like connection allows for two children to sit between those adults raising the potential passenger number to six in total. The shaping of the seats offers some restraint to the passengers against the vehicle movements, whilst the choice of fabric for the seats creates an elegant, almost cosy atmosphere in the vehicle.

Interior space - Although the vehicle only provides limited visibility to the exterior through the sides it does feature a full glass roof, which creates a spacious feeling within the cabin. The cabin can be entered from one side through full-height sliding doors that appear to be controlled by the vehicle rather than through access buttons. Much like the ULTra vehicle in its Heathrow application, the even entry from a platform provides easy access to a reasonably sized cabin that provides enough space for a wheelchair, however, there are no restraints offered to wheelchair users. The homely styling of the interior does suggest a comfortable ride and is likely to relax the passengers.

HMI - Opposite to the door a single screen is mounted parallel to the wall. This touch screen is used to start the journey, no destination selection is offered due to the vehicle operating on a one-stop route. The placement of the screen on the side of the vehicle requires the passengers seated along the same side to look at it from a very shallow angle.

5.2.3. Olli - Local Motors

The Olli, built by Local Motors as a proof of concept project represents the second generation of driverless first and last mile mobility. Rather than being guided by a predefined track, it relies on the advancement in driverless technology to navigate. Making use of LiDAR and other sensor types it can pick a path around obstacles and can to some extent participate as a vehicle in regular road traffic. Trials with the Olli are taking place in various locations around the world, with a permanent installation at the EUREF Campus in Berlin according to Local Motors (tctmagazine 2017).

Aesthetics - The Olli's design is in stark contrast to the two previously mentioned vehicles. Due to being a much more recent concept, the Olli also adopts the public transport design language but using a contemporary look. The exterior features large glass panels, allowing an almost undisrupted view to the exterior and the two-tone colour accentuates the simple but clean shape. The predominant material inside and outside is vacuum-formed ABS plastic but a glossy finish with spots of bold colour is refreshing and creates a quality finish. Local Motors promote their vehicle as 3D printed, with some components, such as the wheel arches and the lower vehicle structure being made by fusion deposit manufacturing.

Seating & Access- The Olli offers space for 12 passengers with bench seats on three sides of the cabin. Rubbing shoulders amongst the passengers is unavoidable with the tight seating space. The benches only offer limited support and options to hold on, which could prove a problem for those seated along the side. The lack of armrests could also pose a problem to elderly passengers requiring support to push off a seat. The full standing height cabin provides good all-around visibility and sufficient space for a wheelchair. However, as it is the case with the other vehicles, no fixtures or support for wheelchair users has been integrated. Further, there are no options to stow away luggage securely.

HMI - The outstanding feature on this vehicle is the approach Local Motors and IBM designed for the passenger-vehicle interaction (IBM 2017). Aside from a single information screen, the Olli relies on the Watson Computer to "talk" with the users. Local Motors propose that in the future the passenger can ask Olli to suggest a destination based on a question and the vehicle will automatically travel there. In the scenario when an individual traveller is using the Olli, a mobile app is proposed as the main interface with the vehicle. There is no mention of an added connectivity to the vehicle or cell phone network in the documentation, possibly due to the vehicle predominately travelling in well-connected urban areas.

5.2.4. Navya Arma - Navya

The Navya Arma is currently involved in several permanent trials: in Sion in Switzerland, Perth in Australia, Lyon in France with additional demonstrations occurring throughout the world. Increasingly it is also installed as a permanent service at worldwide locations such as the Christchurch Airport or in Paris on the Ile de France Mobilites (Navya 2019).

Aesthetics - The design of the Navya Arma attempts a progression from traditional automotive styling with bolder shapes and symmetric front and rear treatment. One of the outstanding design features is the visible structural beam which can be seen from the exterior as well as the interior. It indicates to the casual onlooker the construction of the vehicle and through that, potentially create a sense of safety.

Seating & Access – The French Navya Arma is the largest capacity vehicle currently tested, with space for 15 passengers, nine of which can be seated. Bench seats are located in either end, whilst there are three-fold-down seats along one side of the vehicle. The interior provides a full standing height and one equally tall coach door provides access from one side. Like most other examples, the doors are also operated by illuminated buttons.

In regard to the cabin space, it should be noted that whilst there is sufficient space for a wheelchair, there is currently no build-in ramp or provisions for securing a wheelchair.

The trial in Sion, Switzerland, running under the Swiss PostAuto name shows an external ramp being used to provide wheelchair access.

Interior Space - The cabin itself provides great visibility as the view is only obstructed by some small structural components. The large glasshouse, allowing the passengers to follow the vehicle path and actions. Although the interior features some bright colours in the seat fabric, it does appear somewhat sparse and subsequently uncomfortable.

HMI - Four information screens mounted in four corners of the vehicle provide information about the journey and offer the passenger a selection of stops which are superimposed on a map. Two further displays communicate vehicle movements and actions, such as "currently boarding" as pictograms to people on the outside. The external HMI provides a simple solution that has the potential to increase the trust by the occupants into the vehicles when they operate in pedestrian zones. The Navya Arma is currently the only vehicle that attempts a dialogue with other road users, in an attempt to increase the trust from the public and other road users into the vehicle behaviour by informing them about the upcoming actions.

5.2.5. Navya Cab – Navya

Navya has a second vehicle in their portfolio, the Navya Cab, priced at 260.000 Euros. Whilst the Arma vehicle is a shuttle bus the Cab is envisaged to cater to smaller groups as a driverless taxi service. The vehicle was demonstrated to the public in Paris as part of the official launch and at the 2018 CES in Las Vegas where it performed a shuttle service on public roads in a separate lane (Navya 2019).

Aesthetics - On the exterior the vehicle design seems to strongly emulate a current MPV (Multi-Purpose Vehicle or Family Van) with a very tall shoulder line, which finishes just below the head height of the seated passengers, creating a cocooned feel.

Seating & Access - The vehicle features two each other facing bench seats in a low cabin which requires the passengers to stoop into. The cabin evokes a traditional automotive feel with light coloured soft fabrics and the bench seat which is broken up into individual seats with headrests and seatbelts.
Once seated, the passengers have sufficient headspace and are able to observe the exterior through the all-around window band. The cabin does not appear to feature any wheelchair access or fixtures.

HMI - A large display band wraps around the front of the vehicle capable of displaying intricate graphics. A further touch screen, located centrally within the cabin between the two benches, provides trip planning, booking and payment options. The screen also provides access to pre-planned city tour options, however, the vehicle can also be booked and accessed via a mobile app. The placement of the screen, however, is only visible from a very shallow angle and can only be reached by those seated closest.

5.2.6. EZ10 - EasyMile

The EasyMile EZ10 is the second French build vehicle and is in direct competition with the Navya as it is also commercially available and is currently deployed in a long-term trial in Gelderland, the Netherlands. Further trials are currently undertaken in Dubai, Singapore and Helsinki, Finland, following a successful demonstration at Vantaa (Finland), in which the vehicles travelled among regular road traffic on public roads (Easy Mile Use Cases 2019).

Aesthetics - The EZ 10 vehicle is very box-like and has almost no outstanding design features that try to break this look.

Seating & Access - The EZ10 seats six people comfortably on individual seats, which are mounted in the front and rear of the vehicle. In between the seats is sufficient space for several standing passengers or alternatively a wheelchair. Access to the full standing height cabin is from one side only, through full standing height coach doors.

The vehicle, unlike many of its competitor's features a wheelchair ramp, however, there appears to be no fixtures or support for the wheelchair user to secure themselves with.

Interior Space - The interior of the cabin is spacious and offers good visibility to the exterior. The overall impression is one of typical public transport furnishing, handrails are available and illuminated buttons operate the doors. The interior appears like any other typical public transport design.

HMI - Two screens, mounted central along the side, one at hip height, the other above the heads, inform the passenger about the vehicle route and stops. The same touch screens allow the passenger to select a stop from a map, which is based on a satellite image. The Transdef App, awarded with innovation track 2016 at the European Mobility Expo 2016, informs passengers about travel times and the arrival of the next free vehicle.

5.2.7. NEXT – future transportation

The NEXT vehicle stands out as it is designed to operate in a swarm with several vehicles interconnecting during the journey to permit passengers to change over into a different vehicle with a separate destination. The concept has won the support of the Dubai RTA development fund and is likely to be trialled there (RTA 2017).

Seating & Access - To allow passengers to change between the vehicles whilst docked together, the doors are located on the front and the rear of the vehicle. This has a knock-on effect on the interior layout, requiring a clear passage from front to back. The individual bus style seats, therefore, are located on either side of the vehicle, all in a forward-facing direction. The vehicle is shown with a wheelchair ramp, stored beneath the cabin floor.

Interior Space - The cabin itself offers full standing height and all-around windows. Apart from the seats, the cabin is very sparse, however, it should be noted that the vehicle is still under development.

Part of the concept is that the different vehicles offer different services such as a coffee bar or higher-grade seats, which can be booked via a mobile app and accessed when the vehicles are interconnected.

Aesthetics - The exterior of the vehicle is a large box shape with the upper half with large dark-tinted glass surfaces. Due to the location of the doors, the vehicle is able to rotate on the spot to permit the passengers to board safely from the sidewalk through the front door.

5.2.8. eGo Mover – eGo Mobile

The Aachen, Germany, based eGo Mobile AG has developed a shuttle bus concept which is aimed to be functional with the autonomy levels zero to four.
The leading thought behind this decision was that the vehicle can be deployed initially with a driver, allowing the vehicle sensors to gather data without controlling the vehicle, with autonomous capabilities added gradually thereafter.

Interior Space - This has a significant impact on the cabin layout of the vehicle, with a driver cabin occupying the front third, a considerable amount of potential passenger space. Furthermore, it prevents the passengers to be able to observe the exterior in front of the vehicle, a strong factor in passenger discomfort, particularly in driverless vehicles.

Seating & Access - The gloomy cabin can be accessed through a single door on the sidewalk facing side of the vehicle. A high step up onto the level cabin floor opens up a narrow cabin which features an L-shaped bench seat. The bench gives the otherwise sparse interior a more pleasing feel, however, it does not provide anybody support against lateral movements or handholds to support getting up from the seat surface. A single handrail is mounted centrally on the ceiling, impeding directly into the otherwise sufficient headspace.

HMI - On the back of the driver cabin is a large screen showing the line-up of stops and arrival times. The vehicle does not appear to have any provisions for wheelchair users, lacking a ramp and space in the interior.

Aesthetics - The exterior of the vehicle is distinctly modern with the vehicle volume having the appearance of being made up of two cubes. The large box shape is also difficult to read in regards to where the front of the vehicle is, potential leading to confusion of other road users when the vehicle is not in motion. The dark tint of the glass surfaces combined with graphics spanning the entirety of the vehicle makes it impossible to look into the vehicle from the exterior as well as causing the interior to be relatively dark.

Emotional Experience - The multilevel autonomy approach is unique to this concept and is the reason for several compromises in the vehicle design, such as the requirement for a driver cabin, which could suggest that the leading factor in the development was technological rather than humanistic. Therefore it could be argued that it is a technological demonstrator rather than a vehicle design, a debatable approach as the vehicle is intended to introduce driverless first and last mile mobility to the general public of Aachen.

5.2.9. Hannah TEAGUE

The design consultancy TEAGUE from Seattle, US, has experimented with a new vision for the iconic yellow American school bus with their concept Hannah. The background to the concept is that many school children are picked up every day by a school bus shuttle which is organised by their school, the downside to this system, however, is that there is a large amount of rolling stock sitting idle for the majority of the day. TEAGUE further argues that a large number of accidents are caused due to the fact that some school children have to walk to a collection point rather than being picked up at their home directly. The Hannah pod is intended to tackle these issues through a much smaller capacity, only six students fit, vehicle and the ability to be converted for other usages during the day.

The smaller capacity would permit the vehicle to function within a “hub & spoke” system in which smaller vehicles collect students from far spread locations and transporting them to collection points. The vehicle is also said to contain a supervisory system permitting parents as well as school transport organisers to observe the underage passengers throughout the entire journey.

Seating & Access - The vehicle itself, merely a concept study at this moment, is a large box shape with softly rounded edges and a pleasant minimalistic design. Two door openings on either side allow for quick access and a ramp ensures easy accessibility for anyone.

The perfectly symmetrical design of the vehicle streamlines the vehicle routing choices according to TEAGUE, as the vehicle is able to stop on either side of the road without having to perform a U-turn. The cabin height is difficult to judge as the digital renders show distorted and differing proportions.

HMI & Emotional Experience - An exterior facing HMI is proposed, showing the destination, including the classroom and school, to the passenger, addressing the school child directly by name. This is intended to break the distrust barrier by the parents who may be unwilling to trust their offspring to a driverless vehicle. An illuminated band runs along the top edge of the front and rear of the vehicle, displaying the vehicle status.

5.2.10. SEDRIC - VW

The SEDRIC is the first driverless mobility vehicle designed by a major automotive manufacturer, indicating that this segment is gradually becoming more mainstream.
The VW concept is also taking a different direction to the aforementioned vehicles in the intended application as, according to VW, the vehicle will operate at higher speeds and cover longer distances. A theoretical route would be from the city centre to an airport terminal on the edge of the city (VW 2018).

Whilst there have not yet been any public trials of the VW Group SEDRIC since the vehicle was introduced to the public at the Geneva Motorshow in March 2017, there are images showing a prototype vehicle being tested.

Seating - The vehicle, therefore, is designed to provide a comfortable journey for a longer time for up to four passengers, seated on one bench seat and two folding down seats, arranged face to face. The permanent forward-facing bench seat is clearly separated by a large armrest and appears to wrap around the passengers for additional support. The fold-down seats are intended as jump seats for shorter journeys, providing a visibly less comfortable ride. The choice for an asymmetrical seat layout is intended to offer additional floor space for large luggage pieces, although no suitable restraints exist.

Interior Space & Access - The material choice for the interior, especially the seat fabrics, suggests a warm and comfortable environment, which is reinforced by a good amount of light streaming into the cabin through the floor to ceiling glass doors. A bar runs across the mid-section of the doors, offering a storage space as well as a sense of protection to the passengers. Differing from many other larger shuttle vehicles, the SEDRIC was not designed symmetrically on the exterior but rather with a clear forward direction. The low cabin can be accessed through two wide opening doors from either side with the passengers required to stoop down. The step up to the cabin is high and there are no handholds available to support in the entry. No provisions appear to have been made for a wheelchair entry either; the floor of the cabin is high off the ground and whilst there may be sufficient floor space, it is doubtful that the ceiling is high enough for a wheelchair user. This leads to the impression that the vehicle is impractical for those who may benefit from a door to door mobility service the most, the mobility and sight impaired and could even be considered uncomfortable for able-bodied users.

HMI - The exterior HMI on the SEDRIC is made up of two parts, a light strip frames both the rear and front window, presumably indicating the vehicle status and a display integrated into the front window showing animated headlights which may be perceived as eyes. This touches on the key issue of vehicle to other road user communication and which signals are required to be communicated and how.

In regards to communicating with the vehicle as a potential passenger, VW plans that in the future the vehicle could be ordered via a small key fob which features an illuminated ring light indicating the order status.

5.3 Vehicle Rating

Table 5.3 Rating Scale for the benchmark of current last mile mobility vehicles

Rating Scale

Not Applicable	Unacceptable	Poor	Average	Good	Excellent
N/A	- -	-	o	+	++
	-2	-1	0	+1	+2

Table 5.4 Benchmark of current last mile mobility vehicles

	ULTra	GRT	Zero	Navya	EZ 10	Olli	NEXT	eGO	Hannah	Sedric
Accessibility										
• Ingress	-	+	-	o	o	+	++	o	o	+
• Egress	-	+	-	o	o	+	++	o	o	+
• Disabled Access	N/A	N/A	N/A	From V4	+	N/A	++	N/A	+	N/A
Interior Design										
• Visibility to Exterior	-	+	o	++	+	+	+	o	+	+
• Luminosity	-	++	o	++	+	+	+	-	+	+
• Haptic	o	++	-	o	o	+	o	+	N/A	++
• Aesthetics	o	+	-	o	o	+	-	+	N/A	++
• Storage	-	-	--	-	o	-	--	-	N/A	o
Seating										
• Layout	o	o	o	o	o	o	-	o	o	o
• Shoulder Space	-	+	-	-	o	-	o	-	N/A	+
• Wheelchair Restraints	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
• Body Support	+	++	-	o	+	-	+	-	o	++
HMI										
• Booking System	+	o	N/A	App	App	N/A	N/A	N/A	App	Button
• Access System	+	o	o	+	+	+	N/A	N/A	+	+
• Ride Information	o	-	-	o	o	-	N/A	+	+	N/A
• Route Control	N/A	o	-	-	-	-	N/A	N/A	N/A	N/A
Emotional Experience										
• Sense of Control	--	-	--	-	-	-	--	--	-	--
• Ability to Observe	--	--	--	-	-	-	-	--	o	+
Social										
• Ability to interact with others	o	o	o	o	o	o	--	o	o	+
• Ability to work	-	-	-	-	-	-	-	-	--	-
• Mobile Network	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Exterior Design										
• Visibility to Interior	-	+	o	+	o	o	o	-	-	+
• Aesthetics	+	+	o	+	o	+	o	o	+	++
• HMI	o	-	o	o	+	o	-	o	++	+

5.4. Analysis

Aesthetics - There is a predominant public transport theme overarching most vehicles, which may be the result of designers wanting to emulate what the users are currently used to from other forms of public transport to ease the transition. Recognising certain design features familiar from regular buses and trains will increase the trust in the new technology, as the tried and tested features will be seen as reliable even on the new vehicle type. This does, however, bring a potential new problem with it; passengers are prompted to compare the vehicle and comfort to prior experiences with more traditional transit modes, which have been refined for many years.

The exterior design also holds a significant potential over the satisfaction of the customer, a capsule-like design like the ULTra might create a sense of security due to its robust look although this example, in turn, has a negative impact on the interior as it limits the interior space. This signifies the importance of striking a balance between an open airy cabin for the passengers to observe the surroundings to allow them to anticipate and understand vehicle movements and a shape that symbolises a robust and protective vehicle.

Accessibility - Unlike current public transport vehicles however, many of the concepts are unsuitable for those who would benefit from the technology the most; the elderly and mobility impaired. A group identified by Rode et al. (2015) as an increasingly important demographic due to their lack of access to public transport offers and a decrease in car ownership amongst them. For this group, a driverless last mile mobility service could be the key to accessing public transport and regaining some autonomy. Therefore, the accessibility to these vehicles needs to be improved with an even entry or ramp, adequate safety systems and an HMI that is within reach and not reliant on good eyesight alone (Halsey 2017).

The most prominent problem is the lack of handrails and armrests, which could offer some stability and consequently evoke a more secure feeling in the passengers.

This is a particularly important comfort aspect in driverless vehicles as passengers often cannot anticipate vehicle movements and strain themselves against it. In relation with these considerations is the amount of physical effort required to travel on this vehicle, high entry steps and seats without side support can be problematic to those who have greater mobility requirements such as the elderly and disabled.

Interior Space - The liberation of the vehicle interior from the vehicle controls and most importantly the driver, that driverless technology promises, creating new spaces and novel arrangements, has not been fully explored in the majority of the concepts. Some vehicles, such as the VW SEDRIC begin to explore the possibilities of creating a flexible vehicle interior with flexible seating changing from a four-seater for commuting, to a 2-seater with additional space for longer journeys. However, the development of the majority of the vehicles appears to be have been driven by the technological requirements with the passenger playing a subordinate role, creating cabin interiors which are cramped and small, frequently offering too little headspace to the passengers.

Another aspect which is not fully addressed by any of the vehicles is the need for travellers to securely store their luggage.

Some vehicles such as the EZ10 or the Olli offer some small space behind the seats to place a small item which however places it out of sight for the passenger and the items are likely to move during the journey. The SEDRIC concept as part of the flexible interior proposes two fold-up seats in the front of the vehicle which creates a space for larger luggage items, which however reduces the occupant capacity to two, with no luggage retention system in place.

Emotional Experience - A further observation can be made about visibility. Some vehicles offer great all-round visibility such as the Olli, Arma and the NEXT, whereas other vehicles, often due to a very dark tint in the windows have barely any visibility, making it difficult for passengers to observe the vehicle actions.

The view to the exterior and the path ahead is believed to play a significant role in the trust passengers have into the automation as well as the potential of them experiencing motion sickness (Diels & Bos 2015). So far this is not addressed sufficiently in any of the vehicles, as in all cases there is still a number of passengers seated backwards to the direction of travel and subsequently not benefiting from the improvement in visibility. Often however the backwards seats are a result of the packaging requirements, which aim to maximise the space within the cabin, challenging designers and engineers to find a compromise.

HMI - The interaction between the vehicle and the passenger is still very limited, which may be due to most vehicles still being in the concept and trial stage, often limiting the vehicles to a set route. However, as those vehicles become more advanced, the HMI will be the key point to the accessibility and usability of these vehicles. The Olli showcases the first concept of a free and intelligent destination choice, where the user is not limited to pre-set stops, currently however this is only an idea as the current vehicle is still operating on pre-set routes.

The designers will also have to develop solutions to communicate between the passengers, the vehicle and other road users, a so-called external HMI. Only if everyone involved feels like they are provided with sufficient information about what the other party is about to do, they will be able to trust and function alongside each other. First concepts, such as the light bands on the eGo Mover and the SEDRIC, are exploring how the vehicle can communicate its status to other road users and pedestrians, however, without a common signal language, it is difficult for the untrained user to understand it (De Clercq 2019).

5.5. Summary & Conclusion

The review highlights several key issues in regards to the design of current driverless pods such as the visibility from and into the cabin.

It also shows the shortcomings of the interior space design, where the layout of the seating often requires a number of passengers to travel backwards, which is likely to cause motion sickness. Furthermore, aside from the VW SEDRIC, none of the benchmarked vehicles have dedicated spaces for luggage.

The absence of solutions for passengers with mobility impairments and other disabilities is also poignant as these vehicles should be designed to be inclusive. In this category, handrails and armrests provide the necessary support for passengers to move through the cabin, lower entry steps and an automated wheelchair ramp are also required.

For the interaction between the passengers and the vehicle, as well as between the vehicle and other road users a number of different concepts are trialled with the benchmarked vehicles, many however are only at a concept stage and not fully integrated and are therefore not yet providing the passenger with the required information.

In conclusion, it can be stated that there remains a need for further development in regards to the vehicle interior, with a particular focus on the passenger in order to improve the overall passenger comfort in driverless first and last mile mobility vehicles. It can also be said that the vehicle concepts are relying on established features and layouts rather than attempting to reimagine new concepts which make more use of the liberty and space on offer.

With the importance of the user experience and comfort demonstrated as part of the comfort model development (chapter 4.0), it is evident why the developers of driverless last mile mobility solutions need to evolve their technical demonstrators into more refined products.

Furthermore, the number of pod concepts and vehicle trials has been rapidly growing in the past year and subsequently the exposure to unaware users increasing, this is the right moment to create an acceptance for this new technology by demonstrating the benefits without disappointing potential future users.

2nd Objective Part 2

The benchmark of 10 driverless first and last mile mobility vehicle concepts completes the second objective and provides an insight into the shortcomings of the current vehicles in regards to the passenger comfort and experience. These findings will be carried forward to the design requirements and subsequently inform the exemplary vehicle design concept.

6.0. Scenario and Persona Development

6.1. Introduction

When designing a successful product or in this case a driverless first and last mile mobility vehicle concept, a core requirement is detailed knowledge of the target user group during the design process (Gould, 1995; Margolin, 1997; Preece, 2002). González & Palacios (2002) state that products are given a more significant value for the market i.e. are more successful if designers have a comprehensive picture of the users and their needs. Holt (1989) also suggests that all those engaged in the product design process should be concerned with the users.

Tognazzini (1995) however points out that designers tend to seek out users who are like themselves to provide feedback on the design, which is counterproductive to understanding the true end-user. To avoid this happening, scenarios and personas are created based on research derived from a wide range of sources including consumer reports, observations, focus groups and surveys. Scenarios and personas are traditional tools used by designers in the product development process to improve their understanding of the consumer and the context in which the product will be used. They provide a narrative for the design process, helping stakeholders, designers and engineers to visualise the user as well as the environment into which the product will have to fit (Adlin &Pruitt 2010). Typically, several similar real-world scenarios are combined into a small number of representative scenarios and personas, which can then be used throughout the process to illustrate specific design details. Using this technique, large amounts of data can be combined and subsequently used to not only inform the design process at the start but also to continuously challenge the proposed designs throughout the development, to ensure that they remain relevant to the identified target users (Adlin &Pruitt 2010). Doing so helps to avoid creating a product based on potentially incorrect assumptions and instead improves the chances that the final product will fit into the environment it was intended for and subsequently be a success (Cooper & Kleinschmidt, 1990).

The three scenarios discussed in detail below are each representative of one of three different categories; technology parks, university campuses and large historic sites, which are likely use cases for a driverless first and last mile mobility vehicle. Those three scenarios represent 91 technology parks and 59 campus universities in the UK (UKSPA 2019) and also over 500 historic sites operated by the National Trust, located on over 248.000 hectares of land (National Trust 2019). To ensure that appropriate personas are created for each scenario, at the beginning of the MiCar design process representative scenario locations were visited and available online data was analysed to establish who the key users are.

The MIRA Technology Park, on which HORIBA MIRA is based, was selected as a representative use case for large technology park sites featuring a private road network, across which employees frequently are required to travel. At the site, a set of one-site observations was conducted and combined with an employee survey, which gathered information about the commuting behaviour to the site, as well as mobility requirements on the site. The online presence and the internal informational material for the HORIBA MIRA employees provided further information about the future aims of the company and the likely developments concerning onsite mobility (National Trust Volunteers 2019). The list of facilities available on the Technology Park such as the coffee shop, the logistics centre and the gym indicate the likely journeys taken and subsequently inform the scenario and personas.

The Warwick University Campus, was used as a representative university campus. Following an onsite, observational visit, student and employee numbers were gathered and information about existing mobility offers, such as the UniCycles (Warwick Estates 2019) was synthesized and provide the starting point for the persona and scenario development. A further source for was the accessibility evaluation conducted by the university, which encouraged staff to attempt to move across the campus whilst relying on wheelchairs and mobility scooters (Warwick Estates Accessibility 2019, Warwick Blog 2018).

The ethical guide for sustainable living published by the university which provide guidance to students was also used as basis for the development of the personas, as it provides an insight into what will be relevant to the future university student (Warwick Ethical Living Guide 2019).

The National Trust property "Stowe Gardens" served as a representative scenario for large public parks and historic sites and a visit was conducted, observing the visitor types and typical behaviour. Furthermore, the annual report published by the National Trust was used for insight into visitor numbers and demographics as well as the future direction of the organisation. Within the report, the improvement of the user experience through increased accessibility of the sites whilst maintaining a low carbon footprint is highlighted. The National Trust Access Guide gave insight into the offers created for those who have additional mobility requirements as well as systems to support people with accessing the web services (National Trust Access 2019). The personas were further inspired by the information provided by the National Trust about the volunteering possibilities offered by the organisation, a program which is very popular, attracting over 65.000 people who spent 4.8 million hours in 2018/19 (National Trust Volunteers 2019).

From the data gathered at the three representative scenarios, several personas representing the key users of each scenario were developed by combining the information about travel requirements with the demographic data. Each of these fictional personas represents a number of potential users and their specific user requirements.
Based on Eason (1987), three different types of users can be identified: primary, secondary and tertiary. Primary users are those who directly use the product (e.g. passengers), secondary users will only occasionally use the product or interact with it through an intermediary such as a supervision software (e.g. supervisors and mechanics). The tertiary users typically are those who make the decision about the purchase on behalf of an organisation for example or are influenced indirectly by the product as it is a competitor to their own business (e.g. operators).

All three types are relevant in the design of a vehicle, therefore the personas created for this research cover users from a range of backgrounds who interact with the vehicle in differing ways, with the main focus on the passengers. Personas typically also include an image representing the person to provide a visual reference to the designers and stakeholders. In the following section, the scenarios are discussed in combination with the relevant personas.

6.2. Scenario Development

6.2.1. MIRA Technology Park (Business Park)

The MIRA Technology Park scenario was the first scenario to be developed based on the technology park on which the research sponsor HORIBA MIRA is located.

Due to the fact that technology parks can be self-contained environments, they are likely to be one of the first scenarios in which the general public will be able to experience fully automated vehicles (KPMG 2015). The MIRA Technology Park features a private road network, permitting prototype vehicles to be used on the roads, trialling driverless first and last mile mobility solutions.

The technology park covers an area of 800 hectares and consists of a range of testing facilities and office buildings spread across the entire site with employees and visitors currently using private vehicles to move from one to another (HORIBA MIRA 2019). The use of private vehicles, as discussed in the first chapter has a significant ecological and economic impact on HORIBA MIRA and a network of driverless first and last mile mobility vehicles may help reduce this impact. On the MIRA Technology Park, a vehicle of this kind would cater for two different scenarios; providing door to door mobility for the employees by travelling from one office building to another and providing access to the site to visitors from the entrance of the site directly to the location they want to reach.

Therefore, two main routes were identified in the survey of the travel behaviour; from the main office block in the south sector to the control tower building located central in the north sector and the security check-in at gate 1 also to the north sector.

Without any intermediary stops, these journeys both take approximately 6-7 minutes. The majority of the rides will be undertaken by the employees who can book a ride through the company network and integrated calendars and then use their access cards to activate the vehicle. However, there will also be visitors who will require an access code, in the form of a QR code, for example, to access the vehicle and then be taken to their intended location as the technology park is a secured site.

As a consequence, the vehicle becomes the entry point to the site and needs to create a secure corridor between the car park and the meeting space. The vehicle will also be used by groups to travel to the canteen located in the south sector from all across the site, putting the system under maximum demand whilst a large number of employees attempts to use the service in a short period of time.

6.2.1.1. Japanese HORIBA MIRA research student

The 28-year-old male research student who frequently visits his supervisors at his industry sponsor HORIBA MIRA. He suffers from a severe visual impairment but using his smartphone, he can access company emails and apps via the text to speech function.

He reaches the MIRA technology park via the public bus line stopping on the main access road to the site. From there he has to reach his office located at the control centre. As a regular guest to the site, he was issued with a company pass on his first day. This pass indicates which areas he does and does not have access as well as specific requirements. He only carries his notebook back with him and a small shoulder bag with his lunch.

Height 170cm

6.2.1.2. Receptionist

In her mid-30s, the receptionist for the main office building travels to work in her own car. She does would however like to use the MiCar to reach events and conferences across the technology park where she supports the visitor welcome team as a host.

For these events, she travels with a small notebook bag, a small handbag and often a box with name tags and other event paraphernalia. Her mobility is slightly affected by her pregnancy and she, therefore, prefers to be able to sit down during the journey across the site.

Height 165cm

6.2.1.3. Maintenance Worker

His main role at HORIBA MIRA is responding to small incidents across the site, where leaks or electrical faults have to be corrected. Furthermore, he also remotely observes the MiCar system from his office space, maintaining an overview of overcharging levels, distribution of the vehicles and responds to any calls made by passengers through the vehicle communication system. He himself also uses the vehicles to travel from his office to the incidents whilst carrying a toolbox and frequently also replacement parts.

Height 195cm

Figure 6.1. Persona Images: Research Student, Receptionist, Maintenance Worker

6.2.2. Warwick University (Campus University)

The Warwick University Campus is based on a 290-hectare site on the outskirts of Coventry, with the town of Warwick located 3.4 miles to the east. It is made up of three smaller sites which are all within walking distance and is the home of 26.531 students, 6.300 of which live in mixed residences across the site as well as 6.525 academic, research and support staff (Warwick 2018).

The university also plays host to a large number of events each year as well as numerous open days, attracting large crowds. The vehicle could be used in two different modes in this scenario, a personal transport service at low demand times as well as a service in a pre-set loop, providing transport for larger numbers at peak times. The vehicle would operate on the road network (speed limit 20mph) as well as in pedestrianised spaces and be accessible to students, staff and the general public.

6.2.2.1. Family of 3 visiting university student

A family consisting of a 42-year-old father, 37-year-old mother and their 11-year-old daughter are visiting their second son who is studying medical sciences in his first year at Warwick University. Both adults own a smartphone and frequently use different apps for navigation and collecting rewards when travelling and shopping. They are unaware of the area as it is the first visit for all to the campus.

The mother suffers from osteoporosis and therefore needs some assistance to step into the vehicle and then prefers to remain seated for the rest of the journey. Whilst travelling across the campus they are carrying one medium-sized bag filled with supplies for university student.

After arriving at the university main car park, they use the phone app which was recommended to them by their son, to hail a driverless pod to take them to their son's accommodation.

They await their pick-up at a designated area on the outside of the multi-storage car park, hoping to identify their vehicle by a number displayed by the vehicle.

Heights 190cm/ 167cm/ 110cm

6.2.2.2. Maths student (wheelchair-bound)

The 19-year-old female student is using an electric wheelchair to move around the campus independently. However, in order for the charge in her electric wheelchair to last for the whole day, she prefers to use a driverless pod to travel the long distances.

Her daily routine starts with booking a vehicle via the app to take her from her accommodation to the first lecture on the opposite side of the campus. She relies on the app to communicate to the vehicle that she requires additional space within the cabin, i.e. make sure the vehicle is not fully booked as well as to ensure that the vehicle to deploy the wheelchair ramp automatically when it arrives at her pick-up. During the journey, she would like to be able to have a verbal interface to the vehicle as to the second option to her app, in the case that her phone runs out of battery or has a slow connection.

6.2.2.3. Senior History Lecturer

The senior history lecturer who is aged 63, does not own a smartphone and is, therefore, unable to book any mobility service through a phone app or website. When moving across the campus from lecture to lecture as well as for the lunch break he always carries his heavy briefcase with him. Due to his age, he suffers from mild arthritis, making it difficult for him to hold on to any handholds for a longer duration.

After catching a bus from Coventry, the senior lecturer arrives outside Warwick university campus before taking a small walk over to a driverless pod pick-up point across the road. Once there, he would like to be able to have priority access to the system to ensure he reaches his teaching commitments on time. He types destination and requests a vehicle. Before entering a vehicle he would like to spot a free seat as he would be unable to remain standing for the entire journey.

Height 195cm

Figure 6.2. Persona Images; Visiting Family, Maths Student, History Lecturer

6.2.3 Stowe Gardens, National Trust (Public Park)

The National Trust property Stowe Gardens is located near the town Buckingham in Buckinghamshire in the UK and one of the best known English country-style gardens in the UK.

At this property the main entrance is located approximately a mile away from the main gardens, requiring all guests to take a 20-minute walk before reaching the starting point of the main garden walks. Visitors with limited mobility currently have the option to use a volunteer-driven open golf buggy to reach the starting point, visitors with prams or wheelchairs, however, cannot use this service.

In this scenario, a driverless mobility vehicle could transport visitors with mobility issues as well as visitor travelling with small children in prams or wheelchair users to the main site and beyond that also function as a driven tour around the entire garden. As a shuttle between the entrance to the site and the starting point for the walks the vehicle could transport groups of people in a looped scheduled service, whilst the sightseeing tour could be an additional on-demand booked service.

The type of service influences has an impact on the number of vehicles required, a shuttle service could be achieved with two or three vehicles, whilst an on-demand sight-seeing tour would require a large number of vehicles as each booked vehicle is unavailable for other users during that time. At this time, extended golf buggies with open sides are used to offer sight-seeing tours with the narration provided by the driver, passengers can elect to leave the vehicle at the main sights to take pictures before continuing the tour.

6.2.3.1. Elderly lady

The elderly lady regularly visits the Stowe Landscape Gardens to participate in one of the volunteer gardening groups which run once a week. Whilst she feels she is still mobile and could walk the distance, she does prefer to take a ride directly to the site where the group is working that day since she is carrying a small case with her gardening tools.

At 64 she does not want to use her smartphone to interact with the vehicle as she is used to a volunteer-driven golf cart, which she previously used. Due to an ear infection she had as a child, she is unable to hear on her right ear and subsequently struggles to understand more than one voice at once. When she arrives at the visitor centre at the entrance to the garden she uses the pod call point to request a vehicle to take her and the other members of the gardening group to the gardens. Larger equipment such as a wheelbarrow will be brought over by the full-time landscapers but the group still brings their own tools and lunch packs with them.

Height 165cm

6.2.3.2 Foreign Family

The young family of four travelled to the UK for a week-long holiday but due to their fascination for old country estates, they decided to travel to the Stowe Landscape Gardens. Having travelled from Spain, the language barrier makes it harder for the family to use the booking system for the vehicle but they have downloaded the National Trust App which is available in Spanish. When arriving at the gardens the family requests a vehicle at the call point for a sight-seeing tour. They board the vehicle, bringing with them a picnic hamper and a bag of toys for the kids. Halfway through their journey with the pod, they want to request a stop to have lunch in the gardens. They are going to use their phone app to request a pick up to return to the carpark. During the sight-seeing tour, they would like to learn more about the property and the gardens.

Heights 180cm, 165cm, 100cm, 90cm

6.2.3.3 Young Child

The young child is visiting together with his mom during the school holidays. Since he is inseparable from his scooter, even during the visit to Stowe Gardens he has to bring it along. The two only want to use the shuttle to get from the visitor reception to the start of the walks and only take the vehicle on the off chance as one was waiting at the pick-up point. As they are sharing the vehicle with other visitors, the scooter is folded out and stored away for the journey. As it's their first visit to the gardens they need the vehicle to notify them when it stops for the walks. Normally he wants to sit next to his mother when travelling on buses or the train.

Height 110cm

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The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.

Figure 6.3. Persona Images; Elderly Lady, Foreign Family, Young Child

6.3 Summary & Conclusion

The scenarios developed in this chapter represent three scenarios in which driverless first and last mile mobility vehicles are likely to be seen first for each of the scenarios three personas were created, each representing a different user group with specific requirements for the vehicle. All of the three scenarios and the nine personas will be carried over to the following chapter 7 in which the vehicle design requirements are developed in detail. Here the user requirements established through the personas will be the basis for the design work. As previously discussed in the methods, the scenarios and personas will be an integral part of each of the following steps, initially informing the design process and then guiding the evaluation process.

1st Objective Part 2

In order to fulfil the second part of the first objective, the three scenarios and nine personas above were developed. These synthesise the information gathered as part of the literature review and direct observations into exemplary personas and scenarios for the context of driverless first and last mile mobility. The personas and scenarios are an important foundation for the design work conducted in chapter 8.0 and will also inform the selection of the trial participants for the studies.

7.0 Design Requirements

7.1. Introduction

An initial list of requirements for a mobility solution was developed in mid-2015 by a team from the Horizon Scanning Department at HORIBA MIRA as part of the redevelopment of the MIRA Technology Park. They also named their vision "MiCar" in line with the HORIBA MIRA project naming policies and therefore the vehicle and design will be referred to as MiCar in the following work. The group of researchers in the field automotive engineering created the initial list of engineering requirements and basic design requirements which was then further expanded with the requirements identified in the comfort model (chapter 4.0) and the benchmarking detailed in chapter 5.0.

The list was further influenced by the personas and scenarios developed in chapter 6.0. They provide an in-depth understanding of the users and their requirements for the vehicle as well as the demands the environment put on the vehicle. The use cases help to identify the kind and number of potential passengers which will use the vehicle and under which circumstance and with what goal. Each of the personas combined with any one of the scenarios creates unique demands; a family with a toy scooter, for example, requires a place to safely store it during a sightseeing tour, whereas during a short journey it may be acceptable for one of the adults to hold it.

The list, therefore, covers basic engineering and design requirements as well as requirements based on their business operations. The MiCar vision has to provide mobility for employees across a large business park whilst also being a suitable vehicle for a guided tour on a country house estate or transporting students from one lecture to another.

7.2. List of Requirements

This list is broken up separate categories, a summary of the users and environments and the requirements associated with each of those, and the vehicle design and engineering. The first two categories highlight the case-specific requirements and the third and fourth category provide a general set of requirements which apply to each scenario.

Users (detailed as personas in chapter 6.0):

- Disabled (wheelchair access, auditory & visual support)
- Elderly (may have back & neck condition)
- Business people (have briefcases & people from abroad may have luggage)
- Families (travelling with children & prams)
- Students (large backpacks)
- Tourists (language barriers

Environments (detailed as scenarios in chapter 6.0):

- Business Parks (productivity during the journey & small luggage items)
- University Campuses (larger groups & peak demands)
- Public Parks & Spaces (guided tours & families)
- Transport hubs (Large Luggage Items)

Cabin & Vehicle Key Design Features:

- 2+2 seater (increase conversation & maintain personal space)
- 4 seats facing centre (table/screen), high headroom, nice seats (not public transport)
- Quiet (To encourage conversation)
- Desirable/unique design
- Large windows
- Natural Light
- Full standing height
- Luggage space

- Armrest & Handrails
- Announcements through the speaker – In case of emergency, bus stop announcements
- Navigation screen
- Individual Lighting for each seat
- Comfortable seating and legroom
- Flexible wheelchair & pram space
- Automated wheelchair ramp
- Low entry step
- Handholds by the door
- Clear door aperture marking

Engineering

- Driverless/autonomous
- On-road only (not off-road or cycle lanes/pavement)
- Lightweight construction (<800kg) for battery efficiency)
- Contactless recharging at main stops
- EV range 30 miles (1/2-day)
- Ability to manage inclines (Bridges etc.)
- 30mph/50kph capable
- Safety systems – avoid 3-point belts if possible
- Electric Powertrain
- Innovation from HMI, packaging, autonomy, drive-by-wire, safety systems
- Automatic Climate Control (Heating & Cooling)
- Drive in either direction (omnidirectional holonomic drive)
- 'Connected car', on-demand

7.3 Summary & Conclusion

The list highlights the variety of requirements which have to be taken into consideration to satisfy the diverse range of users and scenarios in the development of the MiCar design concept.

The combination of mobility solution and marketing results strongly influences the overall vision and design of the MiCar. The vehicle is expected to be easily used and provide a comfortable journey experience but also represent a new category of vehicles. It is required to be a functional object at the same time as being a representation of future mobility.

The engineering requirements are dictated by the Mira Technology Park site which were established through drive cycle analysis drives conducted by HORIBA MIRA engineers. However, these requirements are also chosen to remain applicable to other scenarios.

The three access requirements are a result of the specific requirements of the Mira Technology Park secure access policies, however as they are the most difficult to achieve, they will suit an application as part of the public transport network.

Overall the list of requirements provides the basis to develop the technical underpinning of a vehicle concept as well as informing the vehicle shape and styling.

3rd Objective Part 1

The first part of the third objective was to synthesise the information gathered as part of the literature review, comfort model and benchmarking, to produce a design specification for a driverless first and last mile vehicle for the MIRA Technology Park scenario.

The design specification will provide the basis for the second part of the objective, the creation of an exemplary driverless first and last mile mobility vehicle concept.

8.0. Design Work

8.1. MiCar Concept

8.1.1 Introduction

The following chapter will detail the design process which leads to the MiCar vehicle concept. It is based on the list of requirements and includes an initial vehicle platform which was developed with the support of engineers at HORIBA MIRA. As discussed previously, an iterative design process was used and thus the initial design was continually refined throughout the research project (Fig 8.1). The following part will, therefore, discuss the initial design work and the first iterations. The additional changes to the design, which were done as a consequence to findings in the studies, are briefly described at the end of each study and are summarized in the final discussion (chapter 10.0).

Parallel to the design process, a group of 20 engineers from HORIBA MIRA also engaged in a “Grand Challenge” with the MiCar project as their focal point. The aim of this work was to develop a basic engineering package in connection with the vehicle design. The findings of this work directly influenced design decisions and vice versa, the design direction established at the beginning of the design process directed the engineering requirements (Fig.8.1). The results of the engineering work will be discussed as part of this chapter, in direct relation to the design features.

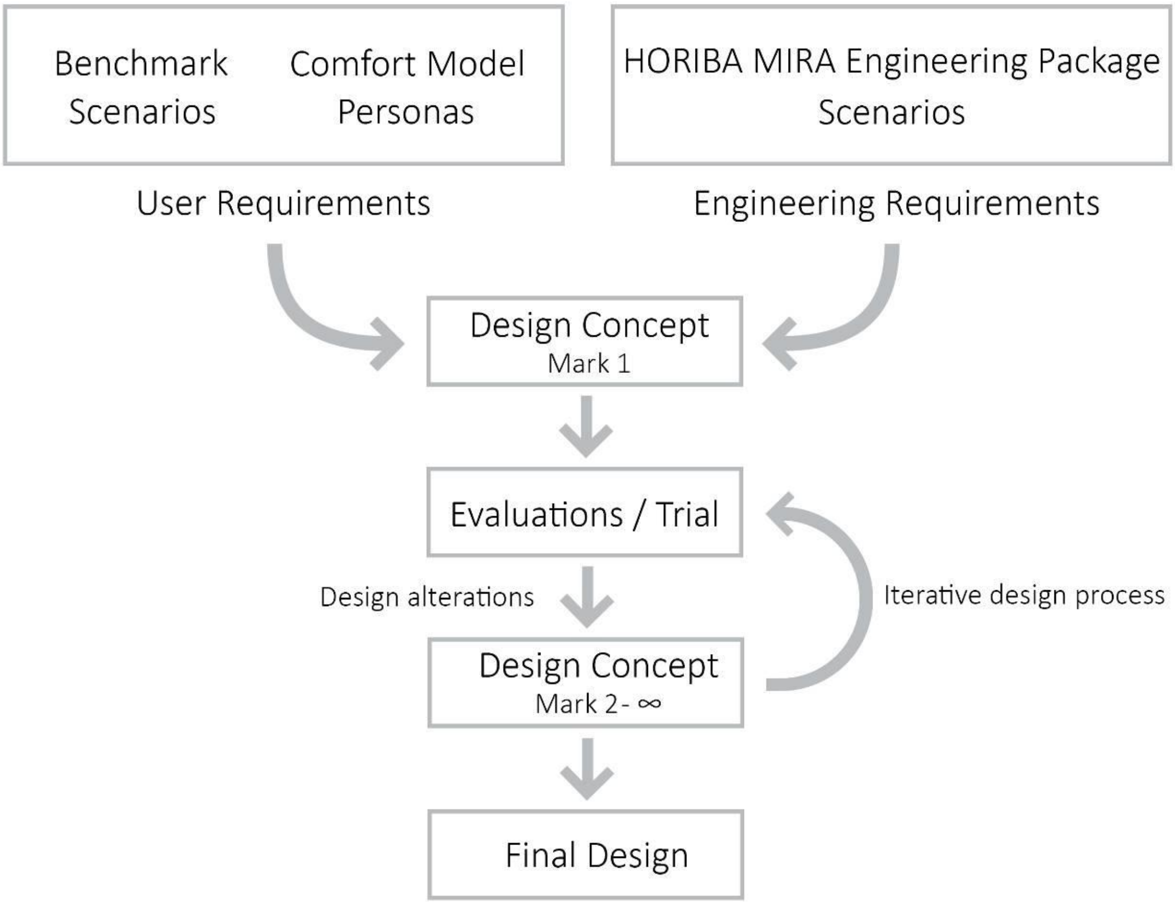


Figure 8.1 Influences into the design concept & Iterative process

8.1.2 Vehicle Platform

The platform is comprised of two electric motors (VOCIS 4SED) and converter units located on either end of the vehicle, immediately between the wheels (fig. 8.2). The two motors are combined with a gearbox each, with the gear ratios split into 1&3 in one and 2&4 in the other. This setup creates a redundant system in which only one electric motor is used at a time, with the software changing seamlessly between the motors depending on the gear required. All wheels can be steered in order to achieve a holonomic drive, allowing the vehicle to move at equal speed in all directions. The battery pack built with Samsung 18650 batteries, with a capacity of 45Kwh, is fully integrated into the floor section of the vehicle between the two bulkheads and is a structural component of the chassis. The integration into the structure creates a very low-profile battery, reducing the height of the entry step whilst maintaining the required road clearance.

The tyres used for this platform are on 10inch rims in order to fit the whole tyre and suspension assembly beneath the full-width seating. The chassis structure was designed to comply with the standardised road car crash requirements in regards to the bumper crash bar placement (45cm above ground).

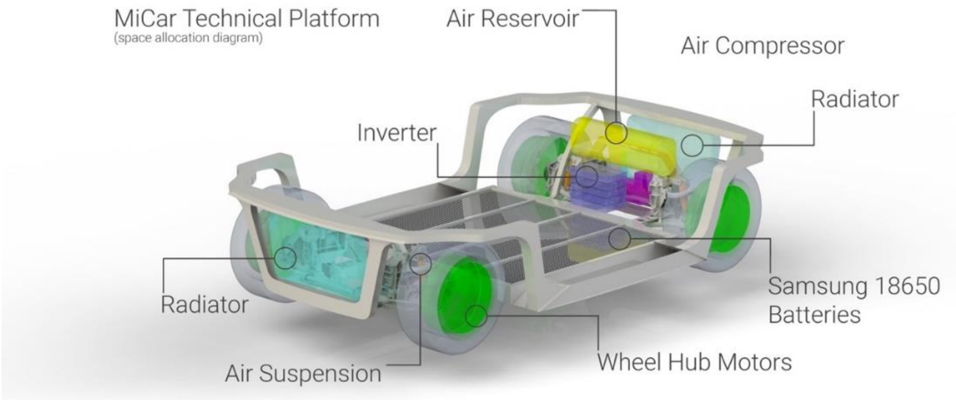


Figure 8.2 Vehicle Platform Packaging Diagram

The engineering team identified inductive charging as a requirement and incorporated it into the battery pack, centrally below the vehicle. The AC/DC inverter and motor control units required for any electric drivetrain were packaged with the motor unit beneath the seats. The overall aim of this vehicle platform concept is to package everything, with the exception of the sensors (Lidar, radioscopic and cameras), within the chassis of the vehicle to maximise the space for the occupants. The resulting chassis shape is frequently seen in this type of application and is commonly referred to as “electric skateboard” (Financial Times 2019). The overall dimensions of the vehicle are 220cm in width, 320cm in length and 210cm tall.

8.1.3 Cabin Layout

Different arrangements for the four seats, which were stipulated in the design requirements, were tested digitally and ultimately arranged in a two-plus-two layout (fig. 8.3). Other layouts which were explored had seats facing outwards for better visibility, which however did not allow for a wheelchair space to be integrated.

Another concept featured a row of seats along the side of the vehicle, which would improve the capacity of the vehicle but also subject passengers to unpleasant sideways accelerations. In the two-plus-two layout, the two sets of seats are facing each other and are located above the drivetrain and suspension components. Pushing the seats to the extremities of the vehicle cabin creates a flat central floor space, sized to accommodate a wheelchair.

The seats themselves are both rotated inwards by 15 degrees based on two factors; firstly, the slight angle aims to increase the ability for passengers who are seated backwards, to view the direction of travel in their peripheral vision. This feature relates to the comfort factor physical wellbeing as travelling backwards is likely to increase the possibility of experiencing motion sickness (Salter et al. 2019). The second reason is the aim to simplify and subsequently provide an incentive to communicate with the seat partner. Piro et al. (2019) demonstrated in their research that arranging two seats so that they are rotated towards each other does increase the quality of the conversation. In their research they discovered that an angle of 45 degrees is the most preferred option, this, however, would make it difficult to view the exterior, which is why for this design a compromise between the two arrangements was chosen. In the initial version, this also creates a small space between the two seats which can be used to store small luggage items.

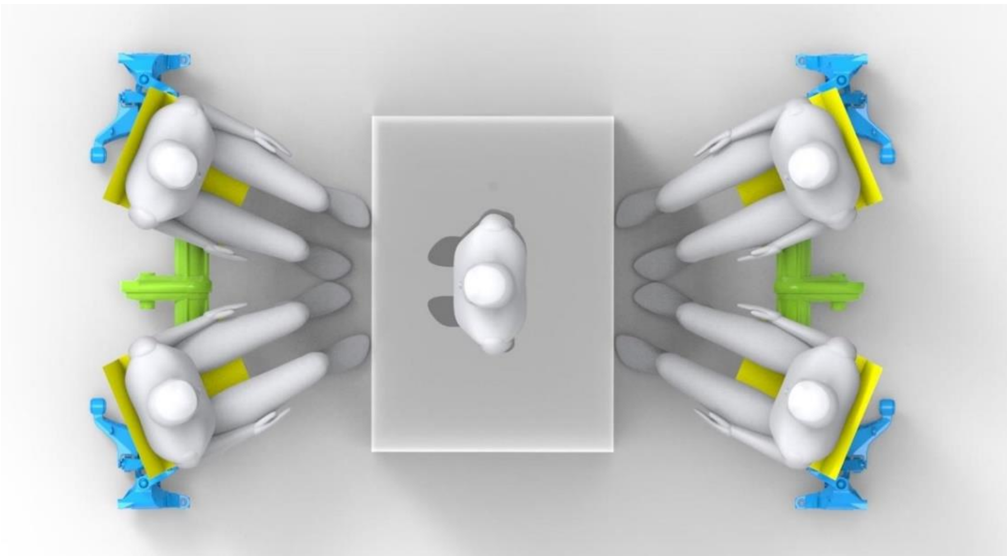


Figure 8.3. Initial Cabin Layout (incl. Wheelchair space)

8.1.4 Initial Exterior Design

Structure & Day Light Openings - The starting point for the initial sketches was the aim to create a vehicle with a large interior volume, especially at head height. Therefore, the sketches explore variations of a cabin shape which expands upwards. Additional to the volume expanding, the design attempts to underline this visually by positioning the structure angled outwards as well. Typically, vehicles are designed with a tumblehome angled inwards to create a dynamic shape and reduce the wind resistance. In the case of this vehicle type, the latter can be neglected due to the low speed at which they operate (fig 8.4).

Throughout the sketch development, the exterior design of the vehicle evolved to reflect that the vehicle is expected to travel in both directions through asymmetrical front and rear. This also extends to the lights and signals on the vehicle, which have to be able to switch depending on the direction the vehicle is moving to communicate the driving direction to other road users.

The sketches are also influenced by the seating layout, with the seats above each of the axles, the placement of the doors in the centre of the body and the uprights of the body structure behind at the shoulder of the passengers. This creates large openings on the front and rear of the vehicle as well as on the sides.

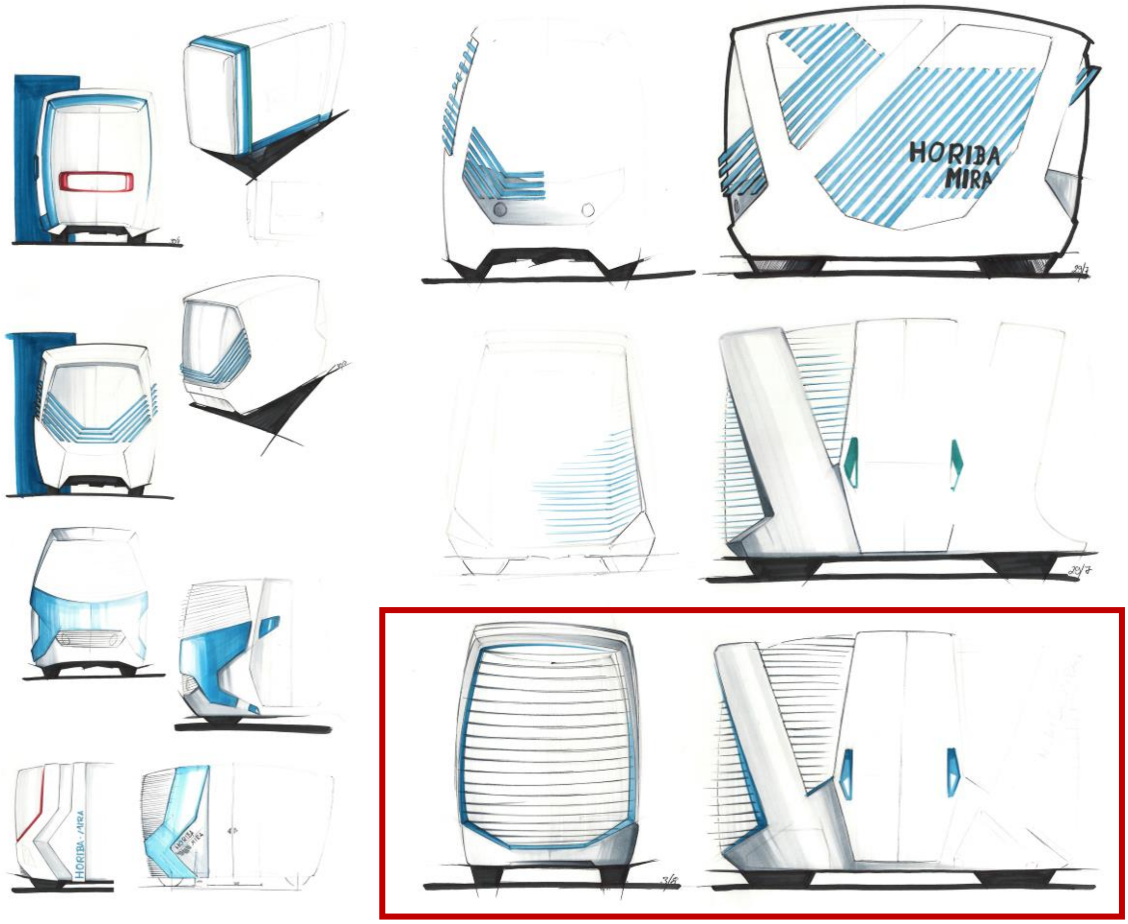


Figure 8.4 Initial MiCar Sketches & Key Sketch (red frame)

Using the HORIBA MIRA logo as inspiration (fig. 8.5), for the early sketches, horizontal rings were arranged to replicate the logo. This was not carried forward however, due to the lack of symmetry and the impact this arrangement would have on the visibility into and from the vehicle cabin.

Figure 8.5 HORIBA MIRA Logo

The expanding body volume also played a significant role in the design of the glasshouse, initially resulting in a very boxy design but over time this developed into a softer shape with rounded surfaces which maintains the large interior volume whilst being more pleasing to the eye.

The sketches also developed towards an increasingly larger DLO (Day Light Opening), particularly in the forward and rearward facing surfaces, to provide a generous amount of natural light in the vehicle cabin and as a direct connection also a good view from and into the interior. Both design factors are related to the comfort model aspects pleasure and of peace of mind, the latter based on the requirement for users to be able to see what is happening around the vehicle in order to anticipate the upcoming events.
A prominent feature in the design are the equally spaced horizontal rings (fig 8.4) surrounding the vehicle. Informed by the comfort model established in chapter 4.0, these rings are intended to serve several purposes: shading the vehicle (Physical Wellbeing) as well as creating a sense of enclosure for the occupants (Peace of mind).

Headspace - The headspace in the cabin was a requirement set out in chapter 7.0, as a full standing height cabin (suitable for an approximately 95th%ile Dutch male 1959mm) provides easy access and comfortable standing space, features which influence the physical wellbeing of the passenger and the usability of the vehicle. Easy accessibility of the vehicle is further created through two equal doors on either side, with a large aperture, opening sideways to be wide enough (110cm) for a wheelchair to comfortably fit through.

Wheel cover - A design choice made early on in the process was, to fully cover the wheels and hide them behind the bodywork of the vehicle. This was done in order to prevent the onlooker to see the unusually small 10” wheels which could cause the vehicle to appear unstable. The integration into the bodywork allowed for the wheel covers to be exaggerated to suggest that larger wheels are concealed beneath, which in turn suggests a stable vehicle.

This optical illusion is possible to uphold even during the journey, as the vehicle, due to the battery pack and motors being packaged low within the chassis, has a low centre of gravity, which guarantees stability. Just hiding the wheels without suggesting their presence and size with the bodywork could lead the onlooker to believe that the vehicle is floating, which would contradict the suggestion of stability.

Therefore, following the sketch development, the sketch highlighted by the red box in fig. 8.4, was chosen to be carried forward into an exploratory 3D CAD model which can be seen below in fig.8.6. The chosen design features large window openings with two narrow columns holding up the cabin.

Figure 8.6 Initial Exterior Design Concept Mark 1

8.1.5 Initial Interior Design

The initial layout established the requirement for four individual seats to be included in the cabin, two on either end of the cabin. The initial interior design, therefore, included seats which were shaped like typical car seats, with high backrests and small lumbar and thigh supports.

This type of seat design was chosen in order to move away from typical seats found in public transport vehicles as the aim of this vehicle concept is to provide a more comfortable and flexible experience.

In order to comply with the personal space requirements, related to the factor of proximity in the comfort model, the seat spaces are separated through an armrest. A novelty in this design, however, is Y-Shaped handrail, where a split in the handrail provides an isolated portion of the handrail to each of the passengers (fig. 8.7).

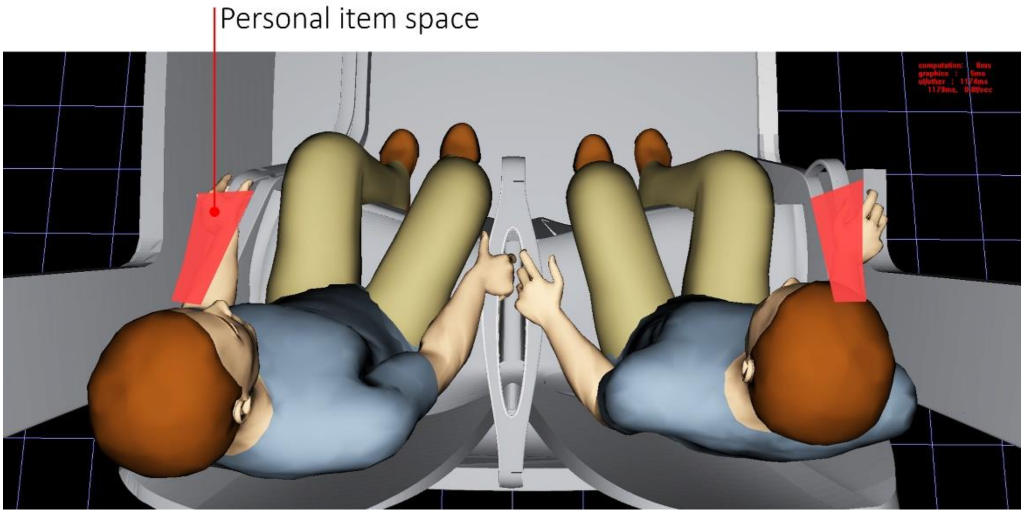


Figure 8.7 MiCar Interior Concept Mark 2

Between the dividing handrails was a small tray in the Mark 1 interior concept which can be used to deposit small luggage items such as handbags, items which typically have to be kept on the lap of the passenger or placed on the floor. Keeping these items close to the passenger and within their field of vision, relates to the peace of mind aspect of the comfort model, as it eliminates any potential worries about the safety of their belongings. However, in the Mark 2 interior, due to the seat shape change, this space was relocated to the left- and right-hand side of the handrails. The handrails were continued across the floor as visual lines, with the same appearance of the handrails, to further underline the communal setting of the cabin.

Small screens are mounted directly to the outlying handrails, providing each passenger with personal access to the vehicle infotainment system. To improve the access to the seat the screens can be rotated to the side (Fig. 8.8 (here shown in their resting position)). A further larger screen is mounted centrally to the side of the cabin to allow wheelchair users and standing passengers to also access the infotainment system. Splitting up the access points to the HMI and spread them across the cabin is supporting the requirement of easy usability and the proxemics, giving the passenger better control over their journey and immediate surrounding.

The interior concept shows a small luggage space, large enough to accept carry-on luggage items on the far side of the cabin (Fig. 8.8). Here the handrail extension that runs across the floor is raised to double in function as a retaining rail for the luggage space. There is no dedicated luggage space beneath the seats as the drivetrain components are located there.

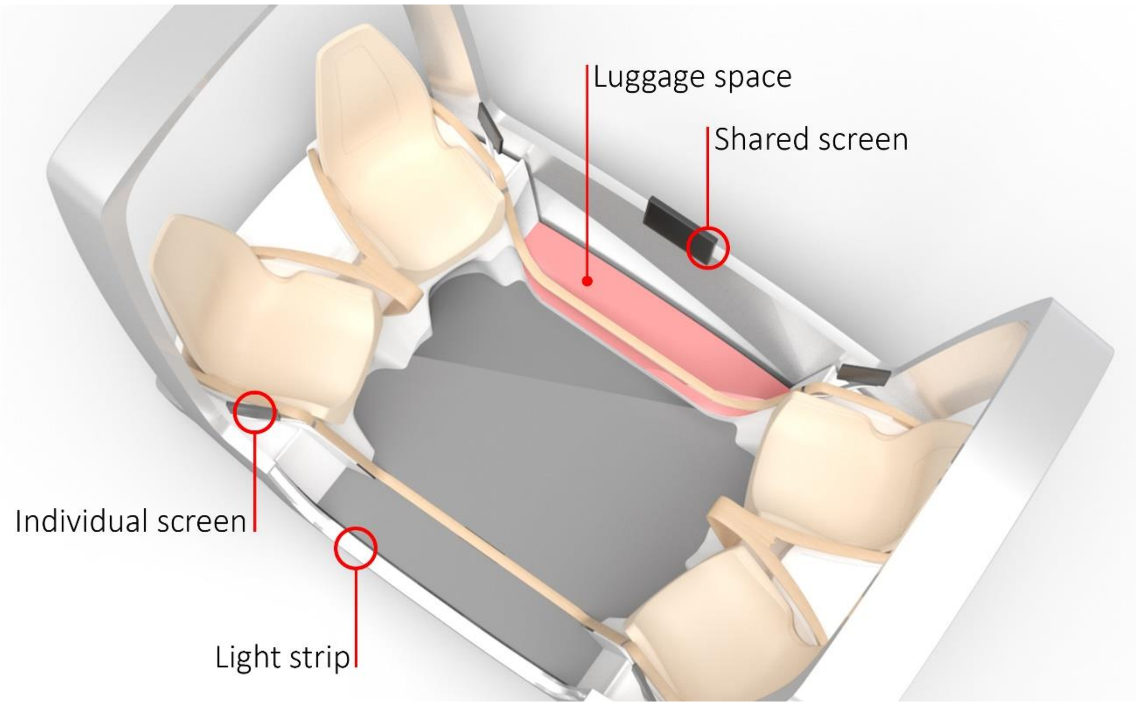


Figure 8.8 MiCar Interior Concept Mark 1

8.1.6 Wheelchair Access

Wheelchair accessibility was a key aspect of the design from the start of the design work. The package and layout identified a central point in the cabin as most suitable for a wheelchair spot, as it provides a support against which the wheelchair can be affixed. The size is based on the "Public Service Vehicles Accessibility Regulations 2000" which stipulate that the wheelchair space shall not be less than:

- 1300mm measured in the longitudinal plane of the vehicle
- 750mm measured in the transverse plane of the vehicle
- 1500mm measured vertically from any part of the floor of the wheelchair space

The wheelchair space is placed directly in front of the central armrest on one side of the vehicle, in order to leave sufficient space for other passengers and to provide the wheelchair user with a backrest which extends from between the two seats (Fig.8.7). This allows one wheelchair user and two seated passengers to travel in the vehicle at the same time.

A small self-extending ramp is also included into the design, which in combination with the capability of the vehicle to "kneel" down towards the curb or road (by deflating the air ride suspension) allows a wheelchair user or a passenger with a pram to reach the interior without a step.

As this vehicle will operate at low speeds only at this point the wheelchair will not be restrained with any fixtures within the cabin other than the brakes fitted to the wheelchair itself. Automated wheelchair restraining systems are available, however, they do require a large amount of packaging space, which could be integrated into a vehicle with a larger platform.

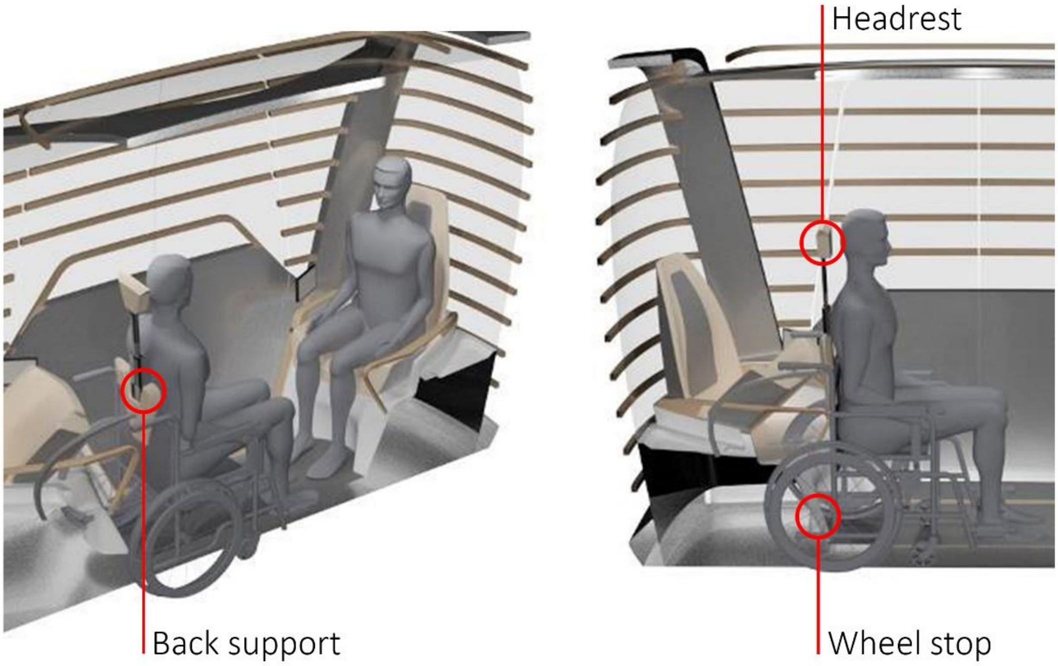


Figure 8.9 Wheelchair placement & Support

8.1.7 Revised Exterior Design

The initial vehicle design featured two doors, one on either side of the vehicle, however, it became clear that due to the holonomic drive of vehicle it was not necessary to provide access from both sides as the vehicle can travel equally as well in both directions and can, therefore, approach a stop with the door always facing the right way.

As a consequence, the first iteration of the design concept removed one of the doors and reshaped the exterior around the remaining door, adding a door frame with contrasting material and a light strip to make it easier to spot where the door opening is located. Identifying the opening may be difficult for passengers with visual impairments but a stronger contrast through illumination and different materials can simplify it. The light strip on the lower edge of the door aperture also changes in colour depending on the door opening or closing (Fig. 8.6).

The cabin structure itself was also updated with a cross beam which connects the two upright structures on either end of the vehicle.

The beam stretches from each corner of the vehicle to provide structural rigidity to the vehicle and integrates four light features above each seat. The individual light sources are intended to emphasise the personal space each seat provides.

The external rings in the updated version are made from wood and decrease in thickness towards the top and bottom of the vehicle whilst the spacing between the rings decreases to visually stretch the vehicle vertically. Wood was chosen as it is a softer and warmer material to avoid the look of a cage.

The previously used equal spacing between the bars, however, had a similar effect and was frequently remarked upon in the exterior review (chapter 9.1) as being too similar to prison bars. The new arrangement introduces further benefits; the design elements now suggest to the potential passenger the large available headspace prior to entering the cabin as well as freeing up viewing corridors. The placement of the rings was optimised to avoid impeding the view of seated and standing passengers alike, with the largest gaps in the middle of the vehicle. As previously discussed in the comfort model (chapter 4.0), the view to the outside world is essential as it provides the passengers with the possibility reassure themselves that the vehicle is operating safely, which is part of the peace of mind factor.

HVAC (Heating, Ventilation & Air Conditioning) Systems are a large contributor to the energy consumption in electric vehicles, decreasing the vehicle range between 30-40% on average depending on the system size and drive cycle (Zhenying et al. 2018). Especially during the summer and winter months, this becomes a critical element in the comfort experience in electric vehicles as it requires to balance the vehicle range and the climate within the vehicle interior. Due to the large glass surface, this is a particular concern for the MiCar concept, as the cabin is likely to heat up in direct sunlight. Equally, the large door aperture causes cold air to enter the cabin in the winter months, making it difficult to contain heat within the vehicle.

To prevent the cabin from heating up during the warmer months, the design includes a set of wooden rings surrounding the vehicle. These were designed with a double function in mind; creating a sense of enclosure for the passengers and subsequently a sense of protection and secondly shading the interior in a similar fashion to those found in the architecture. These passive elements help to reduce the amount of solar radiation that reaches the interior and subsequently the amount of active cooling required (Hernández et al. 2017). The final layout and size, as well as the effectiveness of these louvres, is not optimized at this design stage and therefore remain as a potential further study. The louvres, however, are not the only method to influence the climate within the vehicle; automated air vents in the ceiling of the cabin are used to prevent hot air accumulating within the vehicle. To provide a comfortable journey experience during the colder months, the MiCar concept utilizes heated seats, a technology already frequently used in personal vehicles, to provide seated passengers with a personal comfort zone. These components combined aim to provide passengers with a comfortable climate during their journey.

The upright structure on either end of the vehicle, the "hoops", provide a perfect mounting point for the LiDAR sensors and cameras required for driverless technology. They are located on all four corners of the vehicle and allow for the sensors to be mounted high up on the vehicle avoiding any obstruction. The engineering team at HORIBA MIRA, which additionally to providing their automotive engineering expertise also conducted an initial structural assessment to support the MiCar concept development. For passive crash protection, the chassis features internal crash structures at the same height as passenger vehicles (455mm above ground) (RCAR 2010), which protects the vehicle occupants during a low-speed front or rear impact with another vehicle. The structural assessment of the MiCar concept did also inform the design of the cross beam which connects the two upright structures, it connects the two upright structures on either end of the vehicle. The beam stretches from each corner of the vehicle to provide structural rigidity to the vehicle and integrates four light features above each seat. The individual light sources the personal space each seat provides.

8.1.8 Scenario Renders

Following the design changes, the vehicle concept was rendered on the MIRA Technology Park, the National Trust Garden Stowe and the Coventry City Centre, in order to provide visual references, displaying the vehicle in the intended environment (Fig. 8.10/8.11).

These images are essential to contextualise the vehicle in the environment, allowing both the designers and the general public to better evaluate the design in regards to the size and impact.

Figure 8.10 Environment Render MIRA Technology Park (Top) & National Trust Stowe (Bottom)

Figure 8.11 Environment Render Coventry City Centre

8.2. MiCar HMI Concept

8.2.1 Introduction

As established in the previous work, the interaction with a driverless first and last mile mobility vehicle is a crucial part of the journey experience and subsequently the success of this type of vehicle.

An external and internal HMI (Human Machine Interface) is a potential solution to support passengers and other road users in the anticipation of the vehicle movements. External HMI elements such as headlights and indicators are well established and universally understood symbols in the road space. For driverless vehicles, however, they will have to be expanded, as they no longer suffice to communicate the vehicle intention, as the eye-to-eye contact between drivers and road users is no longer given. A number of solutions are being explored such as LED strips, which run along the beltline of a vehicle and indicate a registered object with a change in colour.

Other solutions propose a display on the outside of the vehicles, which communicates with other road users with written messages such as ”WALK & DON’T WALK”. Those have been proven to increase the trust other road users have into the automation and feel more comfortable acting in their direct surrounding (Clercq et al. 2019).

The internal HMI can also play a role in informing the passenger about the vehicle movements; indicate which will be the departure direction or the upcoming direction changes. A concept for an interface that communicates the vehicle behaviour is a LED array integrated into the overhead handrails. Using this array, light cues for the vehicle movement can be displayed, a concept based on the research by Pretto et al (2009), where screens displaying pixels moving through space are used to indicate movements. To expand on this concept, in the MiCar light pixels are displayed along the overhead handrails and move based on the vehicle movements.

A further study to evaluate the efficacy of this concept in informing passengers about the vehicle movements is being prepared at the time of writing. Overall, an interface concept to communicate vehicle movements to both, passengers and other road users is not yet implemented at this stage in the MiCar, as it requires additional in-depth research.

However, an initial Human Machine Interface (HMI) concept was developed to be integrated into the MiCar vehicle concept.

The development was based around the data gathered on the MIRA Technology Park site, which was visually collated in the form of a user journey map, a traditional design tool used in product design, showing each interaction with the vehicle at each stage of the journey.

8.2.2 User Journey Map

The user journey map (Fig. 8.12) is to be read from the top to the bottom with the red lines indicating the connections between each stage (grey boxes) in the interaction with the vehicle. Parallel running red lines show the different options that are available to choose from at each given point.

The different interactions are grouped thematically and are highlighted by the coloured squares. In addition to the red lines indicating the users, the green lines show the vehicle actions or reactions related to the user input. The map also includes the projected duration for each interaction to highlight how long a user may dwell on each step and where the biggest efficiency gains can be made.

Using the map, the required interfaces were identified and the use cases analysed:

Tablet / Smartphone / Call Point / *Computer*

The map highlights the complexity of the interaction between the user and the vehicle and shows that this begins a long time prior to entering the vehicle with pre-booking journey or ordering one for direct use.

Pre-booking a journey can be done through a number of platforms and interfaces for which an application or webpage have to be created.

A pre-booking system could include the option to create a personal account which could store preferred destinations, save payment details and other requirements.

For a driverless first and last mile mobility vehicle which is installed on a private company site, the pre-booking system could also be fully integrated into the company network, allowing users to book the vehicle as part of the calendar software if the appointment requires them to travel across the site.

For those who do not have access to a mobile booking system, a call point at the main stations or central points of interest can provide users with the options to book a vehicle.

External HMI

The external HMI serves several purposes, the initial role in regards to the passenger interaction is to provide identification for a user, such as displaying the vehicle signature, a name or number. Only if the user is able to quickly and unmistakably identify the correct vehicle the comfort factors, ease of mind and usability can be fulfilled. Beyond entering the vehicle which has the correct journey preprogrammed, this becomes even more important if the user has opted to create a personal account which stores the user preferences, such as the need for a wheelchair ramp or a different language.

A secondary role of the external HMI is to communicate with those around the vehicle, informing them of vehicle movements, direction changes or that the vehicle has registered them at a pedestrian crossing.

Whilst this is a separate complex topic and therefore not further explored within this thesis, the vehicle design does include a space suitable to integrate an external HMI on the front and rear on the back of the seat base.

QR Scanner / NFC Chip Reader

However not only the users have to be able to identify the vehicle, but the vehicle itself also has to be able to register the user as well. A QR scanner would allow a user to unlock and connect to the vehicle through a QR code which is printed or displayed on a screen. An NFC Chip Reader would be able to provide the same service for passengers with traveller cards or employee cards.

Registering the user is required in order to provide the user with the required service, deploying the wheelchair ramp for example.

Similar to the payment systems already in use in public transport services, scanning a card to unlock the doors could be used as a payment system and on secure sites, such as the MIRA Technology Park, it could serve as access control.

Internal display

The internal display is mainly used to communicate the route and estimated arrival time but may also be extended to further use cases such as current news, vehicle information, sight-seeing commentary or commercials. The internal HMI, therefore, plays an important role in regards to the comfort model factor "peace of mind", which is the most critical, as well as the factors of "usability and pleasure".

The need to provide information about the driverless technology as well as the electric powertrain is based on the findings that many passengers are drivers themselves and will, therefore, be extremely sensitive to the vehicle performance and capability (Horswill & Costa 2002). Communicating this information to passengers within the vehicle through the HMI may fulfil this need and subsequently support the growth of trust (i.e. peace of mind). If the HMI can inform the user reliably about the vehicle performance, then, according to the System-Wide-Theory where one component of a larger system gains the trust of the user, this trust will be transferred to other elements, such as the vehicle behaviour, as well (Keller & Rice 2010).

Beyond a first and last mile mobility application this display could further be used for the passengers to take influence on the journey or the vehicle behaviour, potentially offering users options such as a premium service at a cost, which allows the vehicle to travel fast but depletes the batteries quicker.

The internal display also holds the potential to explore the concept of personalisation in a driverless shared mobility vehicle. This is based on the notion that shared vehicles typically lack any option for personalisation, which presents a unique opportunity to differentiate a particular service.

The internal displays for the MiCar vehicle concept are split into two types, a central display which can be seen by all and provides access to the infotainment system to those who are not seated in one of the four seats, next to which are four smaller screens for each of the passengers.

Whilst the following development focuses on the visual interfaces, it should be noted that in order for the interaction between the vehicle and the passengers to be fully inclusive, it can not only rely on a visual interface but also requires other modalities such as sensory (i.e. vibrations) or auditory.

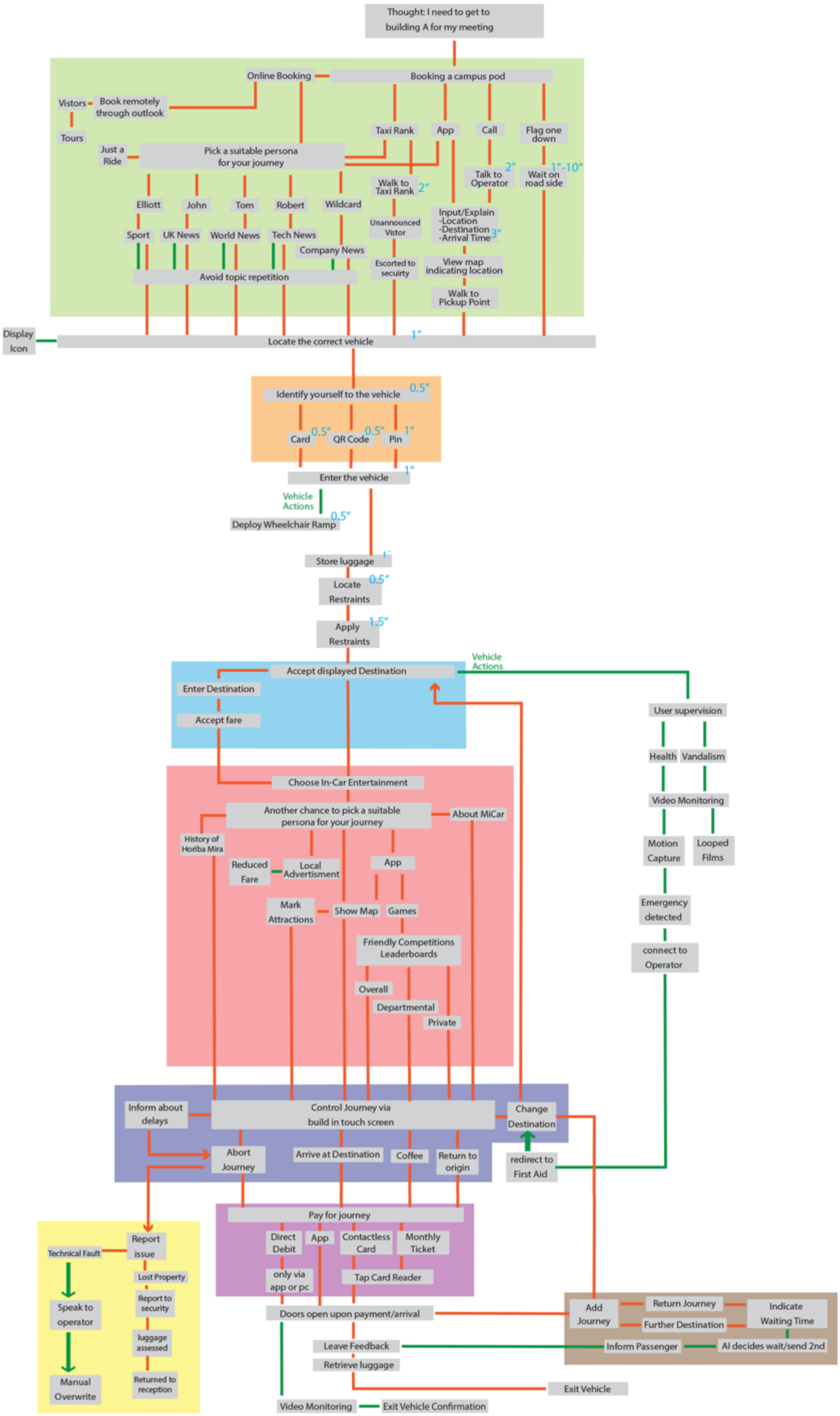


Figure 8.12 User Journey Map MiCar

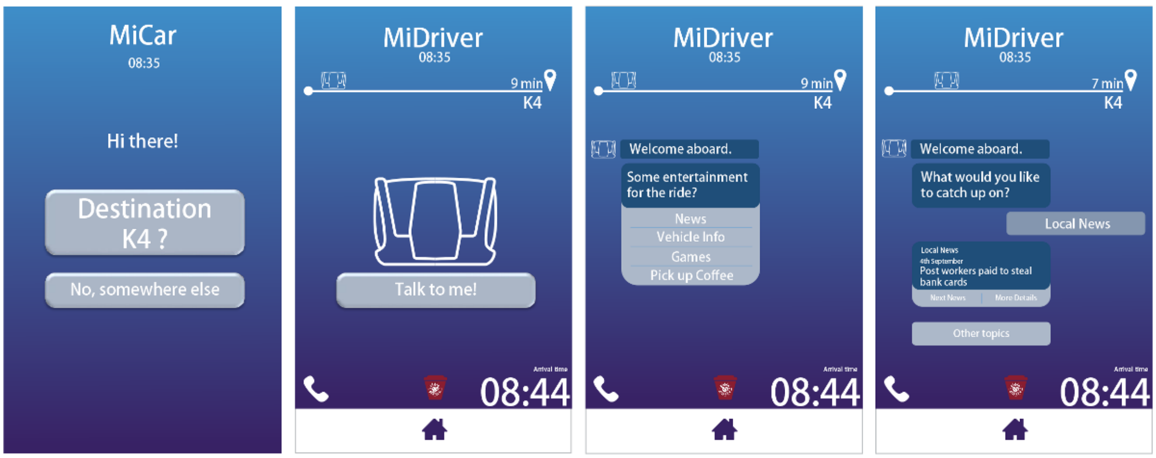
8.2.2 HMI Prototype

Based on the customer journey map discussed previously, an HMI prototype for the interior screens was developed. The other three interfaces, the pre-booking system, the external HMI and the door button were not developed in this thesis due to time constraints.

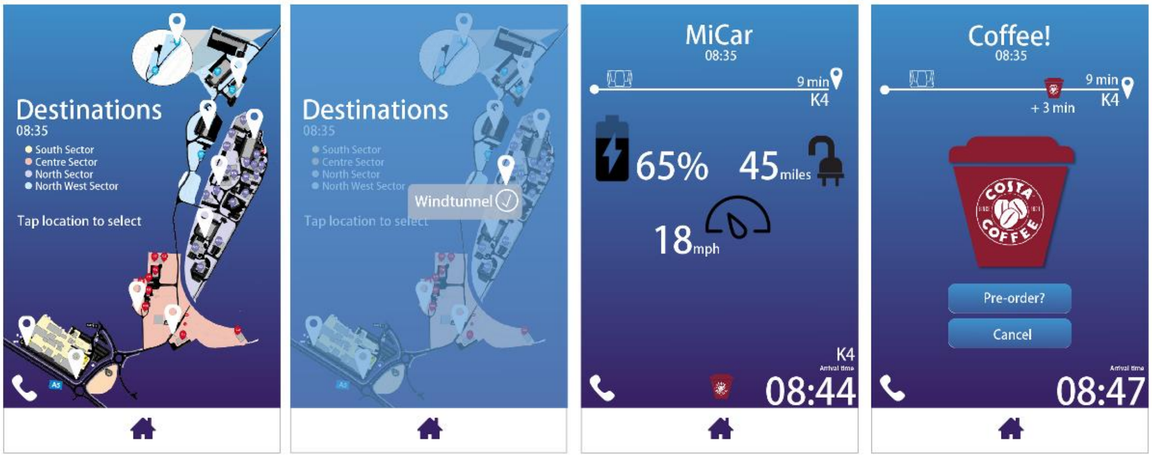
For the interior displays, which are located next to each of the seats, a small touch screen tablet (20”) was selected. As each seat is directly connected to one screen, this setup provides the opportunity to provide personalised content for each passenger. To simplify the use, the vehicle itself is capable to track a passenger who scans their card to enter the cabin and is, therefore, able to identify which seat the passenger chooses. This screen can then display content that is tailored for the passenger based on their stored preferences.

The first screen (Fig. 8.13, No. 1) therefore welcomes the passenger and indicates through a highlighted option that it is aware of the pre-programmed destination.

The following main screen is split into four sections: the journey overview, the central interactive space, the taskbar and the return home bar (Fig. 8.13, No. 2-4).



1 2 3 4



5 6 7 8

Figure 8.13 MiCar HMI Test Build Screenshots

The *Journey Overview* shows the trip progress on a standardised timeline on which a graphical representation of the MiCar moves from left to right, from the start to the destination. The destination is named beneath the destination icon on the right-hand side of the screen, which is also where the time to destination is located.

In order to cater to the peace of mind and ease of usability factors in the passenger comfort model, the overview intends to provide all significant information at one glance and keep them visible at all times.

The *Interactive Space* is intended for a number use cases; with the main option allowing the passenger to interact with the vehicle through an avatar like communication system. Other use cases are the integration of external services, such as a coffee order app (Fig.8.11, No. 8), which would reroute the vehicle to pick a prepaid coffee up or providing general vehicle information.

The communication system in the form of a chatbot would allow users to interact with the vehicle in a natural manner, communicating with the vehicle through written text. This will allow users to access any submenu such as the vehicle information, detailed journey information, the news page or even games.

As previously discussed there is a need to provide detailed information about the vehicle capability and actions (Fig. 8.13, No. 7), the system, therefore, allows passengers to access this information at their leisure, recognising that not all passengers want to be confronted with technical detail and that the need, in general, may reduce with increasing familiarity.

Games were added to the HMI to provide on route entertainment by allowing passengers in the same cabin to compete in a game of digital air hockey for example. This could be extended to other vehicles of the same type and operating on the same site, allowing passengers to compete with those from other vehicles, providing a moment of unexpected joy and distraction (features of delight in the Kano Model).

The interactive space is also the field used to display a map with destination options (Fig. 8.11, No. 5/6) if the user decides to change from their current journey or in the case of a passenger using the MiCar without prior booking.

The *Task Bar* is an extension of the journey overview providing additional information to the passenger such as the time of arrival. It further includes the call button, which connects the user to a remote vehicle supervisor in the case of a situation which requires assistance. The call assistance button is deliberately designed to be easily spotted, without being an overly distinct feature, such as a large red button, which may suggest to the passengers that this is an option frequently required, potentially increasing distrust.

The *Home Bar* is a simple however important feature as it gives the user the option to return to the main page from anywhere within the system, avoiding situations where users get lost within the system with no way of returning to the essential information.

8.2.3 Summary

Overall the design has two aims: 1) provide the passenger with the essential information at all time, curated in a way that a single glance is sufficient to retain it, and 2) to engage the passenger with the vehicle and to familiarize them with the capabilities, but permit them to choose if and for how long they would like to view the relevant information.

Providing vehicle information and giving users an insight into the vehicle functions through the HMI will allow them to compare their own expectations with the vehicle reaction to any given situation. Matching those two is essential to grow trust into the vehicle capabilities and ultimately put the passenger at ease, setting the foundation for a comfortable journey experience. Following a period of familiarisation, however, the provision of alternatives to the vehicle or journey information such as games or a news update becomes increasingly more relevant and offers the opportunity to create a unique selling point.

However whilst an HMI was researched and then a first prototype designed and implemented on a tablet inform of a mock-up, no further evaluation or development was conducted as part of this PhD. This is due to the time constraints and the belief that this topic requires a more thorough investigation, which could be undertaken as a follow up to this work with the MiCar as a platform (discussed in 11.3).

8.3 MiCar Cargo Variant

8.3.1 Introduction

Not only passengers need to be transported in the first and last mile, but the transport of goods is also a rapidly growing market. Subsequently, the option for a driverless goods transporter as part of the MiCar vehicle line-up was explored.

For the design concept, the technical platform of the MiCar was therefore used as a chassis for a cargo variant of the MiCar.

The low packaging (discussed in chapter 8.1.2) of the MiCar was seen as ideal for a driverless low profile platform with interchangeable top-mounted cargo solutions.

8.3.2 MiCar Flexi Concept

The MiCar chassis from the passenger vehicle provides the opportunity to create a vehicle which can be adapted to different requirements, aiming to reduce the overall time the vehicle is not used.

In the context of electrified vehicles, this provides the opportunity to maximise the use of the most expensive components, the electric drive train and battery components. This further allows the interchangeable component to become more specialised and context-specific and even explore other used cases such as pop-up stores or spaces.

As the flexible concept is based on the MiCar passenger vehicle, the main design cues were carried over with the aim to create a similar vehicle profile. The two upright hoops which make up the structure around the glasshouse of the passenger vehicle were carried forward as structural elements for the cargo space. In the design of the cargo concept, the distinct graphical elements which cover the wheels on the passenger vehicle can be found again on both, the cargo box and the carrier platform.
The main difference, however, is the stance of the vehicle which is due to the cargo concept travelling in a singular direction as opposed to the passenger version, which is designed to travel in either direction. Therefore, rather than a symmetrical design, the cargo concept features some distinct body lines which rise from the front to the rear, suggesting a more dynamic vehicle (Fig. 8.14).

As previously discussed, the vehicle consists of two parts; a lower platform which contains the chassis and drivetrain components and an interchangeable unit. This unit can be designed to suit any number of applications such as a cooled delivery box, a pop-up store or a mobile meeting space.

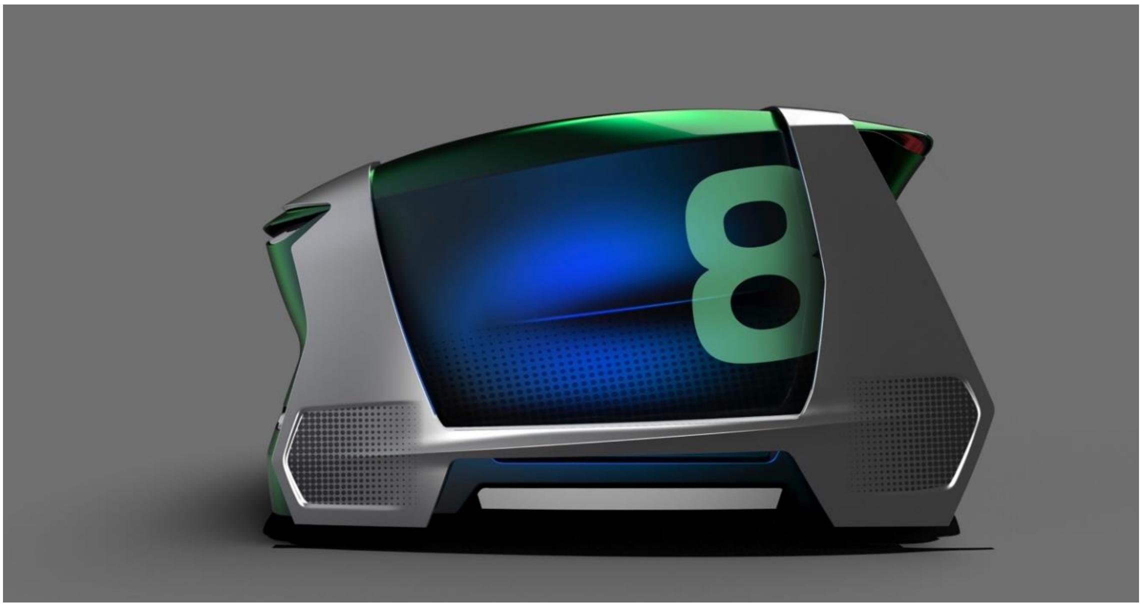


Figure 8.14 MiCar Cargo Concept

The underlying principle for this concept is the ability of the driverless platform to lower itself using airbag suspension and drive underneath the unit. Following that, it can then lift itself with the cargo box fixed to the top up and proceed to the destination. Using this technology the platform is able to transport a number of different units throughout the day, maximising the use of the drivetrain components whilst the units are used for their purpose (Fig. 8.16).

As part of the design exploration, four exemplary units were created (Fig. 8.15); a mobile meeting space which can be booked to temporarily provide a space at project locations, a container for construction material to be transported just in time into city centres, a goods delivery unit and a pop-up coffee store which can be placed at hot spots.

Figure 8.15 MiCar Variations (left-right Office, Construction, Road Safety, Coffee shop)

Figure 8.16 MiCar Cargo Concept Platform

8.4 Summary & Conclusion

In the context of this thesis, the development of the vehicle concept provides the research process with a tool to communicate the findings to expert and lay audiences. And subsequently allows for the theoretical model to be evaluated in context. It further provides trial participants with a basis to verbalize their thoughts and comments on the different aspects.

3rd Objective Part 2

The design completes the third objective, which was to create a vehicle design (interior & exterior) inspired by the previously gathered information. This will provide the foundation for the remaining components of this work, the design of the ergonomic buck, the studies and the simulation.

8.5 Disclaimer

Whilst the initial MiCar concept was created by myself, the refinements, the HMI concept and the cargo version were developed under my leadership together with two groups of automotive design student interns. Over two eight week periods, two teams of four designers created the visualisations for the MiCar and sketched and developed the cargo variant.

9.0 Studies

This chapter covers four separate studies; the Exterior Design Review, the MiCar Vehicle Design Evaluation using Jack, the MiCar Ergonomic Buck Evaluation and the MiCar Vehicle Design Evaluation using Mixed Reality as well two further sections discussing the build of an Ergonomic Buck and the development of the Mixed Reality Simulator.

The studies are the basis of an intrinsic iterative review process of a vehicle design with the aim to evaluate if the features created based on the comfort model discussed in chapter 4.0 prove successful.

The design of the trial methods, with exception of the first study, was based on a Hierarchical Task Analysis (HTA), which was conducted to identify the individual tasks and subtasks required to complete a typical journey envisioned for the driverless pod (discussed in detail in as part of the first study 9.2).

9.0 Exterior Design Review

9.1 Introduction

This study is a review of the exterior design of a selection of driverless first and last mile mobility vehicles (Pods), which was conducted with a group of participants recruited from environments in which an application of these vehicles is likely. The review was conducted to establish how people perceive a vehicle of this type on their first approach, as a first impression can have a crucial impact on the consumers' perception of a product or in this case a vehicle. Whether it is in regards to a product on a shop shelf or a vehicle on the road, the impression people gain from its design can have a significant impact on the overall perceived qualities of this product (Black and Baker, 1987; Bruce and Whitehead, 1988; Gemser and Leenders, 2001; Roy, 1994; Thackara, 1997).

The review consisted of an image survey, in which six examples of driverless pods were first individually assessed and then directly compared and ranked.

The survey questions were based on two theoretical design principles, the roles of product appearance and the Kano Model.

9.2 Vehicle Exterior Design

The design of a vehicle is commonly understood to be the exterior styling of a vehicle and is typically created around aspects such as the volume, the profile, the silhouette and the stance (Hull 2018). Ordinarily, the interior would also be part of the vehicle design, however, this study focuses on the exterior styling only. To create the profile and silhouette, designers use elements such as the front and rear overhangs, the cabin position the tumblehome (side window angles) and the windscreen rake (the front screen angle) which influences how dynamic the vehicle appears. The general volume is shaped using feature lines, such as a shoulder line, to add visual structure to the vehicle body. The wheel arches can be flared to create an impression of power whilst undercuts are used to reduce the visual weight of the car. Finally, the graphics such as the grill, lights, windows (DLO - Day Light Opening) and shut lines (where body panels are divided) are added together with the surface finishes, working with colours and contrast. Typically, those graphics on the front of the vehicle combine to what is commonly known as the "face" of the vehicle, here the headlights, the grill and the air intakes create an analogy of animal or human faces, known as anthropomorphism.

Shared first and last mile mobility vehicles, however, introduce a new context, in which the vehicle design carries a different meaning and importance.

In this context, the main role of the design is no longer just to excite a consumer and support a purchasing decision but other aspects such as communicating the vehicle capabilities and attitudes become more important as they are likely to influence if the consumer is willing to continuously use the vehicle. Especially in the context of driverless vehicles, they will have to introduce new technology to new users and convince them of their capabilities.

It is therefore important to understand which design features of a driverless pod will influence potential passengers. Studies in the field of household product design show how the exterior of a product can influence a potential buyer and will be in the combination with traditional design theory used as a basis in this study to develop a better understanding of the influence of vehicle exterior design on potential passengers.

9.3 Roles of Product Appearance

The review was designed as a comparative study using a selection of images, which was based on two different models from the traditional product design theory; the Kano Model (Kano) as well as "The Different Roles of Product Appearance in Consumer Choice". The latter was developed by Creusen and Schoormans (2005) and established six product appearance roles; aesthetic, symbolic, functional, ergonomic information, attention-drawing and categorisation, that subsequently influence a consumer in their choice and behaviour. In their development, the only relevant aspect was the product appearance, with participants comparing two products from the same category, without being allowed to handle the product whilst only presented with a minimum of additional information about the capabilities or price of the product much like a product would be presented in a shop.

Below is a summary of the six values and their effects, however as the main application of these values is in the field of consumer product design, the values were rewritten to be applied to driverless last mile mobility pods, and further comments were added regarding their suitability for this context.

Aesthetic Product Value, describes the pleasure derived from looking at a product without considering its utility. The value is largely based on emotional and felt psychological responses to colours, visual organisation, proportions and symmetry. These factors differ however based on cultural backgrounds and the era (Whitfield and Wiltshire, 1983) and likely to be the deciding factor between two products of similar price and functionality.

Pods – The pleasure derived from looking at the vehicle without considering its utility but instead the colour, shape and proportions of the vehicle. The value is also likely to be influenced by the "perceived aesthetic fit" (Bloch 1995) with the environment in which it is to be used. It is further shaped by the prototypicality of the product, whether the vehicle is representative of another known product or category (this overlaps with the categorisation value) (Hekkert, 1995; Veryzer and Hutchinson, 1998; Whitfield and Slatter, 1979). Hekkert et al. (2003) add, that products with an optimal combination of prototypicality and novelty are preferred aesthetically, a finding that is supported by a more recent study by Diels et al (2013).

Symbolic Product Value, can convey which kind of person the consumer would like to be (Belk, 1988; Landon, 1974; Sirgy, 1982; Solomon, 1983). It can also communicate a message such as cheerful, childish or represent a certain time period. It can also cause consumers to attach brand elements such as prior experiences i.e. the quality or reliability to other unknown products from the same brand.

Pods – The value is based on what kind of person the consumer would like to be, such as a modern independent or an ecologically conscious traveller.
Some passengers may want to the vehicle to project this image when using this vehicle. The value also communicates an image of the vehicle itself; the Pod may create a sense of trust for example, by looking friendly and approachable. It can also cause passengers to attach brand elements (prior experiences, such as quality or reliability) to unknown vehicles from the same brand.

Functional Product Value, can communicate quality by looking reliable or solid (Srinivasan et al., 1997; Yamamoto and Lambert, 1994). It also provides immediate information about the utility of the products with cues such as a handle which communicates that the object is portable. The size can have an impact as well as a larger product may suggest a higher power of a product when compared to others.

Pods – A vehicle can communicate quality and safety by looking reliable or solid and cues such as a visible structure communicate that the object is stable and safe.

Furthermore, the size of the vehicle can suggest the power as well as the protection it may offer to the occupants when compared to road vehicles. In the case of pods, a novel vehicle type, this may be a key aspect due to potential passengers having to judge if the vehicle appears to feel safe enough for them to subsequently be willing to use it. Prominent sensor placements could reiterate the driverless technology whilst suggesting to the passenger that the vehicle is well aware of the surroundings.

Ergonomic product information, suggests how easily the product can be used (Norman, 1988). The consumer may form an impression on whether buttons are easy to use or if a handle appears comfortable. For a positive purchase decision, it is essential for the consumer to perceive the product as easily used. It is suggested for example that a screen indicates a more complex product, whereas a small number of controls can suggest an easy to use product.

Pods - Suggests how easily the vehicle can be used; the consumer forms an impression on whether the door buttons will be easy to spot and reach or if a handhold appears comfortable. The size of the door aperture and overall vehicle height, for example, will inform the passenger how easily they will be able to enter it. It is essential for the passenger that a vehicle appears to be easily used, especially with a vehicle that has such a strong technological provenance. The findings of the Creusen et al. (2005) also imply that the addition of a screen implies a more complex vehicle; whereas a small number of controls can be interpreted to be easier to use. Therefore the HMI, such as door buttons and signs, are a critical point of the impression.

Attention Drawing, a product that stands out visually against its competitors has a higher chance of receiving attention from the consumer during the purchasing situation (Garber, 1995; Garber et al., 2000).

This can be further enhanced by increasing the size and using bright colours, in order to stand out against the background, therefore the colours and materials of the direct competitors and the purchasing environment need to be considered. However, it is also important to consider the environment into which it is to be placed as the product has to fit in with others previously purchased. It is important to strike a balance between being noticed on the shelf and appearing garish in the intended environment.

Pods - A vehicle that stands out visually against its competitors has a higher chance of receiving attention from the consumer when selecting which vehicle and form of transport to use. This can be enhanced by increasing the size and using bright colours, elaborate shapes and unusual designs stand out against the background. However, for this scenario, in particular, one needs to consider in which way this product value remains relevant or may even have a negative impact as these vehicles are not an individually sold product and passengers do not select a particular bus to undertake a journey because of the vehicle design.

If a deployment of driverless pods in a mixed traffic environment is considered, the colours and shape may be a safety aspect, raising awareness by other traffic participants for the vehicle. Furthermore, in the initial implementation phase of driverless pods, they will generate media interest and a stand out design may be considered beneficial to draw attention to a particular trial or project.

Categorisation, impacts on what the consumer compares the product to (Bloch, 1995; Veryzer, 1995). As an example, this could be used to create a positive association with a higher quality product, implying that the new product is of the same quality as the existing one but could also have a negative impact if this association leads to the consumer noting an absence of features in comparison with the competitor. A possible solution can be an atypical appearance, as it may result in customers thinking of the new product in its own class.

Pods - Products for which prestige, exclusiveness or novelty are important in order to promote a new technology, an atypical appearance is advisable as it can result in customers thinking of it as its own class. This avoids similarities and subsequently comparisons with other products, which in the case of driverless pods may avoid the comparison with regular road cars, most of which are of known quality. However, if users reference another reliable and safe public transport vehicle such as a bus and perceive the new vehicle to be of the same quality, it may ease the introduction of the new vehicle as it will also be seen as reliable and safe. Therefore, any comparison needs to be carefully managed.

All six factors demonstrate that consumers create an impression of many of the product features from the external design appearance without having used or handled the product. Therefore, the exterior design of a vehicle has to communicate the relevant features to the consumer to positively influence their decision to use the vehicle. Some of these features can also be grouped, using the Kano model described in detail below, according to the way they influence the user.

Table 9.1 Product Roles and related Design Features

Product Role	**Pod Design Feature/s**
Aesthetic Product Value	Shapes that integrate with the environment
Symbolic Product Value	Represent the modern urban mobility
Functional Product Value	Visible structures and size suggesting safety and protection
Ergonomic Product Function	The number of interfaces and buttons as well as clearly recognisable handholds
Attention Drawing	Shapes, graphics, material and colour choices
Categorisation	The similarity to public transport vehicles

9.4 Kano Model

The method was developed by Noriaki Kano in 1984 to describe the relationship between the end-user and specific product attributes (Kano). The model as shown in Figure 1 describes the relationship between the "Customer Satisfaction" on the Y-Axis (Low – High) and the "Product Function" on the X-Axis (Absent – Fully Implemented). Three separate types of attributes were defined as performance, threshold and excitement, all impacting on the same product in a different manner:

Performance Attributes: Attributes such as features or battery capacity, the more there is of it, the more satisfied the user will be.

Threshold Attributes: Attributes which the user expects to be present to archive basic satisfaction, airbags or ESP and successfully completing a journey from point A to B, for example. Are those not present or archived, it is likely to cause grave dissatisfaction.

Excitement Attributes: Attributes which are add-on features such as ADAS (Automated Driver Assistant Systems). If included in the product, they will add excitement value, if missing however will not cause dissatisfaction.

However, with recurring uses as well as with time passing from the initial release of the product and more current products reaching the market, excitement attributes can become threshold attributes as expectations grow over time and once novel technologies become more common.

In the context of driverless first and last mile mobility vehicles, basic requirements such an obvious door aperture and full standing height cabin will fall under the threshold category, whilst a futuristic design can contribute to the excitement category.

For many users, the complex engineering challenge of a driverless technology itself, such as navigating a complex environment using LIDAR and other sensor technology only contributes to travelling from A to B, which in itself is a basic requirement of any vehicle and is subsequently seen as a threshold attribute. Therefore, when considering the current limitations experienced with these vehicles, in order for driverless pods to be successful products and accepted by the general public, they will have to also score in the other categories.

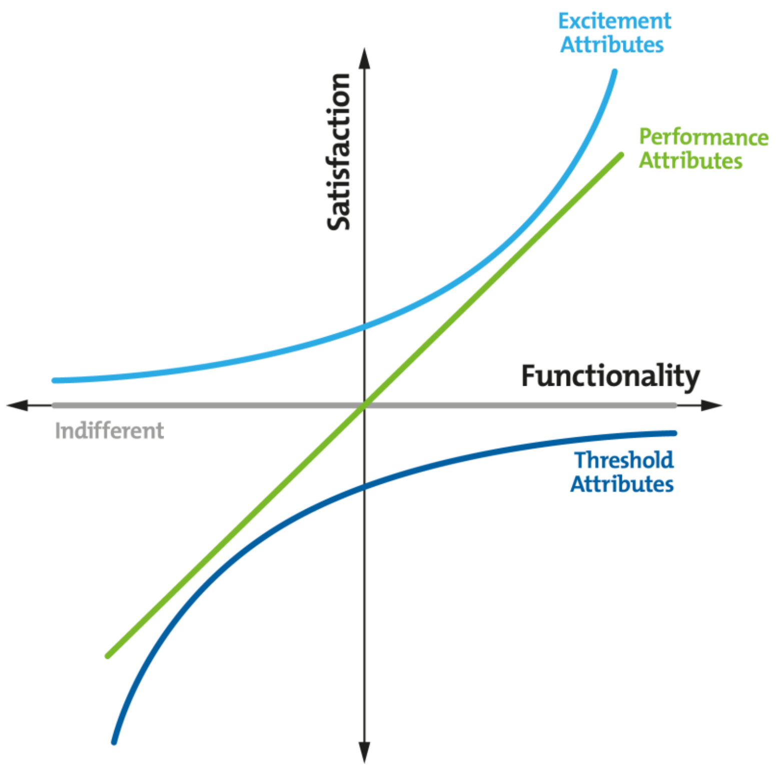


Figure 9.1 Kano Model

The two theories demonstrate the potential influence the exterior design of a vehicle holds over the perception of future users and it is, therefore, essential to understand how different vehicle design philosophies are received by those. Subsequently, a survey with six vehicle designs was created and completed with the help of three groups representing potential users with the detailed process described below.

9.5 Methods

9.5.1 Participants

The participants were recruited and met at three different locations aligned with the scenarios discussed in chapter 6.0. The first group was organised at the National Trust property Baddesley Clinton and consisted of staff and volunteers employed there. The second group was recruited at HORIBA MIRA, representing a cross-section of the employees of the MIRA Technology Park. A third group was gathered at Coventry University consisting of university students and employees as well as a small number of Coventry City Council employees.

The total number of participants equated to 28 across all three scenarios, consisting of 11 females and 14 males (three elected to not to disclose their gender).

The participants were categorised into four age groups; 18-24 (n-3), 25-44 (n-10), 45-64 (n-10) and 65+ (n-4), with one participant not disclosing their age.

Table 9.2 Participant Groups

National Trust Baddesley Clinton	Mira Technology Park	Coventry University & Coventry City Council
8 Participants	9 Participants	11 Participants
Age Groups: 45-64 (n-3), 65+ (n-4)	Age Groups: 25-44 (n-6), 45-64 (n-5)	Age Groups: 18-24 (n-3), 25-44 (n-4), 45-64 (n-2)
Transport for visitors from the entrance to the main attraction as well as sightseeing tours	Mobility across the site for employees, visitors and guests.	Part of the public transport network to provide mobility for students and city visitors alike.
Unexperienced users consisting of elderly visitors and families	Regular, technology aware users combined with unexperienced visitors	Unexperienced users who over time likely to become regular users

9.5.2 Study locations

To conduct the study, three groups were set up at a location which was in the typical environment of the participants. This meant that the National Trust group was met at one of the local National Trust venues (i.e. Baddesley Clinton), the HORIBA MIRA employees on their technology park, and the students and Coventry City Council staff in a meeting space at Coventry University. Meeting the different participant groups in the relevant environment was intended to support them in the task of imagining a scenario in which a driverless first and last mile mobility vehicle would operate. At each of the locations, a screen was used to present the general introduction and following that the vehicle images.

9.5.3 Procedure

The survey was preceded by a short introduction into the topic of driverless vehicles, explaining to the participants what Level 4 SAE (SAE 2014) entails. It further summarised existing driverless last mile mobility vehicle trials (WEpod 2016) conducted with EZ10 vehicle by EasyMile in order for the participants to become aware of the stage in which the technology currently is and therefore comprehend that it is a realistic scenario to consider. To avoid creating bias by providing more information about one vehicle included in the survey, the EasyMile EZ 10 vehicle was chosen to be excluded from the survey and instead to be used as a representative vehicle in the description.

In addition to providing an overview of the technology, the introduction was also adapted for each of the three groups in order to propose a local scenario: National Trust, Mira Technology Park and the Coventry University Campus. All three are based on the scenarios developed in section 6.0, in the National Trust scenario a driverless pod could be employed at large sites to transport people from the main entrance towards the main attraction or as sightseeing vehicle, whereas in the Mira scenario a vehicle of this kind would provide mobility to guests and employees across the site.

For the final scenario at Coventry University a pod could transport students from accommodations to lecture halls and back. A relatable scenario for each of the groups was chosen in order to encourage the participants to envisage themselves as part of this particular scenario.

9.5.4 Materials

For the study six vehicles were selected, four of which were part of driverless last mile mobility vehicle trials at the time of the survey. The Olli by Local Motors, the Pod Zero by RDM, the ULTra by Global PRT and the Autonom Shuttle by Navya. The two additional vehicles chosen were design studies, the VW SEDRIC as well as the MiCar Concept discussed in the previous chapter 8.1. The vehicles represent three different design philosophies of driverless pods, the ULTra and Pod Zero are small capsule-like vehicles, whereas the Navya and Olli are shuttle bus like and lastly the Sedric and MiCar are two vehicle concepts, subsequently, all six are representative of the majority of driverless pods. A detailed review of all vehicles can be found in the benchmark (chapter 5.0).

In preparation for the survey, an image of each vehicle was selected with approximately the same ¾ view in order to facilitate an easier comparison between the vehicles. As the vehicles differ quite drastically in size a figure (approximately 95th%ile Dutch male 1959mm) was added to the image and sized uniformly across all six images.

In an effort to disguise and subsequently avoid any prior brand association, brand identifications such as badges and signage were removed. In the survey, the images were presented on a projection screen (approx. 120x200cm) for the whole group to view at once, one vehicle at a time.

Figure 9.2. Six driverless first and last mile mobility vehicles included in the exterior design review. (1. RDM POD Zero, 2. Olli Local Motors, 3. ULTra Global PRT, 4. SEDRIC VW, 5. MiCar, 6. Navya Arma)

9.5.5 Measures

Prior to starting the main questionnaire, the participants were asked to provide some basic demographics, i.e. age (18-24/25-44/45-65/65+), gender.

Participants were then asked to rate the following questions based on both the Creusen and Schoormans product roles and the Kano model:

Q1. From a purely aesthetical point of view, how visually pleasing would you rate the vehicle? (Very pleasing/Not at all pleasing) *Aesthetic Product Value*

Q2. How similar does the vehicle look to a common passenger car? (Very similar/Not similar at all) *Categorization*

Q3. Does the vehicle have a futuristic design or an ordinary design? (Unconventional/Conventional) *Aesthetic Product Value*

Q4. How do you think the overall vehicle looks? (Cute/Aggressive) *Aesthetic Product Value*

Q5. Looking at the car what impression does it give? (Submissive/Dominant) *Symbolic Product Value*

Q6. The front of the vehicle has a: Friendly Face/Angry Face *Symbolic Product Value*

Q7. How trustworthy/reliable does the vehicle look? (Very/Not at all) *Functional Product Value*

Q8. What is your impression of the vehicle size? (Very large/Very small) *Functional Product Value*

Q9. When encountering pedestrians, this vehicle's tendency is to be: Yielding/Assertive *Symbolic Product Value*

Q10. Considering the look of the vehicle, would it fit into these environments? (Yes/No) (Historic Market Town/Technology Park/City Centre & High Street/Country Park & Leisure Areas) *Attention Drawing*

Q11. Does the vehicle design create an impression of solidity and stability or does it appear unstable and weak? (Solid & Stable/Weak & Unstable) *Functional Product Value*

Q12. How comfortable to do you perceive the vehicle to be? (Very comfortable/Very uncomfortable) *Ergonomic product information*

Q13. How keen would you be to be seen using the vehicle? (Very keen/Not keen at all) Symbolic *Product Value*

Q14. How easy or difficult is it to enter the vehicle? (Very easy/Very difficult) *Ergonomic product information*

Q15. How safe would you feel in the vehicle? (Very safe/Not safe at all) *Ergonomic product information*

Q16. Does the vehicle design remind you of a known brand? (Yes (please specify)/No) *Categorization*

Q17. Any other additional comments you would like to make

The questions were repeated for each of the six vehicles. A seven-point Likert scale was used for 14 of the questions, one further question gave four options to select. Of those four options, all could be answered individually with either “Yes” or “No”.

Two further questions required written answers; one inquired if the vehicle reminded the participant of any brand and if so which one and a final question provided the participants with the opportunity to add any further comments.

In order to avoid that the order in which the vehicles were shown could influence the participants, each of the survey groups was presented the vehicles together in random order. As the groups consisted of several participants (up to 10) all were instructed not to vocalise their thoughts during the survey. They were invited to share their thoughts and concerns in a 10-minute group discussion which followed on from the survey.

At the end of the survey, following the detailed evaluation of all six vehicles, the participants were asked to rank the vehicles, based on their personal preference in regards to the appearance, whilst being shown an overview of all the vehicles.

9.5.6 Analysis

The data was analysed using SPSS Statistics 25 and the remaining written answers were captured based on the survey groups. The mean of the SPSS data was calculated and tested for significance using Friedman's ANOVA as it provides the possibility to detect differences across multiple samples. Following the test for significance, a post hoc analysis was conducted as pairwise comparisons were carried out in order to evaluate the relationship between the individual samples of the same question. Finally, the numerical data was visualised in bar graphs using the graph builder in SPSS as well as Microsoft Excel.

9.6 Results

9.6.1 Exterior Design Ratings

Q1. From a purely aesthetical point of view, how visually pleasing would you rate the vehicle?

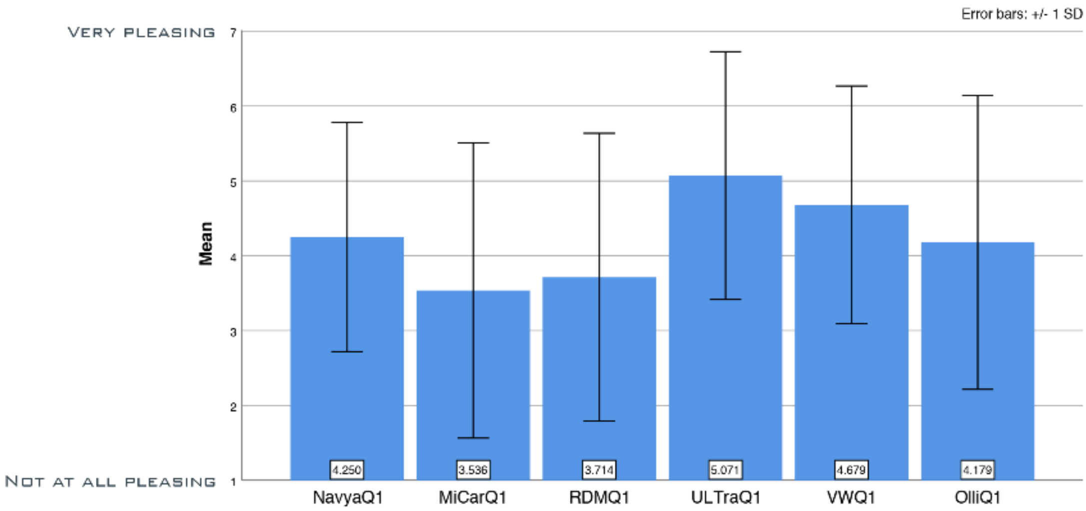


Figure 9.3 (Visual Impression) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was significant across the six samples ($\chi 2=14.135$, $N=28$, $df=5$, $p < 0.05$).

A pairwise comparison analysis was carried out showing a statistically significant difference between the ULTra and the MiCar vehicle, where the ULTra was found to be more visually pleasing (Z= -1.536, P=.032; Bonferroni correction applied).

Whilst all vehicles scored similarly in regards to how visually pleasing they appear to the onlooker, the MiCar is seen as the least visually pleasing with the only significant different being the ULTra.

Q2. How similar does the vehicle look to a common passenger car?

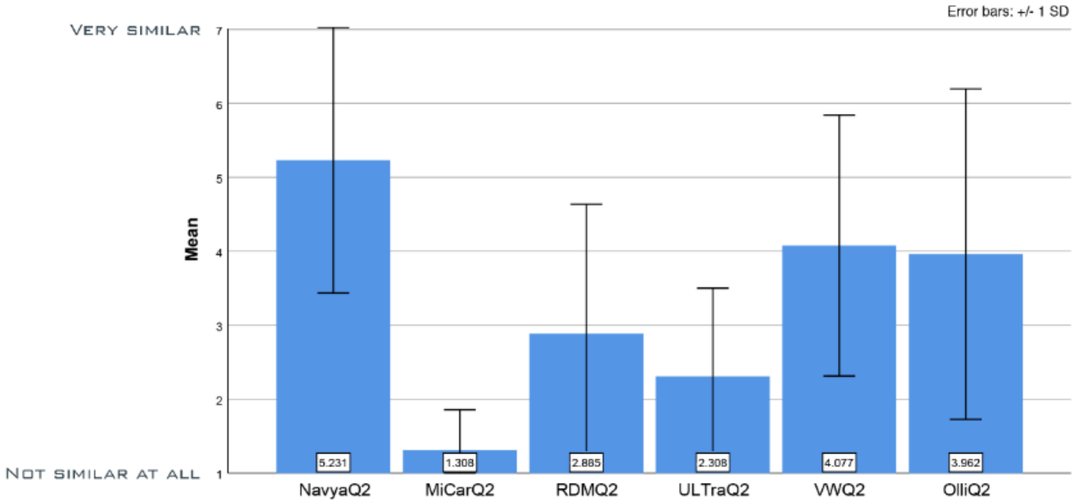


Figure 9.4 (Similarity to common cars) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was significant across the six samples (χ2=59.90, N=26, df=5, p < 0.001). A pairwise comparison analysis was carried out showing a statistically significant difference between the MiCar and four of the vehicles where the MiCar is the least similar to a common passenger car (RDM Z= -1.558, P=.040; Olli Z= -2.327, P< 0.000; VW Z= -2.577, P< 0.000; Navya Z= 3.327, P< 0.000; Bonferroni correction applied).

A further statistically significant difference was seen between the Navya and the ULTra (Z= 2.269, P< 0.000; Bonferroni correction applied) as well as between Navya and the RDM (Z= 1.709, P= 0.01; Bonferroni correction applied).

Aside from the Navya vehicle, which is the highest scoring sample, the results overall show a tendency for the vehicles to be seen as dissimilar to common passenger vehicles. The MiCar is seen as the least similar to these vehicles with the majority of samples scoring much higher. The ULTra and RDM vehicles are also perceived as very unlike common passenger cars.

Q3. Does the vehicle have a futuristic design or an ordinary design?

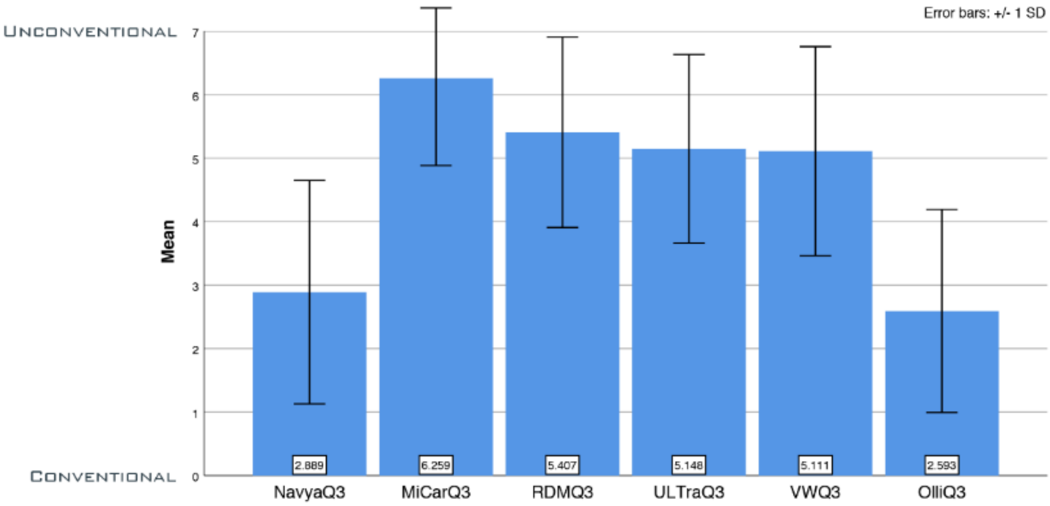


Figure 9.5 (Futuristic or Ordinary Design?) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was significant across the six samples (χ2=67.673, N=27, df=5, p < 0.001).

A pairwise comparison analysis was carried out showing a statistically significant difference between the Navya and all other vehicles, with the Navya appearing significantly more conventional (VW Z= -1.722, P=.011; ULTra Z= -1.741, P= 0.009; RDM Z= -1.944, P< 0.002; MiCar Z= -2.963, P< 0.000; Bonferroni correction applied).

A further pairwise comparison analysis was carried out showing a statistically significant difference between the Olli and all other vehicles, with the Olli appearing significantly more conventional (VW Z= 1.981, P=.001; ULTra Z= 2.000, P= 0.001; RDM Z= 2.204, P< 0.000; MiCar Z= 3.222, P< 0.000; Bonferroni correction applied).

The MiCar scores highest in regards to how futuristic and unconventional the design looks, with the RDM, the ULTra and the VW scoring similarly high. The Navya and Olli vehicles, however, are seen as far more conventional designs.

Q4. How do you think the overall vehicle looks?

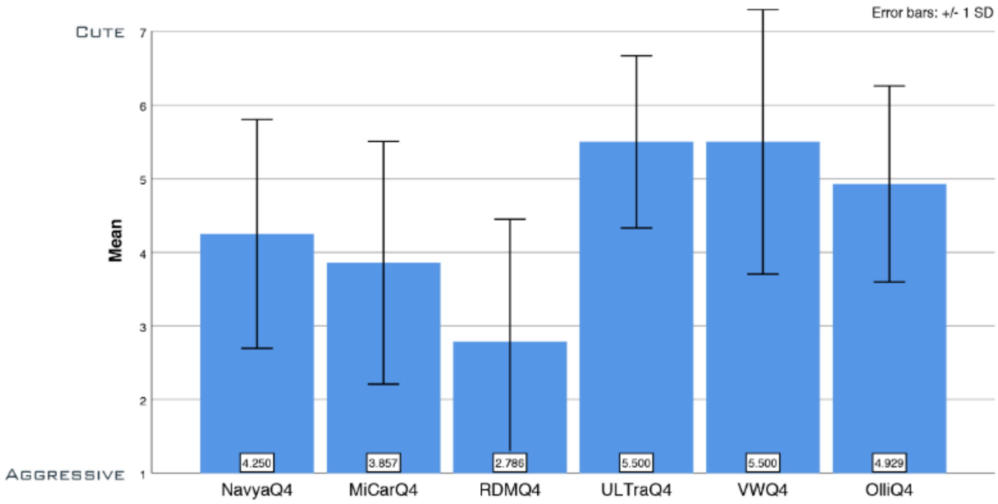


Figure 9.6 (Vehicle Personality) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was significant across the six samples (χ2=39.409, N=28, df=5, p < 0.001).

A pairwise comparison analysis was carried out showing a statistically significant difference between the RDM and the VW, ULTra and the Olli, with the RDM appearing significantly more aggressive (VW Z= -2.446, P, 0.001; ULTra Z= 2.357, P< 0.001; Olli Z= -1.893, P= 0.002; Bonferroni correction applied).

A further pairwise comparison analysis was carried out showing a statistically significant difference between the MiCar and the VW, with the MiCar appearing significantly more aggressive than the VW (Z= -1.518, P= 0.036; Bonferroni correction applied).

When scoring the overall looks of the vehicles, the RDM was ranked the most aggressive of the samples with the Navya and the MiCar scoring neither aggressive nor cute. The ULTra and VW, as well as the Olli, were scored with a tendency towards a cute appearance.

Q5. Looking at the car what impression does it give?

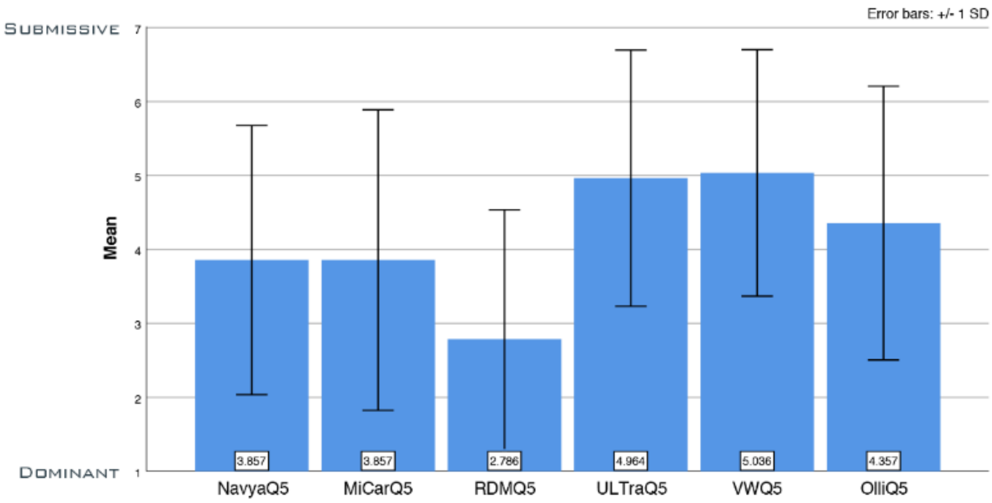


Figure 9.7 (Vehicle Assertiveness) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was significant across the six samples ($\chi 2$=24.635, N=28, df=5, $p < 0.001$). A pairwise comparison analysis was carried out showing a statistically significant difference between the RDM and the VW as well as the ULTra, with the RDM appearing significantly more dominant (VW Z= -1.875, P= 0.003; ULTra Z= -2.036, P= 0.001; Bonferroni correction applied).

The RDM was seen as the most assertive of the vehicles with the Navya, the MiCar and the Olli being ranked average. The ULTra and the VW were ranked slightly above average, appearing more submissive than the other vehicles.

Q6. The front of the vehicle has a: Friendly Face/Angry Face?

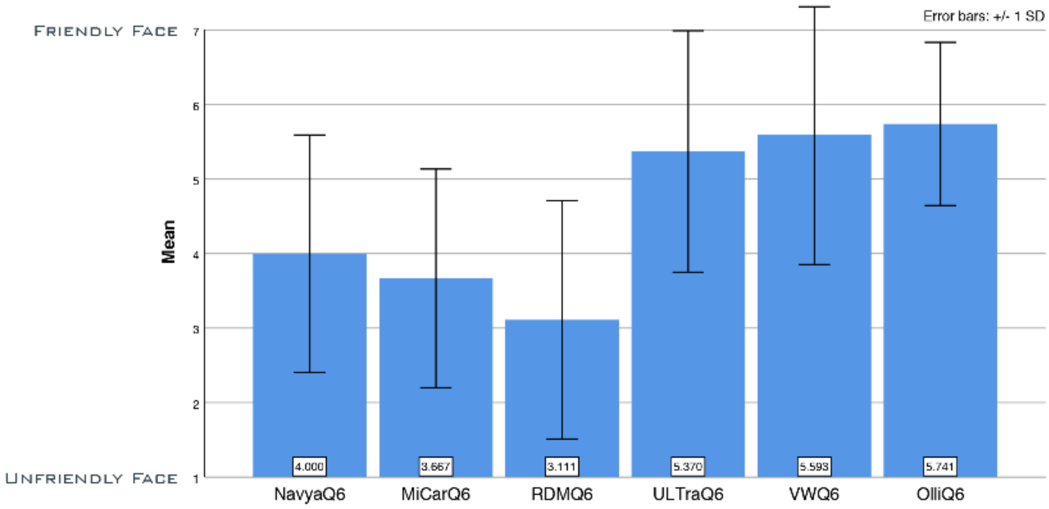


Figure 9.8 (Vehicle Face) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was significant across the six samples ($\chi 2=50.672$, N=27, df=5, $p < 0.001$). A pairwise comparison analysis was carried out showing a statistically significant difference between the Navya, the MiCar and the RDM, with these three having significantly less friendly "faces" compared with the ULTra, VW and Olli (Navya -Olli Z= -1.704 P= 0.012; Navya -VW Z= -1.709, P= 0.006; Bonferroni correction applied) (MiCar-ULTra Z= -1.704, P= 0.012; MiCar -Olli Z= -1,944 P= 0.002; MiCar -VW Z= -2.000, P= 0.001; Bonferroni correction applied) (RDM-ULTra Z= -2.148, P< 0.001; RDM-Olli Z= 2.389, P< 0.001; RDM-VW Z= -2.444, P< 0.001; Bonferroni correction applied).

When ranking the vehicle "face", the RDM was scored with the least friendly face, ranking lower than the Navya and the MiCar which were also ranked with a tendency towards a less friendly face. The ULTra, the VW and the Olli were all ranked with a tendency towards a perceived friendly face.

Q7. How trustworthy/reliable does the vehicle look?

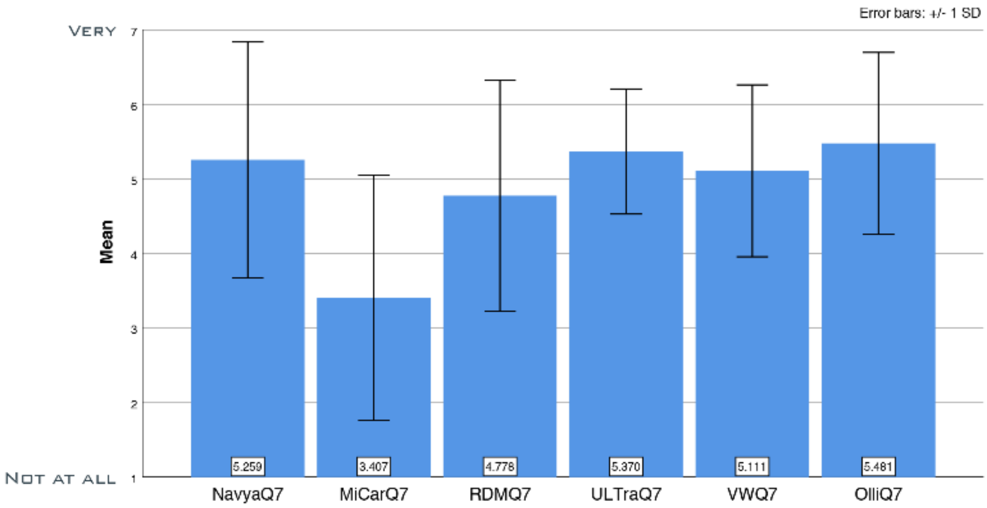


Figure 9.9 (Reliability) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was significant across the six samples (χ2=24.692, N=27, df=5, p < 0.001). A pairwise comparison analysis was carried out showing a statistically significant difference between the MiCar and all other vehicles (with exception of the RDM), with the MiCar appearing significantly less trustworthy and reliable (VW Z= -1.500, P= 0.048; Navya Z= 1.759, P= 0.008; ULTra Z= -1.852, P= 0.004; Olli Z= -2.019, P= 0.001; Bonferroni correction applied).

When judging the reliability, the MiCar is perceived as the least trustworthy vehicle. All five other vehicles are considered similarly somewhat trustworthy, with the Olli being just head of the Navya and the ULTra.

Q8. What is your impression of the vehicle size?

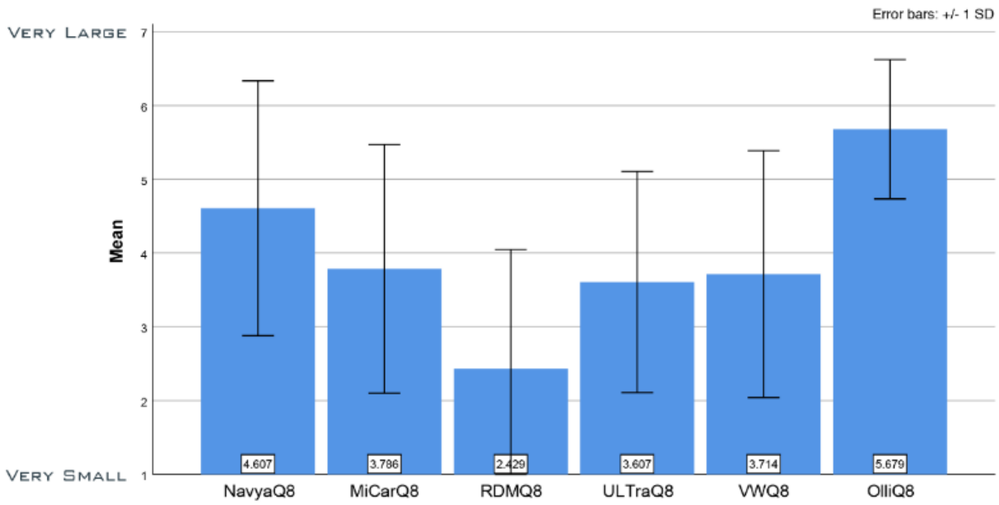


Figure 9.10 (Vehicle size) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was significant across the six samples ($\chi 2$=54.965, N=28, df=5, $p < 0.001$).

A pairwise comparison analysis was carried out showing a statistically significant difference between the RDM and the Navya as well as the Olli, with the RDM appearing significantly smaller (Navya Z= 2.125, P< 0.001; Olli Z= -3.232, P< 0.001; Bonferroni correction applied). A further pairwise comparison analysis also showed a statistically significant difference between the Ultra and the Olli, with the Ultra appearing significantly smaller (Z= -2.214, P< 0.001; Bonferroni correction applied). A third pairwise comparison analysis also showed a statistically significant difference between the VW and the Olli, with the VW appearing significantly smaller (Z= -2.214, P< 0.001; Bonferroni correction applied). A final pairwise comparison analysis showed a statistically significant difference between the MiCar and the Olli, with the MiCar appearing significantly smaller (Z= -1.982, P< 0.001; Bonferroni correction applied).

The perceived vehicle size varies across all samples, the RDM is seen to be the smallest whilst the MiCar, the ULTra and the VW are all seen to be similar and about average. The Navya vehicle is seen to be slightly larger than the aforementioned three but the Olli is with some margin perceived as the largest.

Q9. When encountering pedestrians, this vehicle's tendency is to be: Yielding/Assertive?

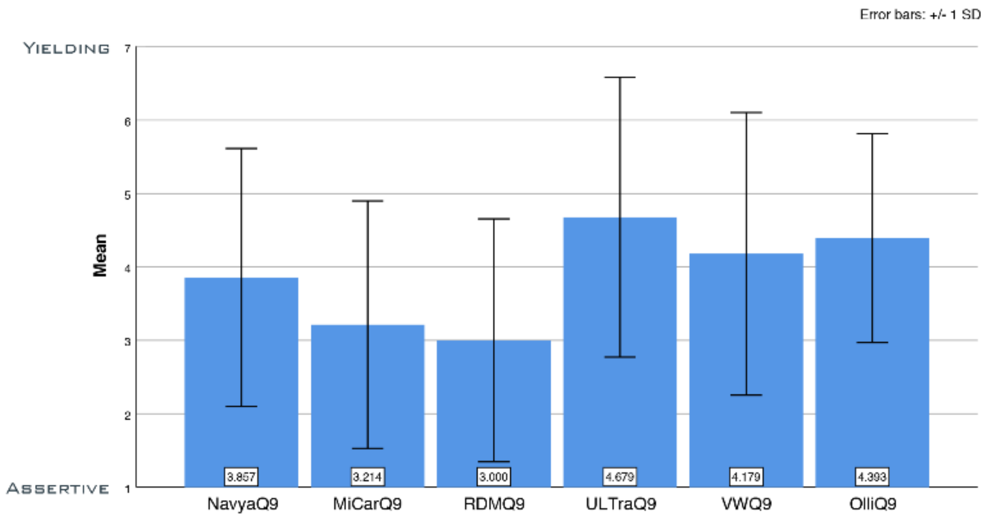


Figure 9.11 (Vehicle Tendency) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was significant across the six samples ($\chi2$=15.313, N=28, df=5, p= 0.009). A pairwise comparison analysis was carried out showing a statistically significant difference between the RDM and the ULTra, with the RDM appearing significantly less assertive than the ULTra (Z= -1.643, P= 0.015; Bonferroni correction applied).

All six vehicles are considered to be similar, neither particularly yielding nor assertive. The MiCar and the RDM show a small tendency towards being seen as assertive whereas the ULTra is seen to be the most yielding of the vehicles.

Q10.1. Considering the look of the vehicle, would it fit into this environment?

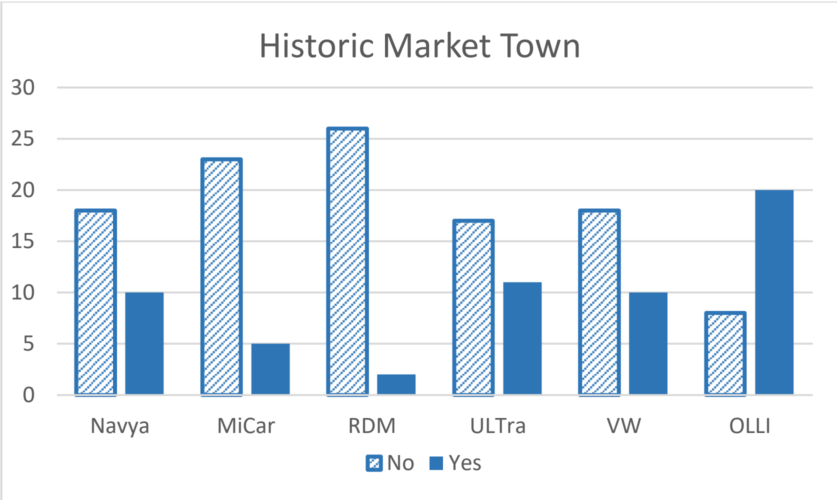


Figure 9.12 (History Market Town) Yes/No Count

A related samples Friedman's ANOVA was significant across the six samples ($\chi 2=30.213$, $N=28$, $df=5$, $p< 0.001$).

Considering how well any of the samples fit into a historic market town, only the Olli received an overall positive vote. All of the five remaining vehicles were judged not to fit into this scenario, with the RDM and the MiCar scoring particularly low. The Navya, ULTra and VW received some positive responses, the negative ones however predominated.

Q10.2. Considering the look of the vehicle, would it fit into this environment?

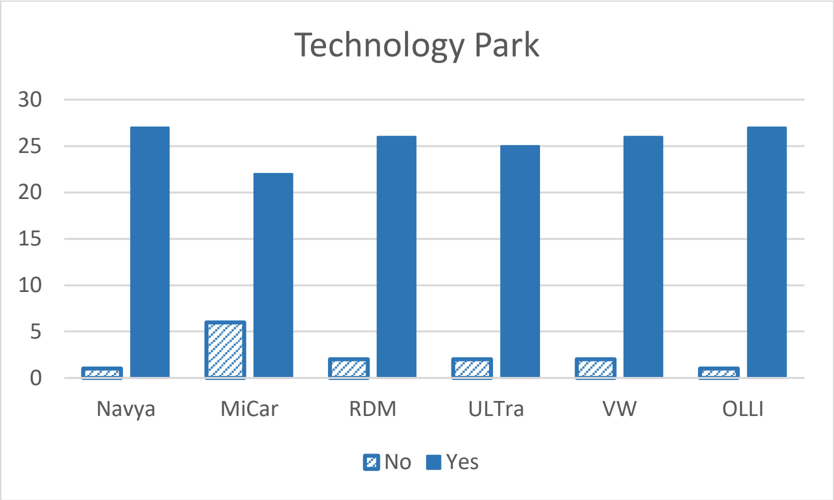


Figure 9.13 (Technology Park) Yes/No Count

A related samples Friedman's ANOVA was not significant across the six samples ($\chi 2=8.387$, $N=28$, $df=5$, $p= 0.136$).

Considering how well any of the samples fit into a technology park, all vehicles were judged to fit well into this scenario with the positive responses overwhelming some negative ones. Only the MiCar received a notable number of negative responses.

Q10.3. Considering the look of the vehicle, would it fit into this environment?

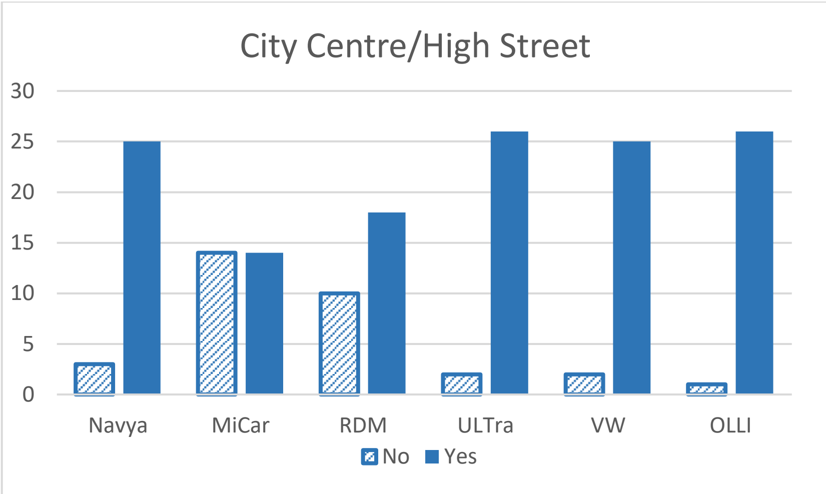


Figure 9.14 (City Centre/High Street) Yes/No Count

A related samples Friedman's ANOVA was significant across the six samples (χ2=30.794, N=28, df=5, p< 0.001).

Considering how well any of the samples fit into a historic market town, only the Olli received an overall positive vote. All of the five remaining vehicles were judged not to fit into this scenario, with the RDM and the MiCar scoring particularly low. The Navya, ULTra and VW received some positive responses, the negative ones however predominated.

Q10.4. Considering the look of the vehicle, would it fit into this environment?

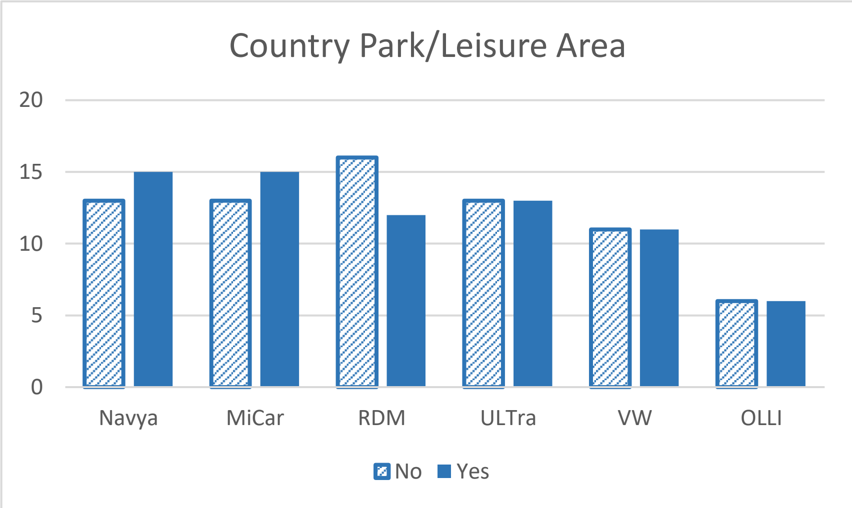


Figure 9.15 (Country Park/Leisure Area) Yes/No Count

A related samples Friedman's ANOVA was not significant across the six samples ($\chi2=8.485$, $N=28$, $df=5$, $p= 0.131$).

Considering how well any of the samples fit into a country park or leisure area, the RDM vehicle is the only judged not to fit into these scenarios. The Olli and VW, as well as the ULTra, almost received equal positive and negative votes, only the MiCar and the Navya were judged to fit by a narrow margin.

Q11. Does the vehicle design create an impression of stability or does it appear unstable?

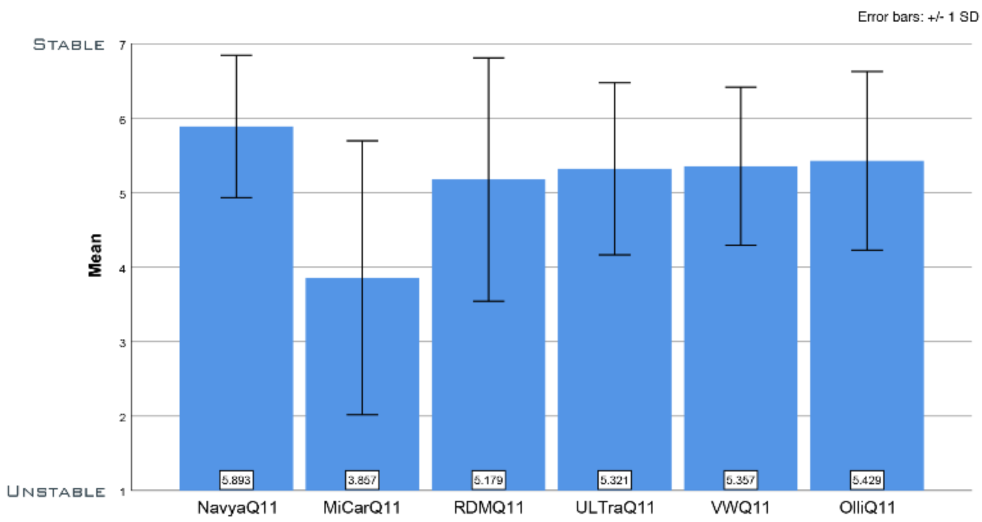


Fig. 9.16 (Stability) Mean rating with error bars representing +/- Standard Deviation

A related samples Friedman's ANOVA was significant across the six samples ($\chi2$=23.391, N=28, df=5, p< 0.001). A pairwise comparison analysis was carried out showing a statistically significant difference between the MiCar and the Navya, with the MiCar appearing significantly less stable than the Navya (Z= 2.107, P< 0.001; Bonferroni correction applied).

Considering how well any of the samples fit into a country park or leisure area, the RDM vehicle is the only judged not to fit into these scenarios. The Olli and VW, as well as the ULTra, almost received equal positive and negative votes, only the MiCar and the Navya were judged to fit by a narrow margin.

Q12. How comfortable to do you perceive the vehicle to be?

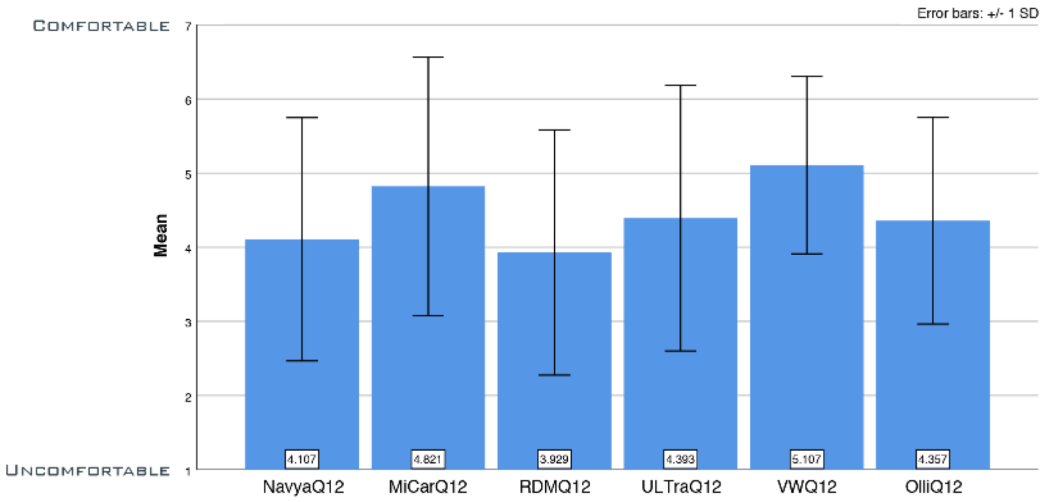


Figure 9.17 (Comfort Perception) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was not significant across the six samples ($\chi2=10.440$, N=28, df=5, p= 0.064).

The perceived comfort did not show a significant difference between any of the vehicles, the VW scored highest, closely followed by the MiCar. The ULTra and Olli were perceived to be a little less comfortable and the Navya and RDM were perceived as the least comfortable.

Q13. How keen would you be to be seen using the vehicle?

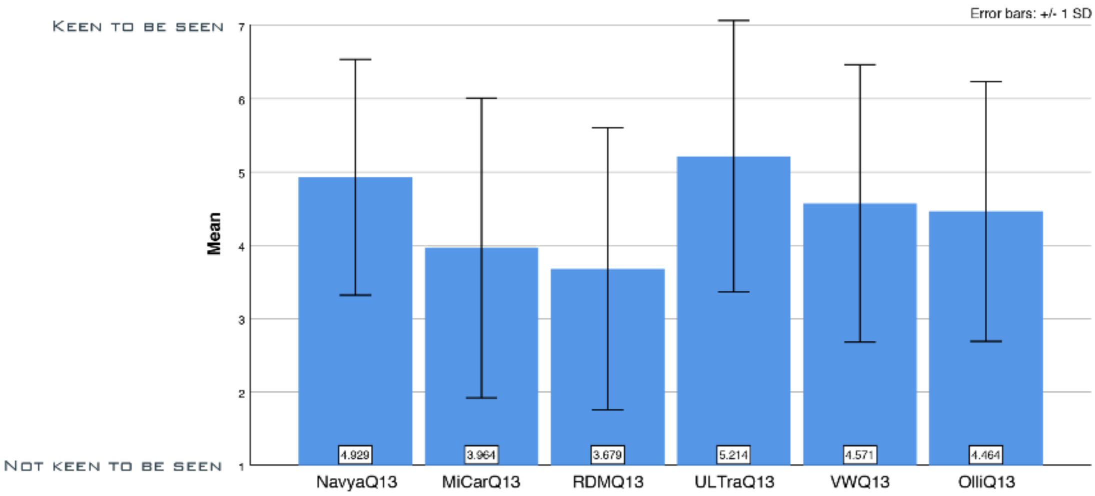


Figure 9.18 (Willingness to be seen) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was significant across the six samples (χ2=12.419, N=28, df=5, p= 0.029). A pairwise comparison analysis was carried out, however with the Bonferroni correction it is not showing a statistically significant difference between the six samples.

Without the Bonferroni correction applied, the pairwise comparison analysis shows a marginal significance between the RDM and the ULTra as well as the MiCar and the ULTra, with users being less willing to be seen in the RDM and the MiCar compared to the ULTra (RDM Z= -1.411, P= 0.05; MiCar Z= -1.393, P= 0.05; Bonferroni correction not applied).

In regards to how keen people are to be seen in any of the vehicles, the ULTra scores highest, closely followed by the Navya, the VW and the Olli. People were least keen to be seen in the RDM, being slightly keener to be seen in the MiCar. Overall the vehicles are rated very similarly.

Q14. How easy or difficult is it to enter the vehicle?

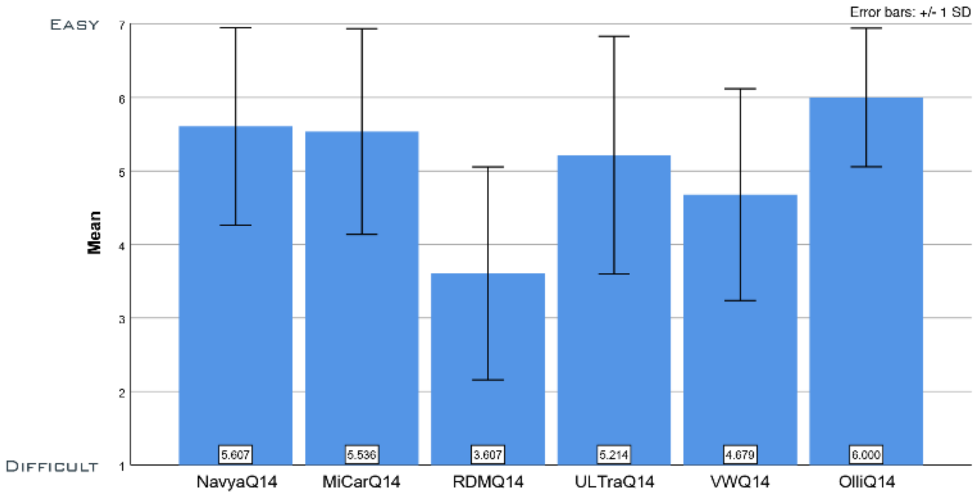


Figure 9.19 (Ease of Entry) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was significant across the six samples ($\chi2$=41.319, N=28, df=5, p< 0.001). A pairwise comparison analysis was carried out showing a statistically significant difference between the RDM and four of the other vehicles, with the RDM appearing significantly less easy to enter then the ULTra, the MiCar, the Navya and the Olli (ULTra Z= -1.714, P= 0.009; MiCar Z= 2.054, P< 0.001; Navya Z= 2.179, P< 0.001; Olli Z= -2.571, P< 0.001; Bonferroni correction applied). A further pairwise comparison analysis was carried out showing a statistically significant difference between the VW and the Olli, with the VW appearing significantly less easy to enter than the Olli (ULTra Z= -1.554, P= 0.020; Bonferroni correction applied).

Overall the vehicles appear to be easily entered, with the Olli scoring very high. The Navya, the MiCar and the ULTra are also perceived to be easily entered. The VW is judged to be a little harder to enter, with the RDM being seen as the hardest to enter.

Q15. How safe would you feel in the vehicle?

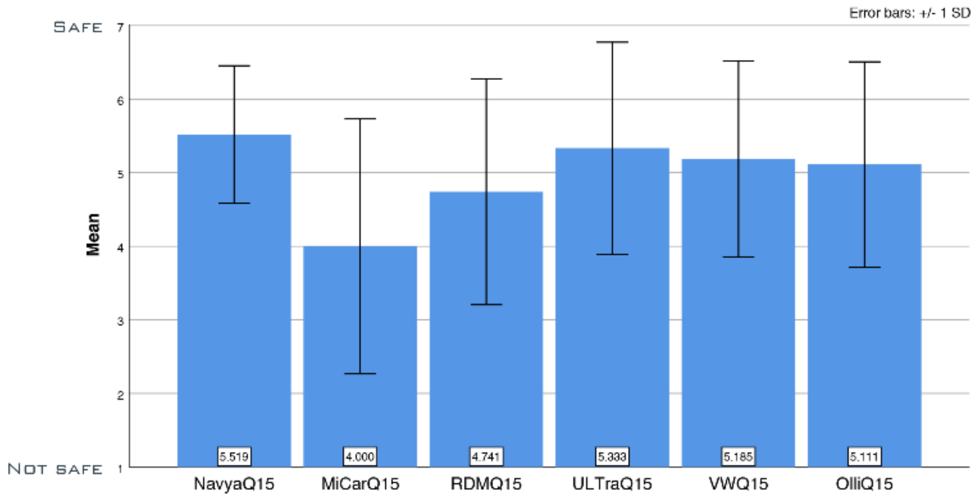


Figure 9.20 (Safety Perception) Mean rating with error bars representing +/- SD

A related samples Friedman's ANOVA was significant across the six samples ($\chi 2$=15.566, N=27, df=5, p= 0.008). A pairwise comparison analysis was carried out showing a statistically significant difference between the MiCar and the Navya, with the MiCar appearing significantly less safe than the Navya, (Z= 1.500, P= 0.048; Bonferroni correction applied).

The perceived safety in all vehicles is rated high with all vehicles with the exception of the MiCar which was rated slightly lower, neither particularly safe nor unsafe.

Overall Vehicle Ranking

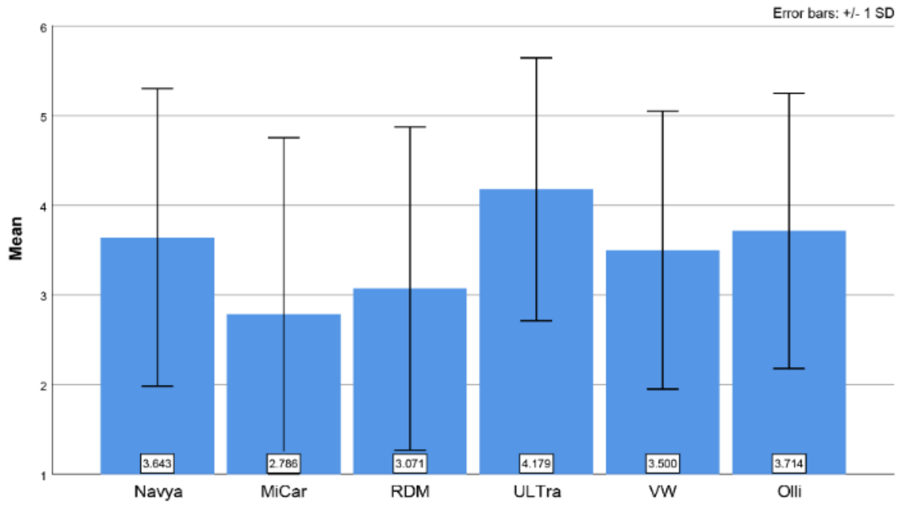


Figure 9.21 (Ranking indicating Visual Preference)

A related samples Friedman's ANOVA was not significant across the six samples ($\chi2$=9.519, N=28, df=5, p= 0.09).

The overall vehicle ranking based on the visual preference, shows the ULTra to be the highest-ranked followed by the Olli and Navya which are both closely together. The VW was ranked fourth with the RDM being scored just above the MiCar which is the lowest-ranked vehicle.

9.7 Discussion

The results of the survey will be discussed in the order of the questionnaire with all vehicles being compared individually for each question before analysing the overall ranking.

The general visual impression was covered in the first question, ranking the vehicles from very pleasing to not at all pleasing.

The MiCar and the RDM vehicle were both perceived as the least visually pleasing, contrary to the ULTra PRT vehicle, which performed best. All vehicles, however, are closely ranked together, with all scoring close to average, suggesting that none are particularly visually pleasing or displeasing.

This may be due to, as was revealed in the focus group, that most vehicles were seen as too utilitarian and often compared to either public transport vehicles or mobility solutions at airports, vehicles with which consumers rarely identify based on the design.

When scoring the similarity to common passenger cars, the Navya scored highly, indicating a strong similarity, whereas the MiCar scored the lowest, suggesting the opposite. The Olli was also ranked with a high similarity to common passenger cars, displaying a common theme of creating designs which relate to existing public transport vehicles, which was reflected in recurring comments during the group discussion; "standard city bus" (Olli), "regular bus" (Navya) and "reassuringly familiar" (Olli). In contrast, the lack of similarity of the MiCar highlights the novelty aspect of the vehicle type and does not create any direct comparison with other existing vehicles.

This trend can further be observed in the question whether the participants perceive the design as unconventional or conventional. The MiCar is the least conventional vehicle with the Olli ranking as the most conventional, similarly to the Navya.

Here the MAYA (Most Advanced, Yet Acceptable) principle becomes relevant, which theorises that when dealing with everyone but design and art experts, the most novel design that is still recognizable as a familiar object or environment is perceived to have the greatest aesthetic appeal (Hekkert et al. 2003). Therefore, the aim of the designers should be to create a design that remains relatable yet is advanced enough to avoid direct comparisons with existing vehicles.

As this poses the risk that features from existing vehicles, that due to their familiarity are considered threshold attributes will, therefore, be considered the same in the new vehicle, reducing the opportunities for excitement attributes to be created.

The following question focused on the personality of the vehicle, ranking it between cute and aggressive. The RDM Pod Zero was seen as the most aggressive looking vehicle whilst the VW SEDRIC was closest to “cute”. The ranking of all six vehicles, however, indicated that the general tendency was to perceive the vehicles as more aggressive than cute.

The following question ranked the vehicles between submissive and a dominant impression and the RDM scored lowest again whereas the ULTra PRT, as well as the VW SEDRIC, were perceived as the most submissive.

Based on research by Windhager et al (2008) where participants saw emotional expressions such as anger and aggression in cars, the following question aimed at ranking the pods between a friendly face and an angry face. The RDM Pod Zero scored low and was therefore seen to feature an angry face and the Olli, as well as the VW SEDRIC, were judged to feature a friendly face. Based on Landwehr et al. (2011) it can be argued that the Olli and VW SEDRIC were perceived as friendlier due to their grills, or graphic elements which replace the classic grill as they are either a neutral flat shape or even turned upward. Combined with the round headlights of the Olli or the slanted headlights of the VW this created a friendly impression.

The two lowest-scoring vehicles, the RDM and the MiCar did not feature a face at all, which is likely to prevent the onlooker from anthropomorphising the vehicle and therefore not being able to spot a friendly expression. The Navya did feature a grill and headlights, however, the downward shape of the grill (suggested by the body panel shut lines) and the arched headlights, cause it to be perceived as somewhat aggressive, a finding that aligns with the research by Landwehr et al. (2011).

The three aforementioned rankings describe the perceived “personality” of a vehicle, which is important to consider when the vehicles will share a space with pedestrians, as a more dominant and aggressive look may cause the vehicle to be feared. A very approachable impression, however, may also put pedestrians into danger as they may feel too comfortable in the direct vicinity of the vehicle, and subsequently may get too close to it.

The comments during the group discussion also revealed that the colour choices had an impact on the perception of the vehicle “personality”; “Dark colour makes it (RDM) look aggressive” with one participant suggesting that the dark colours make it look “cold and corporate” and would prefer to see lighter colours being used.

The participants were also asked to judge the reliability of the vehicles and the MiCar was seen as the least reliable and the Olli as the most reliable. It has to be noted however that the ranking of the Olli is close to the score of the other vehicles, with the exception of the MiCar, suggesting that most of the vehicles looked somewhat reliable. Here the complexity of the exterior design may influence this choice, much like Creusen and Schoormans (2005) suggest in regards to the complexity of household products; the ULTra and the Olli have very simple surfaces and shapes and score higher than those with a more complex styling.

In the ranking of the vehicle size, the Olli was seen as the biggest, significantly bigger than any of the other competitors, which came as a surprise, since, apart from the RDM POD Zero, they are in reality all of an approximately similar size. The POD Zero was judged to be drastically smaller than all other samples, which does align with reality. In this case, however, the size of the vehicle did not appear to influence how the vehicle personality is perceived, contrary to the findings by Dey and Terken (2017) who found larger driverless vehicles to be more intimidating than smaller ones. The smallest vehicle was seen as the most aggressive looking and when ranking the tendency the vehicle displays when interacting with others, the RDM Pod Zero was also seen as the most assertive.

The ULTra, in contrast, was judged to be the most yielding vehicle. These findings show that an aggressive face is correlated ($r = 0.566$, $p > 0.01$) to the vehicle be seen as assertive.

The vehicle face, the headlights and grill in particular, therefore provides designers with an opportunity to influence the perception of the vehicle and subsequently the reactions of the other road users it encounters.

In the following section, participants were asked to indicate if they would see a vehicle fit into either of the four suggested scenarios; Historic Market Town/Technology Park/City Centre & High Street/Country Park & Leisure Areas. For the first scenario, the historic market town only the Olli was seen as fitting, eight participants still saw it as unsuitable and on average only one third saw the other five vehicles as suitable. For the second scenario, the technology park, all vehicles were clearly indicated as suitable with only one or two participants judging it differently. In the city centre & high street scenario, four vehicles were clearly accepted, with the MiCar being equally divided between acceptance and disapproval and the RDM being the only rejected vehicle where only approximately one third saw it fitting. For the last scenario, a country park or leisure area, all five were accepted, albeit in close decisions with the exception of the Olli. The RDM Pod Zero was rejected with 16 votes against it. Overall only the Olli was accepted in all four scenarios with the RDM Pod Zero being rejected for three of the four scenarios, indicating that, despite an overall acceptance of driverless first and last mile mobility vehicles, they are still not judged to fit in most scenarios.

Judging how stable the vehicles appeared, the Navya ranked best with the MiCar appearing the least stable. The four other vehicles ranked equally close to the NAVYA, indicates that the participants perceived them as generally stable.

This suggests that unusual design of the MiCar, which is the only one that appears to expand in volume towards the upper half in order to create more headspace, does seem to negatively impact on the overall impression of stability. As in contrast, the design of the other five vehicles features an inward tumblehome, placing the visual weight further towards the lower half of the vehicle and impression which was also reflected in the comments during the group discussion "too high – so probably unstable" (Olli).

The question regarding the impression of comfort did not yield any significant results with all vehicles scoring similarly, only the MiCar and VW Sedric scored marginally above average. This suggests that it is difficult to judge the vehicle comfort from the exterior impression of a vehicle.

When asking the participants how keen they would be to be seen in one of these vehicles, the ULTra received the highest score whereas the RDM Pod Zero was the vehicle they were least keen to be seen in. These results correlate ($r = 0.286$, $p > 0.05$) with the vehicle impression where the RDM was seen as the most aggressive, contrary to the ULTra, which was perceived as the least aggressive. The correlation between the perceived vehicle aggression and the lack of willingness to be seen in the vehicle poses the question to what extent a vehicle, even as a shared public transport context, is still seen as an extension of personality the user themselves.

Judging the perceived difficulty of entering the vehicle indicated that the Olli was seen as the easiest to enter whilst the RDM appeared difficult. Aside from the RDM however, the vehicles overall were seen as easy to enter, with the taller vehicles being rated higher than those that have a lower roofline such as the VW Sedric. The low score of the RDM suggests that beyond a low roofline, a small interior volume may also play a role as the RDM vehicle is taller than the VW, yet score the lowest.

When asked how safe the vehicles appear to the participants, all vehicles were seen as somewhat safe with the exception of the MiCar, which scored slightly lower.

A safe initial impression is necessary to convince users to adopt driverless first and last mile mobility vehicles and the ratings by the survey participants indicate that in general all of the vehicles presented do fulfil that requirement, albeit improvements can be made to all designs.

Here design choices such as an exposed vehicle frame, as it is featured in the highest-scoring Navya appear to positively enhance the safety perception as it was also noted in the comments: "Bars inside make it look safe".

The participants were also asked if the vehicle does remind them of a brand, and if so, which brand. The answers ranged across most automotive companies but also included companies producing household items such as Miele, G-Tech Airram and Henry Hoover. A large number of answers also referenced public transport systems or vehicles. As previously discussed, this may lead to associate negative as well as positive brand attributes to a vehicle, a consequence that needs to be carefully managed but can be used as an advantage as well. Existing vehicle manufacturers could translate their current safety record to a new driverless pod in their range for a positive impact and new manufacturers could mimic existing public transport vehicles to benefit from the general confidence into these vehicles.

As a final task, the participants ranked all of the vehicles from 1-6 with 6 being the best, 1 the worst. The results do show a clear ranking; with the MiCar being the lowest ranked, followed by the RDM, VW, Navya, Olli and the ULTra being the top-ranked. The rankings, however, were very close with only 1.393 points separating the best and worst ranked vehicle.

9.8 MiCar Detailed Discussion

As the MiCar vehicle is a design that was created as part of our research work (chapter 8.1), the following highlights some of the results and their impact on the design.

The MiCar was seen as the least pleasing of the six vehicles reviewed possibly due to the colours and graphics used for the vehicle. Therefore the colour choices should be reviewed and graphic elements should be added to create a vehicle face, which the vehicle currently does not feature and based on the findings discussed previously could positively impact on the perception of aggressiveness and assertiveness. Adding more distinct graphic elements such as feature lines and separate colour choices could also help to alleviate the poor impression of stability, by adding more visual weight to the lower half of the vehicle which in turn should increase the impression of stability in the vehicle. This could then have a positive knock-on effect on the perception of safety.

The MiCar was further judged to be very futuristic, with a low similarity to regular road cars which suggests that the design is possibly too advanced to still be fully accepted according to the previously discussed MAYA principle. Adding some design details that consumers recognise from existing vehicles, particularly from the public transport sector may positively influence user acceptance.

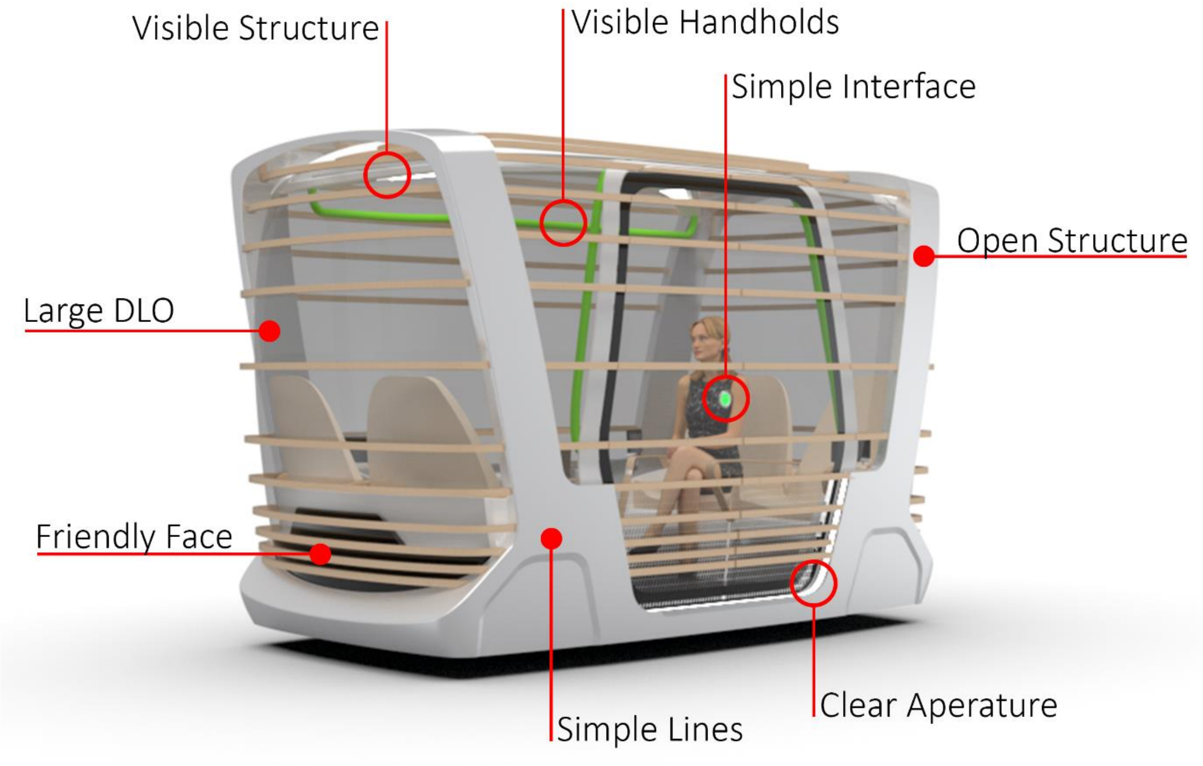


Figure 9.22 Summary of the key exterior design features

9.9 Conclusion

In conclusion, it can be said that driverless first and last mile mobility vehicles are seen as unusual and as a consequence, the first impression does create diverse reactions. Some vehicles are designed to mimic traditional public transport vehicles, which based on the comments in the group discussion, seems to suggest greater reliability to onlookers. An impression that appears to be further enhanced through simple designs with clean lines and shapes.

Despite using existing public transport vehicles as a design inspiration, the vehicles are still seen to stand out in any environment. Unsurprisingly, the more modern the surroundings are the better the vehicles appear to integrate.

A further conclusion suggested in the results is of correlation between an aggressive face, which appears to suggest a dominant vehicle that does not yield to other road users and a subsequent lower willingness to be seen in this vehicle. However, as previously discussed this could be utilised, if carefully managed, to establish a safety zone around these vehicles by creating an appearance that does not invite others to step too close to it or even bully it much like in a "game of chicken" as described by Millard-Ball (2018). It argues that the concept of driverless vehicles being safer, due to not being distracted and being programmed follow traffic rules closely, gives pedestrians an "incentive to pretend to be drunk or to ostentatiously behave as if they had no conception that (driverless) cars could be dangers". Further research could establish if it is possible to counteract this behaviour by using the vehicle design to create a more cautious approach by pedestrians without instilling fear in these vehicles.

The most important factor in the perception of this kind of vehicle is the impression of safety, the novelty of driverless technology inherently creates a sense of the unknown and therefore it is essential for the vehicles to portray a safe appearance. All of the vehicles which were part of this survey were deemed to fulfil that factor, although there remains room for improvement.

4^{th} Objective

The evaluation of user acceptance-based the vehicle appearance through questionnaires and focus groups fulfils the fourth objective and provides insight on how the external features of these vehicles are perceived. Whilst the main focus of this work is the interior design of the vehicle, many features also affect the external appearance which is what any potential passenger will encounter first and thus will influence the first moments of the experience.

A number of small changes to the MiCar vehicle concept were made as a consequence of these findings and are noted at the beginning of chapter 11.0.

10.0 Digital Ergonomic Evaluation

10.1 Intro

Part of any vehicle design process is an extensive ergonomic evaluation in order to ensure that the final vehicle is comfortable and easily used. The ergonomic evaluation is typically done using two methods:

1. Digitally using manikins which can be placed into a 3D model
2. Physically using an ergonomic buck or prototype vehicles

The digital ergonomic evaluation is typically done prior to building a physical model, as alterations can still be made quickly and easily when issues are identified. Also in this project, the digital evaluation was the first step in a set of evaluations leading to user trials with a physical full-scale model.

This chapter, therefore, describes the digital evaluation of the MiCar vehicle design, which focuses on the reach for handrails, the seats and visibility from the vehicle, using the Jack PMS Software by Siemens (Siemens 2017). The 3D CAD model of the MiCar vehicle concept which was created as a part of the design process was used as a basis for the evaluation process.

Some design changes were made following the exterior evaluation in chapter 9.0, prior to conducting the digital evaluation: a faded shade was added to the doors, eliminating the exposure of the lower body halfway through the doors. Secondly, the horizontal wooden rings were also rearranged from an equal distribution to a less rigid pattern in which the gaps decrease in size towards the top and the bottom of the vehicle.

10.2 Methods

10.2.1 Alias AutoStudio

Autodesk Alias AutoStudio 2018 is an A-Class modelling software typically used to create 3D vehicle models during the initial design phase described in chapter 8.0 (Fig. 10.1). The software creates surfaces based on Bezier surface and NURBS modelling method, giving modellers a great degree of freedom in modelling the surfaces of components. Combining various components, vehicle models can be created to include interiors as well as mechanical features such as the driveline and suspension. Each component can be grouped and organised within the software, enabling the user to hide or select specific groups of components (Autodesk Alias AutoStudio 2018).

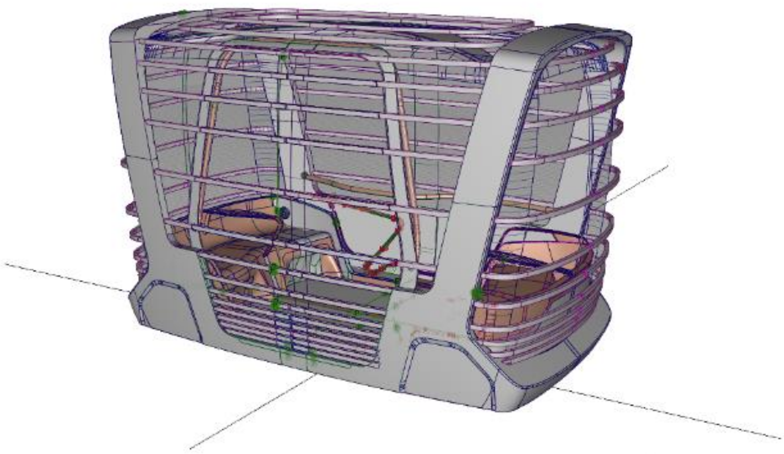


Figure 10.1 (3D CAD Render Alias Autostudio 2018)

Alias was selected to create the digital model following the design phase (chapter 8.0) as it allows to quickly create precise surfaces and continuously edit them throughout the process.

10.2.2 Jack

For the digital ergonomic evaluation of the vehicle design software tools such as RAMSIS Technica or the Siemens' PLM Jack can be used. This type of software allows for the evaluation of basic occupant packaging aspects such as reach, fit, and visual field (Porter et al. 1993). In this case, Jack was used rather than RAMSIS due to its availability and existing documentation at Coventry University.

In order for the evaluation to be conducted in Jack, a digital model can be placed within a 3D space in the software. Within that space, digital manikins can be placed and manipulated into set postures as well as animated for short movements (Fig. 10.2). The size of these manikins is based on several anthropomorphic databases covering different demographics (ANSUR, Asian-Indian, Canadian Land Forces, Chinese, German, NHANES and North American Auto Workers anthropometric databases).

From these databases, suitable manikins can be selected and sized to represent 5th%ile or 95th%ile passengers or altered to highlight specific proportions. After placing the manikins within the digital model, each of their limbs can then be individually manipulated into the required postures. This setup can now be used to perform visual clearance and fitment checks as well as to compute a "Comfort" Analysis included into Jack Software

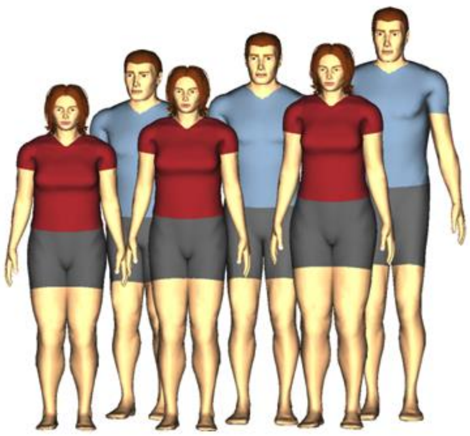


Figure 10.2 3D Manikins Jack

The tool used for the calculations is called "Occupant Packaging Toolkit" (OPT) and is an optional add-on to the Siemens PLM Software Jack. Using the software, it is possible to benchmark the vehicle design against other vehicles or design variants using the SAE J-Standards tools. OPT permits posture predictions within the vehicle and subsequently to evaluate how comfortable they would be, additionally it can also analyse what the occupant can reach and see. It calculates the muscle strain of a set posture and presents the output as a bar graph, indicating each body part with the experiences strain and threshold limits.

10.2.3 Task Analysis

In order for the evaluation to be conducted, potential use-cases of the vehicle had to be explored and detailed, in order to then be individually modelled within the software.

The hierarchical task analysis (HTA) is not only used to analyse the steps required to complete an activity, but they also provide a systematic overview of the sequence of tasks and subtasks (Hollnagel 2003). For this HTA (Fig. 10.3), a fictional journey (overall task goal) on board of the MiCar was separated into four main tasks: 1) contact and connect with the vehicle, 2) physically entering the vehicle, 3) travel onboard, and 4) exiting the vehicle. Each main task was divided into several subtasks describing in more detail, depending on different passenger requirements the steps required to complete the main task.

The HTA formed the foundation for the evaluation using Jack, acting as a guideline for each activity and posture which were modelled and further also in all following evaluation methods, as it defined which processes required analysis and in which order. Furthermore, it ensured that in all stages of the evaluation tasks were completed in the same order, permitting the analysis of progressive changes across all three methods.

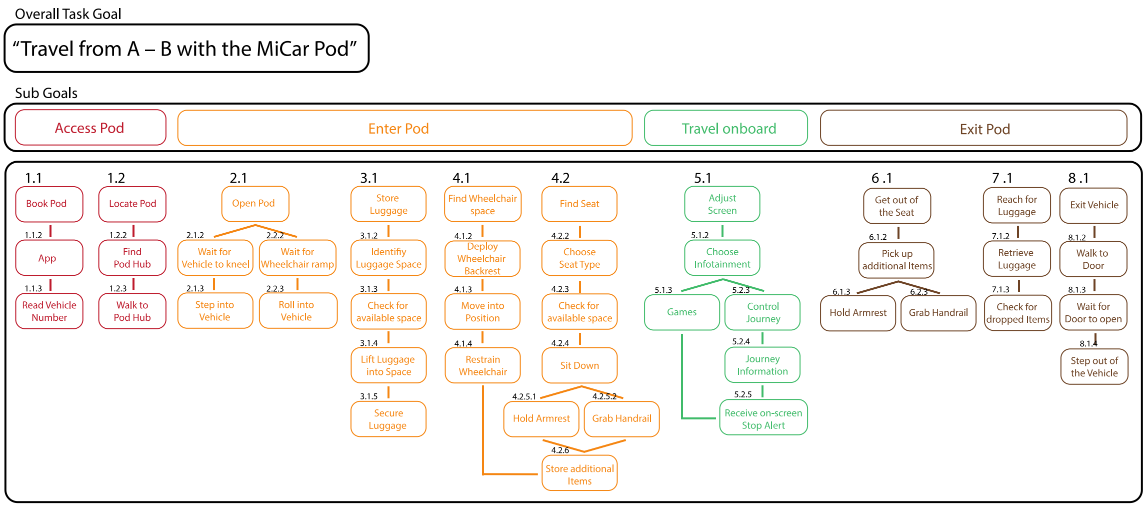


Figure 10.3 HTA – Travel On-board of a Driverless Pod

10.3 Evaluation

A selection of the aforementioned steps were each individually modelled within the Jack software with two manikins. The head clearance and the minimum space required was evaluated by placing a 95th%ile male manikin (named "Jack") into the virtual model and minimum reach requirements and maximum heights, of items such as the seat base, were evaluated using a 5th%ile female manikin (named "Jill"). The 95th%ile male and 5th%ile female are the traditional guidelines used in the automotive industry to evaluate the packaging of vehicle interiors (H-Point 2014).

Table 10.1 Statue (Body Height) of the trial manikins

	Statue (Body Height)	5th%ile	95th%ile
Jack	Male	1672mm	1959mm
Jill	Female	1528mm	1799mm

The four aspects this review focused on were: the reach to the overhead handrail, if there is sufficient space for a seat to be shared by mother and her child as well as the seat fitment with both of the Jack and Jill manikins. A fifth evaluation tested the view angles from both a seated and standing position.

Tasks which are made up of a pattern of movements, such as ingress and egress or loading luggage into the luggage space, were not evaluated at this stage, as the attempt to program animation sequences caused the software to fail. It was later revealed during a Jack training by Siemens that any sequence lasting over 5 seconds was not achievable with this program version (Jack 8.4). Furthermore, it was decided that these activities, including the usage of the vehicle with a wheelchair, would be better evaluated using a physical experimental setup.

An HMI, more specifically the placement of buttons and screens, was also not considered as they were not yet sufficiently developed.

A visual evaluation will be the main technique, using the digital model and manikins to establish if the manikin fits into the intended space and is able to reach handholds or place the feet on the intended surface. As the manikins can only be manipulated according to normal human movements, it is also possible to visually check if the task can be completed in a natural posture, both methods were used to evaluate the seat design as well as the overhead handrail. As previously discussed, Jack can also calculate the muscle strain experienced in any of the positions the manikin was manipulated into, this was therefore also used for the evaluation of the reach to the overhead handrail.

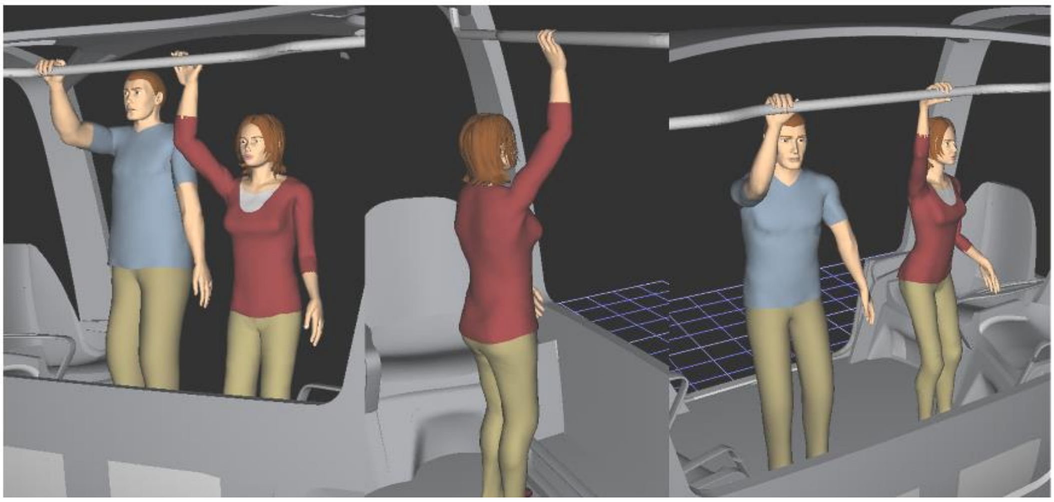


Figure 10.4 (Top Handrail Reach 95th%ile male & 5th%ile female)

The handrail mounted above the luggage space, which is aimed at providing an overhead handhold for those standing in the middle of the vehicle, was particularly difficult to place correctly as the luggage space prevents passengers to stand directly beneath it and the height needs to be within reach for shorter passengers and not encroaching the headspace of taller ones. This was the key reason for initially placing the handrail above the luggage space where the roofline is at its lowest without encroaching the headspace of taller passengers. In order to evaluate the placement, the tall manikin Jack and the shorter Jill were manipulated into reaching for the handrail (Fig. 10.4).

The visual check indicated in this case that reaching the handrail is physically possible for both manikins. The position of the luggage space does, as expected, prevent the passengers from standing directly beneath the handrail and knocking their heads, which does however also increase the distance between the rail and the floor space the passengers can stand on. The male manikin can reach the rail with ease, the female manikin, however, has to almost fully extend her arm in order to reach the rail suggesting an uncomfortable pose. For either manikin, the handrail forces them to stand in a posture parallel to the direction of the main vehicle movement, which may make it uncomfortable when attempting to look towards the front.

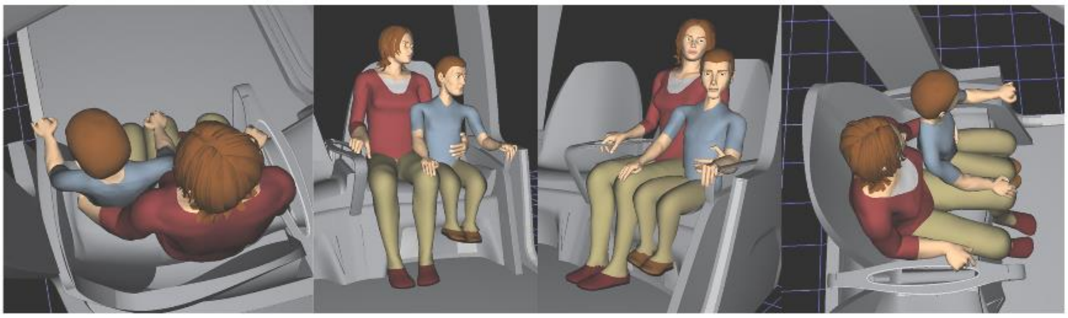


Figure 10.5 (Shared Seat Space 50th%ile female & 3-year-old Child)

A unique feature of the MiCar interior are two symmetrical bench seats on either side of the vehicle, which themselves are asymmetrical shaped. Typically existing vehicles of this kind either feature individual seats, which offer little flexibility or continuous bench seats which offer little body support. Therefore a novel seat design was developed for the MiCar concept, here both benches are split into two individual spaces; the side closer to the door of each of the bench seats is designed to be wider in order to accommodate mother travelling with a young child (Fig. 10.5).

This allows for greater flexibility in the use of the seat whilst providing the same level of support as an individual seat. For the evaluation the female manikin Jill was resized to match a 95th%ile female and was placed next to a manikin that was manually sized to fit an average 3-year-old boy (952mm). The visual fitment check indicated that there is indeed sufficient space for the two manikins to be seated side by side in the space provided.

The child-sized manikin does not reach the vehicle floor and is also not able to lean on the backrest of the seat which, however, leaves room for the accompanying adult passenger to hold it from around the back.

The proposed seats are unlike those currently found on public transport vehicles, individual seats with little shape and padding, as the MiCar is designed to be used in different scenarios where users are likely to expect a higher standard. In the scenarios developed in chapter 6.0 such as the National Trust, for example, passengers are likely to spend a longer period of time in the vehicle, making the seating comfort a more important requirement. The different applications, from a technology park to a public park also require the seats to provide more flexibility in their use, allowing passengers to assume different postures.

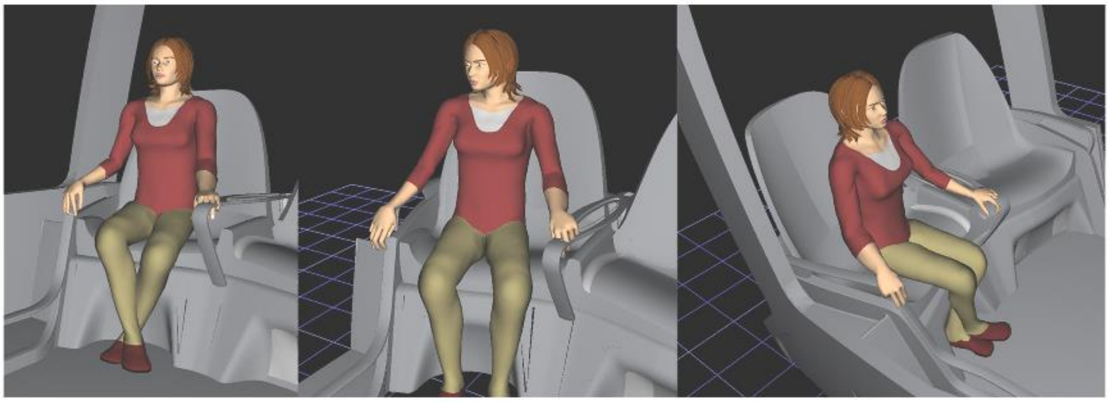


Figure 10.6 (5th%ile Female Individual Seat)

The depth and height of seat pan of the other side of the bench seat, the single-seat, were also evaluated with the 5^{th}%ile Jill Manikin (Fig.10.6). The small female manikin was used as short passengers need to be able to place their feet on the floor whilst sitting on the seat. The manikin was manually posed on the seat and two typical leg postures were trialled, extracted from the research conducted by Kamp et al (2011), whilst the reach for the armrests was also evaluated. Whilst the initial seat design was based on research and measurements by Vink (2016), the shape of the seat which tries to allow for two different postures, made it difficult to apply them accurately.

The digital review confirmed that as it showed that the depth of the seat pan is too great for the Jill manikin, preventing the manikin from fully resting against the backrest of the seat. The height of the seat pan does, however, allow the manikin to fully rest their feet on the floor as well as assume different postures. The armrests are within reach for the Jill manikin, vital for any passengers to be able to steady themselves during the journey. The armrests are also required whilst sitting down as well as to push or pull out of the seat when leaving the vehicle.

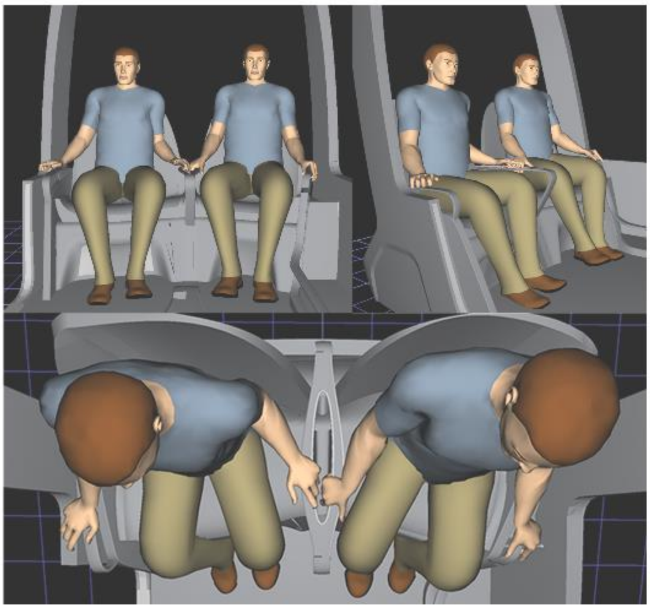


Figure 10.7 (95th%ile Male Individual Seat)

The same evaluation of the bench seat was also conducted with the 95th%ile male manikin (Jack) in order to judge if two large male passengers can comfortably sit in both of the sides of the bench seat (Fig.10.7). The visual check indicated that there was sufficient clearance on either side of the seat for the manikins to sit. It also showed that the shape of the seat created an inward rotated seating position or an optional position looking straight ahead, as it was intended in the design. The evaluation of the central armrest, which separates the two seating spaces, was also conducted with the aid of two Jack manikins; the possibility to grab around on of the two parts where the armrest is split without getting caught in the gap as well as being able to rest the underarms of both passengers on the armrest.

The visual clearance check showed that the hands of both manikins fit into the gap and can comfortably grip around it. The gap is based on the minimum measurement of 45mm stipulated within the regulations for public transport vehicles (Public Service Vehicles Accessibility Regulations 2000).

These guidelines were further used as a basis for the handrail diameter of 35mm and the placement at no less than 800mm above the floor and no higher than 1900mm from the floor.

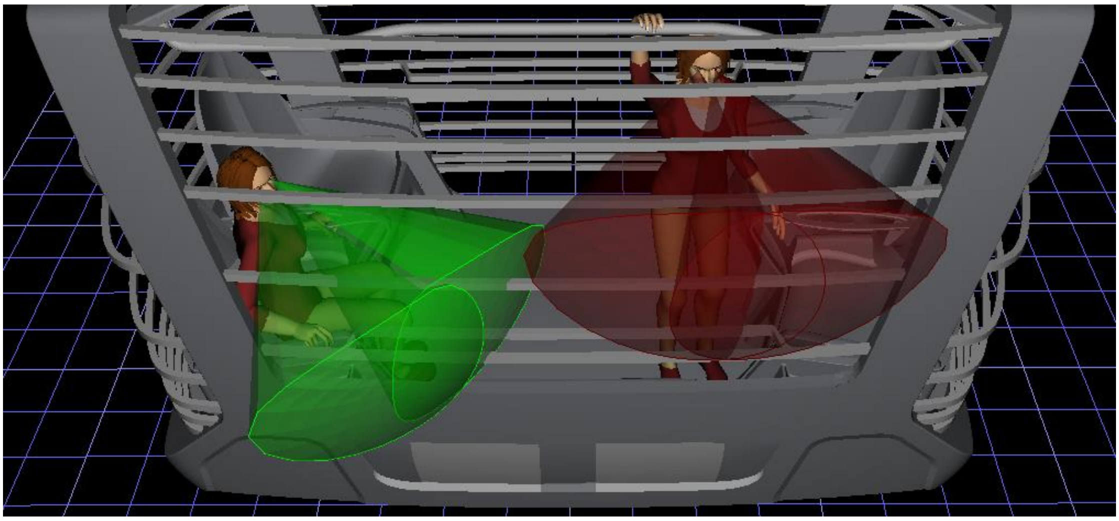


Figure 10.8 (5th%ile Female Viewing Angles (Seated/Standing))

The software was also used to evaluate the viewing angles of the potential passengers from two positions, seated as well as standing in the vehicle. Two coloured cones, representing a combined paracentral visual field of 60° (Lachenmayr 2005), were created with the origin being located in both of the eyes of each manikin (Fig.10.8). These automatically moved based on the head position. This technique indicates the complete viewing angle from each of the positions with anything that is within the cone may lead to visual obstruction. The evaluation showed that for both positions the lateral rings shading the vehicle did interfere with the view, to what extent however is difficult to judge within Jack.

The uprights of the roof structure, however, do not interfere with the view to the exterior. As the view to the exterior is a crucial element in this project, the impact of the rings will undergo further evaluations in a participant-based trial.

10.4 Summary & Discussion

Using the Siemens Jack PLM software to evaluate a vehicle design does provide instant insights into general fitment and spacing requirements of differently sized users. The evaluation of the MiCar did show that the bench seat was wide enough to accommodate any passenger within the 95th%ile (Dutch male) and did also provide sufficient space to be used jointly by a mother and child. Whilst the height of the seat pan was suitable for all users, the depth was too great and prevented the 5th%ile (Chinese female) passenger to reach the backrest.

The evaluation of the ceiling-mounted handrail did indicate some issues for shorter users, which had to almost fully extend their arm to hold it. The simulation showed that this may be caused in part by the luggage space being directly beneath the handrail, preventing passengers to stand closer to it. In the following design iteration, a different placement of the handrail or alternatively a reduction of the luggage space should be trialled as a potential solution to this issue.

The evaluation of the viewing angles showed that the structural pieces of the roof such as the uprights do not impede on the view of the passengers. The lateral rings that surround the cabin do have an impact on the view, how great the impact is, will be evaluated in a further study.

Whilst the previously described evaluation of the vehicle design did provide helpful insights regarding the tasks identified in the task analysis, a drawback to this method is that only tasks and behaviours known to the software user could be tested.

Therefore, the ergonomic evaluation of the design with the Siemens Jack PLM software is only an intermediate step to using methods such as a full evaluation with participants using an ergonomic buck.

5th Objective Part 1

The fifth objective is split into three sections, the first of which is addressed in the chapter above. The digital evaluation of the MiCar vehicle concept using Siemens Jack PLM provides the first insights into the ergonomic challenges which the vehicle attempts to address. However, as discussed above, the digital evaluation has its limitations, which is why the following studies will address the remaining parts of the firth objective.

11.0 Ergonomic Buck Build

11.1 Introduction

The ergonomic buck, a physical full-scale representation of the digital MiCar model was constructed at the National Transport Design Centre (NTDC) at Coventry University. It will provide the foundation for the following studies (chapter 12.0 & 14.0) as well as the development of the Mixed Reality Simulator in chapter 13.0.

An ergonomic buck is a physical representation of a vehicle cabin for the purpose of ergonomic evaluations and commonly used to assess aspects such as ingress and egress and habitability (e.g. Richards and Bhise, 2004; Ling et al. 2013). Using an ergonomic buck, also known as "seating buck", a vehicle design can be evaluated by designers as well as non-expert users, which can be observed during the completion of a task, potentially highlighting unknown use cases and or issues. Hence, an ergonomic buck was constructed to conduct trials with a range of target users, evaluating a variety of vehicle interactions. The buck provided an accurate representation of the access openings, floor-space, seating height and luggage space. The floor of the buck was raised to the same height above the road surface as the proposed real vehicle, permitting an evaluation of entry from road level. The buck also included a ceiling, to allow judging of the cabin volume, as well as providing handholds such as stanchions and armrests. It also included a specifically designed bench seat, which holds a central point in the concept, as it is designed to maximise the space on-board as well as providing flexibility to the passengers to choose their seating posture. The armrests were milled from high-density foam and reinforced with glass fibre and mounted to the bench seat.

Design Changes following the digital evaluation:

- The height and depth of the seat pan were adjusted to better fit the smallest passengers (5^{th}%ile female). The depth of the seat pan was shortened to 44cm, and the height lowered to 40cm.

- The position of the handrail above the luggage rail was noted as unsuitable and different alternatives were prepared to be tested in the ergonomic buck.

The ergonomic buck will be used in a following step to evaluate the ergonomic aspects, such as the reachability of handholds, if the seat placement and shape is suitable for all users, the size of the door aperture, the suitability and accessibility of the luggage storage solution and the placement of the wheelchair space.

11.2 Construction

The construction of the ergonomic buck was undertaken in several stages; the initial planning stage was based on digital drawings generated from the MiCar CAD model using Autodesk Illustrator. This step was required to add dimensions to the line drawings as well as setting up 1:1 scale printouts from individual sections, due to the MiCar design featuring a multitude of curved parts, which were used to transfer the linework onto the material to ensure an accurate build.

11.2.1 Steps for the ergonomic buck build

1. Digital design (CAD)
2. Illustrator (Line drawings)
3. Seat Base Build
4. Roof Structure
5. Seat Milling
6. Handrails & Armrests build
7. Mixed Reality Integration

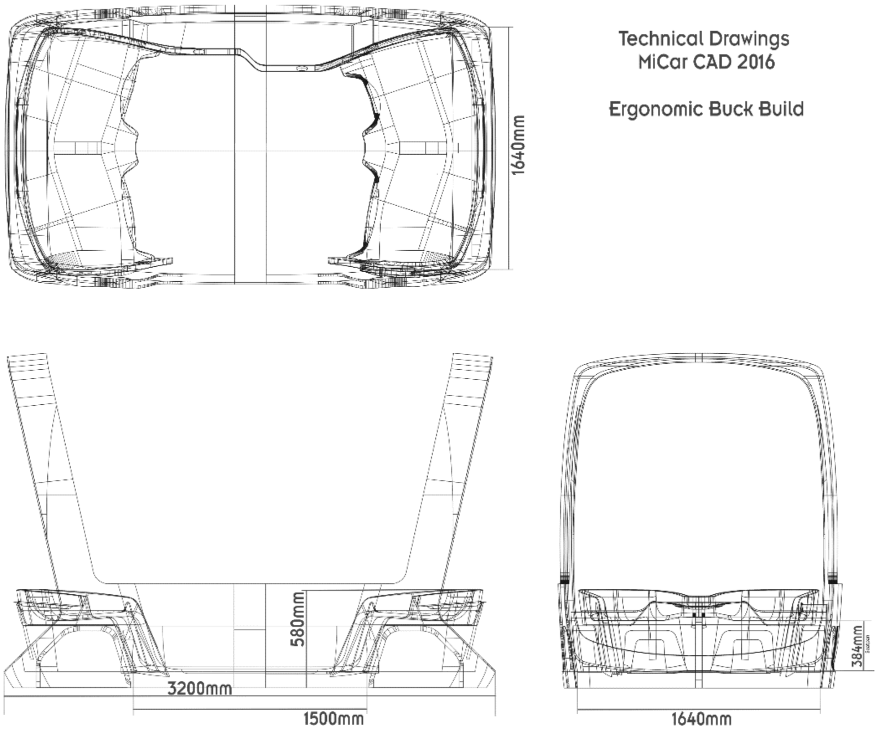


Figure 11.1 Technical Drawings based on the MiCar CAD

The build of the ergonomic buck itself was also split into several steps in order to allow separate trials to be conducted which focus on individual aspects of the design. Using several construction steps made it possible to “layer” the amount of design detail that was included into the ergonomic buck, ensuring that each step could be evaluated without overwhelming the trial participants with a large number of new features. Therefore, following from the planning phase the first part of the ergonomic buck was constructed; the lower half of the vehicle up to the seat base.

11.3 Seat Base

This consisted of a rolling platform (for logistical reasons) with two raised platforms on either end supporting four place holder seats sourced from a public transport bus (see Fig. 11.2). The seats were used to indicate where the final seats would be located without drawing the attention towards the seat design, away from the floor space.

The internal and external skin of the vehicle model were also constructed using thin (3mm) plywood over a structure of wooden ribs shaping it according to the curves in the technical drawings. At the far side of the interior the luggage rack, a 100mm raised platform was built as well, as a provision for later trials.

The whole buck rested on four stands providing stability to the structure and placing the interior floor precisely 245mm above the road surface, as it was designed to be. This was important to be able to simulate and evaluate boarding the vehicle from road level.

Figure 11.2 Lower Section of the Ergonomic Buck

11.4 Roof Structure

Having evaluated the floor space in with a participant trial, the second stage of the construction was undertaken, i.e. adding the roof structure to the buck. The roof structure serves several purposes. It allows the onlooker to gain an impression of the overall dimensions of the vehicle as well as providing a sense of the interior space for the trial participants. It further also provides a structure to which the handrails were mounted. Initially, handrails were placed at two locations in the vehicle, two upright stanchions on either side of the door aperture and a further handrail above the luggage space, stretching almost the full length of the interior. The bright green tape was attached to the handrail surfaces to simulate the high-vis paint typical in all public transport vehicles (fig. 11.7).

Figure 11.3 Construction of the Roof Structure

11.4 Access Aides

Following the completion of the first iteration of the ergonomic buck, an entry ramp was also constructed (Fig. 11.4) to ease the accessibility for wheelchair users as well as in order to be able to simulate accessing the vehicle from a roadside curb to which the vehicle had “kneeled” down using hydraulic suspension.

This entry ramp featured handrails and an anti-slip cover was attached to the floor surface to provide additional grip. The ramp was a stand-alone feature which had to be manually placed in front of the buck whereas the real vehicle would be equipped with an automatically retractable ramp.

The buck was then used in this configuration to run a traditional ergonomic buck study with a number of participants, including some which had mobility and visual impairments. The details of this study are discussed in chapter 12.

Figure 11.4 Ergonomic Buck set up for the initial trial including a placeholder ramp

11.5 Wheelchair Space

During these trials, some flaws in the design became apparent which were addressed in the following design iteration and reflected in the ergonomic buck. One of the adjustments made was in regard to the wheelchair placement within the vehicle. Trials with wheelchair users had demonstrated that a placement further towards the luggage rack would be beneficial as this would allow for a handrail to be added at waist height, a requirement for the majority of wheelchair users as they use it to steady themselves against the vehicle movements. This had the subsequent effect that by creating a 50mm indentation in the luggage space a further seating space could be made available.

11.6 Overhead Handrails

The second alteration made to the design was the removal of the handrail above the luggage rack whilst it was within reach, in a trial it was found to be uncomfortable for older users. Furthermore, work with some visually impaired participants brought to light that additional handholds were required when moving across the cabin. An improved location was therefore found following the shape of the roof structure. Due to being shaped in a compound curve, the handrails were individually made on a jig. A foam core was aligned with the jig and then covered in three layers of fibreglass, which after curing was then covered with body filler. Sanding followed to ensure a smooth and therefore safe surface finish which was then treated with a coat of paint.

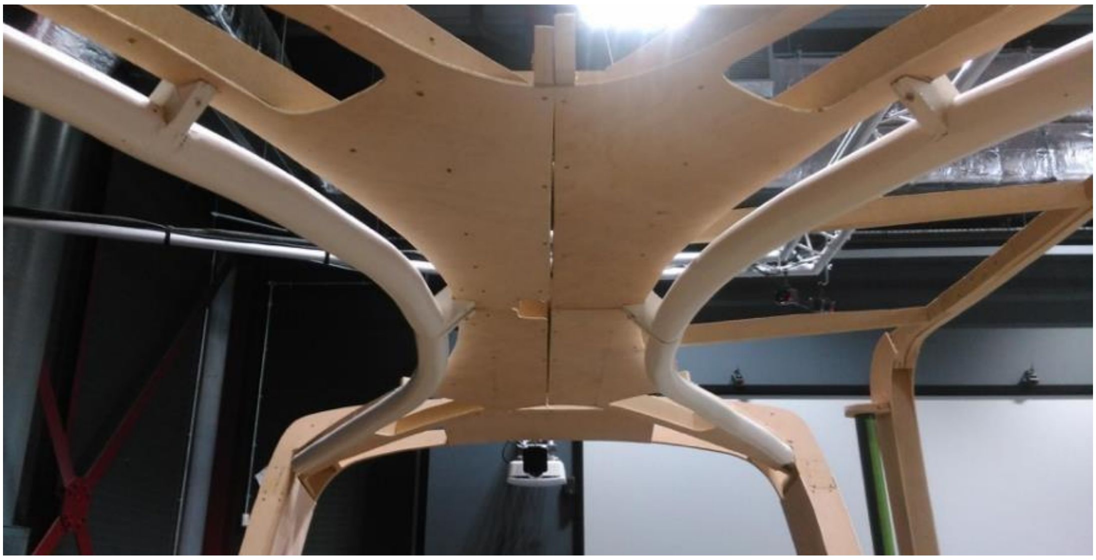


Figure 11.5 Handrails installed along the main Roof Structure

11.7 Bench Seat

The final, at this point, alterations to the buck were made by removing the placeholder bus seats on one side and adding a specifically for this application design bench seat. Due to the complex shape of the seat, it was milled from high-density foam on a three-axis milling machine at the NTDC. At the beginning of this process was the file export from the CAD software into the .stl format suitable for the software writing the g-code required to operate the milling machine. The raw block of foam was constructed by assembling several smaller pieces into the rough shape of the seat.

The block was then milled in portions into the final shape. The back of the seat was not milled as this was not visible to the trial participant and therefore not required, it was however reinforced to ensure that the seat would withstand repeated use.

Figure 11.6 (Bench Seat milled out of High-Density Foam)

Following the milling process, the seat was upholstered using recycled foam matting as well as covered with a fabric finish. The foam added about 30mm to the surface of the seat and made a significant difference in the seating comfort. At this step, a lumbar support was also worked into the foam layer with a denser foam cushion. The bench seat was then permanently installed into the ergonomic buck.

11.8 Armrests

Along with the bench seat, a set of armrests was also manufactured in a similar fashion to the handrails. The set consisted of three pieces, a central armrest, featuring a split into two surfaces, as well as two on either side of the seat, all three with a unique shape. A foam core was milled and reinforced with wood as well as two layers of fibreglass, the resulting structure was then roughly sanded prior to finishing it with body filler and a coat of paint. The armrests were then installed into the buck along with the seat, accurate placement was crucial in this step as users of this buck were expected to make extensive use of these armrests. Therefore, the stability and structural integrity of the armrests was vital to the confidence of the users.

Figure 11.7 (Final installation of the Bench Seat & Armrests)

There are some aspects of the vehicle concept which are not covered by this ergonomic buck as it is a tool focused on evaluating the physical aspects. It is therefore deliberately kept plain in regards to the surface finish, leaving the surfaces unpainted, and without an HMI or lights, as the final aim for the buck is to be combined with a digital model, which can then be used to evaluate the visual aspects of the design. This highlights the advantages and disadvantages of this kind of setup; an ergonomic buck is a low budget and quick method to evaluate the physical space within a vehicle and therefore allows for aspects such as handholds, head clearances as well as the seat positioning and shape to be tested. Evaluating aspects such as the interior trim or an HMI with an ergonomic buck, however, would require a much higher investment in order to integrate these into a realistic mock-up. This is also the reason for the doors not being part of the physical build, the integration with the ergonomic buck would be very expensive without informing the ergonomic evaluation where the door aperture and step height are far more significant.

The first phase of the ergonomic buck build took approximately six weeks including the construction of the roof structure. The fabrication of the handrails, armrests and the seat took a further three weeks.

The whole build was completed by the author using mainly hand tools but further included training on several of larger machines used, namely the three-axis milling machine.

The complete build costs are estimated to add up to approximately 2000 Pounds, with half of the cost going towards the purchase of the foam blocks required for the seat. The costs of the build were shared between the PhD funders; Coventry University and HORIBA MIRA.

11.9 Summary & Conclusion

The ergonomic buck represents a further tool in the evaluation process of the MiCar vehicle concept and allows trials to be conducted with real-life passengers, evaluating the ergonomic aspects of the design. It will provide the foundation for the following studies as well as the development of the Mixed Reality Simulator.

5th Objective Part 2

The build of the ergonomic buck fulfils the second part of the fifth objective, enabling the evaluation of the design through user trials.

12. MiCar Ergonomic Buck Evaluation

12.1 Introduction

The ergonomic buck evaluation is the second evaluation method in the three complementary methods and follows on from the digital evaluation, discussed in the previous chapter 9.3., using the software tool Jack (Siemens 2017).

This allowed for the evaluation of basic occupant packaging aspects such as reach, fit, and visual field. However, more complex tasks, those involving several subtasks, were difficult to model accurately and additionally, only known issues could be modelled. An ergonomic buck, however, permits to evaluate a design with non-subject experts, which may complete a task in an unexpected fashion, potentially highlighting unknown use cases and or issues.

Hence, as part of the second method an ergonomic buck, also known as "seating buck", was constructed to conduct trials with target users evaluating a range of vehicle interactions. An ergonomic buck is a physical representation of a vehicle cabin for the purpose of ergonomic evaluations and commonly used to assess aspects such as ingress and egress as well as the cabin space (Richards et al. 2004; Ling et al. 2013). The build of the ergonomic buck is discussed in detail in the previous chapter 11.

<u>Design changes during the construction:</u>

- Upright stanchions were added to either side of the door aperture to provide support during ingress and egress as well as a handhold during the journey.

12.2 Methods

12.2.1 Ergonomic Buck

An ergonomic buck was constructed at the National Transport Design Centre (NTDC) at Coventry University (see Figure 12.1.), which is discussed in detail in the previous chapter (11.0.). For this evaluation, the buck provides an accurate representation of the access openings, floor-space, seating height and luggage space.

The floor of the buck is raised to the same height above the road surface as the proposed real vehicle, permitting an evaluation of both scenarios; entry from the curb as well as the road. The buck also includes a ceiling, to allow judging of the cabin volume, handholds such as handrails and armrests.

Figure 12.1. Driverless pod render (left) and ergo buck (right)

12.2.2 Participants

The participants were recruited from three user demographics, established in earlier research to represent the most likely user groups of this type of vehicle. Previous findings suggest that SAE level 4 (SAE 2014) driverless vehicles will appear first in controlled environments such as campuses and parks. The vehicle, therefore, was designed for a technology park or campus application and thus the first user group was made up of employees of a technology park. The second group consisted of participants likely to visit a public park or a historical monument.

The third group were recruited from the local council and consisted of special needs advisors. In total, the trial included 26 participants (M=8, F=18), two wheelchair-bound, spread equally over the three groups, with the age ranging between 13-85 years. Ten of the participants also stated a form of disability, mostly causing mobility issues (n=5), whilst hearing (n=2) and sight impairments (n=3) were also represented.

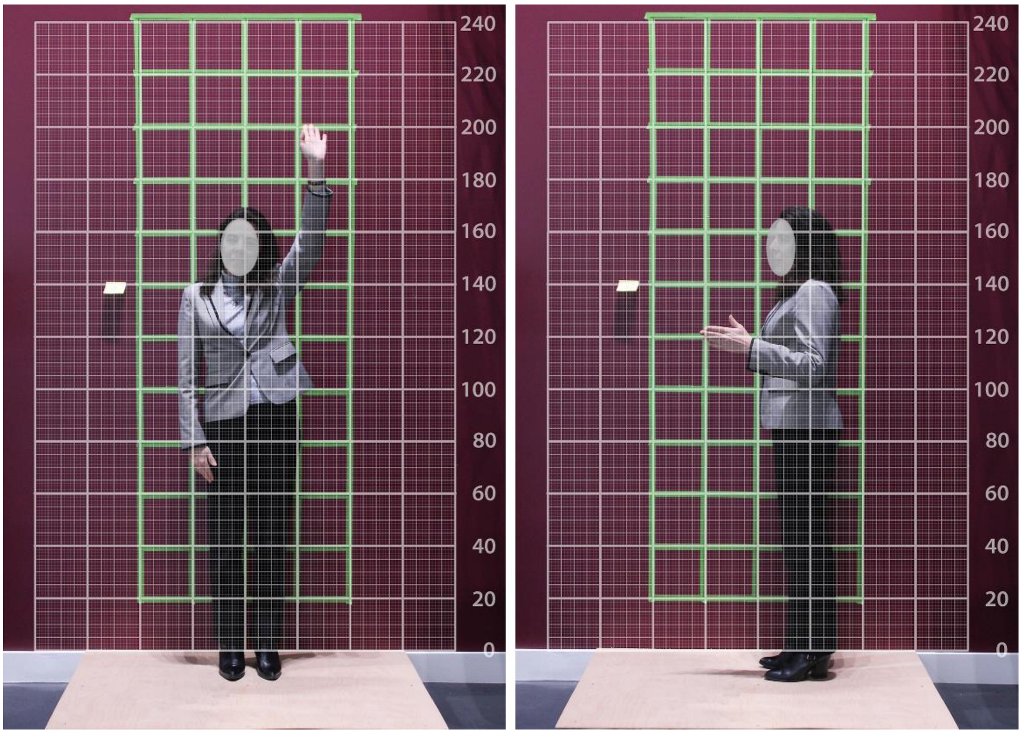


Figure 12.2. Participant in front of the measurement grid

In order to gather basic anthropometric data, the participants were documented using two methods. First, participants were asked to complete a short survey covering aspects such as their age, occupation and disabilities, followed by pictures taken of each participant in front of a scaled measurement grid (Fig. 12.2.).

This enabled us to estimate the length and proportions of body parts at a later stage. The pictures covered two angles; both standing upright with the first facing forward towards the camera and one arm extended above the head, the second, a side view with one arm angled at approximately 90 degrees.

With the lens wrap considered, it provides a good estimate of the body size of each participant and subsequently permits us to evaluate which range of body sizes was covered by the trial. These estimates can then be compared with the expected body size range based on anthropometry data from this demographic, furthermore, it permits us to recreate participants as digital manikins for a digital re-evaluation in future steps.

12.2.3 Materials

Throughout the evaluation process the participants were provided with a number of props to utilize during the tasks; a walk on suitcase (7.5kg), backpacks of varying sizes (5-2.5kg), notebook bags, umbrellas, newspapers and magazines as well as a tablet. These items remained the same throughout all trials to ensure continuity in regards to the evaluation of the luggage space. These items were chosen in order to appropriately reflect the luggage items most likely carried by the passengers identified in the scenarios. As previously discussed, the scenarios cover technology parks and inner-city sites, where passengers travelling with small suitcases, laptops and other small items can be expected, as well as a tourist site where passengers with day backpacks, walking paraphernalia and mobility aids are likely. Therefore a regular-sized wheelchair, with a pair of footrests, was also included in the evaluation process.

The props were selected by the participants themselves based on which ones they would most likely take on a journey with them as this will inform what the end-users perceive as a realistic use case.

12.3 Procedure and Measures

Prior to conducting the evaluation, the participants were briefly introduced to the vehicle concept with visual material and informed about the potential use cases of the vehicle and the connection to the participant selection. Participants recruited from a technology park, for example, were therefore told to envision themselves using the vehicle in a number of relevant scenarios such as a trip from the main gates to their office or the trip to the canteen from their workplace.

As each scenario has a different journey time, for this evaluation an average time of 5 minutes was assumed, after which the participants were asked to exit the vehicle. The simulated journey time was used by the participants to engage in activities they believe they would do during a real journey such as reading or hold conversations.

For the ergonomic evaluation stage, the participants were asked to perform tasks, listed below in table 12.1, in the ergonomic buck, based on the HTA. These tasks were all performed as part of a group, as this represents the most likely use case; a shared public mobility application. A group consisted of five or six passengers, which helped to observe how these passengers interacted with each other during the completion of the task. For the tasks involving a wheelchair, participants were initially asked to enter the cabin until they considered it full, to determine the maximum occupation. This number was then carried forward for the following tasks including a wheelchair user. Whilst performing a task, participants were asked to verbalise their thoughts and those were documented. Noted was also their behaviour and reactions as well as general metrics such as task time to completion, task success and errors, as these can indicate if and how efficiently the task can be completed.

The routes chosen by the passengers when they moved through the cabin were also of interest, thus they were documented with an overhead camera, which permitted each path to be traced and subsequently compared in the analysis, a method based on Bhise (2011) suggesting the use of a film camera to record the evaluation for post-analysis. This technique helped to understand how people move around obstacles, as well as documenting the time required to complete the tasks. Specific issues such as reaching angle or lack of space were documented separately with photos.

Table 12.1. Participants' tasks for evaluation purposes

- Enter vehicle (Curb Height)
- Enter vehicle (Road level)
- Enter vehicle with luggage & place luggage (Curb Height)
- Enter vehicle with wheelchair present (Curb Height)
- Enter vehicle with wheelchair and place wheelchair (Independent) (Curb Height)
- Enter vehicle with wheelchair and place wheelchair (Assisted) (Curb Height)
- Sit in vehicle whilst passengers enter
- Sit in vehicle
- Grabbing Handrails Overhead
- Grabbing Handrails Door-side
- Exit vehicle
- Exit vehicle with luggage & retrieve luggage
- Exit vehicle with wheelchair present
- Exit vehicle with wheelchair (Curb Height)
- Exit vehicle with wheelchair assistance (Curb Height)

Following the completion of the tasks, questionnaires were used to gather information on individual aspects such as perceived ease of use and personal space. One of the focal points of the evaluation was the interior space. Participants were asked specific questions to gauge their sense of space within the vehicle:

- Did you have sufficient headspace?
  (Yes/No)
- Did you have a sufficient leg space without the wheelchair present?
  (Yes/No)
- Did you have a sufficient leg space with the wheelchair present?
  (Yes/No)
- Were you able to reach for the ceiling-mounted handrails?
  (Yes/No)

- When travelling on board of this type of vehicle, what activity would you like to do? (Read, Talk, Observe, Sleep, Other)
- Would you be able to perform your preferred activity in the vehicle?
  (Yes/No)
- Would you be comfortable to use this vehicle for a sight-seeing tour?
  (Yes/No)
- Would you be comfortable to use this vehicle for a daily commute?
  (Yes/No)
- When in the vehicle with a group of passengers, did you feel cramped?
  (Yes/No)
- How many passengers would you think is the maximum capacity of this vehicle? (1-~)
- Did you find sufficient space for your luggage?
  (Yes/No)
- How difficult was it for you to place your luggage into the luggage rack? (1-10)
- How would you rate the visibility to the exterior from a seated position? (1-10)
- How would you rate the visibility to the exterior from a standing position? (1-10)
-

  (1= easy/great & 10 = difficult/poor)

Following the questionnaire, the participants were given the chance to provide comments and thoughts and also participate in a focus group discussing their impressions. During the focus group participants were invited to sit in the vehicle and ask questions as well as demonstrate some of the issues they had encountered. Overall the time spend interacting with the pod was on average 60-70 minutes for each group.

The resulting data was analysed using frequency distribution and displayed individually for each question. The comments were noted and grouped according to the trial groups in order to relate them to each of the scenarios from which the participants were recruited.

12.4 Results and Discussion

Following the assessment of the ergonomic buck with 26 participants across five groups, with five or six participants each, the following key findings became apparent. The interior space and view from within is considered excellent, the seating arrangement was seen as enjoyable and ideal for conversations, however, areas for improvement were the availability and placement of handholds as well the wheelchair space. The results of the questionnaire indicated that the space within the vehicle is sufficient and most of the participants would accept a higher number of passengers at the same time as anticipated.

Eight passengers, four seated and four standing was the most frequently mentioned number (Fig. 12.3) and whilst there were also suggestions for more passengers, they were mostly mentioned with regards to other public transport experiences; "in the London Tube its worse". When the wheelchair was introduced to the scenario, the acceptable number of passengers reduced to four or five additional passengers. As this is a higher number than originally considered in the design and the passengers subsequently attempted to use seats located behind the wheelchair, an alteration of the wheelchair space is required in order for it to be given sufficient space.

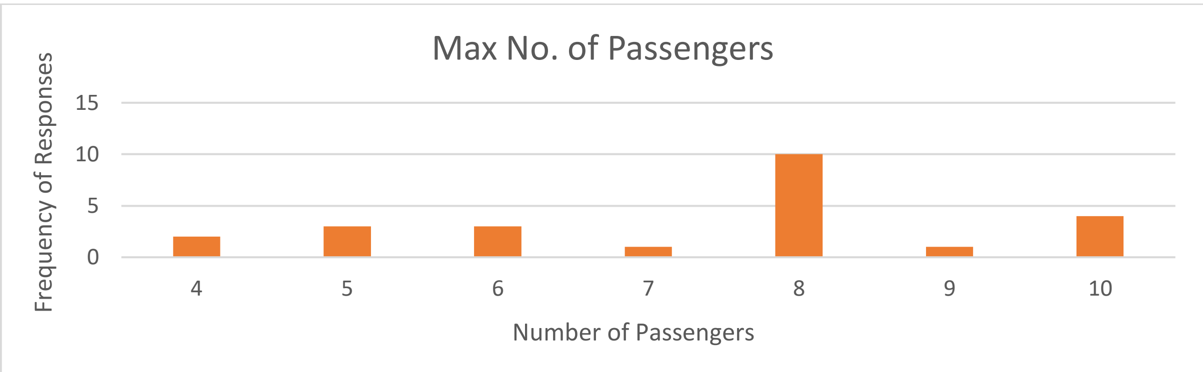


Figure 12.3. Maximum Number of Passengers

Interior Space: Whilst the majority of participants indicated that they feel comfortable with eight passengers in the cabin, six participants also stated that they would feel cramped in such a group.

This suggests that passengers have two different perspectives on the capacity of a cabin, their personal comfort preferences for which they would choose a lower passenger number and their experience of public transport vehicles which is frequently used at the maximum capacity. However, the capacity is only one part of the overall impression of the interior space. Using the ergonomic buck all of the participants also judged the headspace available for standing passengers as sufficient to enter and move through the cabin without clashing their heads. With the cabin at full capacity as well as with a wheelchair present, the participants were further asked to evaluate if there is sufficient leg space available, which in either scenario was positively confirmed by the majority.

Accessibility: In order to evaluate the accessibility of the vehicle, they entered the ergonomic buck in different scenarios whilst carrying a number of different items.
The entry into the cabin from the curb height did not cause any problems for the participants, who were able to step into the cabin without stepping up. The handholds on either side of the door aperture were actively used by the older participants in the trial. The entry into the cabin from the road level required the participants to step up into the vehicle, which resulted in the majority of users reaching for the handholds by the side of the door. Aside from wheelchair users, the step did not appear to pose a particular issue and was described as “easy” and the low height of the floor was remarked upon. Carrying luggage items proved unproblematic, only older participants who were holding items in both hands struggled with grabbing a handhold during the step up into the cabin.

Entering the cabin with a wheelchair did require a ramp, which in the concept is automatically deployed if the passenger indicates their demand for it. However, for the trial with the ergonomic buck, a placeholder ramp was constructed which was also used to simulate the entry from a curb. Whilst all wheelchair users were able to reach the cabin using the ramp, some stated that it was too steep to be used without much effort.

The width of the door aperture and the floor space were deemed suitable however and all participants managed to move their wheelchair into and through the cabin with ease.

Leaving the cabin and stepping from the cabin onto the curb or the road also involved the handholds at the door. The majority of participants used these when stepping from the vehicle, indicating their importance as part of their cabin. Stepping onto the curb from the cabin was accomplished by all participants with ease, a small number of passengers did move slower when stepping down onto the road.

Handholds: The available handrails have a significant influence on the occupant capacity of the cabin and were commented on frequently by the participants. The cabin featured three handrails, two located on either side of the door aperture, running vertically from the floor to the ceiling and a third mounted horizontally above the luggage rack on the ceiling opposite to the door (Figure 12.4 left). Whilst these were sufficient for the able-bodied users, for others they were beyond comfortable reach and they stated that they would require additional handholds to navigate the cabin; "a centre ceiling handrail would be useful". This was particularly apparent in the scenario when the wheelchair was present in the cabin, reducing the available floor space significantly and subsequently limiting the choice of routes to the remaining seats. Here the partially sighted in particular commented that the lack of handholds at head height was an issue, as the reduced vision impacted their balance, an issue magnified by having to look downwards to place their steps. Here a handrail or a series of handholds above their heads would be required to enable them to negotiate the narrow paths.

A traditional handrail, with flexible handholds hanging below, however, would encroach too far into the headspace of the passengers, which goes against one of the basic requirements of a full standing height cabin. Whilst the available headspace was positively noted by the participants, taller participants still duck automatically when entering the cabin despite the interior space being able to accommodate all within 95%ile of the population, the most widely used design criterion (Helander, 2016).

Figure 12.4. Handrails (left) and communal seating (right)

To ensure visibility the handrails do also require a special colour treatment as comments by the participants suggested; “preferably (in) yellow or (with) lights running through”. Any luminescent colour such as lime green or “bright yellow” would be ideal, yellow being the ideal choice to accommodate those with colour vision deficiency. A light strip within the handrails was described as the perfect solution as this would assist those with vision limited to light perception. Missing handrails were also a key concern for the wheelchair user who participated in the trial. The main comment was that wheelchair user requires a handrail to run parallel to the wheelchair space to restrain themselves against the lateral movements of the vehicle. According to the comments, this is as much of a physical as it is a mental aid. Here it is important to note that the previously discussed handrails are an additional requirement to the armrests located on each individual seat. Those are utilized by passengers to move in and out the seats as well as providing stability during the journey.

Cabin layout: The inwards rotated seat arrangement was also frequently commented on; "very nice to have individual seats at an angle". An overwhelmingly positive response was accredited to the fact that it supported a more conversational setting (Figure 12.4). This is supported by the survey results which showed that the most preferred journey activities for most passengers was to talk (Figure 12.5). The cabin layout, therefore, was designed with the aim to provide an ideal setting for a communal experience, a fact recognised and welcomed by many participants who stated that; "talking to the next person is perfect".

The closely-ranked second activity, observing the land and cityscape was also frequently mentioned by the trial participants. This is related to the ability to observe the movements of other members of the traffic which surround the vehicle and subsequently being able to witness how the vehicle reacts to it. Being able to observe the vehicle successfully navigate and solve difficult situation allows the passengers to grow confidence into the vehicle behaviour (Walker 2016).

The results of the trial indicated that the view is overwhelmingly considered to be great both for standing and sitting passengers (Fig. 12.6) with participants further describing it with; "excellent visibility" and "very good all-around visibility".

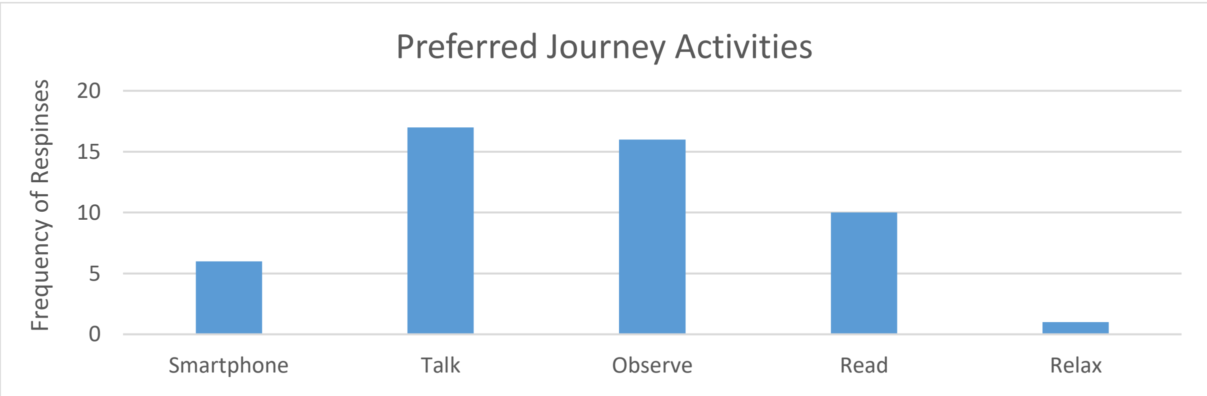


Figure 12.5. Preferred Journey Activities

Whilst in the activity ranking the interaction with the smartphone was only ranked fourth after reading, it was the most frequently displayed activity by the participants during the trial. The comments during the focus group also showed that they would like to use their mobile phones as a connection to the vehicle, permitting them to book and control their journeys. The partially sighted participants, in particular, stated that this would be key to improving their mobility as it allows them to plan their journey without being rushed for time on a system they are familiar with. One participant stated their reliability on an intelligent verbal assistance application to interact with their mobile phone to utilize functions such as maps or looking up times.

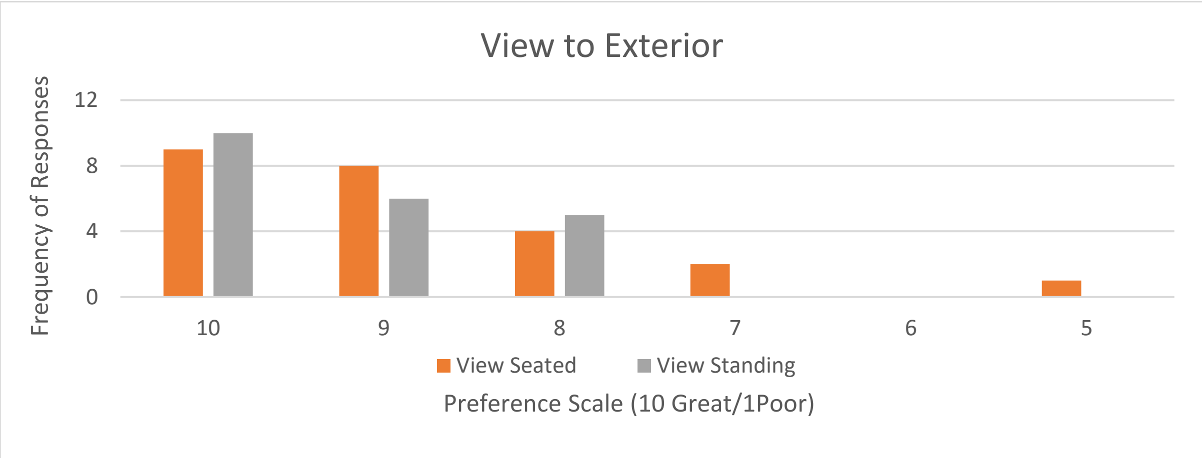


Figure 12.6. Ability to view the exterior

Overall all participants stated that they do feel like they are able to undertake their preferred activities.

Wheelchair space: The layout, however, was less successful when a wheelchair was present. For this trial, it was placed centred against one side of the seats achieving the maximum distance available between the footrests and the opposing set of seats (Figure 12.7).

During the trial however it became apparent that it would be better to place the wheelchair closer to the luggage space, bringing it closer to a handrail mounted parallel to the wheelchair.

As a knock-on effect, this also frees one more seat up in the cabin and generally improves accessibility. The low entry step onto the even floor of the vehicle is crucial aspect of accessibility, permitting all participants to enter the vehicle, although some expressed difficulty with the height of the step. Here it should be noted however that the vehicle design includes air suspension which does allow the vehicle to lower itself, a design feature which could not be replicated in an ergonomic buck, which simulates the vehicle at regular ride height.

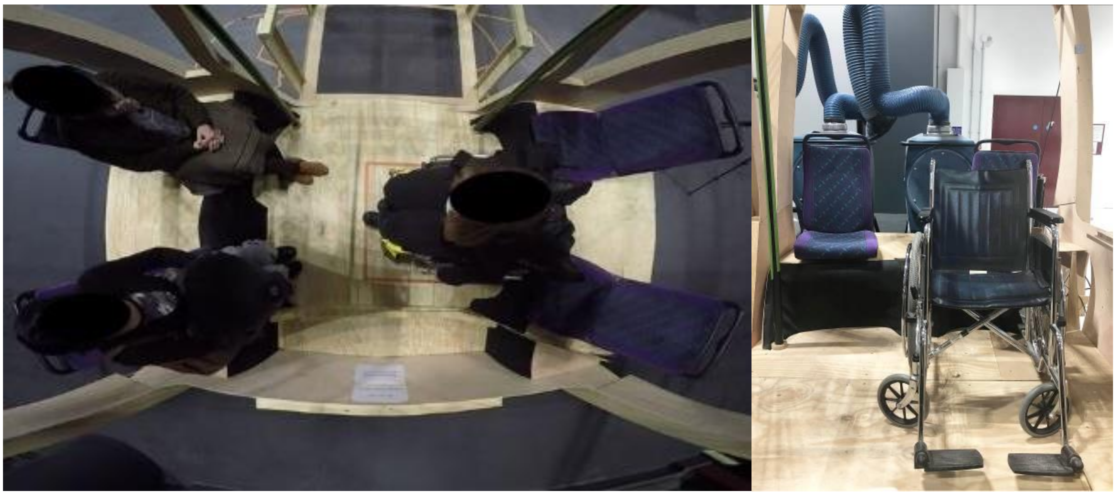


Figure 12.7. Initial wheelchair space (left) & adjusted wheelchair space (right)

Stowage: Lastly, the availability of storage space for luggage was also a point of interest during the trial (Figure 12.8). The proposed spaces, a small tray beside each of the seats away from the door as well as a larger space for walk-on suitcase opposite to the door were identified and used by the participants.

Standing passengers and those seated on the door side, however, stated that they would prefer to hold their items rather than placing them in the space, which relates back to the findings from the comfort model where being able to observe personal items when stored was a key aspect of being comfortable during the journey according to the eight comfort factors. These points are most relevant in a situation when travelling with strangers, when there are exclusively familiar people in the vehicle, the attitude may change.

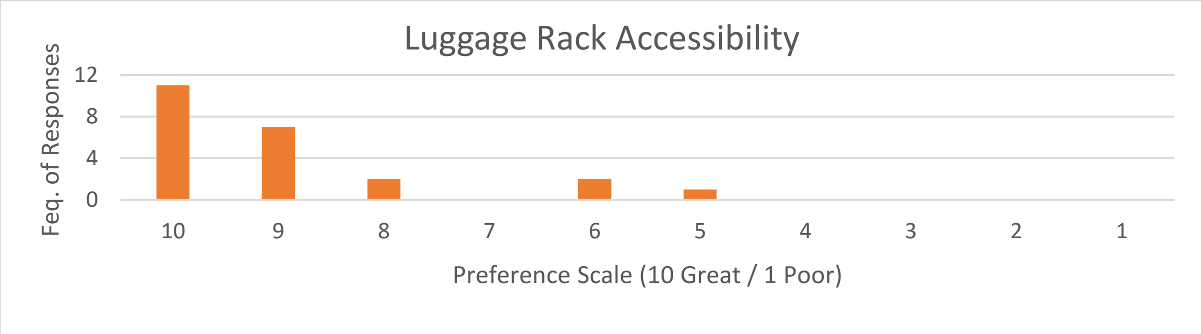


Figure 12.8. Luggage Rack Accessibility

12.5 Summary & Conclusions

Overall, the vehicle design was rated positively. However, there were also potential points for improvement. The particular needs of passengers with additional mobility requirements and those with other disabilities, need to be taken into consideration to create an inclusive solution.

Areas which can improve accessibility were; the availability and placement of handholds as well a space to accommodate a wheelchair with appropriate handholds and the possibility to secure it back against the direction of travel. Furthermore, it can be noted that the space the cabin offers combined with the view to the exterior were seen as crucial factors by all passengers (Figure 12.5). A seating arrangement that omitted travelling sideways and offered individual spaces, was seen as enjoyable and ideal for conversations, contributing to an improvement in passenger comfort.

Comparing the aforementioned results to the previous digital ergonomic analysis with Siemens PLM Jack, it showed that a physical evaluation with an ergonomic buck is likely to unveil additional requirements and issues and hence is an essential step in the development of a vehicle interior design which can be conducted with limited resources.

5th Objective Part 3

The evaluation of the ergonomic buck with test passengers completes the fifth objective. It permitted the evaluation of the design in two stages, digitally and following the build of the ergonomic buck also with real test passengers. A disability support group was also involved, who themselves tested the ergonomic buck which further informed the design.

Disclaimer

This chapter contains passages previously published as a conference paper at the 2018 Human Factors and Ergonomics Society Annual Meeting in Philadelphia, US. The paper can be accessed under: Wasser, J., Diels, C,. Baxendale, A., Tovey, M., (2018) Ergonomic Evaluation of a Driverless Pod Design, Proceedings of the Human Factors and Ergonomics Society 2018 Annual Meeting, Philadelphia, US, doi.org/10.1177/1541931218621317

13.0 Mixed Reality Simulator

13.1 Introduction

A Mixed Reality (MR) toolset was devised to create an interactive and immersive design evaluation environment at a very early stage of the development of an autonomous (driverless) vehicle. A detailed description is provided of all the components required to combine a virtual reality (VR) system with a full physical ergonomic buck. This chapter describes the integration of commercially available software tools with appropriate detail to enable replication of this design set up and allow designers to create an evaluation environment with greater immersion and face validity than using current VR tools alone. The resulting system will allow participants not only to experience the visual and physical layout of the pod vehicle but also to experience the vehicle in operation along a simulated test route.

The development of the MR method discussed below, took place using the MiCar concept developed in chapter 8.1 as an exemplary design.

13.1.2 Mixed Reality

In the traditional automotive design process, ideas are conceptualised in 2D sketches, either on paper or digitally (Tovey, 1992). Those are then converted to physical quarter or fifth scale clay models and digital 3D CAD models. The following step to full-scale clay models and concept vehicles requires significant financial and time commitment (Ait El Menceur et al., 2008; Laughery, 2005; Siegel and Soederman, 2005), the latter increasingly becoming an issue due to shorter product life cycles, requiring manufacturers to update their models in increasingly shorter intervals (Bernard et al. 2012, Schrader et al. 2002, Holweg et al. 2001).

Virtual reality (VR) can make a significant difference throughout the process, permitting designers, decision-makers and user trial participants to experience the vehicle design and evaluate alternate iterations, prior to committing to a full-scale model build.

Prior research established that "there is a need for both types (Physical & Digital) mock-ups when evaluating HFE (Human Factors & Ergonomics) and validating user requirements" (Aromaa et al 2014) due to the limitations of either method.

Virtual Reality is already widely used in the automotive industry in a range of applications; common are VR CAVEs, semi-immersive environments where images are projected onto three walls, the ceiling and optionally also the floor, which are being used for design reviews and for training purposes. In these applications, the user wears 3D glasses which enable depth perception (Lawson et al. 2015). Head-Mounted Displays, now commercially available as VR Headsets are also frequently used in design reviews as well as customer demonstrations for high end or custom vehicles. VR can also be used collaboratively with products such as the *Virtalis ActiveWall* a large back-projection screen on which a three-dimensional model and environment can be displayed, visible to a group of people wearing 3D glasses similar to those used in a VR Cave. Project partners can link two or more systems via the internet and view the content simultaneously, allowing international stakeholders to review work at the same time (Virtalis 2010). However, a crucial factor is that these systems are currently unable to provide haptic feedback, relying purely on visuals, a disadvantage if the evaluation aims to analyse the physical interaction with the vehicle.

Therefore, this chapter will document the development of a method which builds on current practise and combines physical and digital rendering in an interactive and immersive experience, based on a traditional ergonomic buck as a platform. This type of method is termed *Mixed Reality* (MR) and describes environments between virtual and real, where virtual objects are superimposed upon, or composited with, the real world (Azuma, 1997).

13.1.3 Vehicle Concept

For the Mixed Reality simulator development, the *MiCar concept* developed in chapter 8.1. was used as the digital model as well as for the construction drawings of the ergonomic buck (Fig 13.1).

Figure 13.1 MiCar Concept in Context (Digital Render)

13.1.4 Requirements

The MR system should combine a high-fidelity digital model with an accurately built physical mockup. The simulation should incorporate accurate vehicle movements, sounds, interactions and virtual environment to fully immerse the user into the scenario (Parkes 2013). This immersion should focus on providing participants with the possibility to judge the vehicle design, which requires the materials, colours and light to be reproduced accurately. The environment should be populated with other virtual actors such as vehicles, pedestrians in order to be able to evaluate the user reactions to different on-road scenarios.

In order to capture realistic data, it is important to create a mixed reality tool that allows the participant to fully immerse themselves into the scene and task and behave naturally. A large part of the immersion is based on the user locating real-world features where they are shown in the digital environment.

Thus, all the elements that the participant may physically come in contact with are required to also be physically represented in the ergonomic buck. Therefore, for this evaluation, it is essential that the placement of the physical features such as the handrails, seats and handholds in the ergonomic buck accurately match the digital model. As this method creates a number of potential research avenues, such as internal and external HMI trials or the study of the reaction to certain vehicle behaviours, the system has to be flexible and allow changes to be made quickly. Overall the system has to be designed in a manner that allows any participant to interact with it independently, in order to make it accessible to all potential user groups.

The development of the Mixed Reality simulator, therefore, required several steps to be completed in a specific order, as shown below. The scheme lists the individual software and hardware packages required, which are described in detail. It should be noted, however, that whilst this scheme presents a specific method, there are other possible routes to creating a similar system due to advances in software and hardware development or varying user-specific workflows. This chapter shows the level of fidelity which can be achieved in a mixed reality simulator which allows for realistic user behaviour to be observed and therefore provide the basis for evidence-based design decisions at a very early stage of a product development process.

13.2 Methodology

A number of hardware and software components were combined in order to create the Mixed Reality Simulator. These components are individually discussed in detail below.

13.2.1 Software

A range of software applications were used for the initial phases of design; CAD modelling and rendering, as well as for the following evaluation stages; creation of the VR application, controlling the hardware components and the trial. The following sections provide a detailed description of the individual applications in their order of use.

Autodesk Alias AutoStudio 2018

This is an A-Class modelling software typically used to create 3D vehicle models during the initial design phase (Figure 2). The software creates surfaces based on a Bezier surface and NURBS modelling method, giving modellers a great degree of freedom in modelling the surfaces of components. Also included in the software are extensive surface evaluation tools ensuring continuity between the surfaces, a tool essential for A-Class modelling. Combining various components, vehicle models can be created to include interiors as well as mechanical features such as the driveline and suspension. Each component can be grouped and organised within the software, enabling the user to hide or select specific groups of components (Autodesk Alias AutoStudio 2018).

The software also includes a basic material library as well as a renderer, which can be used to gain an impression of the model prior to switching to a dedicated visualisation software.

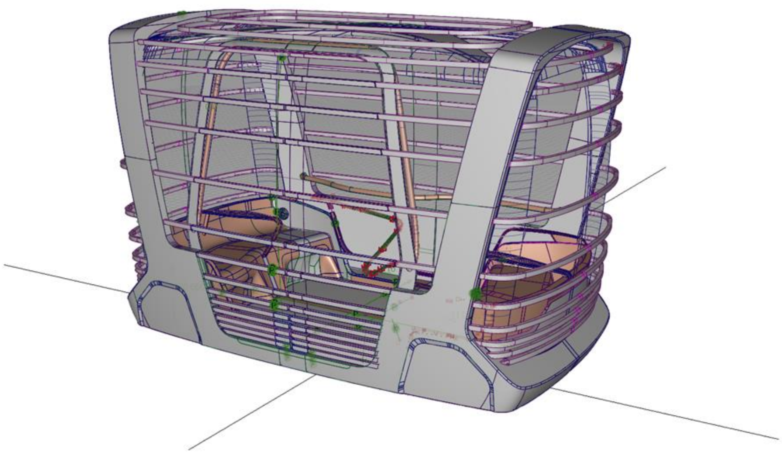


Figure 13.2 3D CAD Render Alias AutoStudio 2018

Other digital modelling software can also be utilized to create 3D content such as *SolidWorks, Blender, Rhino3D or Z-Brush*. The type of content that is to be created will lead the decision about which software is the most appropriate. If the aim is a game character, *Z-Brush* will imitate working with traditional clay, whereas *SolidWorks* is aimed at a more engineering lead product design process, with the capability to generate technical drawings and a vast library of standardised components such as fittings.

Alias AutoStudio was chosen for this project, as it is most suited to quickly mock-up and shape rounded surfaces and subsequently the vehicle shape.

Autodesk VRED Pro 2018

Autodesk VRED Pro 2018 is a high-end visualisation software from the same Autodesk product family, which allows for CAD data to be rendered. Within the software materials and textures can be applied to surfaces and lights can be added to the scene. Each can be edited in great detail, allowing for the visuals to appear highly realistic. The rendering capability of visualisation software such as SPEOS (ANSYS SPEOS 2018) goes beyond that of VRED as the light rendering algorithms are physics-based and are therefore able to render light accurately and realistically, making this software industry standard for these applications.

The main application for VRED, however, is creating photorealistic impressions of a design concept within short time frames. Two different render modes are available; direct preview to set up the model and scene and ray tracing, a highly demanding process (the software uses CPU cores exclusively for ray tracing) in which virtual light rays are repeatedly bounced off the surfaces and the scene to compute accurate reflections and shadows. In both modes, the software can render out a still image or animation (a series of still images to be combined as frames in a video) or alternatively be used as a live view. A frequently used solution to combine live viewing with improved visuals is “baking” in the shadows and highlights, which means that these are precomputed and added to the live view scene as an overlay (Autodesk VRED Pro 2018).

Combined with a VR Headset, *VRED* permits the user to step into the scene and conduct a design review. Hand controllers give the user a limited set of tools to switch between environment and design options, furthermore different viewpoints can also be selected.

Autodesk 3ds Max 2018

Autodesk 3ds Max is a further product from the *Autodesk* group which is also used to create 3D geometries, predominantly for the use in computer games, television and TV. Whereas Alias *AutoStudio* gives explicit control over the surface modelling, *3ds Max* is designed to create animations and realistic lighting features, particularly useful for the modelling of game characters. Due to its close relation to game design, the program has a direct export as .fbx file which includes, additionally to the geometry, material properties and component structures (3ds Max vs. Alias Autostudio 2011). The aforementioned rendering capabilities do compare with *VRED* once rendered if the additional effort is considered to achieve a similar result; the data transfer from *Autodesk AutoStudio* requires a file conversion and the render pre-sets for the materials, lights and scenes demand additional work to be set correctly. The difference in visual quality between a direct import with live render in *VRED* and *3ds Max* can be seen below (Fig. 13.3), the reflections on the left resemble reality more closely and help the viewer to understand the shape of the surfaces. The glass surfaces are also represented more realistically in VRED Pro, giving a truer impression of the vehicle overall.

Figure 13.3 (Live Render Comparison Autodesk VRED & 3ds Max)

Due to the aforementioned limitations, for this project, Autodesk *3ds Max* was only used to convert and subsequently export the model into the fbx format, commonly used for CAD files containing material and lighting data, in order to ensure that the vehicle model data is compatible with non-native *Autodesk* software used in the next step.

For the following steps, two software tools were considered, both with similar capabilities; the *Unreal Engine 4* as well as *Unity*. Both were trialled in the initial phase of building the MR system, however, *Unity* was ultimately carried forward due to the expertise available at the NTDC.

Unreal Engine 4

The *Unreal Engine* software was developed by *Epic Games* as a first-person game engine but has since been used in various other genres and applications (Unreal Engine 4). The software is used to create games for a multitude of platforms and operating systems. Within the software, the modeller is able to drag and drop objects from an asset library into a 3D workspace. Those objects can then be manipulated and edited within the space. Furthermore, the modeller is able to apply materials and textures to the objects whilst also adding and editing lights and other environmental features. It is also possible to add animations and sounds and combine those with trigger points.

Unity

Unity is a cross-platform game engine developed by *Unity Technologies* commonly used to create 2D and 3D video games. Similarly, to the aforementioned *Unreal Engine* software, it is designed to support the creation of digital game content (Unity Automotive 2018). Within *Unity,* it is possible to import the *MiCar* model and place it within a 3D workspace. This workspace is equivalent to the virtual space the user will be placed within a finished application. As *Unity* is a game engine, it also allows for interactive options to be programmed, such as touchable buttons, light and sound triggers and ultimately animations of the surrounding space. This capability, for example, enables the system to be used for HMI trials, where touch screens, buttons or even audio messages are programmed as part of a simulation. Essential to conducting a variety of evaluations using a Mixed Reality simulator is that both applications, *Unity* as well as *Unreal Engine*, are capable to not only provide visual information but can also compute incoming data, such as from a tracking system. This enables the inclusion of external hardware such as the *HTC Vive* Tracking system and the Leap Motion sensor.

The pivotal aspect which lead to the choice of *Unity* was the existing expertise at the NTDC as well as the extensive online support that is available. Both applications are used in the automotive industry as simulation interfaces, however, whilst Unreal provides a better visual output, *Unity* has a superior integration of other software code and more frequent software patches, which was valuable when developing the Mixed Reality system. Gaming engines now provide a simple platform for a graphical output of simulations and algorithms.

Unity Automotive is a result of this development, where *Unity* provides custom software to the automotive industry for applications in UI (User Interface) development, VR and AR (Augmented Reality) in the areas of design, engineering and training.

Autodesk VRED is beginning to support the creation of rendered simulations; however these currently still require combination with other software packages and therefore are not yet as capable as the game engines described above.

SteamVR

The *SteamVR* software acts as an interface between the VR Hardware and the software running the program or game. *HTC* uses *SteamVR* as an intermediary between the simulation or gaming software, to seamlessly control their hardware; the headset, base stations and hand controls and monitor the system during usage (Steam VR 2018).

13.2.2 Hardware

HTC Vive Pro

The *HTC Vive Pro* system consists of a head-mounted display (HMD)(Fig. 13.4), also known as virtual reality headset, two base stations and two hand controllers. The headset features two AMOLED displays (1440 x 1600p per eye, 2880x 1600p combined) which provides a 110-degree horizontal field of view. The first-generation *HTC Vive*, which was initially used as part of this setup, has a lower screen resolution 1080 x 1200 pixels per eye (2160 x 1200 pixels combined).

The front cover of the headset also features a dual-camera (currently not activated by the manufacturer) which can be used to view the play area without taking off the headset and an array of dimples, which are essential to the tracking feature of the system. Furthermore, the pro headset features built-in earphones and a much-improved head strap (HTC Vive 2018; HTC Vive Pro 2018).

Figure 13.4 HTC Vive Pro with the Leap Motion sensor mounted

The tracking is established through the two base stations, also called lighthouses, which are required to be positioned roughly two meters above ground, opposite to one another, in a direct line of sight. These base stations cast out infrared light which bounces off the dimples on the headset which is then received by the base stations again. This permits the system to track the headset in space, with the hand controllers functioning in the same manner.

Leap Motion

Leap Motion Controller is a sensor device which can be retrofitted to any VR Headset (Fig. 4) to enable the tracking of the hands and fingers in digital software applications. Similarly, to the *HTC Vive* tracking system, the LEDs in the controller generate a pattern-less infrared light with cameras capturing the reflected light at nearly 200 frames a second (Leap Motion 2018). This allows for the hands to be tracked with an average accuracy of 0.7mm (Lawson et al. 2016).

Paired with the *Leap Motion* Inc. software Orion the controller is capable of tracking hands in a virtual reality environment in which the software produces a skeleton representation which can be overlaid with different "skins", a translucent "skin" was chosen for this application (Fig. 13.8).

Computer

The hardware requirements for this type of setup are significant, especially to support the graphics computation. The initial setup was based on an *NVidia GEFORCE* GTX 1080TI, a high end commercially available graphic card, predominately used for gaming applications. An SLI Bridge with two *NVidia GEFORCE* GTX 1080TI was considered, however, the benefits are doubtful as the application has to be optimised for such a hardware setup in order to provide performance benefits. The upgraded hardware setup included an *NVidia* P5000 graphics card (NVidia 2018) which is designed for industrial graphic applications with 16GB GDDR5X memory. This setup furthermore consisted of an *Intel® Xeon®* Processor E5-1650 v4 running at 3.60 GHz (Intel 2017) and 32GB of Ram.

Ergonomic Buck

The ergonomic buck was a physical full-scale representation of the digital model and was constructed in wood at the *NTDC* at *Coventry University*. The buck provided an accurate representation of the interior space of the vehicle, including the access openings, floor-space, seating height and luggage space (see Figure 13.5). The floor of the buck is raised to the same height above the road surface as the proposed real vehicle, permitting an evaluation of entry from road level.

The buck also included a ceiling, to allow judging of the cabin volume, as well as providing handholds such as stanchions and armrests. It also included a specifically designed bench seat, which holds a central point in the concept, as it is designed to maximise the space on-board as well as providing flexibility to the passengers to choose their seating posture. The armrests were milled from high-density foam and reinforced with glass fibre and mounted to the bench seat (Fig. 13.5).

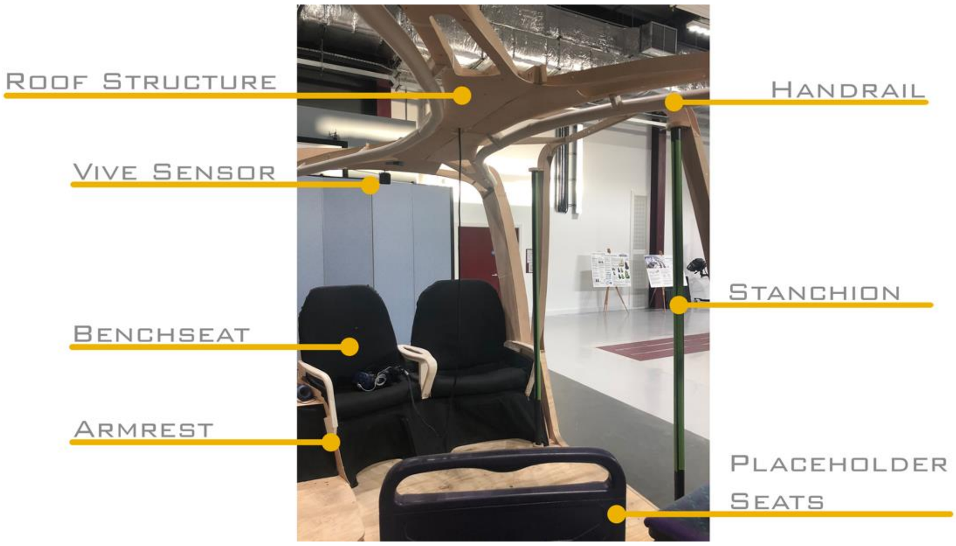


Figure 13.5 Full-scale ergonomic buck based on the MiCar

13.3 Implementation Procedure

Autodesk Alias AutoStudio 2018, was used to create the 3D model. As this particular software creates individual surfaces, once completed they were stitched into separate shells which were then exported in the stp. file format.

As the CAD model is made up of individual components such as the chassis, glasshouse and doors, maintaining the initial component structure throughout the whole process proved essential when material properties had to be assigned to individual parts. Prior to setting up the model within *Unity*, the model was also imported into the *Autodesk VRED* rendering software, which can provide a live view of a rendering scene using a VR headset. This was used by the team throughout the design process to gain an impression of the full-sized vehicle within an environment, move around it and conduct a design review. Due to the simple conversion process from *Alias AutoStudio 2018* to *Autodesk VRED pro 2018*, this step was repeated several times as part of an iterative design process, editing features of the vehicle. Following a conversion into .fbx files, utilizing *Autodesk 3ds Max*, the data was then imported into *Unity*, within which the materials and colours were then applied.

13.3.1 Final Workflow

Step 1.1 Creation of a 3D CAD model based on the *MiCar* Concept (Alias AutoStudio2018)

Step 2.1 Visual Reviews in 2D and 3D (HTC Vive Headset & Autodesk VRED pro 2018)

Step 3.1 Edit of the CAD file from .stl to .fbx (Autodesk 3ds Max 2018)

Step 3.2 Construction of the physical buck based on technical drawings

Step 4.1 Integration into the virtual environment
Data management for controllers (Leap Motion)
Visual Output to HTC Vive
Export application as .exe file

Step 4.2 Place the sensors within the buck
Installation of the wiring harness for Headset Sensors

To simplify the evaluation process for the operator, the software was bundled into a .exe file, creating a launch application, with a small number of manual controls to be toggled by the operator via the control screen, adding the option for night or daytime as well as selecting additional animated passengers.

13.3.2 Virtual Environment and route

A fictional technology park, adapted from an existing site, which was also imported as a 3D model, served as the environment through which the *MiCar* travelled.
The environment was chosen as it represents a scenario which can already be observed as an application for driverless last mile mobility vehicles (Hunsicker et al. 2017). *Steam VR* was used in combination with *Unity* to communicate with a VR Headset.

In order to combine the physical ergonomic buck with the virtual model, the two base stations were mounted on the two opposing ends of the roof structure. They were positioned at an approx. 18° downward angle to improve coverage within the vehicle interior, with it also extending to the exterior.

Some components such as the uprights of the roof structure itself did create some minor blind spots, they did not, however, negatively impact on the evaluation. The computer and the operator workspace were placed outside the ergonomic buck from where the wires of the *HTC Vive* Headset reached into the cabin.

Figure 13.6 Participant during Trial with MR

With the wires (*Vive & Leap Motion*) bundled up and suspended from the roof structure of the ergonomic buck, the VR user could move around the front of the vehicle and inside the cabin.

An assistant was required at all times, to manage the wire to avoid it tangling up and to inform the user of potential hazards such as the step up into the vehicle (Fig. 13.6). The participants used the headset to view the digital model and environment, with the *Leap Motion* sensor mounted to the front of the headset below the two cameras, which provided an accurate representation of their hands in the virtual world.

Following a period of familiarisation, where the participants experiment with the hand tracking feature, trying various gestures and reaching towards the vehicle to gauge their perception of distance, the users confidently placed their hands on the handholds and handrails in the ergonomic buck. After repeated use of the system, users comfortably utilize the tracking feature to interact with the simulation and buck.

A night and daytime option was added to the simulation in order to be able to draw the attention of the participants to different features of the vehicle.
The night option created a dark exterior scene, highlighting, for example, the lighting in the interior of the vehicle whereas the day option allowed the passengers to view the exterior scene in order to be able to evaluate aspects such as viewing angles, visibility and the amount of daylight in the interior.

Rendered avatars occupied both seats on one side of the vehicle (Fig. 13.7.6), as the ergonomic buck only featured one accurately milled and upholstered seat combination on the opposing side.

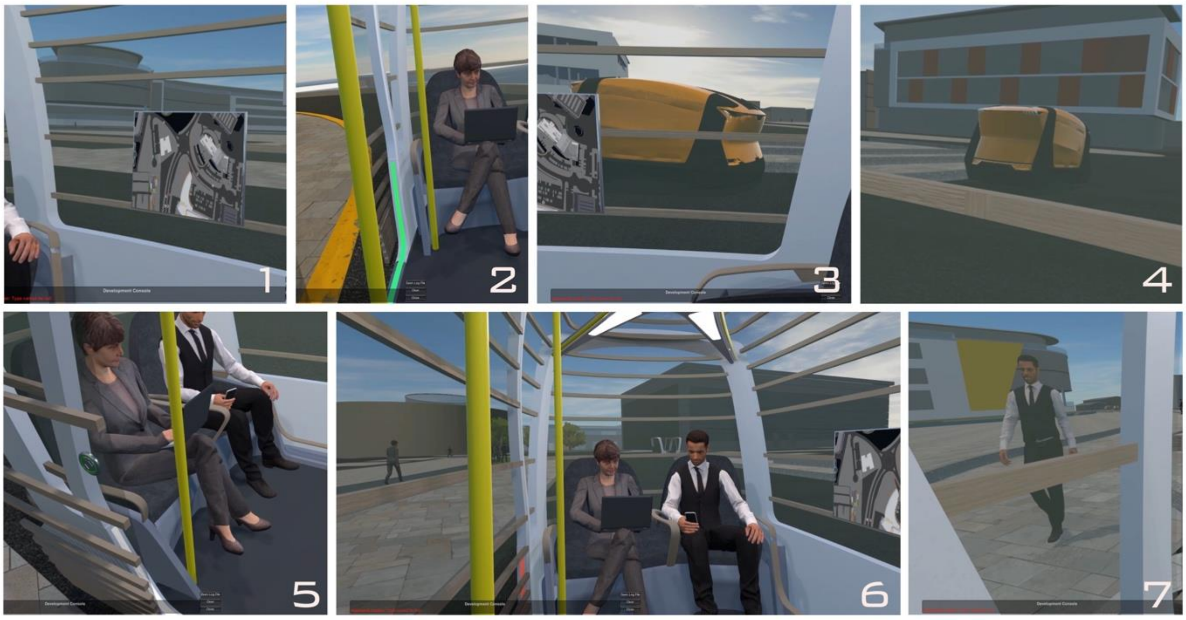


Figure 13.7 Impressions of the view in the Mixed Reality

This was due to the prior evaluation of the seating only requiring one seat combination due to the symmetric design of the vehicle. In order to deter participants from attempting to sit on the side which was not accurately represented in the virtual environment and in order not to disrupt the illusion of the symmetric interior design, two animated (minor movements to suggest breathing) avatars, representing passengers, were placed on those seats. These avatars were chosen from an online data bank (Renderpeople) and are photorealistic scans of a woman and a man in business outfits suitable for the chosen scenario.

13.3.4 Route

For the development and evaluation of the Mixed Reality system, data from MiCar project were used, therefore this particular setup was based on participants experiencing the MiCar vehicle as part of an environment in which it was travelling on an animated route across a technology park. The route took the participants from a stop located by a canteen along a straight road, followed by a right turn onto the main road.

After 40 seconds a roundabout was crossed over and the vehicle carried on towards the next turn point, where it yielded for another MiCar passing by before turning onto a carpark. Another right turn and the vehicle reached the final straight at the end of which a stop was located. “Traveling” from the start to the next and final stop took approximately three minutes.

In the animation, the vehicle movements were programmed to slowly accelerate away from the stop to reach a top speed of approximately 25mph.
The vehicle was further programmed to slow down for corners and come to a full stop at any junction, pausing to adjust to any other traffic.

During the journey the participants did not experience any vehicle yaw or pitch for two reasons; the low point of gravity creates a very stable driving dynamic and further, any movement would require a far more complex actuated vehicle simulator.

13.3.5 Procedure

The evaluation was conducted at the NTDC, for which the participants (n=13) were recruited from the MIRA Technology Park, in order to maintain continuity with the previous two evaluation stages. Each participant started the experience outside of the vehicle, equipped with the headset and the instruction to interact with the vehicle by pressing the virtual buttons with their hands. Two buttons were built into the simulation, so-called trigger points, with the first one located on the virtual vehicle door, which when pressed, opens. The third trigger point is split up into several points/buttons, each located next to a seat in order to be easily reached by the participants. These buttons all trigger two events, the closing of the doors as well as the start of the journey.

Standing outside facing the vehicle, the participants navigated through the environment towards the door, to reach for the opening button. Once the doors opened the participants could then step into the vehicle interior using the available handholds. From the beginning users were supported by audio prompts, heard through the headset, such as "Mind the step" and "Welcome aboard, please press the start button on your side". Optical feedback loops were also included such as the light strip at the door which is red when the door is closing and turns green when it is open. Once seated the participants themselves triggered, using the previously described button, the journey simulation.

During the journey, the participants were verbally encouraged to have a look around the interior of the vehicle as this was the first VR & MR experience and some of the participants were unaware of the liberty the headset provides and subsequently stared straight ahead. Upon arrival another audio prompt; "You have arrived at your destination", informed the users of their arrival, the vehicle doors automatically opened and subsequently the users were able to step out of the vehicle to complete the trial.

13.3.5 Measures

After the Mixed Reality experience, the participants were asked to complete a Presence Questionnaire (Witmer & Singer 1994) which evaluates the perceived presence or immersion in a virtual environment. Witmer and Singer defined presence as “a subjective experience of being in one place or environment, even when one is situated in another, as well as experiencing a computer-generated environment rather than the actual one”. In the context of the Mixed Reality method, the questionnaire was used to evaluate individual aspects of the simulator.

A French version of the questionnaire was validated by the Université du Québec (UQO 2002) by 101 participants and seven groups were combined out of the 24 questions. These seven groups are: Realism, Possibility to act, Quality of the interface, Possibility to examine, Self-evaluation of performance, Sounds and Haptic, the latter two items not being part of the UQO validation. The original English version of the questionnaire created by Witmer and Singer was given to each of the participants, with the option of adding comments at the end.

13.4 Results & Discussion

13.4.1 Survey Results

Directly after the MR simulator experience, the English language variant of the above-discussed presence questionnaire, based on a 7-point Likert scale and an option to add comments, and was completed by 13 participants (one question was only completed by 11). The results from the questionnaire indicate an overall positive impression of the simulator and the Mixed Reality method; three-quarters of the participants judge the interaction with the environment as natural or completely natural. This is an important factor as the main drive behind the MR method is to allow users to interact with and perceive the experience as close to reality as possible. The virtual experience was also seen as consistent with real-world experiences by 8 out of 13 participants, with the other 5 participants spreading equally from “not consistent” to “moderately”.

With 10 out of 13 participants indicating that they perceive the experience as sufficiently consistent with the real world, it can be argued that the MR can be used to gather realistic data, however, additional comparison studies are required to further support this argument.

The participants also felt very involved with the virtual environment experience, with three quarter reporting that they felt either engrossed or completely engrossed. The remaining answers indicate a mild involvement, with no participant feeling entirely disenthralled by the experience. This reflects the comments by the majority of participants who felt transported into another world and responded in a way congruent with behaviour in a real-world setting. Participants reported that at the end of the experience when they removed the headset, they were somewhat disappointed not to have really travelled.

When asked how well the participants were able to visually survey the environment, (a key element to conducting a design review), 11 out of 13 indicated that they were able to examine objects with confidence (pretty closely – very closely) and 8 out of 11 respondents were also able to do so extensively from multiple viewpoints. This reflected the observed behaviour, where participants would slowly approach the vehicle familiarising themselves with the exterior and also taking pause once entering the cabin to have a look around. Even during the simulated journey when seated, the participants would change their postures to continue to familiarise themselves with the cabin interior and view the passing scenery.

The simplicity of the simulator and the quick learnability is reflected in the answers in regard to how well the participants were able to concentrate on the assigned tasks rather than on the technology required to do so; after only one trial run, 9 out of 13 participants stated that they were also able to concentrate completely on the task at hand, the design review. A further 3 participants only felt somewhat able to concentrate on the task, which likely due to general unfamiliarity with digital tools and virtual reality systems.

13.4.2 Discussion

The different software visualisation tools, *Autodesk VRED* and *Unity* have their distinct advantages and disadvantages. Both can be used in order to review a digital design and can compute the common file types created by digital modelling tools such as *Alias Autostudio* or *3ds Max*.

Therefore, it is key to decide early in the development process of a design evaluation tool which capabilities are required and what kind of trials will be conducted. For this simulator setup, the ability to interact with the design physically and through an HMI was key, which lead to the use of *Unity.*

Unity excels the interactive aspect, such as the buttons and animations whilst providing a slightly lower visual quality traditional rendering software such as VRED. However, as interactivity is at the centre of the capability of the software, the leap motion enabled hand tracking could be integrated. Furthermore, being able to include animations controlled with trigger points makes *Unity* an appropriate tool to study the users' interplay with the design concept through any kind of HMI. Combining all of these features enables the user to undertake a simulated journey in a manner akin to the way they would do in reality, starting on the exterior gaining an impression of the design concept prior to entering it and experiencing the interior during a journey.

Pairing with the physical ergonomic buck is the most powerful aspect of a Mixed Reality Simulator, it creates an immersive environment that draws a participant in and allows them to experience a design at their own pace and controlled through their own actions, promoting behaviour consistent with a real-world experience. The ergonomic buck provides the physical reassurance and support and permits trial participants to move through the simulation as they would do in a real prototype. Being able to provide this level of information to any trial participant typically involves a refined prototype vehicle, whereas the combination with VR can create the same sensations with a basic mock-up.

Inviting users to physically interact with the simulation requires the ergonomic buck to feature all surfaces and features a participant may interact with, failing to do so would instantly disrupt the illusion. These features also have to be very accurate and sturdy as participants are relying on the impression they gain through the digital model, thus expecting an armrest, for example, to be usable.

The results of the presence questionnaire indicated that in the case of the MiCar MR Simulator, the participants perceived their experience in the simulator as consistent with reality, suggesting that the physical and digital world were sufficiently well matched.

Using the MR Simulator, the participants felt able to gain an adequate impression of the design concept and trial it, which suggests it is suitable to be used in a follow-up study, in order to evaluate the design of a product rather than the simulator itself. Here participants can then use the MR Simulator to experience a design concept in the intended context with the simulation providing the full functionality of a finished product, such as interior lighting and HMI at a very early stage of the design process.

The possible use cases for a vehicle design evaluation, for example, extends from the material and colour selection for the interior trim, to the number, type and placement of HMI interfaces, the interface software and required user feedback, the impression of the interior space through the shapes, colours and lighting as well as the view to the exterior. The simplicity of editing the simulation with different design variants allows the design to be trialled numerous times prior to committing to a costly physical prototype.
The MR Simulator also permit the trial of scenarios which would be considered unsafe in a real vehicle, a near-crash or control system failure could be simulated to study the participants' reactions whilst not endangering anyone. A limitation of the described MR set-up at the time of writing is the current limit to a single user due to the sensor systems only supporting one headset at a time.

This reduces the potential scenarios that can be explored to interactions between the environment or the vehicle with a single user. A multiple user set-up is possible by networking multiple set-ups in separate locations, though for a Mixed Reality application this would require multiple identical real-world props.

A further complication at this time is the novelty aspect of Virtual Reality as many participants have not yet experienced such a system, or not with this level of complexity. This was particularly apparent with the hand tracking feature, as the attention of many users was drawn to it, exploring which gestures and movements the system was capable of tracking. A longer familiarisation period and repeated exposure may mitigate this issue and potentially permits a more natural behaviour within the simulation.

13.5 Conclusions

In summary, it can be said that Mixed Reality, a combination of a virtual vehicle design model with a full-scale physical ergonomic buck, does provide a useful tool for design evaluations, by submitting trial participants to an immersive simulation where they experience the design in a realistic task context. With the components described above, this method can be applied to a variety of research and design work and with the rapid technological advances, the range of suitable applications is likely to increase.

With an application in the early stages of the design process, the Mixed Reality method can provide valuable insights to engineers, designers and decision-makers as part of an iterative design process. Based on the experience of using the MR Simulator as part of the MiCar Project for the design development, the argument can be made that an introduction of the Mixed Reality tool as described here into the common design process can improve the outcome of that process whilst reducing the overall time requirements. An application beyond vehicle design is also feasible, introducing, for example, the opportunity to investigate the design of buildings or the navigation in transit terminals in combination with any form of transport.

The key feature of this Mixed Reality setup, the haptic feedback, provided by the physical ergonomic buck supported the user immersion as it was reported by the trial participants. Future research could evaluate if the immersion can be increased if additional stimuli such as sound, vibrations and smell were to be added. A future iteration of the MR simulator would also benefit from the inclusion of more realistic vehicle and pedestrian traffic, providing the user with additional information about the scenario and the environment and increase the sense of realism. These can then also be used to investigate further questions relating to the user experience in any vehicle regarding the response of the user to situations occurring around the vehicle.

In conclusion, Mixed Reality is proving itself to be a helpful and efficient tool for the evaluation of designs, permitting designers, decision-makers and end-users to experience the design at an early stage in the process before the necessity to build a full working prototype.

13.6 Acknowledgements

The programming and development of the simulation were only possible with the strong support of the National Transport Design Centre Visualisation Specialist Ryan Lewis.

14.0 MiCar Vehicle Design Evaluation using Mixed Reality

14.1 Introduction

As discussed in chapter 11.0 and demonstrated in chapter 12.0, an ergonomic buck allows the evaluation of a vehicle design with non-expert users, who, assigned with a set of tasks, can give feedback and potentially highlight issues as well as further use cases.

However, as discussed in chapter 13.0, a traditional ergonomic buck, whilst ideal to evaluate aspects such as accessibility, reachability and interior space, does not provide a full impression of the overall design. Therefore, the Mixed Reality (MR) simulator was developed, integrating the ergonomics buck with wearable VR technology to provide a richer user experience and focus on detailed interior and exterior design elements.

This chapter will detail the evaluation of the MiCar design using the MR simulator. For the evaluation, a questionnaire was used to record the impression the trial participants gained of the vehicle design, their judgement over how easily it can be used as well as their ability to interact with it. The questionnaire also featured two identical sections, the first was completed prior, and the second following the completion of the trial. The focus of these questions was to gauge the acceptance of driverless vehicles by the general public and the pre/post comparison was aimed at tracking any changes after experiencing a virtual journey on board of a driverless vehicle.

14.2 Methods

14.2.1 Participants

The evaluation was undertaken in two stages, a first study was conducted at the NTDC facilities with 13 participants. These were made up from two evaluation groups; one representing a cross-section of technology park employees (n-6), the other one supports the local council in disability and accessibility questions (n-7). Of the second group, two group members have visual impairments (cataract), whilst the others have a range of mobility impairments, such as being wheelchair-bound (-2) or requiring a walking aid (rollator) (n-1).

The majority of participants from both groups have previously supported the research at an earlier stage, evaluating the MiCar design as a traditional ergonomic buck.

For the second stage, the participants were not recruited from a specific group or scenario but instead consisted of visitors to the Coventry Transport Museum and are therefore likely to represent a cross-section of the general population. 99 participants took part in the trial and subsequently the questionnaire, whilst several hundred more experienced the simulation without formally providing feedback using the questionnaire. The additional users were observed and provided additional insight about typical behaviour inside the vehicle. No minors were asked to complete the questionnaire.

14.2.2 1st. Evaluation Setup (NTDC)

At the National Transport Design Centre, the ergonomic buck was placed in the design studio in order to conduct trials with small groups (4-5 participants) in the last week of July 2018. An A1 poster board was used to provide the participants with an overview of the research and to introduce possible future applications of this vehicle type.
This study was used to evaluate the Mixed Reality (MR) Simulator, in preparation for a second study conducted at the Coventry Transport Museum. The second study was based on using the MR simulator to evaluate the vehicle design during a simulated journey.

14.2.3 2nd Evaluation Setup (Coventry Transport Museum)

As part of the exhibition “Ticket to Ride” which showcased bus travel throughout history at the Coventry Transport Museum, the research group was given the opportunity to display and demonstrate the setup and conduct trials for seven days. The trials began on Saturday the 4th of August and finished on the following Friday 10th of August 2018. Here the MR simulator was shown in combination with a large banner (2x2m) explaining the individual design steps and how the MR evaluation fits into the process.

The exhibit was further supported by a stand-up banner which explains the research project “Researching passenger comfort and experience in driverless last mile mobility vehicles”, a detailed 10th scale model showing the interior as well as the exterior and lastly a video showing a run through the MR evaluation documented at the NTDC. Interested visitors were able to approach a researcher who would introduce the research work, and offer to take part in the trial.

Figure 14.1 MR Simulator at the Coventry Transport Museum

14.3 Trial Procedure

The procedure and evaluation methods were identical for both evaluation setups at the NTDC and the Coventry Transport Museum. In both cases, participants were asked to complete six pre-trial questions regarding general acceptance of driverless technology, based on questions described by Payre et al (2017) in “Intention to use a fully automated car: Attitudes and a priori Acceptability”. The questions were rewritten to be applicable for driverless first and last-mile mobility vehicles. Those were followed by the participant being equipped with the VR Headset and subsequently instructed to lift their hands in front of their face to demonstrate the hand tracking feature.

The trial commenced outside of the vehicle, approximately one metre away from the door in order to give the participants the opportunity to gain an impression of the vehicle exterior prior to entering.

The participants were then invited to step up into the vehicle, locate the door opening button and trigger it to gain access to the vehicle using their hands. Upon entering, most users navigated through the environment and the vehicle interior using the available handholds and choose a free seat. From the start of the evaluation, the users were supported by audio prompts such as “Mind the step” and “Welcome aboard, please press the start button on your side”. Once seated they themselves activated the vehicle to commence the journey.

14.3.1. Journey Simulation

The following simulation lasted approximately 3 minutes and transported the participants across a fictional technology park to a second stop. The vehicle travelled on the road network at approximately 25mph and displayed the typical behaviour of a manually driven car, slowing at junctions and intersections as well as yielding to other vehicles when turning. The route took the participants from a stop located by the canteen along a straight road, followed by a right turn onto the main road. After 30 seconds a roundabout is crossed over and the vehicle carried on towards the next turn of point, where it yielded for another MiCar passing by before turning onto a carpark. Another right turn and the vehicle reached the final straight at the end of which a stop was located. At the second stop the doors of the vehicle automatically opened and another audio prompt informed the users of their arrival and subsequently, the users were able to step out of the vehicle to complete the trial. During the journey, the participants were encouraged to have a good look around the interior of the vehicle as this was the first VR & MR experience for many participants and some were unaware of the liberty the headset provides and subsequently stared straight ahead.

The technology park map was used as it was identified as a likely scenario for the application of driverless first and last mile mobility vehicles in the literature review (chapter 2.0). Upon arrival at the second stop, the VR headset was removed and the participants were asked to complete the remainder of the questionnaire.

14.3.2 Questionnaire

The questionnaire was organised into four separate sections, the first section consisted of the general acceptance of driverless vehicles questions. These were also repeated in the fourth and final section of the questionnaire with the aim to establish if a change in acceptance can be recorded following the experience. Sections two and three covers the vehicle design, interaction and ergonomic aspects of the design. These questions were based on the task analysis created for the use of a driverless last mile mobility vehicle as well as from a taxonomy of comfort attributes in public transport (Napper et al. 2015).

A total of 53 questions were copied to an online survey platform; https://coventry.onlinesurveys.ac.uk/micar-passenger-survey, which the participants accessed through two notebooks via the web portal. The majority of the questions are based on a 7-point Likert scale and a further seven multiple-choice questions.

For the analysis, the questions of section three and four were grouped into five themes; the sense of protection and safety, the human-machine interface (HMI), the interior and sections for the seats and the view. The questions regarding the general acceptance of driverless cars were evaluated separately.

14.4 Results & Discussion

14.4.1 Sense of safety and protection

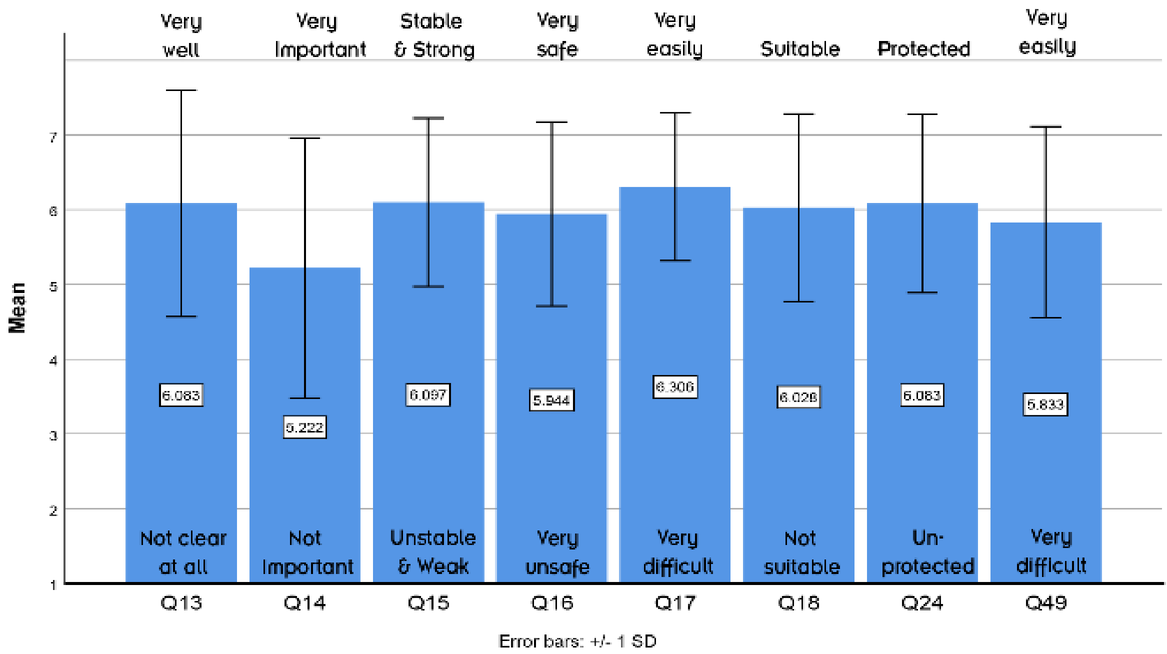


Figure 14.2 Sense of Safety & Protection Survey Results

Q13 - Standing outside, how well can you see into the vehicle interior?

Q14 - Importance of being able to identify who is in the vehicle prior to entering yourself?

Q15 - Standing outside, does the vehicle appear stable & solid or unstable and weak to you?

Q16 - From the outside, does the vehicle appear safe to you?

Q17 - How easily can you identify where the door is located?

Q18 - Is the height of the entry step suitable?

Q24 - Do you feel protected inside the vehicle from the other traffic?

Q49 - Ability to spot potential approaching dangers such as other cars prior to exit?

During the approach of the vehicle, the participants were asked to evaluate how well they were able to see into the vehicle (Q13), as they are being asked to enter a small space with people that are likely to be unknown to them.

The majority of the participants stated that they were able to easily view the interior of the MiCar concept, which is a key design requirement as over three-quarters of the participants indicated that they would like to be able to see with whom they will be sharing that space prior to committing to it (Q14), indicating the importance of a transparent cabin design.

At this stage, the participants were also asked to evaluate the overall impression of the MiCar concept, with the aim to evaluate whether it appeared stable & solid or unstable & weak (Q15) and further if it appeared safe or unsafe (Q16). The former question was answered with either very stable & solid/stable & solid by 71.1% of the participants and 75.3% rated the vehicle very safe/ safe. The importance of creating a positive impression is based on the comfort factor “Peace of Mind” described in (chapter 4.0) which ranks it as the most important factor.

A positive initial impression when approaching the MiCar regarding the stability and safety, therefore, is crucial for a comfortable experience on board of a driverless first and last mile mobility vehicle. The view looking onto the vehicle was also used to verify how easily the door aperture, with the doors closed, can be identified (Q17). Here 95.5% of the participants ranked it between very easy and easy, validating the efforts in highlighting the aperture using lights, alternating materials (gloss/matt) and colours. Once in the cabin, the questions regarding the impression of safety within the vehicle continued, inquiring how protected the participant felt from other traffic (Q24), with 78.1% answering with very protected/protected. Only two out of 99 participants stated that they felt very unprotected / unprotected within the vehicle. Feeling safe is a significant contributor to the passenger’s peace of mind which is the most important factor according to the comfort model, particularly in the context of the driverless vehicle technology, which at this time is an unknown to many.

It was also evaluated whether the participants were able to spot approaching dangers prior to exiting the vehicle (Q49). The majority (72.5%) were able to do so with ease, however, there remains a group (13.2%) for whom it was more difficult, which requires improvements to be made to the vehicle design.

14.4.2 Human-machine interface (HMI)

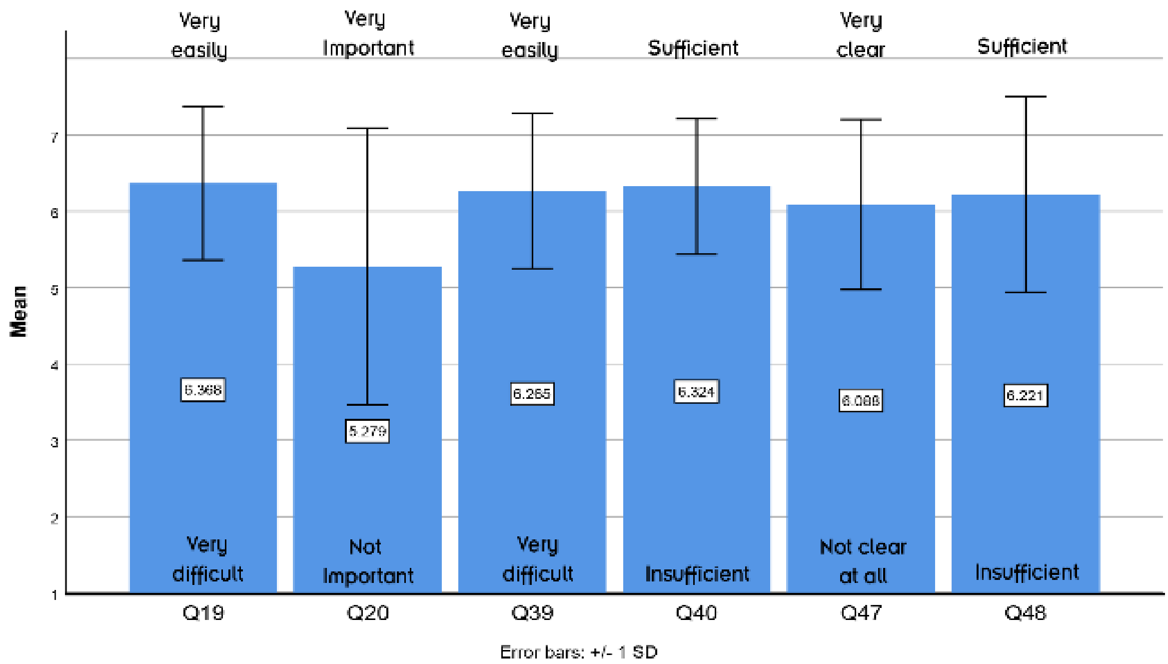


Figure. 14.3 HMI Survey Results

Q19 - How easily can you identify the door opening button?

Q20 - How important is the welcome message to you (Welcome onboard)?

Q39 - How easily were you able to identify the button to “start the journey”?

Q40 - Did you receive sufficient feedback on your action, starting the journey?

Q47 - How clear are the functions of the buttons?

Q48 - Did you get sufficient notification that you had arrived at the destination?

Whilst the questionnaire did cover the interaction with as well as the feedback from the vehicle, it should be noted that the features currently used in the simulation such as the start button were only placeholders for a fully integrated HMI.

Nevertheless, the interaction with the vehicle using buttons, to open the door or activate the journey, was generally seen as easy (Q19) but some issues such as not knowing if it was successfully triggered, were noted by the researchers observing the participants. Triggering the journey start did result into the doors of the vehicle closing and the light bar beneath the door changing colour, this however during the observation it showed that this was not noticed by all participants, indicating that further feedback loops, such as auditory, are required (Q40).

Evaluating the importance of an audible welcome message indicated that only 57.5% considered it important (Q20). There were no comments however describing it as bothersome or annoying, suggesting that if implemented in the final design, it would be beneficial to some without being disruptive for others.

As the journey only simulated travelling between two points, the vehicle stopped automatically upon reaching the second point and opened the doors. Aside from the audio message this was perceived as a sufficient message that the passengers had reached the end of the journey (Q48). However, it is clear that a journey with several stops for different passengers will require a more targeted notification system.

14.4.3 Interior

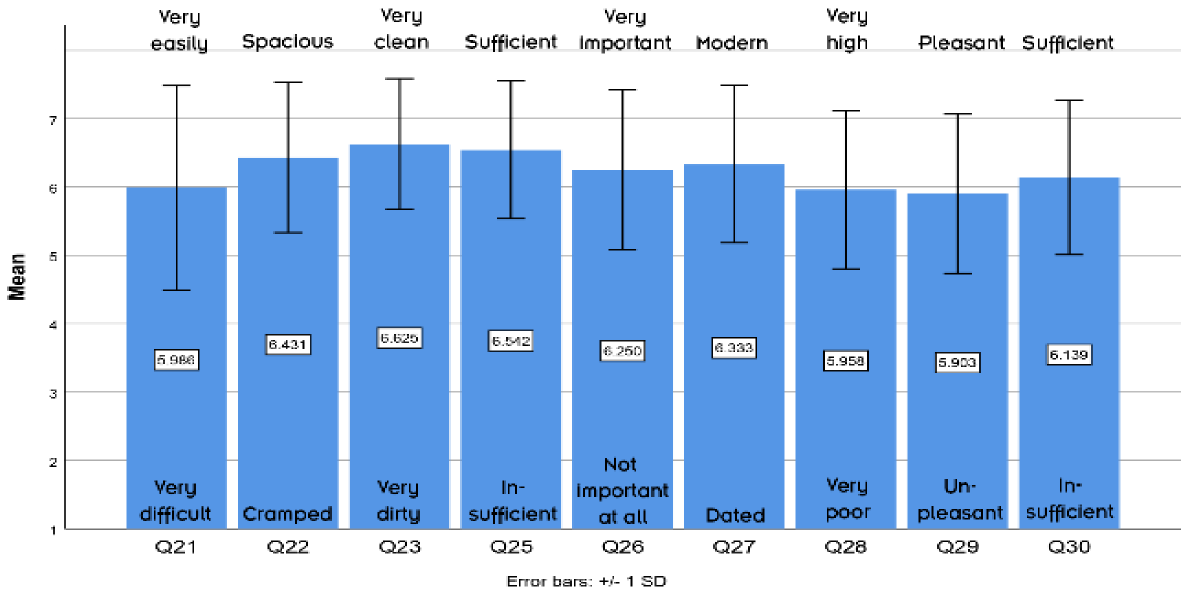


Figure 14.4 Interior Survey Results

Q21 - How easily can you identify handholds, such as handrails?

Q22 - How spacious does the cabin seem to you?

Q23 - Does the interior appear clean to you?

Q25 - Is there sufficient natural light in the cabin?

Q26 - How important is it to you that the inside of the vehicle is illuminated by natural light?

Q27 - Does the interior space look modern or dated to you?

Q28 - How would you rate the quality of the interior?

Q29 - How would you rate the colours of the interior?

Q30 - Were there sufficient handholds and supports available to you?

The cabin itself was also subject to detailed questions, initially judging the spaciousness with the vast majority (91.8%) describing it as either very spacious/spacious (Q22). This is a key element in the design as the vehicle itself is compact but as previously discussed passengers feel uncomfortable entering a small space with unknown other passengers. Several factors from the aforementioned comfort model relate to this design aspect, further highlighting the importance of it, with the spaciousness influencing the "Physical

Wellbeing", the "Proxemics" as well as the "Pleasure" and "Social" aspects. The same aspects also apply to the amount of natural light that reaches the interior of the cabin, of which the participants were asked if it is sufficient and how important it is to them (Q25). 95.6% of the participants judged there to be sufficient natural light reaching the cabin and 84% rated it as very important/important to them (Q26).

Whilst the availability of handholds was questioned (Q30), the main focus in regards to the handrails and handholds was their visibility (Q21). Being able to easily spot supports such as handrails when entering the vehicle is key to ensuring a safe journey. For the MiCar design, 79.4% stated that there were sufficient handrails and almost three-quarter of the participants stated that they were easily identified. An improvement over the findings in the ergonomic buck evaluation described in chapter 12.0, where participants reported issues with quickly identifying the dark coloured handholds.

The quality and the style of the interior, as well as the colour choices, were also part of the questionnaire (Q27, Q28, Q29), as they relate to the aspects of "Pleasure" and "Aesthetics" in the comfort model. The interior was perceived as modern and of a high quality by the majority of the participants, who also described the colour choices as pleasant. Whilst these aspects have a lesser influence on the overall comfort perception, they do still contribute and are likely to be noticed. Whilst many aspects of the vehicle design are relevant for the usability and comfort, the materials and colours as well as the quality of the interior hold great potential to be used as a key differentiator between mobility providers and systems and therefore hold great marketing potential.

14.4.4 Seats

Q32 – Do you prefer to sit or stand if the journey takes less than 5 minutes?

Figure 14.5.1 (Seat preference / Journey duration < 5 min)

Q33 – Do you prefer to sit or stand if the journey takes more than 5 minutes?

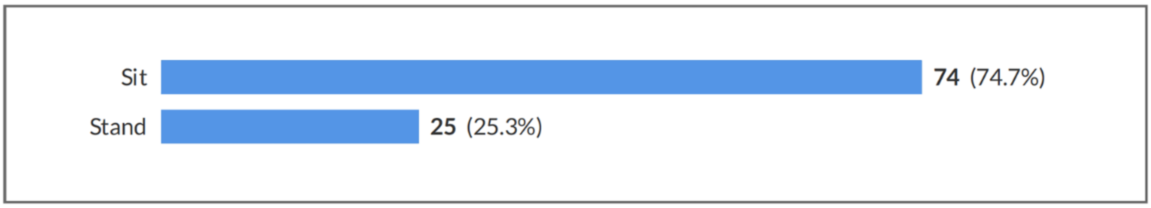


Figure 14.5.2 (Seat preference / Journey duration > 5 min)

The seating plays an important role in the comfort factors of "Physical Wellbeing", "Proxemics" as well as "Satisfaction" and "Pleasure".

Therefore initially it was important to establish whether passengers would like to sit or stand and if that changes if the journey takes longer than 5 minutes (Q32, Q33).
74.4% of the responders preferred to sit even if the journey takes less than 5 minutes if it takes longer it increases to 94.9%, indicating that seating is relevant even in a first and last-mile mobility application where the journey time is very short.

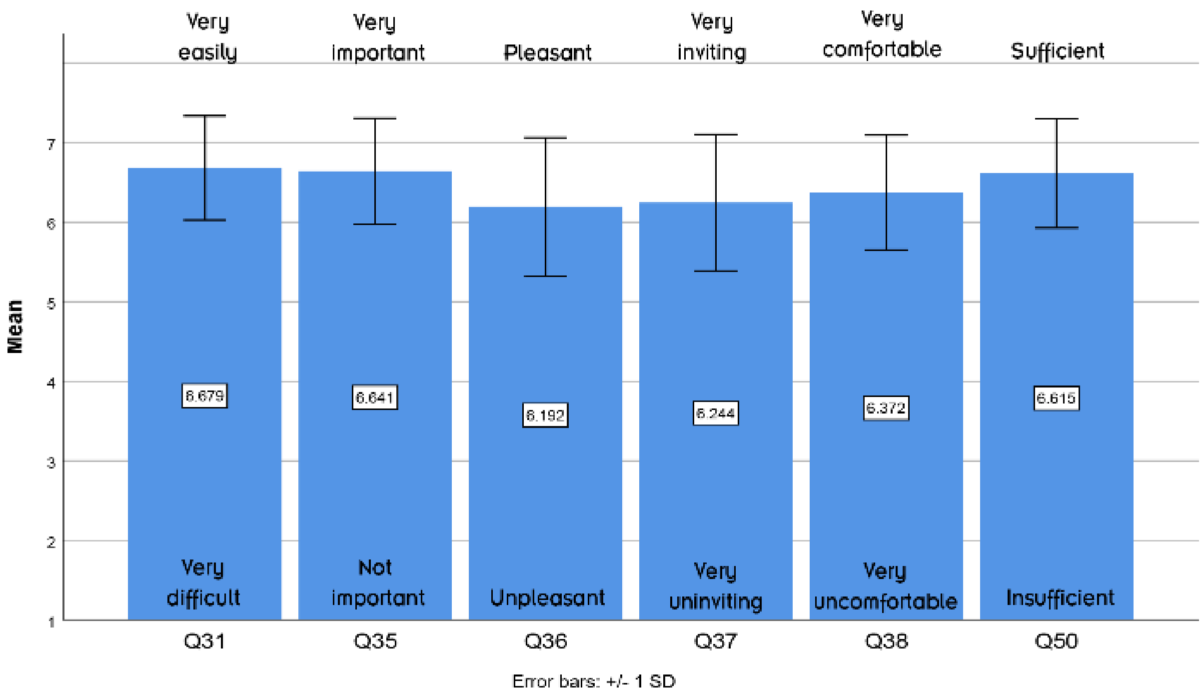


Figure 14.6 (Seats 1 Survey Results)

Q31 - How easy is it to identify a free seat?

Q35 - How important is the cleanliness of the seats in your seat selection?

Q36 - How would you rate the seat colour?

Q37 - Does the seat look inviting to you?

Q38 - Does the seat look comfortable to you?

Q50 - Did your seat provide sufficient separation from the passenger seated to your side?

Initially, the participants accessed how easily they were able to identify a free seat (Q31), which 93.5% described as easy. For the seat, the cleanliness is vital, 93.8% state that they consider it very important/important (Q35).

It is therefore important to choose a design which avoids trapping dirt and can be easily cleaned as well as fabrics which do not highlight minor uncleanliness. In the case of the MiCar a dark fabric was therefore chosen, without a pattern which was seen as pleasant by the majority (80.7 %) of participants (Q36).

Overall, the seats in the MiCar were perceived as inviting as well as comfortable (Q37, Q38), crucial for the overall positive impression the vehicle cabin due to the impact seats have on the passenger comfort. As vehicles of this type are expected to be used as part of a public transport system, it is crucial to provide the passengers with a degree of separation from the other passengers who share the bench seat. 94.9% of the participants considered the central handrail to be sufficient, 36.4%, however, would prefer an additional separating feature at head height (Q50, Q51).

Q34 - Would you want the cabin to offer perch seats? (Surface to lean on or rest against)

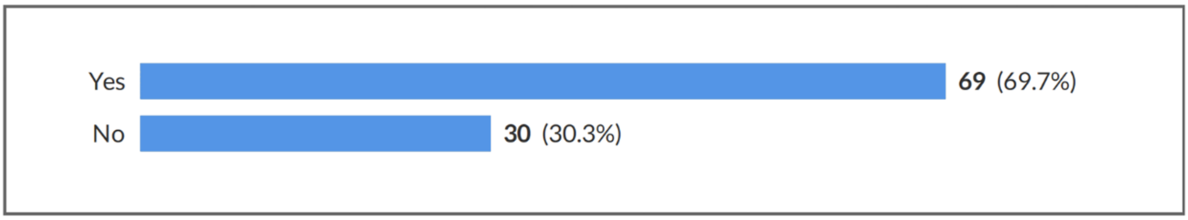


Figure *14.7.1 (Perch seats)*

Q51 - Would you prefer to have additional separating features on the seat at head height?

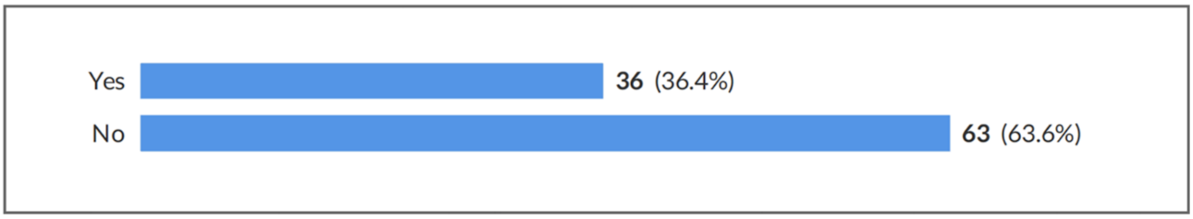


Figure *14.7.2 Separating features between seats*

Q52 - Does the seat allow you to have a conversation with your seat neighbour?

Figure *14.7.3 Separating features between seats*

Q53 - Does the seat allow you to have a conversation with the person opposite?

Figure 14.7.4 Conversation with the seat neighbour

The passengers (69.7%) would also like to have a choice between regular seats and perch seats, a surface that a passenger can lean or rest against (Q34). This related to the need for seating even on short journeys where passengers are looking for any possibility to rest and shows that surfaces to perch on should be integrated into the next iteration of MiCar concept and any other driverless first and last mile mobility vehicle.

All of the participants stated that they were able to hold a conversation with their seat neighbours and 84.8% also with the passengers opposite. A key design requirement for the cabin which was designed to enable conversations, second most preferred way to spend the time during a journey (chapter 12.0), through the seats which allow the passengers to rotate inwards.

14.4.5 View

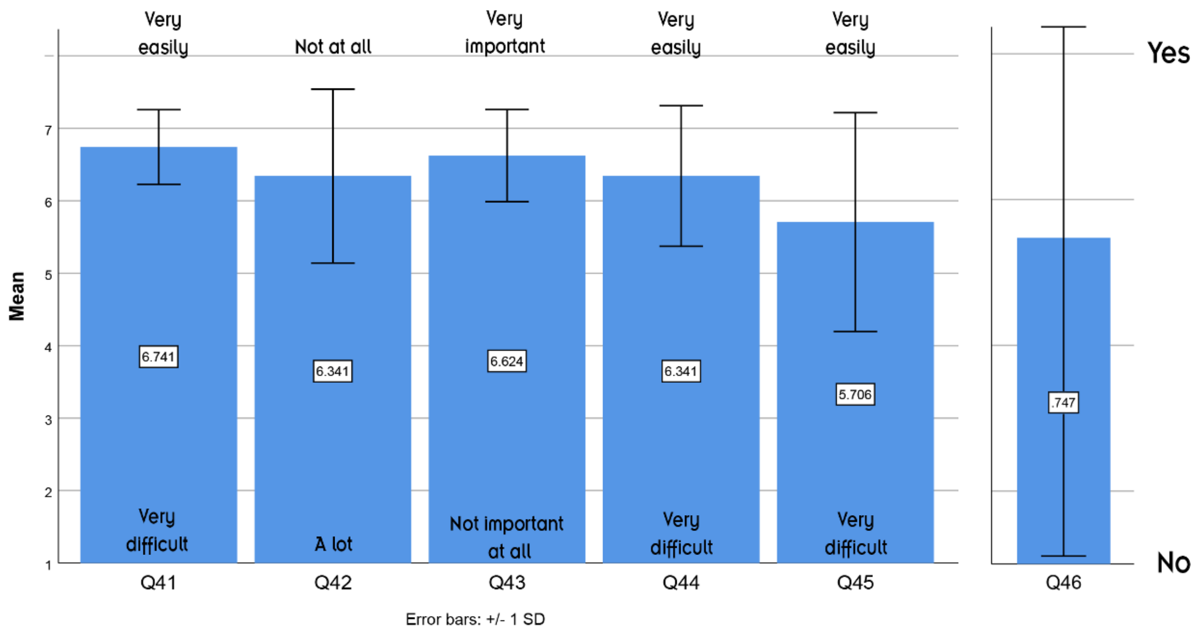


Figure 14.8 View Survey Results

Q41 - How easily were you able to observe the scenery outside?

Q42 - Did the wooden rings impede on your visibility?

Q43 - How important is a clear view to the exterior to you?

Q44 - How easily were you able to view the path the vehicle is about to take?

Q45 - How easily were you able to view behind the vehicle?

Q46 - Did you feel like you were able to anticipate the vehicles next movements?

Allowing sufficient natural light to reach the cabin and providing a clear view to the exterior is key to the MiCar Concept, with large window apertures in the design, as it is crucial to the high ranked comfort factors “Peace of Mind”, “Physical Wellbeing” as well as for the lower-ranked factors “Satisfaction” and “Pleasure”. How easily the scenery on the outside can be seen has received solely positive answers, with 77.4% stating it is very easy (Q41). The importance of a good view to the exterior is also reflected in 88.9% of the participants ranking it very important/important (Q43). Therefore it is important to note that the rings which are intended to shade the vehicle and provide a sense of enclosure do not interfere with the visibility (Q42).

The strong emphasis on a clear view is based on the aim to maintain a view to the path ahead, in order to allow the passengers to anticipate the upcoming vehicle movements. 82.7% of the participants suggest that this is seen as very easy/easy, however being able to view behind the vehicle from inside the cabin, scored lower at 62.9%, possibly due to some participants stating that they did not attempt to view behind the vehicle (Q44, Q45). The ability to anticipate vehicle movements does still require improvement, with 25.3% stating that they were unable to do so (Q46).

Being able to view the path the vehicle is about to take as well as seeing what is occurring in other directions is a key part in generating trust in the vehicle from the participants, as this permits them to observe vehicle actions and compare them to their own expectations. If these align, the user is more likely to trust the vehicle and subsequently the novel technology in future situations.

14.5 Pre & Post Trial Questions (General Acceptance)

The initial set of six questions which were repeated at the end of the questionnaire were aimed at tracing any changes within the general willingness of the participant to utilize driverless first and last mile mobility vehicles.

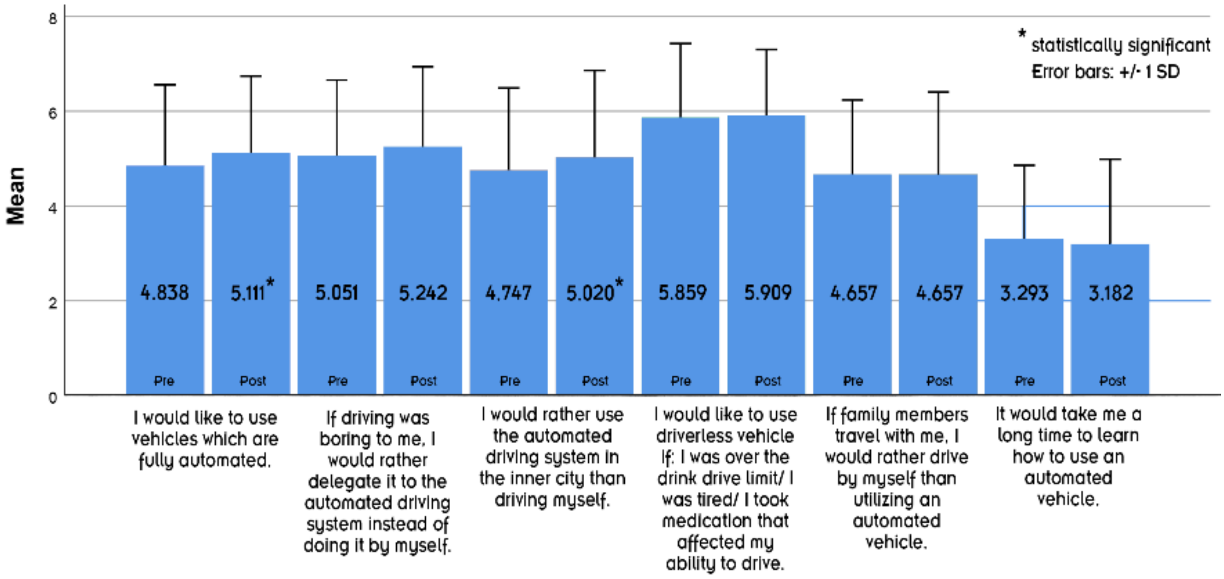


Figure 14.9 General Acceptance

A Wilcoxon Signed-Ranks Test indicated that the question; “I would like to use vehicles which are fully automated” was statistically significantly higher in the post-test ranking Z= -2.294, p= 0.022. A further Wilcoxon Signed-Ranks Test indicated that the question; “I would rather use the automated driving system in the inner city than driving by myself” was also statistically significantly higher in the post-test ranking Z= -2.294, p= 0.022 & Z= -2.408 p = 0.016 respectively. The four other questions did not indicate any significant changes following the experience, however an overall positive, albeit modest, a trend can be reported. The results could be interpreted to suggest that a Mixed Reality experience, one which is specifically designed to inform and teach people about driverless vehicles, may play a role in improving the general acceptance of driverless vehicles.

Analysing the answers individually, they all indicate a positive attitude towards driverless last mile mobility vehicles. Over half of the respondents stating that they would like to use this type of vehicle, especially in circumstances which would not permit them to drive themselves. In contrast, the answer given to the question if they would like to use such a vehicle when travelling with their families had no clear indication, suggesting that for many participants the choice to use a driverless vehicle would depend heavily on the situation. A widespread across the range of answers can be seen regarding the time the participants estimate it would take them to learn how to use such a vehicle, indicating that this technology is still as seen as very complex by many. Further information and potentially prior training could be a solution to support those people in using a driverless vehicle.

14.6 Summary & Conclusion

Overall it can be said that the MiCar Design Concept was rated highly in the trial, which suggests that the Comfort Model does provide a good indication of the passenger comfort requirements.

The assumptions made in the Comfort Model in regards to the importance of a clear view into and from the cabin were confirmed as well as the positive influence of natural light.

The view to the exterior was seen as relevant to the sense of safety that the vehicle has to invoke in the passengers. Furthermore, it was confirmed that the vehicle design does invoke a safe feeling, both when approaching the vehicle as well as once the passengers are in the cabin.

The seating played another important role in the evaluation, the privacy requirements were reaffirmed by the participants, who indicated that they would prefer an additional partition despite overall confirming a sufficient separation from other passengers. Whilst the journey duration did have an effect on the participant's requirements for seating, particularly for any journey longer than 5 minutes, it became clear that sufficient seating is necessary for any journey duration.

In regards to using this Mixed Reality experience to inform people about the driverless vehicle, the trial showed that there is a limited yet positive effect, which may be improved upon with an experience specifically designed for this purpose rather than for design reviews. However, the trial did already show a generally positive attitude towards driverless first and last mile mobility vehicles.

7th Objective

The seventh objective was the evaluation of the MiCar vehicle concept with a test population of users, using the mixed reality simulator.

This was completed using the aforementioned simulator in a large-scale trial at the Coventry Transport Museum, in which participants experienced a journey in the concept vehicle, in order to evaluate the interior design.

15.0 Discussion

15.1 Design Changes

The following chapter discusses in detail the design changes made to the MiCar concept as a consequence to the learnings from the individual studies. Changes being made to the design during the evaluation process are an essential part of the iterative design process described in the methodology chapter (3.0), in which a design detail is reviewed, tested and then if required, altered before being evaluated again. Each design change was directly driven by either comments during user trials and focus groups or based on the collected empirical and statistical data from the individual evaluation stages.

15.1.1 Exterior Review

Following the exterior review discussed in the previous chapter 9.0, some changes were made to the original MiCar design based on the findings.

The first modification to the design was the addition of a fading decal to the lower half of the doors, decreasing in opacity towards the upper half of the doors. The pattern of the graphic decal is based on the angled lines of the HORIBA MIRA logo and was added to the exterior of the door glass. This addition was implemented in response to comments made during the exterior design review, where some passengers, females, in particular, stated that feel too exposed when seated. This highlighted the wider issue of feeling exposed inside the vehicle as a consequence of vehicle designs which feature transparent body panels below the seat surface. This suggests that seats which are directly opposed to each other may also lead to the feeling of being exposed if there is no feature such as a table disrupting the direct view. However, when this matter was probed during the exterior review as well as the following evaluations, no participant confirmed these concerns.

A further design alteration following the exterior review was based on the comments that the horizontal rings, which run around the vehicle, remind some participants of a prison cell.

Whilst the intended function of the rings is to shade the vehicle and provide a sense of enclosure and therefore safety to the passengers, their layout was adapted from equal distribution to a less rigid and natural one. The aim of the alteration was to improve the sightlines for seated passengers as well as avoiding the impression of prison bars. In an evaluation of the updated arrangement during the Mixed Reality trial, participants stated that the rings did not impede their vision at all and they were no longer giving the impression of prison bars.

Additional alterations which were suggested by the findings were the change of the exterior colour scheme as well as adding an exterior HMI such as head and rear lights. These changes, however, were not implemented for the following evaluations as the main focus of the overall research project was the interior of the vehicle, thus only external design features that impacted on the interior were modified.

15.1.2 Evaluation of the MiCar Vehicle Concept using Jack

Following the evaluation of the digital model using Siemens Jack PLM, which was discussed in chapter 10.0, some further changes were made to the original MiCar design.

The evaluation of the seat height as well as of the seat pan depth using the 5^{th}%ile Chinese female manikin revealed that the seat pan was too high off the ground as well as too deep, resulting in the manikin being unable to lean on the backrest or place her feet on the ground when fully seated. Therefore, in the following design iteration, the seat height was reduced to 400mm and the seat pan shortened to 450mm. The final adjustments to the seats were found through several iterations in Alias AutoStudio, which were each re-evaluated in Jack. The new dimensions were carried over to the seat which was milled as part of the ergonomic buck (chapter 11.0). Prior to the milling, the seats underwent a further alteration changing them from two individual seats to a single bench seat. The main reason for the change was the aim to provide each passenger with greater flexibility in selecting their posture; allowing them to choose if they would like to converse with others or view the scenery.

In order to achieve this flexibility without moving components, the width of the seat pan was increased and the backrest was shaped to reach around the passenger on one side. This allows the passenger to lean on it when positioning inwards for a conversation but also provides the space to turn around and look outside comfortably. An additional benefit of the redesign is that the seat is now big enough to provide sufficient space for a young child to share it with their parent.

The Jack evaluation also showed that for the 5^{th}%ile Chinese female the handrail above the luggage space was difficult to reach. However, this issue was not immediately resolved but rather revisited in the trial using the full-scale ergonomic buck prior to any design changes as the participants would be able to inform a better design. Here the aspect of participant lead trials being combined with computer simulation becomes vital, as the researcher is only being able to validate known solutions digitally but participants may introduce novel and unknown ideas.

15.1.3 Ergonomic Buck Evaluation

In the ergonomic buck evaluation, the wheelchair space and access design were tested for the first time. A number of participants who use a wheelchair provided their feedback on the accessibility as well as the space allocated for the wheelchair during the journey. Whilst the door aperture was deemed wide enough for all to enter without issues, the central wheelchair space in the interior of the cabin was not considered ideal. The participants stated that they require a handrail mounted parallel to the wheelchair space to steady themselves against the vehicle movements. Therefore, the wheelchair position was moved closer towards the luggage shelf, which was modified with a cut-out, allowing the wheelchair to be brought even closer to the side of the vehicle where a new handrail was added. The same handrail also doubles up as edge to the luggage space, stopping luggage items from sliding out of the space. Moving the wheelchair space from the centre to the far side, away from the door, also freed up further seating space. This increases the capacity of the vehicle to three seated and two standing passengers when it is used together with a wheelchair user.

The handrail located above the luggage rail was evaluated again and the results from the Jack evaluation; it is uncomfortable to reach, were confirmed. Lowering the handrail to a height which is more comfortable to reach was not possible due to the handrail then encroaching into the headspace of taller passengers.

A further consideration was introduced by the comments of partially sighted trial participants, who suggested that whilst there was sufficient floor space available to cross the cabin towards the luggage space, it requires looking towards their feet. This, in turn, then leads to a loss of balance if there is not an overhead handhold available. The overhead handrail was subsequently moved from above the luggage rail to the cross beam in the centre of the cabin. In the centre of the vehicle, the handrail does not encroach the headspace of the taller passengers as it makes use of the full height of the cabin but gets within reach of shorter passengers where the cross beam descends towards each seating space. This will also support passengers who require a continuous handhold above when moving through the cabin as the handrail will lead them automatically towards one of the seats. Those who would like to stand close to the luggage space can use the handrail which was added to accommodate the wheelchair user requirements.

The evaluation also revealed a difference in the passenger capacity which was presumed in the inception of the design and the number of trial participants who felt comfortable in the ergonomic buck at one time. Initially, it was thought that four seated and two standing passengers would be a comfortable number, however, during the trial, the majority of the participants agreed that there is room for four standing passengers, without requiring any changes to the design. The capacity, therefore, was increased to a total of eight, making the vehicle more sufficient without any physical design changes.

15.1.4. MiCar Vehicle Design Evaluation using Mixed Reality

During the mixed reality evaluation two design changes were identified but not yet implemented (at the time of writing); additional perch seats and a further separation at head height between the seats.

The trial highlighted that passengers would like to have additional seating space in the form of a surface to lean on, also known as perch seats. Mounted in the area of the luggage rack, these seats would add flexibility to the cabin and offer additional comfort during longer journeys (5mins +).

The participants also stated that they would like to see an additional separation at head height, a small privacy screen, separating the two seating spaces on either bench. The challenge for the implementation of these screens is, that there was also a large group of participants who stated that they would like to communicate with their seat neighbour. Therefore, the separation would have to offer additional privacy whilst not restricting the ability of two passengers to converse.

15.2. Design Recommendations

15.2.1 Introduction

Taking the final alterations into consideration and combining them with the learnings from the entire research and development process, provides the foundation for a number of design recommendations for a driverless first and last mile mobility vehicle. The majority of which are believed to be applicable beyond this vehicle type and can be used to inform the design of any driverless vehicle concept.

15.2.2 Design Details

The *exterior HMI,* often described as the “face” of the vehicle, influences how any vehicle is perceived by the public. In the case of driverless vehicles, this becomes ever more important as there is no longer a driver who other road users can trust but instead a vehicle control algorithm which is unknown to them.

The exterior review (9.0) established that an aggressive face, made up by downward angled headlamps and a large grill will cause the vehicle to be perceived as aggressive, an unwanted effect if the aim is to grow trust into driverless technology. Round shapes and smaller or non-existing grills, on the other hand, will instead make the vehicle appear passive. This could, however, encourage pedestrians and other road users to trust the automation too much and subsequently getting dangerously close to it. This effect, therefore, has to be carefully managed in order to protect the public from endangering themselves without impacting the growth of trust.

Figure 15.1 Comparison of "aggressive (left), neutral (center) & friendly (right) vehicle face

(Bosch IoT Concept 2019, Navya Cab 2018, Waymo 2016)

In the context of driverless vehicles, the HMI is likely to extend beyond the traditional headlights and indicators, as it has to communicate additional information to other road users, displaying to them for example, that the vehicle is aware of them. An additional interface is therefore required to highlight identified obstacles and other road users, as well as informing pedestrians that the vehicle is slowing down to let them pass ahead of them at a crossing.

The HMI concept (chapter 8.2) identified a further requirement for a vehicle operating in a shared mobility system; a marking or display making it easy for users to identify the correct vehicle, based on the route or booking, prior to entering it.

The *perceived stability* of the vehicle is key to encouraging users to trust the vehicle, and as a result, be willing to use it. The graphics and proportions of a vehicle, as identified in the exterior review (chapter 9.0), influence the perception of stability greatly. Vehicles which appear to expand upwards in volume, for example, suggest to the onlooker that they are less stable than one which has more visual weight towards the lower half. These effects can be controlled and accentuated using body lines, the shape of body panels and graphics, as the aim should be to appear stable without sacrificing the headspace in the cabin caused by a smaller upper vehicle half. In the case of the MiCar concept, two prominent upright structures are leaning outwards to indicate the available headspace, which however does have the side effect of decreasing the impression of stability as it places visual weight towards the top of the vehicle (Fig. 15.2 left). Two downward and outwards pointing lines aim to counteract that by moving some of the visual weight back towards the lower half of the vehicle (Fig. 15.2 right).

Figure 15.2 Using graphics and wheel covers to suggest space and stability

The size of the wheels also influences the perception of stability, the smaller the wheels, the less stable the vehicle appears; however, smaller wheels are often required due to packaging restrictions.

A possible solution is to cover the wheels and use lines or shapes integrated into the bodywork to suggest larger wheels to the onlooker and therefore a more stable vehicle as it was done for the MiCar concept which in fact uses 10” tyres (Fig.15.2).

A large daylight opening (DLO) and the resulting large amount of natural light that reaches the cabin interior, is an important factor for the passenger comfort in any vehicle, however, in driverless last mile mobility vehicles it gains further importance. These vehicles are typically used in a shared mobility context which results in passengers entering a space with other passengers, unknown to them, causing discomfort. A bright and open space can help to alleviate some of these feelings, as it suggests a larger and more open space within the cabin (chapter 9.0 & 13.0) (Fig. 15.3).

A good view to the interior and exterior is required for several reasons; allowing passengers to observe the vehicle actions, avoid motion sickness and avoid unpleasant encounters as well as general pleasure. In the introductory phase of driverless technology, where the first and last mile mobility vehicles are expected to play a key role, the trust into the technology still has to be developed.

One way of supporting the growth of trust, according to the findings from the mixed reality study (chapter 14.0), is to give passengers the opportunity to view the path and obstacles ahead so that they can compare the vehicle reactions and movements with their own expectations. Giving passengers a clear view to the exterior will also help to reduce the effects of motion sickness, as passengers are able to anticipate vehicle movements. This is a key aspect, especially if the seating arrangement within the vehicle results in passengers sat backwards against the direction of travel. Lastly, a good view to the exterior also contributes to the general pleasure of using such a vehicle as the preferred activity is looking outside and sight-seeing, as was established in the first ergonomic study (chapter 12.0).

A view to the interior from the outside is also a crucial aspect in a shared mobility vehicle with a small cabin, it permits passengers to view into the vehicle prior to entering it, avoiding an encounter with others who they would not like to share a small space with (chapter 9.0).

For the MiCar concept, this was achieved by keeping the structural elements as small as possible whilst providing windows in all directions. The wooden rings which were added to the design to shade the vehicle and create a sense of enclosure were placed with sightlines in mind, giving passengers an unobstructed view both when seated and standing (Fig. 15.3).

Figure 15.3 Large DLO for sufficient natural light and view to the exterior

The colour and material choice for the exterior influences the perception of the vehicle, light-coloured vehicles appear less imposing and less threatening to others, which is particularly important if a vehicle operates in pedestrianised areas (chapter 9.0). A conscious choice also has to be made if the intention for the vehicle is to blend in with its surroundings or to stand out. Blending in can help with the acceptance of the vehicle but carries the risk that people will not notice them as being driverless and therefore be less careful around them.

Standing out can avoid that issue and further work well as advertisement for the technology or the mobility service provider but may be seen as an eyesore in which people do not want to be seen. The external vehicle colours can also be used to create an association with existing public transport vehicles.

The internal colour and material choices are dependent on the scenario in which the vehicle is operating, if it is used as part of the public transport network, a light-coloured seat material will quickly deteriorate and look dirty. The same material however in the context of a technology park where only employees and visitors use it, can create the impression of luxury and exclusivity (Fig. 15.3).

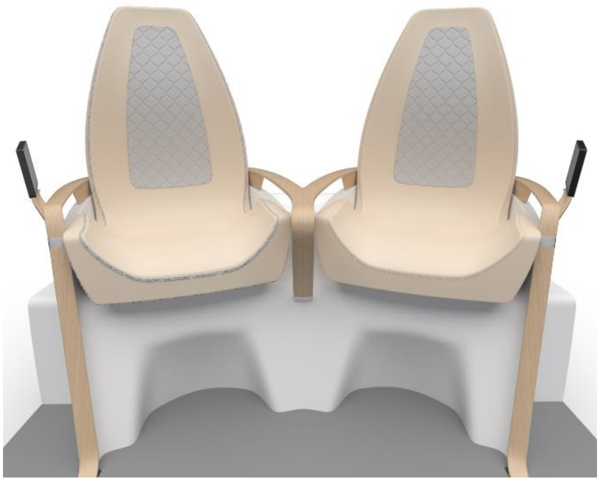


Fig. 15.4 MiCar Interior Version 1

Contrasting colours and materials in key areas such as the door aperture make it easier to spot it and other features such as edges and corners, greatly increasing the safety and the usability of the vehicle. Light strips can also be used in this application to further increase the contrast between different surfaces (Fig. 15.5).

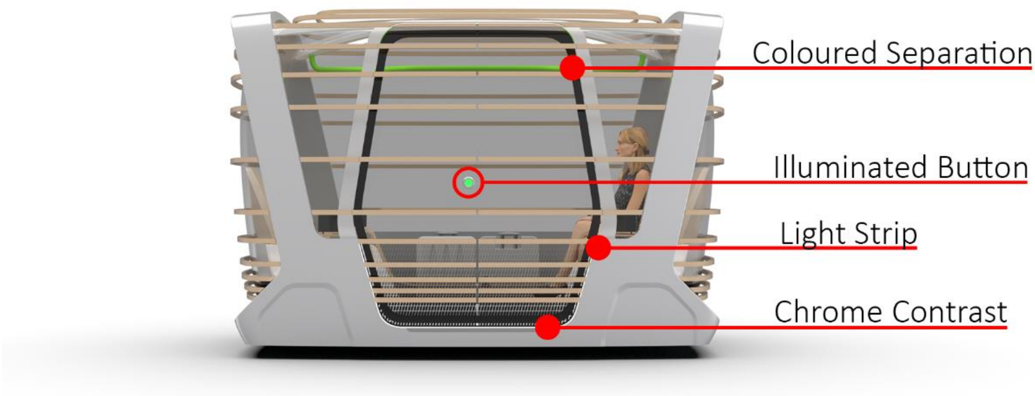


Figure 15.5 Door aperture features

A similarity to public transport vehicles can be a beneficial factor, as users will perceive it as part of a larger known network, reducing the apprehension caused by a novel method of transport (chapter 9.0). The familiarity will help passengers to understand the purpose of the vehicle and also how it is meant to be used.

It will however also raise the expectations for the vehicle as it will be directly compared to other public transport vehicles, this can be difficult in regards to reliability and comfort in the early stages of the driverless technology introduction.

Accessibility is a large topic in the first and last mile mobility context as these vehicles hold the potential to become a tool for those with mobility impairments to regain some independence as identified in the literature review (chapter 2.0).

As these vehicles are believed to become the connection between the starting point or destination with currently existing parts of the transport network, they have to be designed to allow passengers in wheelchairs or pushchairs or those travelling with luggage to enter the vehicle with ease. An automatic ramp which can extend from the vehicle at the press of a button can be a suitable solution for these issues. The ramp itself, however, is only one component, ideally, the system is aware of the next passenger requiring additional space and the ramp and will therefore only direct a vehicle to the customer which can provide both.

In the case of the MiCar concept, the floor space was therefore designed around a wheelchair, ensuring that there is sufficient space for the wheelchair user to manoeuvre themselves into its intended position whilst leaving sufficient space for any seated passengers (Fig. 15.6).

It is, however, equally as important to able-bodied passengers as it influences how easily the vehicle can be used and how little physical strain it requires to enter the vehicle, factors which rank highly in the comfort model (chapter 4.0).
A low entry step, therefore, is key, which can be achieved through a low floor profile and ride hide and further improved through intelligent suspension systems with the capability of adjusting the ride height, i.e. to “kneel down” (chapter 12.0).

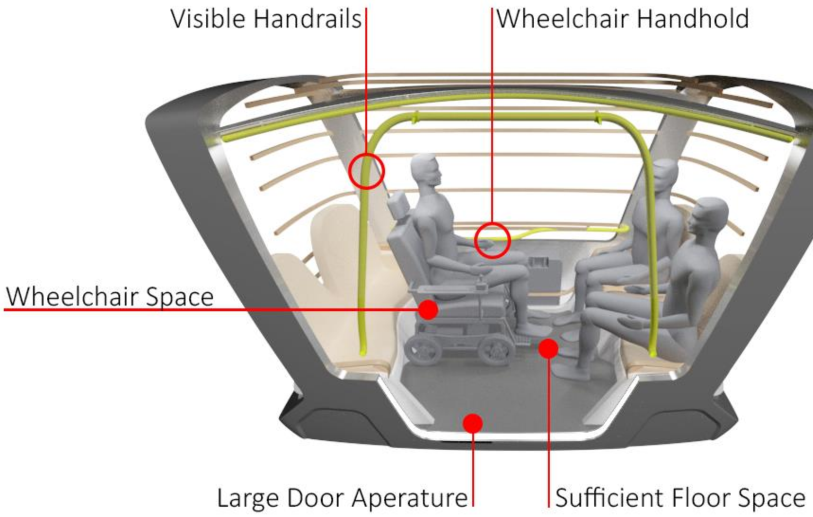


Figure 15.6 Door aperture features

The challenge of accessibility further extends beyond the physical aspects and includes the vehicle-passenger interaction, potentially requiring an HMI with different language settings or one that is easily understood through the iconography only, for those users not able to speak the local language. These requirements should also be integrated into the booking system, storing pre-sets for returning passengers (chapter 8.2).

The seating arrangement in these vehicles has a large impact on the usability and comfort of a driverless first and last mile mobility vehicle. Individual seats can provide each passenger with the required physical support to strain against themselves against vehicle movements, an important criterion especially in the initial phase when the vehicle movements are still a little jerky. It also provides a separation from other passengers, identified as important as part of the proximity comfort factor and something that a continuous bench cannot provide (chapter 4.0). Bench seats which are installed in a longitudinal direction to the vehicle movements can also result in passengers sliding along and possibly into other passengers during heavy braking.

In general, sitting sideways should also be avoided due to the potential neck strains they may experience in the same scenario.

As previously discussed, reward facing seats can cause an increase in motion sickness but are often required to efficiently use the cabin space. Therefore, solutions such as the installation at a slight inward rotated angle, as proposed in the MiCar concept (Fig. 15.7) (chapter 8.1), can be adopted. This proposal allows passengers who are travelling backwards to view the road ahead more easily in their peripheral vision which is likely to help avoid motion sickness. The previously discussed view to the exterior should also to be taken into consideration when arranging the seating as structural elements of the vehicle chassis, for example, may obstruct the view. A seating arrangement which places other passengers into the direct viewing corridor of others should be avoided as well, as this may cause some to feel stared at when the others are trying to look outside.

The arrangement also has to take wheelchair users into consideration who require sufficient space to manoeuvre without obstructing the pathways of the other passengers and a place in the vehicle where they can reach a handhold, a necessity identified as part of the ergonomic buck study (chapter 12.0). Ideally, the placement also allows wheelchair users to interact with the other passengers in the vehicle.

Privacy is also an important topic in shared mobility vehicles as it ranks third highest in the comfort model (chapter 4.0). It is closely related to the seating arrangements but also strongly influenced by societal differences and local circumstances. The comments from the last design review (chapter 14.0) illustrate this well, some passengers would like to converse with their seat neighbour, whilst others prefer a divider at head height. Generally, it can be said that in areas where the use of public transport systems is widely spread and accepted, privacy plays a lesser role than in areas where the concept of shared mobility is still new. It may however in both contexts, grow into a market differentiator as people are increasingly more concerned with their privacy and are willing to pay extra for it.

In this type of vehicle, privacy means creating a space in which passengers feel like their personal items such as the phone screen or documents which they are reading, cannot be overlooked.

The armrests are a vital component for the passenger comfort, specifically in regards to the factors physical wellbeing, proximity and usability (established in the comfort model in chapter 4.0) as they provide separation from other passengers and support when sitting down or leaving the seat (chapter 14.0).

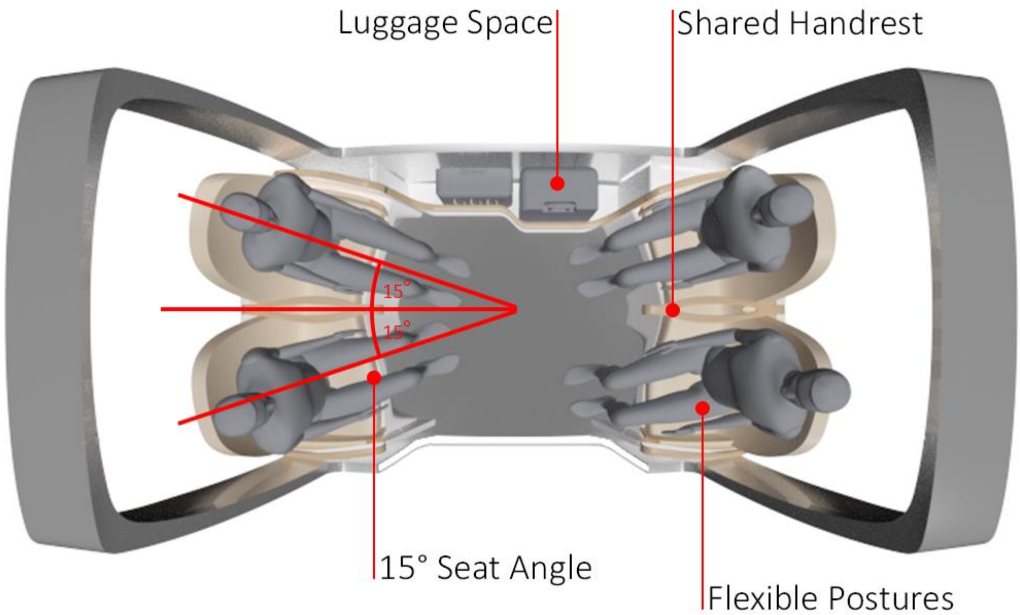


Figure 15.7 Cabin Interior Features

As discussed above, in a shared context the perception of personal space is important and can be shaped significantly through territorial props such as the armrests as they provide separation from others and clearly mark each individual space. The armrests themselves, however, have to be designed with the passengers in mind, as, for example, a single handrail in between two seats will cause issues as only one will be able to use it. Additionally, the armrests should be shaped to allow passengers to push themselves off the front part when trying to leave the seat as well as provide a comfortable place for the lower arm to rest on (chapter 14.0).

The front portion of the armrest has to be shaped in order for any passenger to be able to grip around it, to provide a secure hold when pushing off or sitting down. Splitting the armrest from the point where the passengers' grip around, could allow two passengers to use the same armrest at the same time without having to share the same surface.

The handrails are key to the usability, safety and comfort in any vehicle through which a passenger has to move or may stand-in during the journey. The handrails should be arranged in a way that there are always two within reach from one another as this is vital for any passenger who requires support when moving through the vehicle. This relates to the armrests, where a handrail should be placed close enough, so that a passenger pushing themselves out of the seat, has a handhold available to transition when fully standing, which became clear in the ergo buck evaluation (12.0).

Passengers with sight impairments often struggle with a subsequent lack of balance when walking and therefore require a handrail along which they can guide themselves (identified in chapter 12.0). Here the placement of the handrail can be used beyond helping passengers to steady themselves but also to guide them towards a seat as demonstrated in the MiCar. Here the two overhead handrails allow passengers to follow them to either end, which is above one of the four seats, simplifying the wayfinding towards a seat for those with sight impairments (Fig. 15.6.).

The handrails themselves should be coloured in a shade of yellow, ideally contrasting with the rest of the cabin interior, making them easy to spot upon entry. For the placement of all handrails, the broad range of passenger body size has to be taken into consideration. In the case of overhead handrails, for example, shorter people have to be able to reach it whilst they should not encroach the headspace of the taller passengers, an issue identified using Siemens Jack PLM (10.0).

Providing *luggage storage space*, for both, large items and small items increase the usability for and also the peace of mind of passengers greatly.

First and foremost, it is a safety aspect as luggage items such as suitcases or shopping bags should be stored securely, stopping them from falling over or moving through the cabin. The comfort model in chapter four further established that the aspect of peace of mind also relates to passengers wanting to store their luggage within their view, especially in a shared context. The storage compartment, therefore, should be easily seen from all seats and spaces for smaller personal items located directly by each seat. Due to the short journey duration, the safe placement of larger items should not require time-consuming restraining systems and to avoid any physical strain, should also not require large items to be lifted up high. The MiCar concept provides space for smaller items such as handbags at either side of the seats and a space for larger items along the side of the cabin (Fig. 15.7)

The internal HMI is not discussed as part of the design recommendation due to the limited amount of validation work conducted as part of this thesis.

15.3 Methods Review

This thesis is based on a user-centred iterative design approach and relied on a close collaboration with the research partner HORIBA MIRA to also include engineering and business insight. The design changes which were undertaken based on the findings at each evaluation stage demonstrate that the outcome of this research was significantly improved by the user-centred and iterative research design approach. This approach allowed for design decisions to be challenged in a number of trials and solutions to be developed in direct cooperation with the end-users as demonstrated in the case of the handrails.

Scenarios: The collaboration with HORIBA MIRA also provided the starting point for the research work and subsequently contributed a multitude of vital information and data. For the project, it was essential to have a real-world focal point which ensures that the outcome remains applicable to the initial goal.

Thus, together with the two further scenarios, the MIRA Technology park scenario informed the participant selections for the user trials. Using a number of specific scenarios to limit the scope of the work, however, has not only the advantage of focusing the research but also the disadvantage of potentially limiting how far the work can be applied beyond the selected scenarios. It is therefore crucial that the scenarios are chosen with this conflict in mind.

Design Concept: Using a vehicle design concept as a tool to evaluate a theoretical comfort model proved helpful as it provided a summary of the findings and an ideal tool to communicate them to a lay and expert audiences. Using this approach, the participants were able to better understand and visualise the research as well as more easily verbalise their thoughts using the concept as reference. This may, however, influence the imagination of the participant and limit their thoughts to the proposed design rather than providing a blank canvas to visualise their personal concept.

Digital Evaluation: Using a digital software tool to evaluate the basic human factors of the design provided valuable insights at an early stage of the research. It creates a quick iterative process where the digital model can be tested and then immediately updated based on the findings before being tested again. Whilst this allows the design research to quickly improve on the initial design and avoid basic human factors mistakes it does not replace user trials with expert and lay, users, as only they can inform the process by interacting with the design in potentially unknown ways. Once these use cases, however, are discovered through a user trial, the digital evaluation can then replicate them and alternative solutions can be tested. The two methods, digital and real-world testing, therefore, complement each other and should be used in parallel.

User Trials: Trials with real-world users and experts can provide significant insights into human behaviour and lead to unexpected discoveries as any participant may complete the trial task in a novel manner.

For this project, the trials were staggered to focus on separate aspects which allowed the participants to focus on specific questions without being overwhelmed. Equally, it allowed the researcher team to concentrate on individual aspects and ensure that each aspect was understood before moving on, as it was the case with the first iteration of the ergonomic buck, which evolved to a more complete and complex trial through several stages.

The chosen scenarios also set the parameters for the selection of appropriate demographics from which to recruit participants for the user trials. As the representative scenarios were based on local applications the logical consequence was recruiting participants from these locations. Whilst, similarly to the scenario choice, this may limit the number of findings that can be extrapolated to other scenarios, it does ensure that the users are representative of the scenario. It also made it easier for the participants to envision the proposed scenario as they are familiar with the circumstances and can, therefore, relate it to their existing experiences.

Ergonomic Buck: An ergonomic buck was chosen as an evaluation method for this work as it is a valuable tool to assess a variety of human factors issues within a vehicle such as egress and ingress, reachability of handholds and control as well as the cabin space. As an ergonomic buck can be finished to different standards and fidelities it is a cheap and quick solution to allow a concept to be tested with real-world users and experts.

Low fidelity ergonomic bucks are quickly built and can be created with just some cardboard and office chairs to test the basic outlines but provide only a very limited insight into the overall design of the vehicle. With increasing complexity, an ergonomic buck can more closely resemble the finished the vehicle but the more expensive and time consuming any alteration will become. The fundamental measurements were therefore tested before a more complex version was built.

In the case of the MiCar concept, the ergonomic buck started as a line drawing on the floor with some office chairs to evaluate the floor spacing and subsequently developed over several stages to a more complex construction which showed the entire cabin in full scale with the handholds and handrails replicated as well as an exact copy of the seats. Ergonomic bucks, however, are typically stationary and thus provide little insight into the experience within the vehicle during a journey which why the MiCar Mixed Reality Simulator was created.

Mixed Reality Simulator: The development of the Mixed Reality Simulator was key to the ability to evaluate the holistic design and allowed participants to fully immerse themselves into the trial, evaluating aspects which typically can only be assessed in real prototypes such as the viewing angle and amount of daylight reaching the interior. The Mixed Reality Simulator further enabled the participants to experience the design in the context it was designed for, in this case as a mobility solution on a technology park. The setup also allowed for a journey to be simulated as part of a fictional scenario which further helped contextualise the design.

As the simulator used a Virtual Reality headset in combination with a hand tracker, the novelty of the system did cause a distraction during the trials as for many participants this was the first time interacting with such a system. It is therefore important to create a system which is very intuitive to use as well as providing participants with sufficient time to familiarise themselves with the technology before using the setup to evaluate a design.

The Mixed Reality Simulator proved itself as a tool bridging the gap between a basic physical ergonomic buck setup and a real demonstrator vehicle, which would have been required for more similarly contextual design reviews. With further development and validating, a Mixed Reality Simulator could provide researchers and designers with a valuable tool at the early stages of the product development process.

15.4 Summary & Conclusion

The design details section above provides a number of recommendations for driverless first and last mile mobility vehicles, which were developed on the basis of the findings and results from the forgone aspects of this research. It is intended to provide designers, engineers and decision-makers with a summary of the most important aspects of the passenger comfort and experience which is influenced by the interior and exterior design of such a vehicle.

The comfort model for driverless first and last mile mobility vehicle, which was proposed in chapter 4.0 and the following iterations based on the trials, guided the creation of an exemplary design of a driverless vehicle for the first and last mile. In the trials, it was judged to be an easily used and comfortable vehicle and therefore the learnings from the process subsequently were used to inform the design recommendations.

Overall the work demonstrated that there is a large potential for the improvement of the user experience and comfort in currently existing driverless first and last mile mobility vehicles and proposed a number of design considerations. The review of the methods highlighted that it is important to consider when it is appropriate for them to be used and that the combination of a number of them can enhance the methods.

In the case of this particular research setting close parameters through specific scenarios and use, cases were essential to ensuring that the research scope was not too broad whilst remaining applicable to the likely scenarios. Adding the digital modelling and testing to the physical modelling in the evaluation stages allowed for changes to be made quickly and aspects to be trialled which would only be possible with a significantly higher cost with physical models. The digital methods, however, did benefit from the physical work as they provided tangible structures for participants to interact with.

8th Objective

The list above and the review of the methods completes the requirements set for this research and therefore the overall aim of the research work which was to investigate and evaluate passenger comfort and experience in the context of driverless first and last mile mobility vehicles through a novel design proposal and subsequently to produce design recommendations for such vehicles.

16.0. Conclusion

11.1. Aim & Objectives

The overall aim of this thesis was to investigate and evaluate the passenger comfort and experience in the context of driverless first and last mile mobility vehicles through a novel design proposal and lastly to produce design recommendations for such a vehicle.

16.1.2 Objectives

This was achieved through the following steps:

Initially, a literature review (chapter 2.0) was undertaken which established the state of the art for driverless vehicles, focussing on driverless technology, first and last mile mobility and on passenger comfort. The review was further used to identify and document the likely scenarios, operators and passengers for such vehicles and other possible uses for them (chapter 6.0).

Based on the review, a theoretical passenger comfort model (chapter 4.0) for driverless first and last mile mobility vehicles was established and used as a basis for a benchmark of current vehicles of this kind (chapter 5.0).

The efficacy of the model was then evaluated through three separate studies. However, in order for these trials to be conducted, the gathered information was first synthesized into a design specification for a driverless first and last mile vehicle on the MIRA Technology Park (chapter 7.0).
Subsequently, a design concept was produced which includes the appearance, package and ergonomic features in line with the specification (chapter 8.0).

The first study evaluated the likely user acceptability of six different vehicle appearances through a questionnaire and focus group (chapter 9.0). Subsequently, a digital ergonomic review of the design was undertaken using Siemens Jack (chapter 10.0).

For the following study, an ergonomic buck based on the design concept was constructed (chapter 11.0) and used to undertake user tests focussing on physical comfort (chapter 12.0).

For the last study, a selection and evaluation of suitable software and hardware was conducted for the integration into a mixed reality simulator (chapter 13.0). The mixed reality simulator was subsequently used by a test population to evaluate the vehicle design (chapter 14.0).

The findings were then synthesised to produce an overall evaluation of the design and of the approach used. Ultimately resulting in a list of suggestions outlining design features which will enhance the passenger comfort and experience in driverless first and last mile mobility vehicles (chapter 15.2).

Objective	1	2	3	4	5	6	7	8
Chapter	2.0 6.0	4.0 5.0	7.0 8.0	9.0	10.0 11.0 12.0	13.0	14.0	15.2

16.2. Contributions

16.2.1 Introduction

This thesis contributes a number of different findings in the areas of vehicle design and human factors in relation to driverless first and last mile mobility vehicles.
It further introduces a novel design evaluation methodology; a Mixed Reality Simulator, which was developed and evaluated as part of the research work.

11.6.2. Vehicle Design and Human Factors

The research established a number of key factors which relate to the comfort and user experience in driverless first and last mile mobility vehicle, which were synthesised in a list of design recommendations for this vehicle type.

Many of which also apply to other modalities and can, therefore, be used to inform the development of other driverless vehicle types.

The *comfort model* for driverless first and last mile mobility vehicle passengers proposed eight individual comfort and well-being factors and ranked their importance. It was used as a basis for a vehicle design which was subsequently evaluated and trialled in a number of studies, ultimately validating the comfort model.

The detailed *benchmark* of current driverless first and last mile mobility vehicles and concepts provides an overview of the market and documents the different approaches and design philosophies that drove each development. It also shows the various shortcomings of the current vehicles and demonstrates that the current vehicles were driven by technological development with the passenger needs receiving insufficient attention in their development.

The *MiCar Vehicle Concept* is a design which has undergone several evaluations and user trials and was developed in conjunction with a group of automotive engineers ensuring the feasibility of the concept. It, therefore, provides a platform to continue the development of a fully functional driverless first and last mile mobility vehicle, a project that is, at the time of writing, under discussion with industry partners.

The research also raised a number of unanswered research questions in regards to the vehicle interaction and HMI, for which it provides the basis for further explorations.

16.1.3 Mixed Reality Simulator

The Mixed Reality Simulator was developed in order to provide trial participants with a fully immersive environment in which they can experience and subsequently evaluate a vehicle design. The method was successfully evaluated as a research tool and employed in a large-scale evaluation of the MiCar design.

The Mixed Reality Simulator, however, can also be used for a variety of other applications and provide not only potential users but also designers, stakeholders and policymakers with an opportunity to experience a product from the very start of the development process. Applications for which the simulator could be used, extend beyond vehicle interiors to HMI testing and plane as well as train interiors.

16.3. Research Limitations

A number of limitations to this research are the result of decisions made throughout the process; initially, the selection of three specific scenarios has influenced the design requirements as well as the participant recruitment for this work. It did, however, provide a set of parameters which focused the work and ensured that the results remained directly applicable to tangible scenarios. Without the focus on these specific scenarios, the possible options in regards to the application and use cases would have been overwhelming resulting into an incoherent design concept trying to cater to too many requirements at the same time.

The scenario choice was influenced by two factors; the indication in the literature that these types of scenarios are likely to be the first applications for driverless first and last mile vehicles as well as the availability of data through HORIBA MIRA. The literature showed that technology parks, public spaces or university campuses are realistic scenarios to consider and therefore plausible future applications of the research results. The second influence was the cooperation with the research sponsor HORIBA MIRA who as the operator of the MIRA technology park provides invaluable data and insights to one of the scenarios.

At the beginning of the research project, it was their explicit wish to operate a driverless first and last mile mobility vehicle on their site, a potential direct application of the research work.

Here a large quantity of valuable data was gathered, ranging from the typical movement patterns on the site to employee commuting behaviour, all informing the research work.

Employees from the site also participated in the trials as representatives of one demographic which provided another link to the scenario. It is therefore recognised that as a result of choosing these scenarios, not all findings may be directly transferable to other scenarios beyond this scope. Thus, vehicles which travel at higher speeds and for longer distances or scenarios with higher passenger numbers require additional research to evaluate if and to which extent the findings presented in this work can be transferred.

Some of the fundamental findings however such as the visibility from the vehicle, the demand for personal space and flexibility as well as the overall vehicle impression in regards to safety and stability are likely to remain true.

16.4. Scope for Future Work

16.4.1. Introduction

The research conducted as part of the PhD focused on establishing a user-centred design of a driverless first and last mile mobility vehicle and drew up a set of design criteria for the interior design of this kind of vehicle. Due to the previously discussed limitations, it is not yet established to what extent the criteria can be applied to vehicles which are operating in different scenarios. Further research, therefore, is needed to establish to what extent the criteria can be extrapolated to alternative use cases or instead require different solutions.

However, beyond the vehicle design, there remain some unexplored aspects of the journey and the design that also have an impact on the passenger comfort experience such as the vehicle HMI and vehicle behaviour. On the basis of the research conducted for this thesis, these aspects could be considered as the logical continuation for this work.

16.4.2. HMI

The MiCar design, as well as the evaluation and trial methods developed as part of it, can provide a suitable platform to investigate this factor; the HMI concept could be integrated into the Mixed Reality Simulator in order to evaluate it in context. It could be used to study the impact of an avatar-like interface and the provision of vehicle data on the vehicle–passenger trust relationship.

Studies by Grottoli et al. also explore the internal HMI as a tool to combat the experience of motion sickness by conveying information about the vehicle movements (2018).

The mixed reality simulator would be well suited to further study the influence of travelling backwards in a vehicle on motion sickness and in relation to that if the display of motion cues or changes to the interior arrangement can be used to combat this effect.

Beyond the internal HMI research, the MiCar platform can further be used to investigate the external vehicle HMI. Driverless vehicles, especially those operating in direct proximity to pedestrians and other non-automated road user need to be able to communicate their actions and intentions.

In order for this research to be conducted, the Mixed Reality Simulator can be adapted to place trial participants in an environment where they are interacting with the vehicle in a number of different situations. Approaching a pedestrian crossing for example typically involves a communication between the person attempting to cross and the driver of the approaching vehicle. If the driver of the vehicle is removed from the equation, the interaction with the now driverless vehicle may be replaced by the external HMI.

This proposes research questions such as; “how does a pedestrian communicate with a driverless vehicle” as well as “which signals are universally understood or have to be taught to the general public”.

These questions could be extended beyond pedestrian interaction to other road users such as cyclists or non-automated vehicle drivers. And as previously mentioned in the HMI development, further modalities, such as auditory and sensory interfaces also require further investigation.

16.4.3. Safety Perception

The comfort experience in driverless vehicles is also likely to be influenced by merging distances and following distances between vehicles. As driverless vehicles are likely to be equipped with a vehicle to vehicle and vehicle to infrastructure connectivity, in theory they can be programmed to follow each other within centimetres and cross through intersections without stopping.

As this is behaviour which is currently unknown to drivers and passengers, this is likely to cause discomfort to any passenger in a driverless vehicle. Until a familiarity with the system and the vehicles is widely established, the vehicles may have to be programmed to resemble the current understanding of driving behaviour.

Further research would be needed to establish what is perceived as the appropriate merging or following distances and if giving the passenger control over it, improves the comfort experience. The Mixed Reality Simulator could be used in this context, as it permits passengers to experience a journey within a driverless vehicle, replicating different driving behaviours.

16.4.4. HORIBA MIRA Legacy Project

As a sponsor of the research, HORIBA MIRA is not only interested in the research work which was undertaken as part of the PhD but is considering to take the project further and develop it into an industry lead project.

As HORIBA MIRA is a world-renowned automotive engineering and testing business, their main interest lies within the deeper understanding of the vehicle engineering, the control software and the battery management systems.

However, as previously discussed, HORIBA MIRA is located on the MIRA Technology Park and is, therefore, considering the installation of a driverless first and last mile mobility system on their premises. Up to this point, the research and the vehicle design work provided HORIBA MIRA with vital information in regard to the potential benefit such a system would bring to the site. Furthermore, it supported the decision-makers within the company with picturing the vehicle on their road network.

Most importantly however it provided a platform under which different engineering projects, such as the battery management system or the drivetrain were unified.
These projects are now undergoing further consideration as part of a full vehicle development program.

Looking further ahead, HORIBA MIRA is constructing a test site for driverless vehicles and a prototype MiCar vehicle with an open-source code could be used as a testbed for sensor placements or vehicle control software.

16.5. Personal Note

The PhD research has also had a great impact on myself providing me with the opportunity to work on all aspects of a vehicle development project. It developed my skills as a designer and researcher as well as teaching me how to communicate and document complex concepts for expert and lay audiences.
Entering into a PhD programme directly after completing an undergraduate degree in automotive and transport design was not without its challenges. As a designer one is taught to use the available information but also to use instincts and experience to shape a product, create dozens of concepts to explore what may be possible. This describes a way of thinking and working which does not fully align with academic research rigour

which builds on detailed analysis, data sets, conventions and on precise and accurate wording. For a designer, this means that there are moments in the creative process in which one has to fully commit to the research process which may provide inarguable results that will inevitably push the design into a direction potentially unwanted by the designer. It often removes creative liberties and replaces them with statistical analysis and p-values.

It does however also provide invaluable insight and learnings which can greatly improve the product and ensure that it adequately addresses the issues it aims to tackle. It provides a foundation for design choices which, rather than based on a gut feeling, are based on data and therefore difficult to argue against.

This thesis, therefore, aimed to combine the best of both worlds and create a process in which an informed design process was supported and challenged by user trials and tests. It shaped me into a design researcher, with knowledge in design, human factors, and engineering as well as research methods, creating an unusual crossover between disciplines but leaving me well placed to connect the different fields in any project.

The academic rigour and the requirement to provide a source for each decision and argument has taught me to challenge statements or designs and always look for a reason and back story. I believe this is a valuable skill for any future project I am involved in, ensuring that nothing is ever done because it just seemed right.

This work has also introduced me to the world of academic conferences, cooperation and exchanges and allowed me to travel across the world to present my ideas and concept to peers to have them challenged and therefore improved.

The same rings true for the cooperation with the research sponsor HORIBA MIRA, without whom this project would not have taken place. The connections and insights that were provided by working closely with colleagues shaped this project significantly and brought it to the level it is at now.

Lastly, I owe a large amount of gratitude to those who I have met and worked within this process, those who have given their time, thoughts and inputs to this work. It certainly would not exist in this shape, if at all, if it would not be for the many who shared the same fascination for the topic. The exchange of ideas and thoughts with colleagues and friends was invaluable.

17.0 References

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