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Human-Focused Design Improvements for Autonomous Self-Driving Vehicles

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Abstract

Autonomous electric vehicles (AEVs) are the future that humanity is heading towards. The future of AEVs will heavily be influenced by the user experience, making the technology more accessible to everyone. In this work, we intend to develop guidelines for human-focused design enhancements to AEVs, with the aim to help people make two transitions: from ICE to EV and from non-autonomous vehicle to autonomous vehicle, which will make EV/AEV more inclusive and the implementation process occur more quickly. These guidelines are based on a collection of research papers on human-focused design, human-factor engineering, and real-world self-driving electric vehicle data. Using this foundational understanding, we conducted a hierarchical task analysis (HTA) on how to operate an AEV. The HTA was created to focus on subtasks that differ from ordinary internal combustion engine (ICE) vehicles. To prioritise ergonomic features that improve passenger safety, we surveyed Human-Focused Models which include an Accident Risk Index, an Ergonomic Attributes Index using a Fuzzy Approach and modern AI modelling methods. They will play a central role in the design and production stages of the development of new EVs and AEVs. Furthermore, we point out areas that still require innovation in battery and power propulsion systems which should inspire businesses and researchers to keep up their research and development. Our research aims to close the gap between the human factors essential for the widespread adoption of AEVs and the technological advancements in these vehicles. In the future, we hope to create a world in which autonomous electric vehicles (AEVs) are not just cars but essential easily accessible parts of everyone's daily existence with a focus on efficiency, safety, environmental awareness and inclusivity through human-focused design principles.

Keywords: Autonomous Electric Vehicles, Human Factor Engineering, Human Centred Design, Hierarchical Task Analysis, User Requirements and User-Centred Model Designs, Full Self Driving AI

NOTE: Many driving models and characteristics are proposed and examined in our research paper and each is taken into consideration separately. We draw attention to the intricate relationships between these parts and illustrate situations in which changing one of them calls for a thorough evaluation of the vehicle's overall functionality and performance. Comprehending this intricate concept is essential for creating reliable and strong autonomous driving systems as the interplay among distinct elements greatly influences the overall dependability and efficiency of the system.

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1. Introduction

The advent of marriage between EV and self-driving cars is not only a perfect match in the sense of technology and engineering, but it also marks a significant development in the transportation industry and portends safer roads, less traffic congestion and more environment friendly mobility options. As these vehicles develop and incorporate advanced AI and real-time data sensors, enough attention should also be paid to making sure that these advanced technologies are balanced by a design philosophy with human needs in mind. The academic paper *Human-Focused Design Improvements for Autonomous Self-Driving Vehicles* explores the critical intersection of technological progress, environment awareness and human factors, looking at how design approaches should be applied to create products that prioritise humanity's transition from ICEs to EVs, and from non-autonomous vehicles to autonomous vehicles.

2. Research Framework

2.1 Aims and Objectives

Aim:

Investigating and creating methods to improve the safety and user experience of autonomous electric vehicles (AEVs) is the main goal of the research paper *Human-Focused Design Improvements for Autonomous Self-Driving Vehicles*. This entails comprehending how AEVs should be built and used in a way that properly prioritises safety, energy efficiency, environment awareness and passenger comfort while helping establish autonomous driving regulations in this process. We prioritise user experiences and environmental awareness while focusing on commercial and technological viability.

Objectives:

- **Creation of HTA:** Developing a Hierarchical Task Analysis (HTA) framework focused on a design approach to improve user experience and safety in autonomous electric vehicles.
- **Analysis of User Factors:** To discuss and list the common user requirements for autonomous EVs considering human safety and comfort, especially considering people's experiences when transitioning from ICEs to EVs and from non-autonomous vehicles to autonomous vehicles.
- **Proposing User-Focused Design Improvements:** To suggest various models aimed at optimising user experience and safety of AEVs that convolve with other fronts of this new revolution in the transportation industry, including energy efficiency and environmental protection.

2.2 Methodology

A foundational understanding of the topic was created by reviewing academic research papers published in various journals on human-focused design, human engineering and real-world EV/AEV experiences and data. Using all this information, we developed a hierarchical task analysis (HTA) on how to operate an AEV. The HTA is based on the Nissan Leaf (represented with Model 1 in this work), which is the very first mass-produced electric car in the world, and the Tesla Model X with FSD (represented with Model 2 in this work), which is the closest commercially available fully autonomous electric vehicle (Level 2 based in current SAE standard). Based on the HTA, we highlighted what a balanced yet human-focused design should look like. We then conducted research into certain areas that required improvement and proposed possible solutions to the problems.

2.3 Literature Review

Human-Focused Design of Vehicles

Brooks et al., 2018 stressed the significance of using a human-focused design process when creating passenger compartments for vulnerable groups like working mothers or people with visual impairments. Using interviews with these individuals the study enhanced metrics related to user satisfaction underscoring the imperative need for customised design in electric vehicles. The most significant lesson learned from these interviews is that the opinions of general customers are heavily influenced by their experiences with ICE vehicles. Meanwhile, there is no doubt that EVs have provided new opportunities to revisit classical ICE vehicle designs, offering more satisfying experiences for human transportation.

Experiences and Lessons for Advanced Power Technologies in EV/AEV Development

Power technologies are the very centre of the EV/AEV industry and the origin of this industry revolution. For the time being, battery technology (with Li-ion batteries as the current representative) is the single fastest-developing department of the car industry.

O. J. in 2023 tested and reviewed the ten-year long-term use of Li-ion battery use on the very first mass-produced EV model (Model 1). The findings showed how the Li-ion batteries performed better than expected over long-term use and also pointed out that important improvements should be implemented in EV/AEV design concerning the battery system to optimise human experiences (Jiang, 2023).

The same work also provided important perspectives for future power technologies developments beyond Li-ion batteries and illustrated how electric power technologies are crucial to nearly all other fronts (like sensory technologies) of EV/AEV designs in the future.

Advanced Sensory Technologies for Vehicle Operation

Sensory technology will play a central role in autonomous driving. In the short several years since EVs came to the market, sensory technology’s progression almost rivalled that of batteries. Besides the current development focus on autonomous driving sensors outside of the vehicle, we want to point out that the sensory technologies that support in-cabin awareness and technologies, and that which fuse in and out-of-cabin sensors for decision-making, are also important in future EV/AEV sector growth.

Rahmati and Talebpour, 2017 examined how to integrate cutting-edge driver sensing technologies to track driver activity, cognitive load and state in real time. This approach improves Advanced Driver Assistance Systems (ADAS) and vehicle interfaces making driving safer and more individualised. Tesla's Autopilot system is a prime example of how this is done.

Human-Machine Interface (HMI) Design

Besides the experiences of traditional vehicle ergonomic design, the Human-Machine Interface (HMI) could be crucial for EV/AEV experiences in the acceptance of customers, especially in the phase-in stage.

Chen et al., 2020 emphasised how crucial good HMI design is to enable smooth communication between users and driverless cars. The study stressed the significance of providing support for both automated and manual driving modes and suggested creating systems that facilitate seamless transitions between varying degrees of autonomy thereby augmenting user assurance and safety.

Through our research, we could see the transition to EV HMI could be divided into different stages to help customers adapt to EV/AEV experiences and alleviate stress in the transition from ICE vehicle to EV/AE vehicle. Model 1 and Model 2 clearly show two different stages of this very idea (Jiang, 2023).

Naturalistic Start and Brake Policy and Shared Control

Many studies and real-life experiences with EV/AEV (Model 1 & 2) suggested a divergence of in-cabin human experiences with EV/AEV. For drivers moving from ICE vehicles to EVs, the experiences are overwhelmingly positive. However, for passengers, the results are more mixed. Their main complaints focus on two distinct phases of the riding experience: the initial acceleration and the braking. (This more or less resembles the riding experience on a racing car.) Meanwhile, the feedback on AEVs at the current stage is more mixed, even for drivers. These phenomena are intrinsic to the power system revolution and also related to the experiences with ICE vehicles which have influenced customer expectations. We recommend that human-focused EV/AEV design should work on these issues.

Rahmati et al., 2021 talk about incorporating a naturalistic brake policy that adapts to human driving behaviours and can significantly enhance user trust and safety in autonomous vehicles. Studies show that designing vehicle control systems that inform users of the system's capabilities and limitations, rather than attempting to achieve perfect autonomous navigation, can lead to better user experiences and safety outcomes (Fridman, 2019).

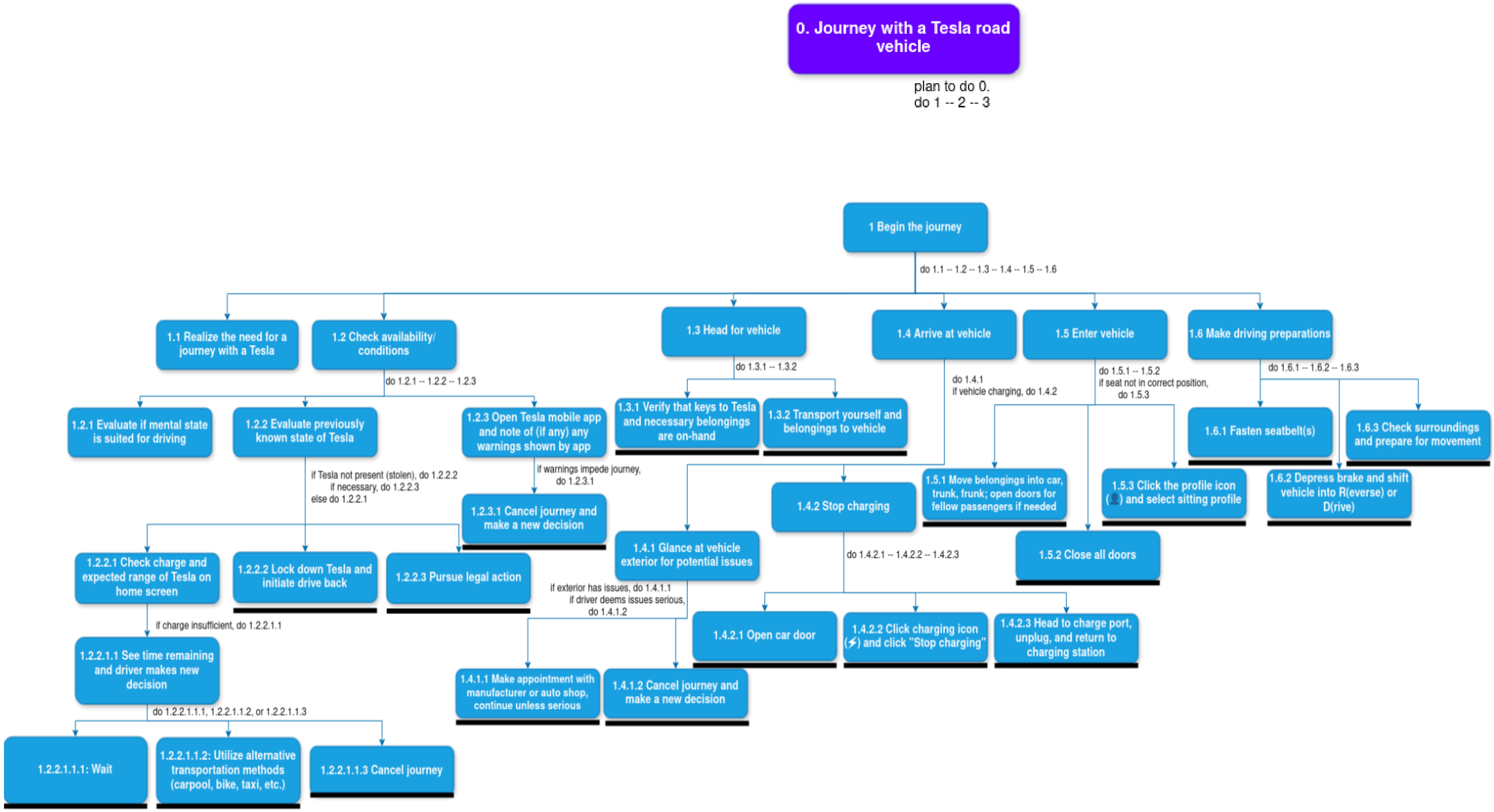
3. Hierarchical Task Analysis (HTA)

Hierarchical task analysis is a method of breaking down a large task (say, making a journey with an EV) into smaller subtasks, allowing for a close-up analysis of what makes an EV journey different from an ICE journey and helping designers and engineers create more functional vehicles per the aforementioned user requirements.

This specific HTA was designed with an AEV in mind and specifically highlights subtasks that differ from typical ICE vehicles, particularly in the areas of charging and the capabilities of the electronic computer inside the vehicle. More in-depth decisions relating to car customisation were not included as they do not pertain directly to the typical car journey, but they may be customised as needed.

Note: under Task 2 (during the journey), different colours determine actions that depend on the preselected mode under which the car is being driven, given designations A (manual), B (semi-autonomous), and C (fully autonomous). Note that certain tasks are to be done for both the B and C cases, in which case the subtask is denoted B/C and the box has a gradient.

Fig 1A:



0. Journey with a Tesla road vehicle
plan to do 0.
do 1 -- 2 -- 3
1 Begin the journey
do 1.1 -- 1.2 -- 1.3 -- 1.4 -- 1.5 -- 1.6
1.1 Realize the need for a journey with a Tesla
1.2 Check availability/ conditions
do 1.2.1 -- 1.2.2 -- 1.2.3
1.2.1 Evaluate if mental state is suited for driving
1.2.2 Evaluate previously known state of Tesla
if Tesla not present (stolen), do 1.2.2.2
if necessary, do 1.2.2.3
else do 1.2.2.1
1.2.2.1 Check charge and expected range of Tesla on home screen
if charge insufficient, do 1.2.2.1.1
1.2.2.1.1 See time remaining and driver makes new decision
do 1.2.2.1.1.1, 1.2.2.1.1.2, or 1.2.2.1.1.3
1.2.2.1.1.1: Wait
1.2.2.1.1.2: Utilize alternative transportation methods (carpool, bike, taxi, etc.)
1.2.2.1.1.3 Cancel journey
1.2.2.2 Lock down Tesla and initiate drive back
1.2.2.3 Pursue legal action
1.2.3 Open Tesla mobile app and note of (if any) any warnings shown by app
if warnings impede journey, do 1.2.3.1
1.2.3.1 Cancel journey and make a new decision
1.3 Head for vehicle
do 1.3.1 -- 1.3.2
1.3.1 Verify that keys to Tesla and necessary belongings are on-hand
1.3.2 Transport yourself and belongings to vehicle
1.4 Arrive at vehicle
do 1.4.1
if vehicle charging, do 1.4.2
1.4.1 Glance at vehicle exterior for potential issues
if exterior has issues, do 1.4.1.1
if driver deems issues serious, do 1.4.1.2
1.4.1.1 Make appointment with manufacturer or auto shop, continue unless serious
1.4.1.2 Cancel journey and make a new decision
1.4.2 Stop charging
do 1.4.2.1 -- 1.4.2.2 -- 1.4.2.3
1.4.2.1 Open car door
1.4.2.2 Click charging icon (⚡) and click "Stop charging"
1.4.2.3 Head to charge port, unplug, and return to charging station
1.5 Enter vehicle
do 1.5.1 -- 1.5.2
if seat not in correct position, do 1.5.3
1.5.1 Move belongings into car, trunk, frunk; open doors for fellow passengers if needed
1.5.2 Close all doors
1.5.3 Click the profile icon ( ) and select sitting profile
1.6 Make driving preparations
do 1.6.1 -- 1.6.2 -- 1.6.3
1.6.1 Fasten seatbelt(s)
1.6.2 Depress brake and shift vehicle into R(everse) or D(rive)
1.6.3 Check surroundings and prepare for movement

Fig 1B:

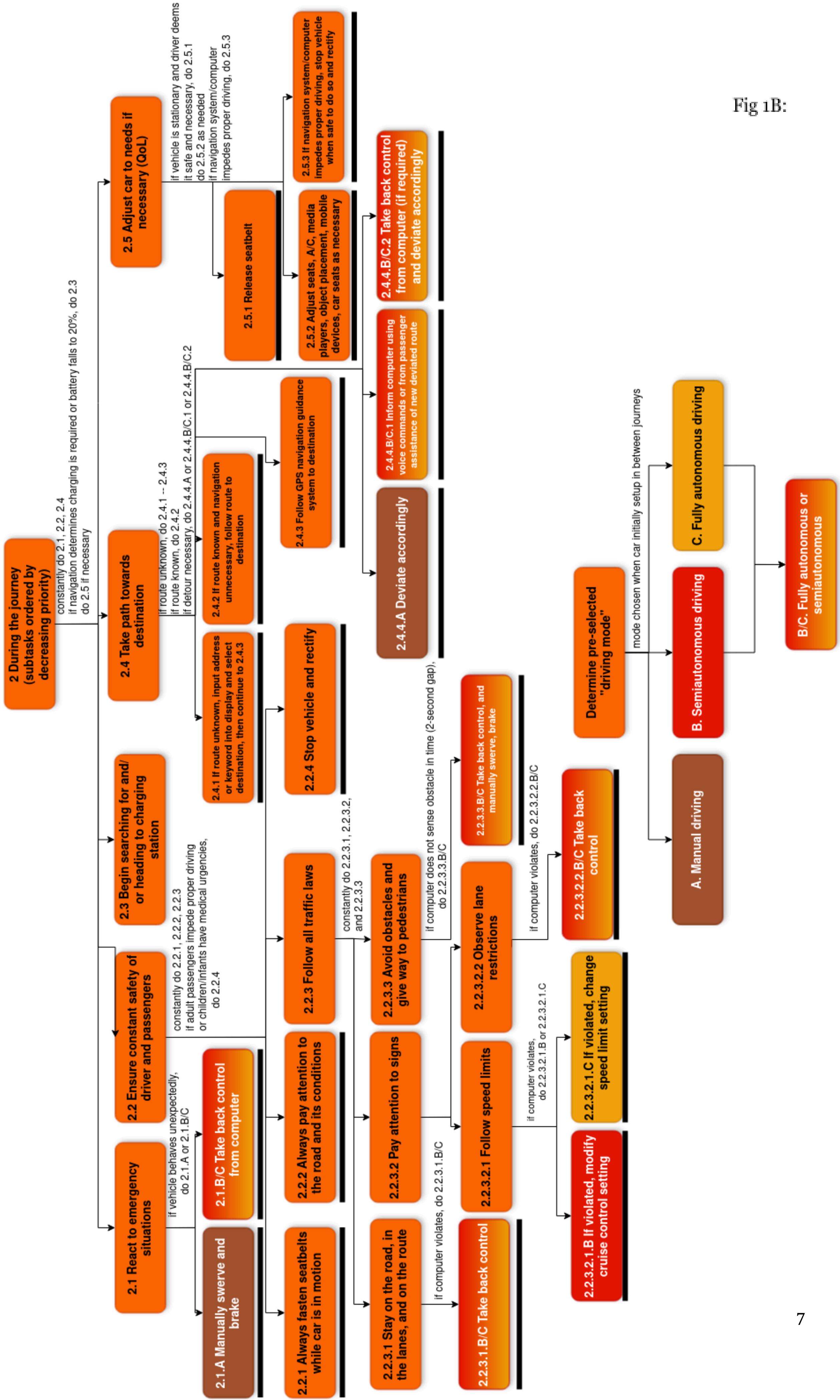
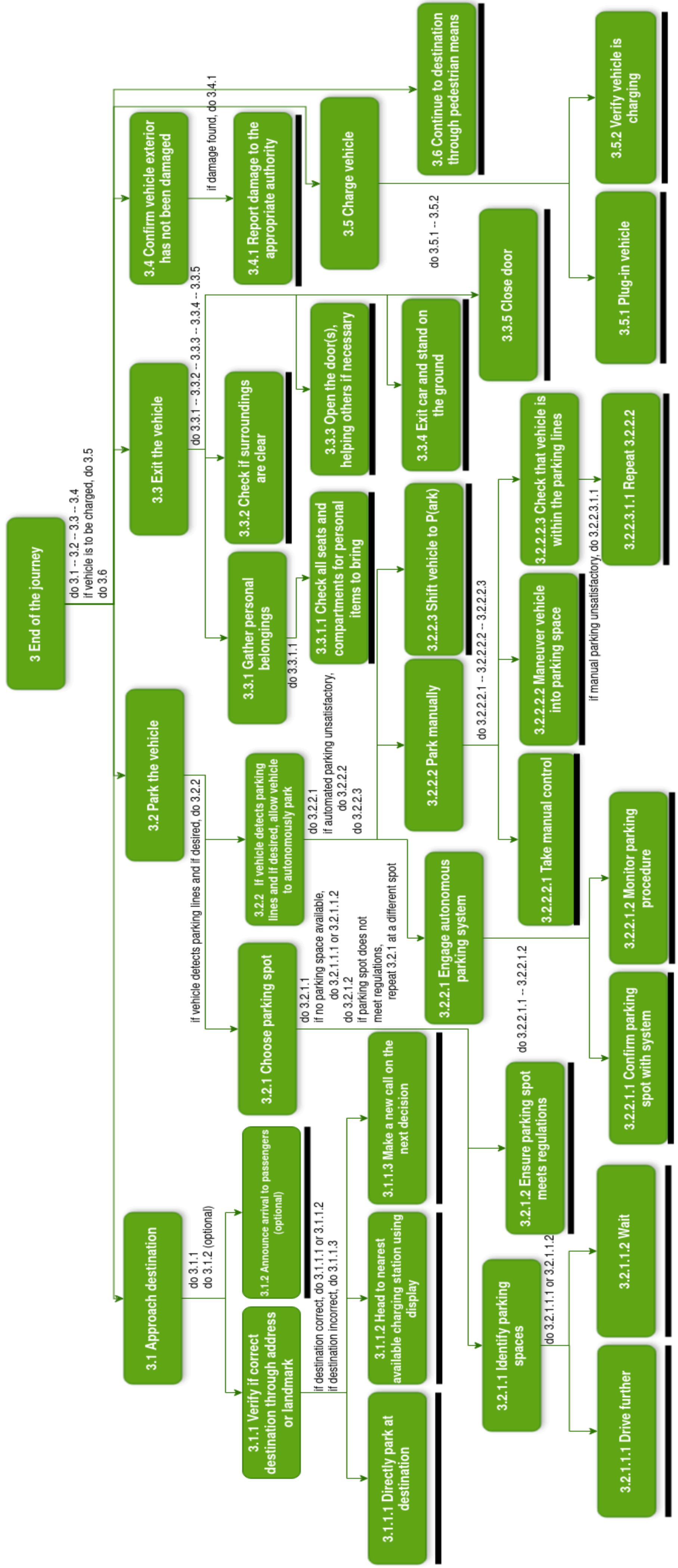

2 During the journey (subtasks ordered by decreasing priority)
constantly do 2.1, 2.2, 2.4
if navigation determines charging is required or battery falls to 20%, do 2.3
do 2.5 if necessary
2.1 React to emergency situations
if vehicle behaves unexpectedly, do 2.1.A or 2.1.B/C
2.1.A Manually swerve and brake
2.1.B/C Take back control from computer
2.2 Ensure constant safety of driver and passengers
constantly do 2.2.1, 2.2.2, 2.2.3
if adult passengers impede proper driving or children/infants have medical urgencies, do 2.2.4
2.2.1 Always fasten seatbelts while car is in motion
2.2.2 Always pay attention to the road and its conditions
2.2.3 Follow all traffic laws
2.2.4 Stop vehicle and rectify
constantly do 2.2.3.1, 2.2.3.2, and 2.2.3.3
2.2.3.1 Stay on the road, in the lanes, and on the route
if computer violates, do 2.2.3.1.B/C
2.2.3.1.B/C Take back control
2.2.3.2 Pay attention to signs
2.2.3.2.1 Follow speed limits
if computer violates, do 2.2.3.2.1.B or 2.2.3.2.1.C
2.2.3.2.1.B If violated, modify cruise control setting
2.2.3.2.1.C If violated, change speed limit setting
2.2.3.2.2 Observe lane restrictions
if computer violates, do 2.2.3.2.2.B/C
2.2.3.2.2.B/C Take back control
2.2.3.3 Avoid obstacles and give way to pedestrians
if computer does not sense obstacle in time (2-second gap), do 2.2.3.3.B/C
2.2.3.3.B/C Take back control, and manually swerve, brake
2.3 Begin searching for and/ or heading to charging station
2.4 Take path towards destination
if route unknown, do 2.4.1 -- 2.4.3
if route known, do 2.4.2
if detour necessary, do 2.4.4.A or 2.4.4.B/C.1 or 2.4.4.B/C.2
2.4.1 If route unknown, input address or keyword into display and select destination, then continue to 2.4.3
2.4.2 If route known and navigation unnecessary, follow route to destination
2.4.3 Follow GPS navigation guidance system to destination
2.4.4.A Deviate accordingly
2.4.4.B/C.1 Inform computer using voice commands or from passenger assistance of new deviated route
2.4.4.B/C.2 Take back control from computer (if required) and deviate accordingly
2.5 Adjust car to needs if necessary (QoL)
if vehicle is stationary and driver deems it safe and necessary, do 2.5.1
do 2.5.2 as needed
if navigation system/computer impedes proper driving, do 2.5.3
2.5.1 Release seatbelt
2.5.2 Adjust seats, A/C, media players, object placement, mobile devices, car seats as necessary
2.5.3 If navigation system/computer impedes proper driving, stop vehicle when safe to do so and rectify
Determine pre-selected "driving mode"
mode chosen when car initially setup in between journeys
A. Manual driving
B. Semiautonomous driving
C. Fully autonomous driving
B/C. Fully autonomous or semiautonomous

Fig 1C:



3 End of the journey
do 3.1 -- 3.2 -- 3.3 -- 3.4
if vehicle is to be charged, do 3.5
do 3.6
3.1 Approach destination
do 3.1.1
do 3.1.2 (optional)
3.1.1 Verify if correct destination through address or landmark
3.1.2 Announce arrival to passengers (optional)
if destination correct, do 3.1.1.1 or 3.1.1.2
if destination incorrect, do 3.1.1.3
3.1.1.1 Directly park at destination
3.1.1.2 Head to nearest available charging station using display
3.1.1.3 Make a new call on the next decision
3.2 Park the vehicle
if vehicle detects parking lines and if desired, do 3.2.2
3.2.1 Choose parking spot
do 3.2.1.1
if no parking space available, do 3.2.1.1.1 or 3.2.1.1.2
do 3.2.1.2
if parking spot does not meet regulations, repeat 3.2.1 at a different spot
3.2.1.1 Identify parking spaces
do 3.2.1.1.1 or 3.2.1.1.2
3.2.1.1.1 Drive further
3.2.1.1.2 Wait
3.2.1.2 Ensure parking spot meets regulations
3.2.2 If vehicle detects parking lines and if desired, allow vehicle to autonomously park
do 3.2.2.1
if automated parking unsatisfactory, do 3.2.2.2
do 3.2.2.3
3.2.2.1 Engage autonomous parking system
do 3.2.2.1.1 -- 3.2.2.1.2
3.2.2.1.1 Confirm parking spot with system
3.2.2.1.2 Monitor parking procedure
3.2.2.2 Park manually
do 3.2.2.2.1 -- 3.2.2.2.2 -- 3.2.2.2.3
3.2.2.2.1 Take manual control
3.2.2.2.2 Maneuver vehicle into parking space
3.2.2.2.3 Check that vehicle is within the parking lines
if manual parking unsatisfactory, do 3.2.2.3.1.1
3.2.2.3.1.1 Repeat 3.2.2.2
3.2.2.3 Shift vehicle to P(ark)
3.3 Exit the vehicle
do 3.3.1 -- 3.3.2 -- 3.3.3 -- 3.3.4 -- 3.3.5
3.3.1 Gather personal belongings
do 3.3.1.1
3.3.1.1 Check all seats and compartments for personal items to bring
3.3.2 Check if surroundings are clear
3.3.3 Open the door(s), helping others if necessary
3.3.4 Exit car and stand on the ground
3.3.5 Close door
3.4 Confirm vehicle exterior has not been damaged
if damage found, do 3.4.1
3.4.1 Report damage to the appropriate authority
3.5 Charge vehicle
do 3.5.1 -- 3.5.2
3.5.1 Plug-in vehicle
3.5.2 Verify vehicle is charging
3.6 Continue to destination through pedestrian means

4. User Experiences and Feedback

Before discussing the various user experiences in an EV, we discuss the nature of autonomous driving and the technology prevalent in autonomous EVs.

Autonomous driving can be classified into the following levels (SAE J3016):

- **Level 0: No automation.**
- **Level 1: Basic driver assistance**, such as adaptive cruise control, lane-keeping assistance and road sign recognition.
- **Level 2: Partial autonomous driving**, where the vehicle can control both steering and acceleration, but the driver must remain engaged.
- **Level 3: Conditional autonomous driving**, where the vehicle can handle all driving tasks in certain conditions, but the driver must be ready to take over at every moment.
- **Level 4: High autonomous driving**, where the vehicle can handle all driving tasks and monitor the environment in specific conditions or vulnerable areas without human intervention.
- **Level 5: Full autonomous driving**, where the vehicle can operate independently under all conditions without any human intervention. (Park and Kee, 2021) (Dai et al., 2021)

The technology of autonomous driving should be developed in the following major aspects:

- **Sensor suite:** EVs have integrated sensors such as LIDAR, radar and full self-driving (FSD) cameras to support autonomous driving features, even allowing for differentiation between real cars (3D) and images of cars (2D). This comprehensive sensor integration enhances the vehicle's ability to perceive and interpret its surroundings accurately, improving the effectiveness of autonomous driving features and ensuring safer navigation by distinguishing between real-world objects and images.
- **Software and algorithms:** EVs are using advanced software to perform real-time decision-making, object detection and path planning. Advanced software and algorithms enable the vehicle to make swift, informed decisions, detect and avoid obstacles and plan optimal routes, enhancing overall driving safety and efficiency.
- **Certain information exchange or communication capabilities to obtain road and traffic network conditions:** We strongly believe that AEVs, especially higher-level ones, would not be possible without certain vehicle capabilities in obtaining road and road network conditions.
- **Safety and security:** EVs have robust cybersecurity measures to protect autonomous systems from hacking and/or unauthorised access. These cybersecurity measures safeguard critical vehicle systems from potential cyber threats, ensuring the integrity and safety of both the vehicle's operation and the driver's personal data.
- **Regulatory compliance:** EVs have to adhere to local and international regulations regarding autonomous driving, including testing and deployment guidelines. Compliance with regulatory standards ensures that the vehicle meets safety and performance benchmarks, facilitates smoother approval for deployment and builds trust with consumers by adhering to established legal and safety protocols. (Dai et al., 2021)

EVs (electric vehicles) are a completely new stage in the automobile market and industry, offering new alternatives to traditional internal combustion engine cars. Firstly, EVs significantly reduce greenhouse gas (CO_2) emissions, contributing to a cleaner environment and reducing consumer impact on climate change—as EVs do not produce gas emissions, they do not contribute to air pollution and improve public health efforts.

Secondly, EVs provide economic advantages. Although the initial purchase price of an electric vehicle can be higher, the total cost of ownership is generally lower due to reduced fuel expenses and maintenance costs. Electric motors have fewer moving parts than combustion engines, leading to, on average, fewer repair expenses and a much longer service life. Additionally, many governments offer incentives, such as tax credits and rebates, to encourage the adoption of electric vehicles, which build an easier ramp for customers to make the conversion from ICE vehicles.

Moreover, advancements in battery technology are extending the range of EVs, alleviating concerns about limited driving distances. The development of robust charging infrastructure, including but not limited to fast-charging stations, further improves the facilities and infrastructure needed to support the owning of an electric vehicle. There are two new technologies on the horizon of the charging sector worth mentioning here.

- One is the battery swap system which has been adopted by some EV manufacturers, e.g. NIO, a Chinese EV company, whose pilot swapping station can replace a flat battery with a newly charged one in only 15 minutes. Not only does this model shorten the customer waiting time, but it also reduces the initial investment amount since the customer only rents the battery, rather than owning it. On the other hand, the asset investment for the manufacturer will increase by a lot. We forecast this model will be promising for the early stage adoption under strong government incentives support, or support from long-term capital investment.
- The other charging technology is wireless charging, including stationary wireless charging and road-embedded wireless charging systems. For stationary wireless charging systems, universal standards or protocols would be our recommendation for a successful human-focused EV/AEV design. On the side of the road-embedded wireless charging system, it is intrinsically a human-focused EV/AEV design which could significantly improve human experiences in road travel. Several European and Asian countries have constructed pilot road sections using this technology. We believe it could be a game-changer for EV/AEV adoption if it can be widely implemented (Thomas, 2023).

As battery production rises, costs are expected to decrease in parallel, making EVs even more accessible and affordable.

Finally, EVs offer a superior driving experience. They provide instant torque, resulting in quick acceleration and good performance. The quiet operation of electric motors also leads to a more peaceful and quiet driving experience (although there are some concerns that this may impact pedestrian notice of oncoming vehicles). With continuous innovation and investment in the EV sector, the future of transportation will be increasingly electric, and such improvements will bring forth significant benefits to the environment, economy, and driving experience.

To realise those targets, there are some requirements for the EV:

4.1 Performance Expectations with Human Experiences in Mind

Overall, EV/AEV performance overwhelmingly prevails ICE vehicles. The performance expectations with human experiences in mind shall focus on how to reduce transition barriers and alleviate the worries of customers when they move from ICE cars to EV cars and from non-autonomous cars to autonomous cars.

- **Range**: From a customer point of view, EVs should have sufficient range to meet daily driving needs and alleviate so-called “range anxiety”. The typical target range is around 400 to 600 km per charge, which ensures that EVs can comfortably handle daily commutes and longer trips without frequent recharging, significantly reducing range anxiety and making them practical for a wide range of driving needs. Expectations on this side shall be addressed through battery capacity and HMI in vehicle design and manufacturing (see section below).
- **Charging experience:** Fast charging capabilities are essential. Based on customer feedback, optimal EVs recharging time could be around 30 minutes (up to 80% capacity). Rapid charging reduces downtime at charging stations, allowing for quick top-ups during long journeys and making daily use more convenient by minimising the time spent waiting for a full charge.
- **Acceleration control:** We now know many early time studies on EV design had some fundamental flaws (e.g. Ulrich, 2005) concerning EV performances. The top acceleration of EVs can intrinsically and easily match top-line ICE vehicles, so much so that it has become a main drawback in riding experiences. This issue became so toxic that it negatively influenced the design decisions of many EVs/AEVs on the market now, e.g. Model 2 in our study, then worsened user experiences in the long run (Dale, 2024 and Steinmetz, 2021). Unfortunately, the pursuit of short-term sales figures still prevails over the long-term user experiences with EVs/AEVs for now. This is one of the most important issues our human-focused EV/AEV design shall address. EV/AEV design shall at least provide an option for a lower acceleration experience for the passengers who wish to have a smooth ride. Furthermore, the

industry shall gradually let the overfixation of the concept of acceleration time (zero to sixty mph) fade away. It's a concept useful for ICE evaluation but not at all appropriate for EVs/AEVs from the first principles point of view.

4.2 Power System, Charging Infrastructure and Electric/Electronic Systems

- **Battery capacity threshold:** Based on long-term user experiences and market feedback, we support the battery capacity threshold design to be implemented throughout the EV/AEV industry as one of the most important human-focused measurements. We support the evaluation from Jiang, 2023 that a 50-60 kWh capacity would be an appropriate threshold for any EV/AEV. This will remove most range anxiety of users (see above section).
- **Battery lifespan:** EVs need long-lasting batteries with warranties covering around 130,000-160,000 kilometres. Extended battery life and robust warranties provide peace of mind to owners by ensuring long-term reliability and reducing concerns about battery degradation, ultimately enhancing the vehicle's value and reducing total ownership costs.
- **Battery technology:** EV companies need to improve battery technology with higher energy density, safety, faster charging and longer range. Advances in battery technology led to greater energy density and safety, shorter charging times, and extended driving range, making EVs more efficient, reliable, and user-friendly, thereby enhancing overall driving experience and convenience.
- **Charging network:** For EVs, we need to have availability and diversity of charging stations in a country (charging stations in cities, small towns, at highway service stations), including fast chargers, to support both urban and long-distance travel. New charging station technologies like the battery swap station and the wireless charging system (discussed in the beginning of Part 4) could not only improve the performance of EV/AEV, but also could be a game changer for human-focused EV/AEV experiences. A well-distributed and multi-layer charging network ensures convenient and accessible recharging options, supports both daily urban use and long-distance journeys and alleviates range anxiety, making EVs a practical choice for all types of travel.
- **Sociability:** If you live in a rural area without access to charging stations, an EV company can assist you in installing a charging station at your home, allowing for convenience in driving and charging. This helps the user maintain social circles and allows for better energy choices that would not prevent social interactions due to a lack of charging options. For example, companies like Tesla offer home charging solutions and provide installation support. Additionally, many local electricians are certified to install EV chargers, ensuring that you have reliable access to charging your vehicle. This enhances your social inclusion and ensures you stay connected with your community.
- **Battery security:** EV batteries should not spontaneously combust. Utilising non-combusting batteries enhances safety by reducing the risk of battery fires or explosions, and increasing the vehicle's reliability and providing greater peace of mind for owners. (DeLuchi et al., 1989)
- **Electric and electronic system:** Since almost all EV/AEV subsystems heavily depend on electric/electronic systems. The reliability design of electric/electronic systems is crucial not only to the reliability, safety and the vehicle, but also decisive to human experiences in both short and long term. This also impacts sustainability and the environment in the long run (Marr3wk, 2021).

4.3 Environmental Impact

- **Sustainability:** EVs need to use sustainable materials and processes in manufacturing EVs and batteries. Most poignantly, the acquisition of cobalt through mining in countries like the Democratic People's Republic of the Congo is harmful for the environment and also comes at great human costs. (This has resulted in Tesla aiming to reduce its usage of cobalt in its EV batteries.) Utilising sustainable materials and processes minimises the environmental impact of production, supports resource conservation, and aligns with eco-friendly practices, making the entire vehicle lifecycle more environmentally responsible. From a wider energy budget perspective, making each electric vehicle with more sustainable components is important to reducing the footprint of the entire vehicle's lifespan.
- **Emissions:** EVs have, by principle, zero tailpipe emissions. This reduces urban pollution and greenhouse gas emissions. Zero tailpipe emissions contribute to cleaner air in urban areas, reducing harmful pollutants and greenhouse gases, combating climate change and improving public health.

- **Research on urban population limits:** Prior understanding and regulation of urban pollution limits by measuring the concentration of particulate matter helps set effective regulations and benchmarks for air quality, ensuring that EVs and other measures contribute to meaningful reductions in pollution and enhance overall environmental health. (Hawkins et al., 2012)

4.4 Cost Considerations

- **Purchase price:** EVs must have competitive pricing with traditional internal combustion engine vehicles, considering government incentives and subsidies. Competitive pricing makes EVs more accessible to a broader range of consumers, while government incentives and subsidies further reduce the initial cost, accelerating adoption and making EVs a financially viable option for more buyers.
- **Total cost of ownership:** Lowering long-term costs is vital—this can be in the form of savings on fuel, maintenance, and potential tax benefits for EVs. Lower long-term costs are achieved through reduced expenditures on fuel and maintenance, as well as possible tax benefits, resulting in substantial savings over the vehicle's lifespan and making EVs a more economical choice for owners. (Patil and Kalkhambkar, 2021)

4.5 Regulatory Compliance

EVs have to adhere to local and international regulations regarding autonomous driving, including testing and deployment guidelines. Compliance with regulatory standards ensures that the vehicle meets safety and performance benchmarks, facilitates smoother approval for deployment, and builds trust with consumers by adhering to established legal and safety protocols.

4.6 Suspension and Driving Comfort

- EVs use modern designs focusing on aerodynamics and energy efficiency. This design approach enhances vehicle performance by reducing drag, improving range and contributing to overall energy efficiency (Bhatnagar et al., 2024).
- EVs shall continue the development of more advanced suspension systems, such as air or adaptive suspensions, to better deal with weight distribution. Because the main weight is located at the bottom of the car (the only place the battery should go), the centre of mass has lowered but the mechanics on the suspension have changed. For this reason, EV ball joints tend to wear down faster, as do the front axles.
- The design of the suspension for ICE cars tends to be mostly the same because the distribution of the weight is the same—it is now settled for the most part that the weight should be either in the front of the vehicle, where the engine is located, or in the back of the vehicle, where a more complicated mechanical design is needed. Most traditional car companies make cars with front-wheel drive, primarily for safety reasons (reducing the chance of a flip). This setup meant the engine was effectively pulling the rest of the vehicle forward.
- The arrival of the electric vehicle caused innovative companies to be excited to begin using a rear-wheel drive approach (it helps with terrain, it's more balanced, better traction, etc.). However, the addition of an incredibly heavy battery underneath the car threw the previously established setup out of the window. Due to the sheer density and weight of the large traction battery under the car, an upper-lower weight distribution analysis proved to be more useful than a front-back approach. As the heaviest component of the entire vehicle, the lithium-ion battery's only possible and reasonable location is under the floor. While this improves stability (it isn't generally safe or sensible to be carrying top-heavy loads), this means that over longer periods of time, the suspension would have to deal with a constant downward push by the heavy battery. Given the clearly novel situation, it seems reasonable to advocate for a complete overhaul of the suspension system. It would be necessary to strengthen the front of the car for front-mounted electric motors or pay close attention to the back for rear-mounted electric motors. Tesla's suspension in particular has led to problems in the running gear and the alignment. Although many different solutions have been tested (air suspension, adaptive automatic suspension, intelligent/real-time adjustment), the fundamental difficulties remain.

- EV/AEV design shall invest more in tyre design, mostly focusing on tyre material research and development. We shall point out that both suspension design and tyre material design not only serve the purpose of riding comfort but also the long-term customer experiences and satisfaction.

4.7 Interior Environment Design and Connectivity Technology

- EV/AEV interior shall focus on environmental design, which includes but is not limited to climate control, ergonomics efficiency, interior material and light design, etc.
- On the design of climate control, the market and industry have concluded, after multiple tried and tested solutions in the past, that at the current stage, heat pump technology should be the choice of solution to provide high-efficient climate control in human-focused EV/AEV design.
- EVs are equipped with spacious interiors and ample cargo space, featuring high-quality materials like Nappa leather and organic, recyclable materials that minimise environmental impact. Infotainment systems in EVs often include premium sound systems such as Bowers & Wilkins or Bang & Olufsen, providing clear and immersive audio experiences. This ensures a luxurious and pleasant driving experience with ample room for passengers and cargo. High-quality materials enhance comfort and luxury, while premium sound systems deliver superior audio quality. The use of sustainable materials also supports environmental stewardship, and the spacious design improves overall travel comfort (Welsh and Pierce., 2018).
- EVs are equipped with advanced infotainment systems, connectivity features, autonomous driving capabilities, and regular software updates, including an app on the mobile phone of the owner for the EV to allow the driver to access the EV easily. For example, the Tesla app can lock the car, control the A/C, plan the next trip, display charging data, and perform other features. These features provide a seamless and intuitive driving experience, allowing for real-time updates, enhanced safety, and convenience through easy access to vehicle controls and information (Bhatnagar et al., 2024).

5. User-Focused Design Improvements

5.1 Car Modelling Based on Driver Safety, Human Factors Engineering and Anthropometrics

Human factors engineering refers to the integration of ergonomic principles into the design and development of devices, equipment, work systems and tasks. It aims to improve the optimal performance of the appliance, prioritise the safety of users and reduce human errors (Anderson, 2024).

Anthropometrics refers to the 'measurement of humans' and is derived from the Greek words *anthro* (man) and *metron* (measure). It focuses on the linear dimensions and functional capabilities, including weight, volume, etc. It takes into consideration the bodily features that vary based on age, population, age, gender, different geographical situations and biological environments (Bhattacharyya and Saikia, 2024).

5.1.1 Formulation of Accident Risk Index

The Electronic Control Unit (ECU) is the electrical component within vehicles that acts as the “brain” of the vehicle by managing all internal functions. The Advanced Driver Assistance Model (ADAS) refers to the set of technologies that aim to improve vehicle safety by automating, supplementing or replacing the driver's control over the vehicle. It utilises various devices and sensors for this purpose. ADAS is a creation that offloads the tasks of a traditional ECU. These systems serve to minimise human errors by reducing reliance on humans by employing these computerised systems. Numerous studies conducted suggest that vehicles equipped with ADAS have a lower incidence of accidents (Ahmad et al., 2019) (Fleetwood, 2017).

This model detailed by Ahmad et al., 2019 possesses the potential to be utilised in the EV industry. Built on the lines of ADAS, the system involves sensor input data and sends it into an algorithm trained to prioritise tasks based on criticality and importance to driver safety.

Impact weight: Sensors equipped in EVs give us valuable information informing us about the state of the vehicle. However, some pieces of information are more important for safety. For example, the external temperature might be good to know but the condition of the tires and the presence of obstacles are more crucial to prevent accidents. Impact weight quantifies how significant the info displayed by the sensors is. It is a vector quantity represented by ω.

- Let S represent the vector representing the sensor's readings for all scenarios. The value is normalised between 0 and 1 which implies minimum risk and maximum risk respectively.
- Then ARI is defined as the vector multiplication of impact weight ω and sensor reading given by the equation $ARI = \omega S_i$.
- The total ARI is given by $\sum_{j=0}^{n-1} \omega_j S_{ij}$, which is the weighted impact sensor reading. This is the aggregate of all the ARI's calculated using all possible scenarios. If an unsafe state is described as per the sensor, then the necessary actuators take control to ensure safety.
- The value of S for a scenario is calculated as per the following formula:

$$S_{sfi} = (f(max) - f(min))\frac{S_v - S_{min}}{S_{max} - S_{min}} + f(min)$$

f(max) and f(min) refer to functions set as per the scenarios.

The formula can be modelled as per the various scenarios prevalent. This model takes into account the different scenarios like rainfall, windspeed, blurriness and surface friction.

Flow of operations involving the calculation of ARI and corresponding tasks to be taken:

- The sensor values are measured continuously.
- ARI values are then calculated using the formula.
- If the ARI surpasses a specific threshold, the algorithm discovers contributory circumstances (culprit scenarios) that increase the risk.
- The actuators select and perform corrective steps to mitigate the indicated risks.
- The process is repeated, with continual monitoring and adjustments to ensure safety.

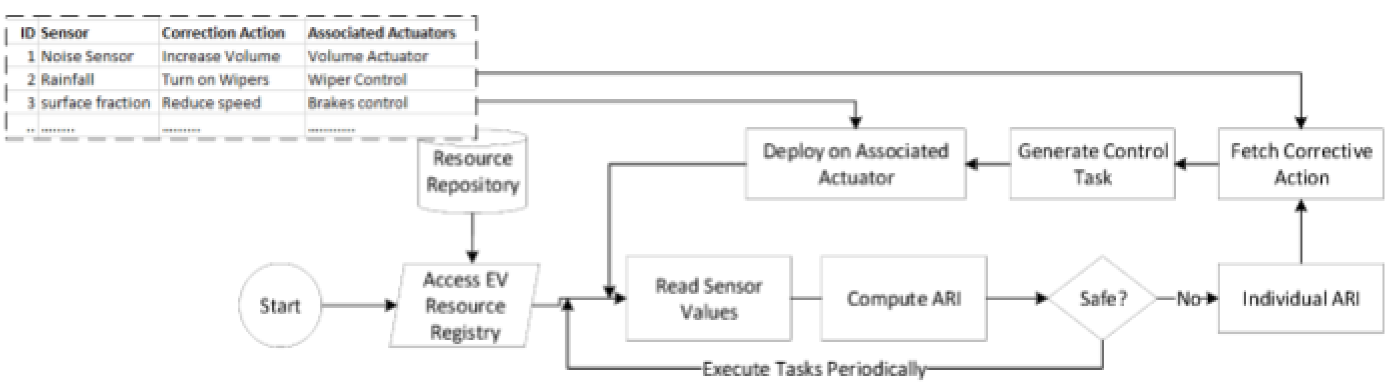


Fig 2: Tasks taken in response to ARI calculation (Ahmad et al., 2019)

5.1.2 Model for Estimating the Ergonomic Potential of Vehicles Using a Fuzzy Approach

Utilisation of this model in Dutta and Rathore, 2020 proposes a method that can be used for building an ergonomic rating index for any vehicle using a mathematical model. It is useful for a potential customer to access a car and compare various models before buying. Few ergonomic and anthropometric considerations are included with the model to provide a framework for building a user-centred vehicle considering the VoC (Voice of the Customer) and focused on human factor engineering.

There are many anthropometric attributes as written in Bhattacharyya & Saikia, 2024 but for this model, prioritising the key ergonomic factors helps in addressing the VoC. It might not be possible to consider all factors for this ergonomic rating index due to the budgetary constraints and time limitations of vehicle manufacturers. Dutta and Rathore, 2020 detail that to achieve prioritisation, relevant factors that contribute to safe and exhaustion-free driving were identified during literature review, conducting surveys.

5.1.2.1 Methodology for Data Collection and Prioritising Car Attributes

For the data collection in the report by Dutta and Rathore, 2020 a survey was conducted with a sample space including car users of different age groups and various backgrounds. The respondents were required to score the significance of each attribute on a scale of 1 to 5, providing insights into customer preferences and priorities. All the data was analysed using SPSS ver.16 and MS Excel software.

The responses given by the responders were used to generate the attribute importance rating by totalling the individual judgement. Now Fuzzy logic or Triangular Fuzzy numbers were used to incorporate variability in the responses. Fuzzy Logic is useful to handle the situation of partial truth where there is no definite answer, rather a subjective response and where the truth may be between responses supporting completely true and completely false.

The membership function assists the Fuzzy Logic for this model. Membership function simply refers to a tool which helps us in determining how much of something belongs to a particular category. Usually, the membership function is graphed.

Example to understand Fuzzy Logic and Membership Function better:

Fuzzy Logic: Let us say we are deciding whether we are going to wear a jacket today. It is a bit chilly but not really cold. Conventional thinking would say that it will either be sufficiently cold to wear a jacket or not . However, fuzzy logic allows you to describe the weather as kinda chilly implying that things are not quite as black-and-white as they seem.

Membership Function: Consider that we have a thermometer that goes from 0°C (freezing) to 40°C (hot). Suppose we wish to use fuzzy logic to define what cold means. To demonstrate that you could use a membership function.

- Below 10°C, it is very cold (high membership)
- Between 10°C and 20°C, it is somewhat chilly (medium membership).
- Above 20°C, it isn't at all cold (low membership)

The amount of fuzziness of ' being cold' can be quantified with this.

The actual formula in the report is explained by the following:

$$\tilde{w}_j = (l_j, m_j, u_j)$$

$$where, (l_j) = Min\{w_{ij}\}; (m_j) = \frac{1}{n}\sum_{i=1}^{n}\{w_{ij}\}; (u_j) = Max\{w_{ij}\}$$

- Let us refer to a respondent's judgement (i) on an attribute (j) as (w_{ij}). The attribute importance rating (AIR) was calculated by aggregating individual opinions.
- The aggregate judgement on judgement (j) is represented by triangular fuzzy numbers $w_j = (l_j m_j u_j)(TFN)$. TFN is defined by 3 parameters—l_j (the lower bound of judgements), m_j (the average of judgements) and u_j (the upper bound of judgements). This approach captures uncertainty by establishing a range (from l to u) in which the true value exists, with m being the most likely value.
- The membership function μ_w is reported as given.

$$\mu_{\tilde{w}}(x) = \begin{Bmatrix} \frac{x-l}{m-l}, l \le x \le m \\ \frac{u-x}{u-m}, m \le x \le u \\ 0, otherwise \end{Bmatrix}$$

- Converting a fuzzy number into a single distinct value is known as defuzzification. The method of graded mean integration representation is applied in this instance. The defuzzified value w_j is calculated via the formula given.

$$w_j = \left(\frac{l_j + 4 \times m_j + u_j}{6}\right)$$

It considers the lower bound l_j and upper bound u_j while giving greater emphasis to the mean value m_j.

5.1.2.2 Computation of Attribute Score

- The AIR is used to determine the normalised importance of each attribute (NIA), with the sum of NIA values of all equal to 1.
- Now for a particular variant of EV, the ergonomic score of an attribute (ESA) is determined based on the degree of fulfilment of that specific attribute by that vehicle. ESA vehicles range from 0 to 5 with 0 meaning no while 5 referring to maximum fulfilment.
- The attributes are then grouped into main three categories which are:
    1. **Overall Safety Factor:** Includes attributes pertaining to safety features, like airbags, brake assist, etc.
    2. **Musculoskeletal or Reach Factor:** Includes attributes oriented toward operator and accessibility ease, like door control sensors, adjustable steering, etc.
    3. **Compatible Man-Machine Interface or Comfort Factor:** Includes attributes related to comfort and usability, like seat adjustments, AC efficiency, etc.
- The AS which provides an overall evaluation of the AEV can be found with the product of NIA and ESA. This considers the fulfilment of attributes as well as their importance for the comfort and safety of a passenger.

5.1.2.3 Calculation of Factor Score (FS) in % and determining the output score of an EV

- The Factor Rating (FR) for each of the three ergonomic factors is the total of the AS values of all the factor attributes. An analogous concept is the Normalised Importance of Factor (NIF) which is the total of the NIA values for each attribute that makes up the factor.
- Finally using the given formula—which effectively normalises the FR by the NIF and scales it to a percentage—the Factor Score in percent (FS) for each factor is determined.

$$FS\ (in\ \%) = \frac{FR}{NIF \times 5} \times 100$$

- Each of the three ergonomic factors receives a factor score (FS in %) for a certain brand and version of an automobile on a scale from 1 to 100, which serves as the model's input. These inputs are fuzzified using fuzzy rule-based models for function approximation based on these scores. Mamdani FIS has been utilised for this research, and the car's ergonomic score is the result of the FIS.

  Mamdani FIS: It is a Fuzzy Inference System that utilises fuzzy sets of info and through defuzzification, produces a crisp output. It is well-known for being widely accepted and intuitive.

  Such data can be useful to manufacturers and automobile designers who might utilise this information to improve the ergonomic attributes of a car. This model will keep the automobile designers in check as they will be required to work on getting a competitive ergonomic score that will cause buyers to choose them over other vehicles.

5.2 Move to Modern AI

With the rise of deep learning and then neural networks, the fuzzy approach has been mostly supplanted by an AI approach instead, especially as large neural nets become more and more feasible for use within vehicle computers. As AI has already been implemented in the design of many vehicle subsystems, we are looking forward to the methodology that will help human-focused vehicle design, especially for EVs/AEVs.

5.2.1 Data Collection

The AI design implementation starts with driving data collection. The first pioneer in this field was Nissan, the manufacturer of the Model 1 car in our study. At that time, the energy consumption and range estimation algorithms almost all came from real-world user-driving data. Nowadays, all EV/AEV designs, including more and more ICE vehicle designs, have real-world driving data collection mechanisms integrated into the system in certain ways.

5.2.2 Autonomous Driving System

On the front of autonomous driving, Tesla, the manufacturer of our test vehicle Model 2 is the first to try and implement it through its (FSD) program. FSD program initially has ECM equipped with thousands of lines of stack code. The initial stage of the stack system served as a test bed for many years to allow Tesla to collect real-world driving data to train its AI model by empowering neural networks to make decisions about the road as opposed to a system that follows strict rules, an approach that often found the car unable to perform well in the real world's foreign situations (Brodsky, 2024). Gradually, Tesla merged the trained AI model with stack code in different road conditions until Version 12, when Tesla announced that it was the first to realise an end-to-end AI and computer vision-based autonomous driving system (Level 2). In addition, AI and neural networks can learn over time, rather than the static nature of 300,000 coded lines of C++.

5.2.3 From Fuzzy Logic to modern AI modelling

The fuzzy logic method was widely used in traditional ICE vehicle designs but the industry is now quickly moving to modern AI modelling-aided vehicle design. Nascimento et al., 2020 found that most of the current work in AI has moved away from fuzzy logic, with more research being performed in the areas of general AI and machine learning for a large system in AEVs, with fuzzy logic now being primarily supplanted by much more powerful statistical learning algorithms like convolutional neural networks (CNNs) and transformers.

5.2.4 Data privacy and ethics

We need to emphasise that data privacy policies and compliance are essential to human-focused designs and should never be overlooked no matter when and no matter how.

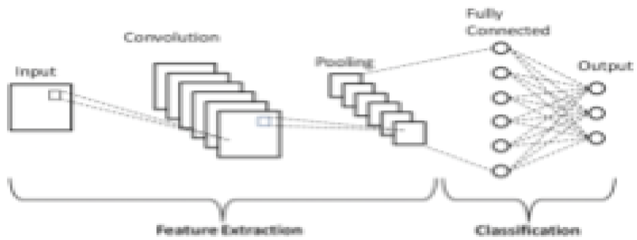


Fig 3: An example of a Convolutional Neural Network (CNN) algorithm https://www.topcoder.com/thrive/articles/overview-of-convolutional-neural-networks

5.3 Future of Power Propulsion Systems in EV

This is responsible for providing the traction force required to move the vehicle by converting electrical energy into mechanical energy. It consists of an energy storage system, the power converter, the propulsion motor and associated controllers.

5.3.1 Understanding the basic terms and current market trends

Traditionally, silicon (Si) has been the choice of material for these switches used in IGBT traction inverters. MOSFETs made of Si limit the switching frequency to a value less than 100 kHz. These materials require 1 or 2 electron volts (eV) of energy to transport their electrons to the valence band to perform the conduction.

Semiconductor switches: These are on-off controllers controlling the amount of power entering the electric motor which affects the efficiency and speed of the vehicle.

IGBTs and MOSFETs: Simply speaking, they are semiconductor devices used for controlling the flow of electricity and regulation of voltage.

Traction Inverter: Used for converting the direct current (DC) stored in the vehicle's batteries into alternating current (AC) needed to power the electric motor.

Saturation Velocity: Maximum speed at which charge carriers in semiconductors can operate in high electric field conditions.

Critical Breakdown Electric Field: The dielectric breakdown happens at a threshold electric field strength known as the critical breakdown electrical field.

5.3.2 New technologies coming up in the industry

Any new developments in the field of EVs should prioritise a common focus on energy efficiency and environmental awareness. Several major directions for this development include improvements to the:

- **Battery system**: moving from solid-state batteries to air batteries, and then to fuel cells, which should be reconsidered to be EVs. More details are discussed in section below.
- **Power control system**: we primarily discuss the semiconductors used in this system below; GaN and SiC should continue their usage into the development of fuel cells, instead of limiting their benefit to the lithium-ion battery
- **Metal acquisition**: in terms of raw materials, the reduction of rare metals is the primary task; the foremost research agenda should be on attempting to reduce and hopefully eliminate Co, Mn, and Ni from the manufacture process

SiC (silicon carbide) and GaN (gallium nitride) have wider band gaps that lead to higher electron mobility with less on-resistance. Carrying more current and switching faster than Si reduces energy losses in conversion. Moreover, a higher band gap allows the devices to operate at higher voltage (AstrodyneTDI). SiC and GaN can handle much higher switching frequencies up to 250 kHz. Higher frequencies mean more power enters the motor, which increases the efficiency of the converter. The usage of SiC and GaN has been increasing due to them offering better performance than Si. SiC and GaN can operate at higher temperatures but require careful thermal heat management to prevent overheating. SiC-based converters are known for their reliability whereas GaN-based converters are known for their efficiency; however, detailed studies on GaN's maintenance needs and reliability are needed for its optimal use.

Currently, insulated gate bipolar transistors (IGBTs) and metal-oxide-semiconductor field-effect transistors (MOSFETs) are used in present-day commercially available EVs, HEVs and PHEVs traction inverters. Si-based IGBTs and MOSFETs will remain the technology of choice until silicon carbide (SiC) and gallium nitride (GaN) based devices are commercially available at a price comparable to silicon IGBTs. (Abro et al., 2023)

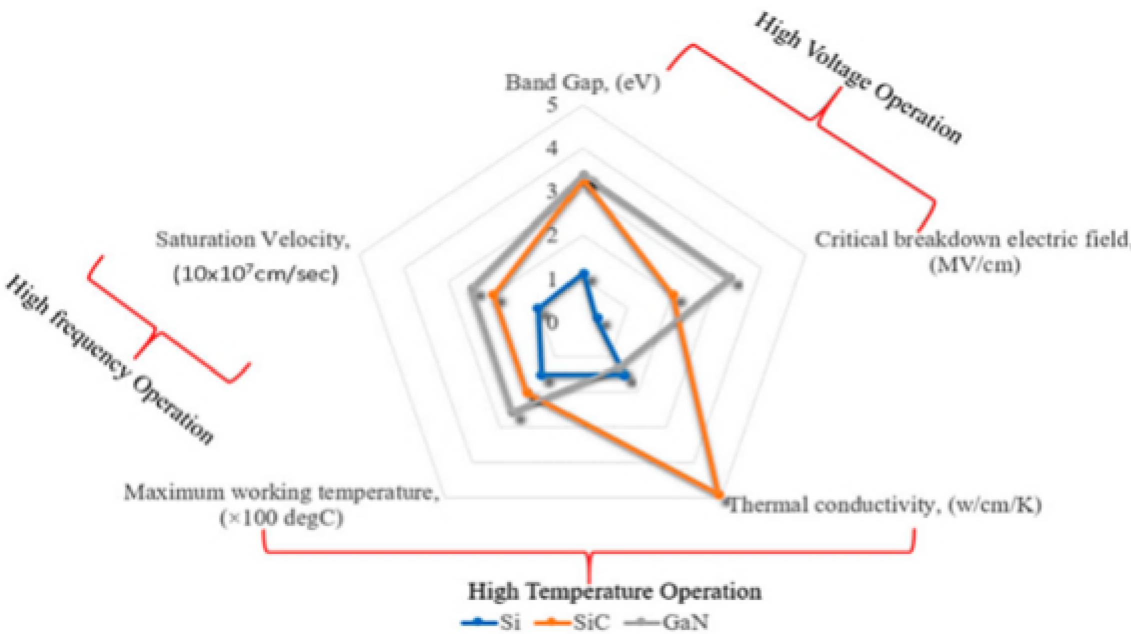


Fig 4A: Comparison between Si, SiC and GaN
(Abro et al., 2023)

5.4 Future in Batteries

Lithium-ion batteries are the most commonly used batteries in an EV. Batteries play an important part in defining the EV's range, performance and overall efficiency. Lithium-ion batteries have a high energy per unit of mass and volume when compared to other electrical energy storage technologies. They also offer a high power-to-weight ratio, excellent high-temperature performance, a long lifespan and low self-discharge. The majority of lithium-ion battery components are recyclable, but the expense of material recovery remains a challenge for the business (U.S.

Department of Energy). While battery usage safety has improved, they can still however pose risks of thermal runaway, leading to fires or explosions under certain conditions.

Thermal runaway: Thermal runaway refers to a situation where an increase in temperature leads to further increases in temperature, creating a self-accelerating feedback loop.

Example Case Study: On Christmas night, a Tesla Model Y caught fire, causing an interstate highway in Alabama to be closed. A massive 136,000 litres of water was utilised to extinguish the fire. Due to thermal runaway, it was difficult to put out the fire, which is a big problem in EVs. (Sharma, 2023b)

5.4.1 Solid-State Batteries

There are an anode and a cathode present, but the battery uses solid electrolytes instead of the liquid or polymer electrolytes found in conventional batteries. The anode is made of Li/V_2O_5 and is connected to a copper foil that increases the conductivity. The cathode can be made using the same compounds constituting the lithium-ion battery like V_2O_5, $LiMn_2O_4$. There is a separator made of a polymer or ceramic material which also acts as a solid electrolyte. Examples include LiPON, $LiBO_2$, etc. (Kim et al., 2015; Linda, 2022)

Functionality of solid-state batteries: During the discharge phase, lithium ions go from anode to cathode via the solid electrolyte, generating energy. This process is reversible: during charging, ions flow in the opposite direction and store energy in the battery. At the anode, lithium ions lose electrons before travelling to the cathode via the solid electrolyte. These ions mix with electrons at the cathode to form reduced ions, completing the circuit and producing energy.

During the charging cycle, Li ions migrate to the anode for the recharging of cells. At the anode, lithium ions lose electrons before travelling to the cathode via the solid electrolyte. These ions mix with electrons at the cathode to

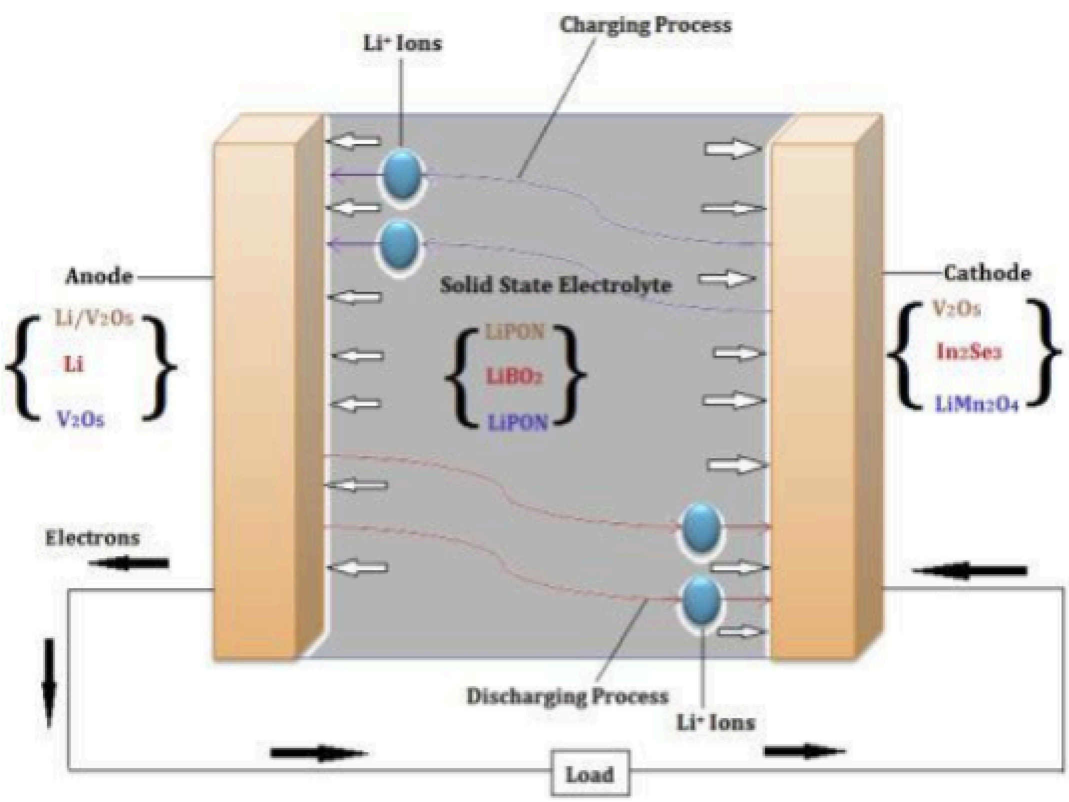


Fig 5: Functionality of Solid-State Batteries (Kim et al., 2015)

Fig 4B: Expected Change in GW demand for Si, SiC, and GaN in the EV Power Electronics Market from 2023 to 2035 (Li,J.2024,June 3) form reduced ions, completing the circuit and producing energy. The Li anode may take up Li ions in the material, frequently intercalating between layers (also known as alloying or lithiation), or they can recombine with electrons, reducing to lithium metal that deposits in or on the surfaces, a process known as plating. (Kim et al., 2015)

A major challenge in solid-state batteries: If a Li anode is employed, intercalation presents a difficulty since the additional Li deposited produces metal swelling. The metal plating may be uneven, resulting in the creation of dendrites and spikes that can rupture the separator between the cathode and the anode, causing short circuits and deactivating the battery. A group of researchers at Harvard University created a composite anode material made of micrometre-sized silicon and graphite (Ye et al., 2024). This composite material protects lithium metal in the anode, avoiding dendrite development and allowing for increased energy density. The silicon particles take some lithium, forming a thin layer without crushing the particles, while the remaining lithium plates out uniformly. This technique combines the benefits of both intercalation and plating, perhaps presenting a solution to the limitations experienced by solid-state batteries. (Kim et al., 2015; Linda, 2022)

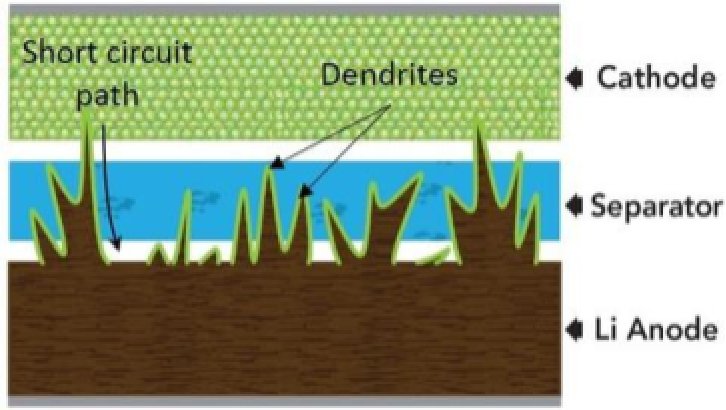


Fig 6: Model of dendrite growths in a lithium battery (MSE Supplies)

Why is it better than Li-ion Batteries?

- Concerns over the safety and efficiency of lithium-ion batteries have intensified following a series of recent battery fires, underscoring the need for safer alternatives.
- In comparison to lithium-ion batteries, solid-state batteries (SSB) provide greater safety and efficiency since they use a nonflammable solid electrolyte in place of the volatile liquid electrolyte, thereby lowering the possibility of thermal accidents and fires.
- Issues with traditional liquid-state lithium-ion batteries include leakage, flammability of the electrolyte that may produce an explosion, dendritic development and poor electrochemical window.
- For solid-state batteries, it is crucial to produce solid-state electrolytes with a large electrochemical window, high ionic conductivity, high ionic mobility, and low contact resistance between the electrolyte and electrode. (Bates et al., 2022)

- Solid-state electrolytes found in SSBs include inorganic solid electrolytes, organic solid polymer electrolytes, and solid composite electrolytes. The inorganic materials, lithium aluminium titanium phosphate, have high ionic conductivity and thermal stability but are mechanically fragile. The advantage of organic alternatives, polyethylene oxide and polyvinylidene fluoride, is flexibility, though they have the disadvantage of poorer ionic conductivity.
- Solid composite electrolytes combine the benefits of both inorganic and organic components, increasing mechanical durability and ionic conductivity.
- While composite electrolytes have made great progress, there are still problems in terms of synthesis complexity and material stability. The careful selection of these electrolytes is critical for developing robust and high-performance SSBs.
- Furthermore, while global SSB production capacity is currently less than 2 GWh, it is expected to rise at a compound annual growth rate of more than 118% by 2035, when the potential SSB market size will most likely approach 42 billion euros. (Liu, 2023)

5.4.2 Lithium-Air Batteries

This type of battery utilises the oxidation of lithium at the anode and the reduction of oxygen at the cathode to generate electric current. It is an encouraging design because it has the theoretical ability to provide the highest specific energy of any type of battery, surpassing even gasoline in energy density on a weight basis.

Functionality of lithium-air batteries: For a non-aqueous lithium-air battery, there is a Li metal that gets oxidised and releases electrons at the anode. These Li ions combine with electrons and oxygen molecules to form lithium oxide (Li_2O) or lithium peroxide (Li_2O_2). Theoretically, the batteries are rechargeable. Upon application of electricity, the lithium-charged species (stored in the cathode) turns back into the lithium metal and oxygen gas. The electrolyte is a dissolved lithium salt in an aprotic solvent and a porous O_2-breathing cathode which is effectively carbon surrounded by O_2 (Kribus and Epstein, 2021).

5.4.3 Self-Healing Batteries

Self-healing batteries, as the name suggests, have the capacity to recover from external stress that extends their operational lifetime and durability.

Functionality of Self-Healing Batteries:

There are two major components: **Non-Metallic Charge Carriers** and **Hydrogel Matrices**.

Non-Metallic Charge Carriers: Researchers have turned to the usage of ammonium ions to support the self-healing mechanism since they do not react strongly with electrode materials that may potentially damage the battery's performance over time.

Hydrogel Matrix: Hydrogels like polyvinyl alcohol possess the ability to absorb and retain huge amounts of water lending flexibility and self-healing properties, protecting the battery from physical stress or tension. The inclusion of ammonium salts ensures the dynamic functioning of such batteries in real-life scenarios by providing mechanical sturdiness and adaptability (Guerra, 2024).

The electrodes of this battery incorporate polymers or other materials which can form dynamic covalent bonds. These bonds can break and rebuild under particular conditions, allowing the electrode material to repair itself after being damaged. For example, silicon microparticle anodes with self-healing binders have emerged to boost the stability of high-energy lithium-ion batteries. These binders can repair cracks and keep electrical contact between particles, considerably increasing the battery's cycle life (Cheng et al., 2022).

Dynamic covalent bonds (DCC): Reversible covalent bonds have been recognized as a powerful tool in constructing surface covalent nanostructures at solid-liquid interfaces (Imato and Otsuka, 2018).

5.4.4 Fuel Cell Technology

In the long term, EVs/AEVs based on fuel cell technology will gradually widen applications as research and development endeavours continue. Fuel cell technology will inherit most of the EV/AEV developments we discussed here and provide further revolutionary progress in the transportation industry. The current example is Toyota's Mirai, which is a hydrogen fuel cell EV.

5.5 Expansion of terminology regarding energy origin

The terminology of autonomous electric vehicles is frequently limited to purely those vehicles which have a solid lithium-ion traction battery buried at the bottom of the vehicle. However, all hydrogen-based cars and all other cars that have fuel cells should be considered as electric as they all involve the generation of electricity, whereas the internal combustion engine requires burning fuel and oxidation to achieve motion. Fuel cells, in fact, would be able to have a more flexible design once they enter the market as their required weight could potentially be less than even ICE cars.

6. Public Opinion

- Research indicates that drivers are hesitant to adopt self-driving autonomous vehicles (AVs), even with active safety measures like warning systems. The benefits of autonomous vehicles, such as improved safety and fuel efficiency, may not be enough to drive broad use. Raising public awareness can accelerate the adoption and improvement of AV technology. According to a survey by Aldakkhelallah et al., 2023, 22% of respondents would not pay for full automation, while 5% would pay more than $30,000. 33% found the notion very enjoyable. 69% believe that AVs will account for 50% of the market by 2050.
- The majority of respondents supported partial automation (level 4: 36.11%, level 3: 24.07%) over fully autonomous cars (level 5), citing the high prices of new technology and AV usage as barriers to adoption.
- The public views AVs as beneficial for safety, the environment, time efficiency, reduced congestion, comfort and convenience, economic savings, increased productivity, less human error, energy efficiency, and improved traffic systems. The benefits of introducing AVs are widely anticipated to be beneficial.
- Public concerns about (AVs) include system malfunctions, cybersecurity threats, AI decision-making, infrastructure issues, ethical dilemmas, loss of human control, and potential job losses.
- AVs have the potential to transform transportation by improving safety, efficiency, and sustainability. They align with worldwide efforts such as the EU's prohibition on new ICE car sales by 2035, indicating a seamless integration of AVs and EVs in the coming decade. (Aldakkhelallah et al., 2023)

- Barriers, such as the lack of available and current charging stations, may impede the transition to autonomous vehicles. The most common EV charging stations only deliver 2 kW of power, creating impediments to adoption. AVs rely on advanced sensors and computers, therefore conventional stations may not be sufficient.
- Adequate charging facilities are necessary to enable autonomous vehicles (AVs), which have a preferred driving range of 200-400 km according to survey data. Respondents raised concerns about the scarcity of maintenance shops for electric and self-driving vehicles demonstrating a current lack of confidence in these technologies.
- Collaboration between automakers and municipal planners is vital for assessing the impact of autonomous vehicles on traffic systems and addressing cybersecurity issues. To build trust and understanding in AV decision-making, manufacturers should do rigorous testing and share their findings.
- The survey highlights the need for effective marketing and communication efforts to educate the public about the features and benefits of autonomous vehicles (AVs). Approximately 70% of respondents are ignorant of AV classifications.
- Although battery efficiency has improved, charging time and driving range remain key impediments to EV adoption, with commercial cars averaging roughly 200 miles (~320 km) per charge.
- A survey revealed that self-driving cars require ads and education. Automakers should explore motivating consumers to buy AVs to enhance market penetration. Motivations can include tax credits and safety. Trustworthy and environmentally conscious (to limit CO_2 emissions). Public decision-making can be heavily influenced by cost.
- Successful integration of autonomous vehicles (AVs) requires tackling cybersecurity threats and ethical decision-making, which have a direct influence on human lives and public acceptance. (Alsalman et al., 2021)

7. Limitations

- **Inadequate Time for Extensive Research:** Conducting comprehensive research within a month can be difficult given the broad breadth of autonomous cars and human-centred design concepts. This restriction has an impact on the scope and depth of the literature review, which may result in understanding gaps in the most recent advancements and complex facets of the subject.
- **Restricted Expert Guidance Access:** Getting expansive feedback and direction on our study methods, outcomes,

and recommendations in just 12 hours of coaching and mentoring sessions has been a significant challenge for us.

- **Breadth and Depth Harmony:** A balance between breadth and depth is needed to address both the technical and human-centred components of autonomous vehicle design. It was challenging to strike this balance in the allotted time.
- **Delivering Originality and Quality:** Sustaining the standard of the research and guaranteeing novel contributions to the area might be difficult under time restrictions.

8. Future Work

- The HTA will be expanded to include more concise steps, taking into account smaller subtasks that may demonstrate differences between ICE vehicles and EVs. Greater analysis will be done to determine the possibility of making all Tesla vehicles accessible for all users including persons with reduced mobility.
- We hope to continue our work in this domain and make more recommendations to engineers and designers in the field to keep human ergonomics in mind in the next generation of autonomous electric vehicles to hit the market.
- Conduct large-scale surveys and research to obtain information about user preferences, behaviours, and expectations for AEVs. This empirical research can help lead the creation of more targeted and effective human-centred design principles.
- Investigate the integration of emerging technologies, such as AI and machine learning algorithms, with human-centred design principles to enhance the AEV experience. This could incorporate adaptive interfaces and personalised safety features.
- Encourage multidisciplinary collaboration among academics in psychology, sociology, ergonomics, and electrical engineering. Such cooperation may result in novel methods to build AEVs that actually suit the demands of all users.
- Evaluate AEVs' long-term sustainability and environmental impact, taking into account both their lifecycle and the broader implications on urban settings and ecosystems. This could help to produce greener and more sustainable AEV designs.

9. Conclusion

- In the scientific research paper titled "Human-Centred Design Improvements for Autonomous Self-Driving Vehicles," we focus on enhancing the user experience and safety of autonomous electric vehicles (AEVs). We embarked on an extensive journey to understand the user requirements, propose user-centred design improvements, and investigate the future of power propulsion systems and battery technology.
- The study investigates the relationship between technological improvements and human needs, emphasising the necessity for design methods that prioritise user comfort, safety, and inclusivity.Our study encompasses diverse aspects of AEV design and functionality, from hierarchical task analysis (HTA) to proposing a model for estimating the Ergonomic Potential of vehicles using a Fuzzy Approach and the Driver Assistance Model for Accident Risk Index .
- The paper also highlighted the potential and comparison of solid-state batteries, lithium-air batteries, and self-healing batteries as the future of energy storage in electric vehicles. We detailed the future of power propulsion systems wherein SiC and GaN take over traditional Si semiconductors, thus integrating AEVs with technological advancements.
- As we wrap up this study, we imagine a future in which autonomous electric vehicles smoothly blend safety, comfort, and sustainability, while addressing the varying needs of users from all backgrounds. We believe that this work will spur additional research and innovation, paving the road for a transportation landscape that prioritises human needs and experiences. Further, the article emphasises the relevance of public opinion in addressing shortcomings and upsides related with the use of autonomous vehicles. The primary goal of the research is to bridge the knowledge divide between the human factors required for mainstream adoption of AEVs and

technological advancements in these vehicles.

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