UMEÅ UNIVERSITY

Journey Towards Independence

Exploring the Potential of Autonomous Buses in Supporting Independence of Children with Mild Cognitive Impairments

LuLu Meng

Department of informatics
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Abstract

The independence of children with cognitive impairments is vital for successful social integration. As emerging technological advancements, autonomous buses possess significant potential in this regard. The study aims to investigate the potential of autonomous buses to support children with mild cognitive impairments in attaining increased independence during their travels. To achieve this goal, two studies were conducted to gather comprehensive data: an analysis of videos provided by the ASALL project and a focus group study involving Skelleftea municipality workers. The study findings shed light on the challenges and needs of children with cognitive impairments during their trips and offer suggestions for how autonomous buses could provide support to increase their independence. It also highlights the importance of considering human factors while designing technology products and emphasizes the need for coordinated efforts combining technological and human support to enhance the independence of children with cognitive impairments. In addition, insights from people familiar with children with cognitive impairments can provide valuable guidance to researchers and designers when creating other technology products.

Keywords: Autonomous buses, Mild cognitive impaired children, Independence

1. Introduction

1.1 Background and research gap

Independent mobility of children refers to their unrestricted ability to move and engage in social activities related to education, community, and health in public areas without an adult. This ability is crucial for children's physical and social development (Hillman, Adams and Whitelegg, 1990; McDonell, 2007), enhancing their learning opportunities from interaction with their peers in a social environment surrounding (Pia, 2004; Morrow, 2003) as well as increasing their level of physical activity, contributing to children's self-identity and social skills (Proshansky and Fabian, 1987; Haveman et al., 2013). Failure to develop independent mobility may hinder those children from participating in age-appropriate meaningful activities and lead to future isolation from the social context (Livingstone and Paleg, 2013). Therefore, encouraging children with cognitive impairments to diminish their reliance on others and increasing their independent mobility have become a public concern.

Public transportation plays a crucial role in society, enabling citizens to participate in community-based and social activities associated with education, employment, health, and daily tasks (Stjernborg and Mattisson, 2016). The 2030 Agenda for Sustainability and the Global Goals highlight the imperative of developing accessible and sustainable transport systems for all individuals, with particular attention to expanding public transportation to address the needs of vulnerable populations, such as those with disabilities. With the advancement of self-driving algorithms, transportation systems are undergoing significant transformations. Autonomous buses have gained considerable attention as innovative technological transportation tools. Both academic researchers and transportation industry practitioners believe that by integrating mobility services and technological innovation, autonomous buses have the potential to provide more accessible travel services to specific populations (Fink, Holz, & Giudice, 2021; Wien, J., 2019). For instance, proponents argue that self-driving buses offer several advantages, including reduced operating costs, extended coverage of transportation services, and customized seating designs to cater to the specific needs of individuals (Fiol and Weng, 2022). According to JKadmin (2019), autonomous buses provide a viable alternative for individuals with disabilities, eliminating the reliance on family members or caregivers by offering automated door-to-door transportation services. Furthermore, a study conducted by Colley et al. (2020) using virtual reality technology discovered that the use of autonomous buses resulted in a decrease in cognitive load. However, these assumptions are based on theoretical benefits, virtual or simulated experiments; there is currently limited empirical evidence demonstrating their effectiveness in assisting these specific populations due to the novelty of this technology. In light of this gap, this research aims to build upon the previous studies, further exploring the challenges of those children during their trip via experimental research and discussing the potential of autonomous buses to improve the independence of travel ability for children with cognitive impairments.

1.2 Research questions

Given the content discussed above, the overarching research question has been formulated as follows:

RQ: ***How can autonomous buses be designed and used to support children with mild cognitive impairments in achieving greater independence during their travel?***

To achieve this goal, the following sub-questions are needed to be addressed.

RQ1: What are the challenges for cognitively impaired children related to travel？

RQ2: What are the potential solutions for cognitively impaired children based on autonomous buses through caregivers' perspective lens？

Two points are worth noticing. First, the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) identifies four levels of cognitive impairment, ranging from mild to profound, and for mild cognitive impairment, independence in daily life can be preserved with minimal assistance (Knopman and Petersen, 2014). Therefore, this study will focus on mild cognitively impaired children with the potential for independent travel. Secondly, because of ethical considerations, time limitations, and difficulty in self-expression due to cognitive impairments, data collection in this study was mainly based on caregivers.

This study utilized a qualitative research approach, conducting two studies to gather comprehensive data. The first study involves video analysis, where observing and analyzing the behaviors and experiences of children with cognitive impairments, their caregivers, and safety staff on autonomous buses using the video footage collected by the ASALL[1] project. The second study involved discussions with a focus group supported by government officers in Skelleftea. This focus group discussion further enhanced understanding of the behaviors and emotions experienced by children with cognitive impairments during travel, exploring potential design opportunities that can cater to their specific needs and improve their travel experiences.

This study identified the challenges of children with cognitive impairment during their trip, providing design suggestions to UX designers and engineers in the transportation field. These suggestions can support tailoring autonomous buses design in the future. Additionally, the study's insights into the attitudes and responses of children with cognitive impairment towards technology, gathered through discussion with caregivers, have significant implications not only for designing travel tools but also for any technology products in the HCI field that target cognitive impairment. Therefore, this study can serve as a reference for designers and engineers in the HCI field, facilitating the development of more inclusive and accessible technology products that can enhance the lives of individuals with cognitive impairment.

2. Related Research

This section aims to provide a comprehensive overview of existing research in the field of Human-Computer Interaction (HCI) pertaining to transportation, with a specific focus on autonomous buses, exploring the prior studies and challenges in promoting independent mobility for individuals with cognitive impairments. By examining previous experiences and ideas, the aim is to gain valuable insights that will inform the research strategy.

HCI (Human-Computer Interaction) is an interdisciplinary field investigating human and computer systems' interaction. Despite the fact that some of the studies reviewed in this section may not be published in HCI-specific academic journals or conferences, they remain relevant and significant for the advancement and application of the HCI field since these studies provide valuable insights into the relationship between humans and technology, offering practical insights into user experience and behavior patterns, thereby informing design decisions and contributing to the development of the field.

2.1 Mobility of individuals with cognitive impairments

2.1.1 Challenges of individuals with cognitive impairments during travel

Individuals with cognitive impairments encounter significant obstacles when utilizing public transportation, encompassing challenges in trip planning, time management, navigation, emotional distress, and safety (Moore Sohlberg et al., 2009). Specifically, they may experience heightened hesitancy and anxiety when orienting themselves and struggle to

[1]https://wasp-hs.org/projects/autonomous-shuttles-for-all-ai-public-transportations-and-people-with-disabilities-asall/

provide accurate solutions for navigation issues (Lemoncello, Sohlberg and Fickas, 2010). Similarly, they may face fear, physical demands, and difficulties, such as getting disoriented, missing their intended bus, uncertainty regarding the bus stops, abrupt stops and accelerations, hard braking, alighting at an incorrect stop, and challenges in comprehending schedules or understanding bus route changes (Risser, Iwarsson and Ståhl, 2012). Moreover, public transportation services can be overwhelming for cognitively impaired individuals with sensory sensitivities, who may encounter stress-inducing factors such as intense lights, loud noises, and crowded conditions (Rezae et al., 2019).

2.1.2 Existing Research on enhancing mobility of individuals with cognitive impairments

Research concerning the mobility of children with cognitive impairments in HCI has predominantly concentrated on the development of technologies and tools aimed at providing support. Patterson et al. (2004) introduced "Opportunity Knocks" (OK), a system that utilizes GPS sensor data to construct a comprehensive user behavior and movement model. This system benefited individuals with mild cognitive impairment by guiding them from their current location to a desired destination.

On the other hand, Fischer and Sullivan(2002) cautioned that technology should not be seen as a cure-all solution that can replace caregivers entirely. Regardless of how advanced the technology may be, caregivers play a crucial role in tailoring support to the needs and capabilities of each individual, offering timely and personalized assistance. Davies et al.(2010) developed a personal digital assistant software named WayFinder. In this system, caregivers actively engaged in the guidance process and program of the route, offering travel advice through voice prompts and suggesting walking routes. Similarly, caregivers also can be involved with applications that support travel for individuals with cognitive impairments, which include features such as advance travel planning, remote programming, and notifications for "off route" or "successful trips" (Riehle et al., 2011; Livingstone-Lee, Skelton and Livingston, 2014).

Carmien et al.(2005) conducted a study to explore the feasibility of using socio-technical environments to assist individuals with cognitive disabilities in utilizing public transportation. The authors identified the challenges individuals with cognitive impairments face when using public transit and proposed that a combination of technology and human collaboration can offer support. The proposed socio-technical architecture consists of several key components: a personal travel assistant, a mobile cueing client, a caregiver cueing script configuration tool, and a monitoring system. By integrating technologies such as smartphones, maps, and GPS with the expertise of transportation personnel and caregivers, a supportive platform can be established to facilitate the use of public transportation by individuals with cognitive disabilities.

In such a design process, the role of the caregivers undergoes a significant transformation. Previously, caregivers primarily provided physical and emotional support while adapting to the needs and preferences of individuals with cognitive impairments. In addition, they ensured a seamless and safe travel experience by communicating and coordinating with various institutions and personnel. However, in the current context, caregivers assume the role of "designers for designers" (Fischer and Giaccardi, 2006) or "programmers/end-user developers" (Carmien and Fischer, 2008) by creating the necessary scripts for the client application.

2.1.3 Challenges in designing for children with cognitive impairment

User-centered design (UCD) is the most widely applied method in HCI, but it faces challenges in providing solutions for intellectually disabled children. Firstly, children with cognitive impairments experience difficulties in memory, visual perception, social and emotional interaction, auditory processing, communication, motor skills, and attention (Kvas et al., 2013). This results in limited learning capabilities and challenges in understanding social norms and expressing their wants or needs (CDC, 2022), posing a challenge for designers to obtain direct insights into the needs and preferences of these children. As a result, designers often rely on caregivers who act as proxies for children or elderly individuals with disabilities to gather insights collaboratively (Piper et al., 2016; Baumer and Brubaker, 2017). However, this approach carries the risk of information accuracy loss or biased information, which can impact the effectiveness of design solutions. Furthermore, it is essential to recognize that there is no such thing as an "ordinary" person; similarly, there is no standard or typical cognitive impairment. Instead, each individual with a disability represents a distinct and unique "universe," characterized by unexpected variations in their abilities and challenges (Fischer, 2001). As a result, enhancing the independent capabilities of children with cognitive impairments poses significant challenges, as there is no uniform behavioral pattern, and designing a one-size-fits-all solution applicable to everyone becomes problematic.

2.2 Autonomous Buses and their relevance to HCI field

Autonomous buses utilize advanced sensors and computer systems to provide travel services between multiple target communities through cities, autonomously sensing their surroundings and following predefined routes. According to the new SAE International Standard J3016 (SAE, 2019), most current autonomous buses operate at SAE Level 4 or above, indicating their capability to operate without a human driver. As a result, the interaction between autonomous buses and diverse user groups is undergoing disruptive changes driven by the transformative potential of technology.

2.2.1 Internal Interaction

The emergence of autonomous driving technology has brought about a significant transformation in human-vehicle interaction. Interactive interfaces such as displays, haptics, and voice control have emerged as the new means of interaction, adding complexity to the interaction between humans and vehicles(Hermann and Singh, 2020). Li et al. (2019) argued that this complexity is evident in the exchange and processing of information across multiple dimensions. The collaborative relationship between individuals and technology, which involves shared decision-making and control, extends beyond interface design and encompasses information processing and transformation in dynamic and complex scenarios. (Muslim, Leung and Itoh, 2022). Furthermore, in autonomous buses with no driver's space, the existing space within the vehicle can be repurposed as a physical interacting space for new activities, thereby enhancing the passenger experience (Detjen et al., 2021; Li et al., 2021).

In order to effectively integrate autonomous buses into society, recent research by Yan et al. (2023) emphasizes the importance of inclusive interior interaction design that caters to the diverse needs of various user groups, including considerations for the elderly, overweight individuals, dementia patients, and individuals carrying large items. To achieve this, a redesign of the interior space and interface interaction is necessary, encompassing factors such as the positioning, type, and range of seats, control devices, and displays.

2.2.2 External Interaction

In addition to the changes in the interior space and interaction of autonomous buses, the interaction between these vehicles and the external environment is also a topic of great interest. Various studies have demonstrated the potential of external human-machine interfaces (eHMIs) to replace traditional human communication. These interfaces facilitate communication of driving intentions to other road user groups, particularly in situations where traffic scenarios may be unclear (Suzuki et al., 2022), influencing the confidence, trust, and perceived safety of pedestrians crossing the street (Wilbrink, Nuttelmann and Oehl, 2021).

One promising approach to external interaction in autonomous buses involves using visual and auditory signals to communicate with other vehicles, pedestrians, and infrastructure. These signals can vary from simple textual information to dynamic displays incorporating color and motion, with the aim of conveying essential details about the buses' trajectory, speed, and behavior to others in the environment (Riener et al., 2021). For instance, deformed arrows can provide information about the buses' path, expected acceleration, and braking, while icons can provide information about the buses' perception of the traffic environment (Mirnig et al., 2022). Additionally, LED strips installed around the buses can provide information about anticipated driving behavior through variations in light frequency, cadence, motion, and range and can also provide information about the detected traffic environment (Ackermann et al., 2019). By harnessing these signals and technologies, autonomous buses can operate safely and efficiently in complex urban settings while simultaneously enhancing the overall experience of passengers and other road users.

Another advantageous method for enhancing external interaction with autonomous buses involves utilizing anthropomorphic design on the vehicle's exterior. This design approach incorporates human-like or anthropomorphic elements, such as facial expressions (eyes, smile) or gestures, into the interaction design of the buses to create a more natural and intimate interaction between humans and the vehicle, thereby increasing the trust of other road users (Dey et al., 2020; Riener et al., 2021). For instance, Chang et al. (2017) added "eyes" to the i-car design, facilitating more trusting communication between cars and pedestrians. Thus, by incorporating human language, posture, expressions, and emotions into the vehicle's design, the interaction between humans and autonomous buses can become more seamless and intuitive, leading to safer and more efficient travel on the road.

However, some experts have raised concerns about the potential drawbacks associated with incorporating anthropomorphic design on the exterior of autonomous buses. For example, Mahdavan et al. (2018) observed a positive attitude toward human-like interaction with virtual robot drivers on the windshield. Nevertheless, they highlighted the challenge of correctly interpreting anthropomorphic cues, such as animated faces or gaze from the eyes. These cues may be difficult to interpret correctly and effectively convey information to passers-by in traffic, potentially posing safety risks. In a similar vein, Löcken et al. (2019) reported that incorporating eyes on a car to simulate eye contact with pedestrians may not provide clear crossing signals and can result in the Valley of Terror effect in human-computer interaction(Walters et al,2007). This effect refers to a sudden drop in trust and confidence when a system behaves in a manner perceived as not fully human-like.

2.2.3 Roles of Driver on Autonomous buses

In addition to the impact on the bus itself, autonomous driving technology has also transformed the traditional driver-bus relationship. While numerous studies indicate increased public acceptance and expectation of autonomous buses (Abraham et al., 2018; Bansal, Kockelman and Singh, 2016), many individuals still harbor concerns and unease regarding the absence of a human driver. For instance, a field study conducted in 2020 revealed that parents expressed concerns about the safety of autonomous buses for their children and were hesitant to allow them to ride without a human driver present in case of emergency (Ayoub et al., 2020). Also, the interaction between autonomous school buses and children may present challenges as children struggle to adapt to the absence of human intervention (Tremoulet et al., 2020). Additionally, Mirnig et al. (2019) argued that the absence of human factors could pose challenges in signaling the next stop and requesting the autonomous bus to stop at an appropriate time. Similarly, older adults and individuals with cognitive limitations have relied on bus drivers for onboard issues such as seat availability and estimated time to destination, and they expect human assistance and have concerns about the ability of autonomous buses to meet their needs (Tabattanon, Sandhu, D'Souza, 2019; Classen et al., 2022). In light of these considerations, while the future of public transportation may undergo changes, the role of humans will remain essential but will transform into new roles.

According to a study conducted by Schuß et al.(2022), the role of drivers will evolve from solely driving the buses to that of an operator, requiring a diverse set of skills to ensure the safety and comfort of passengers. These skills include:

1. **Supervising the buses:** Operators will transition from actively driving the vehicle into overseeing its operation. They will be responsible for being prepared to take control of the vehicle when necessary and ensuring the overall safety of the passengers.
2. **Monitoring the surroundings:** Operators will continuously monitor the vehicle's surroundings, including other traffic users, to ensure safe operation. They will be vigilant in detecting potential hazards, communicating with other participants in traffic, and clearing any obstacles that may impede the vehicle's path.

3. **Psychological skills:** As passengers sometimes experience feelings of anxiety or uneasiness when using self-driving vehicles, operators will need to possess psychological skills. They will be required to introduce passengers to the self-driving vehicle, create a relaxing environment, and help passengers acclimate to the new technology.
4. **Providing explanations:** When unexpected events such as emergency braking or unnecessary stops occur, operators must provide clear explanations to passengers to alleviate any concerns or irritation.
5. **Guiding passengers:** Operators will guide passengers on how to properly ride the self-driving bus, including reminding them to fasten their seat belts and familiarizing them with any specific instructions or protocols.
6. **Special passenger support:** Operators may also have a degree of guardianship, particularly when it comes to providing extra attention and service to special passengers such as older individuals, individuals with disabilities, or children, especially in case of emergencies.

In addition, recent research has been dedicated to the development of digital technologies on autonomous buses with diverse functions to detect the healthy parameters of users, such as blood pressure, heart rate, and other physical data, thus enhancing the operator attendant's ability to provide intelligent assistance (Yan et al., 2023). In summary, although these potential roles have not been formally established, they could play a crucial role in fostering trust and ensuring the comfort of future autonomous bus passengers.

2.3 The role of caregivers when children with cognitive impairments using new technology

The development of "smart devices" has the potential to help people with cognitive impairments improve independence for certain tasks. For example, children with a cognitive impairment can utilize computer programs to learn social and essential life skills. During the utilizing process, it is necessary to gain caregivers' support and interventions(Nabors, Monnin and Jimenez, 2020); helping a person with new technology should be seen as within the purview of the caregiver (Hoppestad, 2012). On the other hand, for increasing the independence of children with cognitive impairments, James et al (2015) believed that it is worth notice to gradually reduce caregiver involvement to develop individual strategies to support ongoing participation. Furthermore, while caregiver reports indicated that technology could improve many aspects of care, such as helping children with intellectual disabilities use the technology to support their independence and reducing stress for the caregivers involved, efforts are needed to make these technologies less costly and consider ease of use and security and privacy issues (Mikula et al., 2022).

2.4 Experience of children with cognitive impairment on autonomous buses

A recent study by Forsblad et al. (2023) investigated how autonomous buses can motivate children with cognitive impairments to make use of them. The study revealed that many children had positive experiences with autonomous buses and highlighted the importance of design improvements to ensure their safety and to shape their specific social environment within the bus. However, the study primarily centered on applying the Self-Determination Theory (SDT) to understand individuals' motivation, behavior, and personal development. While autonomy plays a crucial role in enabling children with cognitive impairments to act independently and make decisions based on their own volition, it is essential to acknowledge that solely focusing on autonomy might not fully address the diverse needs and resources required for these children to travel independently.

2.5 Summary

Existing research suggests that individuals with cognitive disabilities face challenges in various aspects of travel due to their mental and cognitive impairments. While technology possesses the potential to enhance independent travel for them, the role of human support should not be underestimated. Integrating technology and human assistance through Socio-technology can offer a more practical approach to facilitating independent travel for individuals with cognitive impairments. However, previous research has primarily focused on technology products or systems, with limited attention given to buses, likely due to the limitations of conventional bus infrastructure. Autonomous driving technology has brought about significant changes in both visible and invisible interactions within and outside buses and the dynamics between drivers and passengers. This transformation can potentially create accessible transportation options for individuals with cognitive impairments. Thus, the objective of this study is to investigate the experiences and interactions of children with mild cognitive impairments while riding autonomous buses (RQ1) and to identify their specific needs and challenges during travel (RQ2). By addressing these research questions, the aim is to provide recommendations for designing and implementing autonomous buses that can effectively support children with mild cognitive disabilities in achieving greater independence in their travel experiences.

3. Methodology

3.1 Research strategies

Understanding the experiences of children with cognitive impairments will lay a foundation for exploring those children's challenges. However, it is not easy to rely on quantitative methods that prioritize numbers and statistics (Creswell, 2009). Therefore, to gain a deeper understanding of the experiences and needs of intellectually disabled children in autonomous bus travel, qualitative research methods which focus more on participants' individual experiences and feelings will be conducted to obtain more detailed and comprehensive data through in-depth interviews and observations to comprehend and explain phenomena (Hennink, Hutter and Bailey, 2020).

Moreover, since research on autonomous buses by children with cognitive impairments is a relatively new and innovative field lacking well-established theoretical frameworks or hypotheses, this study will embrace an inductive reasoning approach, which allows to analyze a wealth of original textual data and derive summary results from while establishing clear connections between them (Thomas, 2003), exploring and uncovering patterns and relationships inherent in the actual cases and phenomena observed during the study.

3.2 Research method

When designing for the transportation domain, it is crucial to consider the "trip chain" (Suen and Kaulback, 1984), which encompasses a series of actions users undertake to complete their journey from point A to point B, including various stages, such as the journey from home to the station, the ride in the vehicle, and the travel from the station to the final destination (Ståhl, 1997). Potential issues may arise at different points along the trip chain, such as the entrance, public outdoor environments, bus stops, and the buses themselves (Carlsson, 2004). Given this, it is crucial to understand the experiences of children with cognitive impairments comprehensively and consider the challenges and needs they encounter at different stages of their travel before providing design suggestions (Detjen et al., 2022).

Based on this concept, the autonomous bus journey is divided into three phases: **Pre-Trip, On-Trip, and Post-Trip.** This segmentation aims to gain insights into children's experiences, challenges and needs at each journey stage. However, comprehensively understanding the needs and experiences of children with cognitive impairments poses a significant challenge due to their limited capacity for direct self-expression. In such circumstances, researchers often rely on alternative approaches, such as observing their behaviors or seeking insights from people with intimate involvement in their daily lives.

Thus, this study conducted two studies: **a video analysis study** and **an online focus group study**, to understand the possible challenges of children with cognitive impairments when traveling on autonomous buses from the starting point to the destination. Video analysis provides opportunities to capture the external behavior of these children in specific contexts by meticulous observation, capturing their overall experience among others on autonomous buses. On the other hand, a focus group provides insights into internal perceptions and attitudes drawing from the perspectives of individuals closely involved in the daily life of children with cognitive impairments, supplementing insight into the on-trip phase that was unavailable from observation. The data integration from observation and focus groups can lay a foundation for designing targeted interventions and implementing improvements.

4. Study one: a video analysis study

All observation data of videos in this study are provided by the research project "Autonomous Shuttles for ALL – AI, Public Transportations, and People With Disabilities (ASALL)," sponsored by WASP-HS. This project aimed to develop autonomous buses that utilize advanced artificial intelligence technology to offer convenient and inclusive public transportation services. The buses served the Valla Campus of Linköping University and the surrounding residential area of Vallastaden in Sweden. Detailed videos are available at www.ride the future.se.

The autonomous buses are programmed to operate on a 3.7 km route and currently run between 8 am and 5 pm. To ensure safety, a designated "safety staff" member is present on board to monitor the ride and assume control if necessary. The safety staff member is also responsible for addressing passengers' inquiries and concerns. These autonomous buses provide valuable opportunities to observe participants with limited exposure to this technology in the early stages in a small-scale manner in the actual context. Studying this actual context can develop a more comprehensive understanding of children's emotions and experiences during their journeys on autonomous buses. Additionally, it facilitates further discussion and exploration of the roles of caregivers and safety staff and their influence on the travel experiences of these children.

4.1 Participants

The participants in the study conducted by Forsblad et al. (2023) consisted of 16 children with mild cognitive impairments who were recruited from a specific school. The researchers employed the Technology Readiness Index 2.0 (TRI) questionnaire to assess the children's readiness for new technology. Of the 16 participants, 13 completed the questionnaire, revealing that they generally approached new technologies cautiously and felt uncomfortable when others observed them using such technologies, however, they displayed optimism about their ability to use new technologies. The researchers further utilized Raven's Progressive Matrices 2 test to understand the participants better. Ten children were able to complete the test, while six were unable to do so. The average test score among the participants indicated an equivalent level to that of a 6.03-year-old child. Notably, the study ensured the voluntary participation of the children and obtained ethical approval from the national review body.

4.2 Materials details

The video data used in this study was obtained from Linköping University and securely stored on the platform "secure.nextcloud.liu." These video files captured the ride experiences of seven groups of children on autonomous buses during the on-bus, getting on-bus, and getting off-bus moments. Each group consisted of 1-3 children accompanied by 1-2 caregivers. The duration of each video was approximately 50 minutes. The recordings were made using cameras positioned at the front and rear of the buses, ensuring comprehensive coverage of the interactions and details among the children, caregivers, and safety staff on the autonomous bus from various perspectives and angles.

4.3 Data transcribe and analysis

Firstly, the textual data was transcribed from the video content based on individuals' reflections on different events on the autonomous bus. Secondly, customer journey mapping was employed to analyze the critical data from the transcribed data, aiming to understand the experiences of children, caregivers, and safety personnel on the autonomous bus and the challenges encountered by the children during bus usage.

4.3.1 The process of transcribing data from video

A complex real-world scenario appears while transcribing video data depicting children with cognitive impairments traveling on autonomous buses. Various factors coincided and were interrelated, necessitating attention to detail to avoid overlooking valuable information. In that case, the data were transcribed by identifying ***events***, (Details in Appendix A) focusing on the behaviors and reactions of children, caregivers, and safety staff during specific events, such as boarding and disembarking the bus or in emergency brake situations, noting their expressions, tone of voice, and emotional state of understanding their motivations and behaviors. Interactions between the individuals involved were also closely examined to understand their relationships better. Secondly, the design and technology aspects of the buses were documented, including their exterior and interior configuration, technical equipment, performance, and physical and algorithmic interactions. Lastly, employing multiple camera views to cross-check and ensure the accuracy and completeness of the recording minimized the potential for data errors resulting from misunderstandings or omissions.

For example:

1. During the "get on the bus" event, two children eagerly boarded the bus, finding seats either on the side or in the back. They chatted happily with each other while the safety staff rearranged the seating positions. One child preferred the back seat, believing it offered a better view. The little boy successfully fastened his seat belt while the carers ensured their seat belts were secure and reminded the little girl to do the same. The researcher and safety staff accommodated the child's preference for a specific seat.

2. The safety staff mentioned the term "redirect," highlighting that the sensors used to survey the environment may not always be sensitive enough to detect small objects like birds or unconventional objects such as bicycles on walls. This technical limitation must be investigated further to enhance the system's performance and ensure safety.

These filtered data obtained from the first round of data transcribed are intended to be input for further analysis in the subsequent stages of the research.

4.3.2 The process of analyzing data by Customer Journey mapping

The trip chain concept emphasizes the series of actions and stages involved in a journey, requiring researchers to understand the phenomena that occur during each stage. However, it is essential to acknowledge that various factors at each stage can potentially divert researchers' attention from the critical points if not properly addressed or prioritized. In this regard, customer journey mapping can be an analytical technique for researchers (Anderson, 1999), enabling them to focus on phenomena related to users using products and effectively address the specific needs and challenges that arise at each stage, providing a structured approach to capturing individuals' emotions, behaviors, and interactions throughout their travel experience(Meyer & Schwager, 2007). By translating the different stages of the trip chain into customer journey mapping scenarios and applying the frameworks of customer journey mapping, researchers can gain a comprehensive understanding of the travel needs and experiences of individuals with cognitive impairments. That enables researchers to systematically analyze each stage, including the pre-trip, on-trip, and post-trip phases, without overlooking any crucial aspects.

Thus, this study utilized "Customer Journey mapping" as the second analysis method. Firstly, the horizontal columns of the table were utilized to segment the autonomous bus journey into detailed mini-scenarios and events, following the trip chain: boarding the bus, settling down during the trip, experiencing a hard brake, temporary stops, preparing to get off the bus, and disembarking the bus. Secondly, the vertical columns of the table were designed into three distinct categories: interaction, which encompassed the roles of children with cognitive impairments, safety staff, and caregivers; channels, which highlighted the specific touchpoints where interactions occurred; and challenges, which identified the difficulties faced by children during their bus journeys. Based on this structure, the data from study one were broken down and analyzed to gain a deeper understanding of the phenomena encountered by each persona during the events. A small thumbnail of this analysis, please refer to Appendix B. This analytical approach provided valuable insights into the roles of caregivers, safety staff, and technologists in the context of autonomous bus travel experiences and the potential ways technology can support them.

4.4 Ethical consideration

Maintaining the children's privacy and preventing unauthorized individuals from accessing their data was the utmost priority; therefore, a series of measures were strictly implemented. A paper contract was signed, strictly adhering to a confidentiality agreement to ensure the confidentiality of the data and committing to safeguard the data from any unauthorized access by third parties. Retrieving the data required stringent authentication procedures to access the university's network storage, where the data was securely stored. Analyzed and reviewed the data online, ensuring it remained confidential and protected throughout the interpretation process. Conducted data analysis in a secure and private environment and ensured that the data was not visible to anyone outside of the project.

4.5 Findings

The findings from study one revealed the **experiences** of children with mild cognitive impairment using autonomous buses and identified the **challenges** faced by these children in various scenarios during the **On-trip phase.** In addition, these findings also shed light on the roles of caregivers and safety staff during the trip, which will be elaborated on in the discussion sections.

The results showing in the following:

- **Getting on the bus**

  The safety staff opened the doors, carefully observed, and ensured the safety of passengers during getting on and off the bus. Children and their caregivers then proceeded to board the buses; in cases where children have physical disabilities, caregivers or safety staff assisted in helping them onto the bus. Additionally, for children using wheelchairs, caregivers seek the assistance of safety staff to deploy the wheelchair ramp and ensure the child's smooth entry onto the bus.

Challenge: The wheelchair ramp on the autonomous bus does not open automatically, making it difficult for caregivers to assist children in wheelchairs without the assistance of the safety staff when boarding the bus.

- **Settling down**

  Some children demonstrated a proactive attitude by independently fastening their seat belts upon boarding the bus without needing a reminder from the safety staff. However, if children and their caregivers were unaware of fastening seat belts, the safety staff kindly reminded them to do so from the back seat. Caregivers promptly followed the instructions of the safety staff and ensured that both their seat belts and the child's seat belts were properly fastened. In the case of a child in a wheelchair, the safety staff securely secured the wheelchair to the bus's floor to ensure stability and safety during the journey.

  Challenge: Caregivers and children with intellectual disabilities who use wheelchairs may struggle to properly secure the wheelchairs on the bus without instructions from the safety staff. Additionally, some mentally disabled children may have difficulty independently fastening their seat belts, and it should be noted that seat belts are only available in the bus' rear seats.

- **During the trip**

  After ensuring that everyone was seated safely, the safety staff initiated the autonomous bus by inputting the command through a digital display or a physical control lever. Throughout the journey, caregivers might have questions about the autonomous bus, and the safety staff readily provided answers and clarifications to address their concerns. Some children were curious about the bus, interacting with the safety staff who engaged in conversations and responded to their inquiries. On the other hand, some children find the bus to be boring or perceive it to be moving too slowly. Additionally, some children might exhibit excitement, while others, who may have social issues, prefer to gaze out the window or remain quiet. Caregivers observed the children's behavior, ensuring their safety and comfort throughout the trip.

  Hard braking: In the event of a hard brake, the safety staff promptly assessed the situation outside the bus and explained what occurred to caregivers and children. Caregivers, showing concern for the children's safety, immediately inquired about their emotional state while observing their reactions. While some children experienced a startle response, none displayed a loss of emotional control. Some children even said they were not scared in response to the incident.

  Temporary stops: In the event of a sudden stop, the safety officer swiftly took control of the bus, assessed the situation outside the window, and, once deemed safe, resumed the bus operation. Following this incident, the safety staff explained to both caregivers and children, clarifying the circumstances. Caregivers took the opportunity to inquire about the autonomous bus and paid close attention to the children's behavior, engaging in conversation with them to help stabilize their emotions and alleviate any nervousness. Some children expressed curiosity about why the bus had stopped and asked questions of the safety officer, while others observed the surroundings through the window or remained quiet. A few children had felt slightly nervous due to their lack of understanding regarding the sudden stop.

Challenge: During the trip, children may experience boredom and nervousness. The frequent abrupt stops can cause unease and safety risks for children and other passengers. The temporary stops may also confuse children with difficulty understanding the situation, leading to emotional instability.

- **Getting off the bus**

  Once it was established that the bus had come to a halt, the safety staff promptly opened the doors. Some children demonstrated the ability to independently unbuckle their seat belts and disembark from the bus, while others required assistance. Caregivers were there to lend a helping hand to children who could not unbuckle their seat belts and provide support to those with physical limitations, aiding them in safely exiting the bus. Additionally, the safety staff assisted children in wheelchairs by releasing the wheelchair from the floor, facilitating their smooth departure from the bus.

  Challenge: Children may face challenges at the correct stations when getting off the bus due to the lack of clear announcements or guidance.

These challenges highlight the need for external support to assist some children with mild cognitive impairments in completing specific tasks during travel. The observed difficulties in getting on the bus, securing wheelchairs, fastening seat belts, and understanding temporary stops indicate that these children often require assistance from caregivers and safety staff.

5. Study two: An online focus group study

Study two aims to gather insights from people regarding the children's travel experiences, both before and after the trip, as a supplementary component to study one. This study is supported by staff members from Skelleftea municipality, who are committed to enhancing the independence of individuals with disabilities through innovative technologies. Initially, study two planned to conduct semi-structured interviews with each participant to gather their insights and perspectives. However, after consulting with them, they showed stress and were overwhelmed by the proposals of individual interviews. Therefore, a focus group study was conducted instead of individual interviews, which is more suitable for creating a more relaxed and comfortable environment where participants could freely share their experiences and viewpoints. This decision aligns with the principles Krueger (2014) outlined and promotes interactive discussions among participants within a group setting.

5.1 Participants

The online focus group included **five teachers from a specific school** with extensive experience working with these children and **a staff member from Skelleftea municipality.**

Initially, the focus group aimed to recruit individuals from diverse backgrounds, including staff members from transportation departments, individuals with extensive experience working with cognitively impaired children, and taxi drivers who regularly transported these children. By involving participants from different fields, the aim was to gather diverse opinions and perspectives to better understand the travel issues related to these children. However, due to the challenges of coordinating schedules among participants with different working hours, arranging a time that worked for everyone was not feasible. As a result, the focus group was primarily composed of individuals with extensive experience working with cognitively impaired children, deemed crucial for this study. To accommodate the participants' availability and ensure their active participation, the focus group was conducted online.

5.2 Overall design

The focus group meeting was conducted using the secure and reliable platform Microsoft Teams. This platform facilitated efficient and accurate transcription of the discussions, allowing for later review and analysis. The meeting took place in a comfortable and private space to ensure the participants' privacy and comfort during the discussion. A detailed discussion plan and question list based on each stage of the trip chain were developed to guide participants in sharing their experiences and perspectives. This approach ensured comprehensive coverage of relevant topics and gathered the necessary information to fulfill research objectives. For a more in-depth understanding, please refer to Appendix C, which provides a detailed discussion plan and question list.

5.3 Procedure

Taking into account the participants' daily work schedule and ensuring their interest and concentration, therefore the duration of the discussion was limited to one and a half hours.

At the outset of the focus group, the topic and purpose of the discussion were introduced, with the aim of exploring the experiences of caregivers of children with cognitive impairments, the needs of children, and the potential benefits of autonomous buses in improving the travel experience for these children. Following this, each participant briefly introduced themselves and engaged in light-hearted conversation to foster a comfortable atmosphere. Since the focus group was conducted online, the ethics consent form was read aloud to ensure that all participants were fully informed and had given consent for their information to be recorded during the discussion. Participants were also asked for permission to record the session. Emphasis was placed on the importance of protecting participants' privacy and compliance with relevant regulations, including appropriate handling of the recordings to prevent harm or breach of privacy. This segment was estimated to take approximately 10 minutes.

Subsequently, the participants were queried about their familiarity and opinions regarding autonomous buses. It became evident that most participants had limited exposure to this topic. Despite sending the relevant questions before the discussion, it was uncertain if all participants had reviewed them. Hence, around 10 minutes was dedicated to familiarizing the participants with the external appearance, internal configuration, technical foundations, and use cases of autonomous buses to enhance their comprehension of the context of the discussion.

Afterward, a structured discussion proceeded with following the trip chain. This approach effectively maintained the participants' focus without distractions. At each stage, the discussion initially focused on the challenges faced by caregivers traveling with children with cognitive impairments and their experiences, subsequently exploring how integrating caregivers, safety personnel, and bus design (both digital and physical) could enhance the travel experience. This section of the discussion lasted approximately 60 minutes.

The final 10 minutes of the focus group were dedicated to an open discussion regarding the potential opportunities that could arise from integrating self-driving cars and artificial intelligence in the future. Participants were encouraged to share their thoughts, ideas, and visions.

It is essential to mention that this discussion did not strictly follow the initial outline. After the half process, the caregivers' perspectives were found that although not tightly closed to the research question, they were still of particular significance and warranted further exploration. Thus, this discussion followed certain foundational questions as a guide but kept a more open-ended discussion to capture a broader range of ideas and insights from the participants. This flexibility facilitated delving deeper into the caregivers' experiences and gathering valuable perspectives that enriched the understanding of the topic.

5.4 Ethical consideration

Prior to conducting the focus group, all participants were provided with a voice consent form outlining the study's ethical considerations. They were instructed to listen and understand the content of the form carefully. The participants were informed about the research objectives and the purpose of their involvement. They were also aware that their participation would involve recording information for research purposes. Additionally, participants were informed of their right to withdraw from the study at any time if they felt uncomfortable or no longer wished to participate. Explicit consent was obtained from all participants regarding the usage of recordings, and measures were taken to store and maintain the confidentiality of the recorded data securely. The protection of participants' privacy was prioritized, and a strong commitment was made to comply with applicable regulations and ethical guidelines. These steps were implemented to safeguard the well-being and privacy of the participants throughout the research process.

5.5 Data Analysis: Thematic Analysis

Thematic Analysis is a method used for analyzing and interpreting qualitative data. The primary purpose of this method is to identify themes or patterns that emerge from the data and then organize these themes into a set of meaningful results (Braun and Clarke, 2006). The data collected from focus groups are diverse and fragmented. Thematic Analysis can aid in formulating the key points from this data with the six steps suggested by Braun and Clarke

(2006), which include familiarization with the data, developing preliminary codes, searching for themes, reviewing and defining themes, checking the themes, and presenting the results.

During the analysis process, by systematically examining each fragment in the transcript and identifying the critical content, we can assign appropriate labels that capture the essence of the fragment. This labeling process helps organize the fragments and allows for more accessible analysis and interpretation of the data.

At the beginning of the analysis, a total of 256 codes were produced. For example, consider the following fragments:

Participant 1: "We need to plan the structure before the activity."

Participant 2: "(...) explains all these small details (...) in a strict plan before travel; otherwise, children may not go."

In these cases, the content of the fragments revolves around the preparation before travel or activity and its impact on the children's motivation and emotions. Therefore, these fragments can be labeled as "Challenges and needs before the trip: child emotion or motivation and strict structured plan." It is worth noting that participants sometimes described both challenges and solutions together in their sentences, resulting in fragments that may encompass two labels. The labeling process allows for better organization and analysis of the data. Through categorizing the identified fragments, 55 labels were generated after the first round of labeling.

The 55 labels were carefully checked for connection among them and then re-categorized into 23 labels. Here are a few examples of the categorized labels:

"Challenge on the Bus: Emotional Stress," "Autonomous Buses Advantages," "strict structured plan," "Challenges of preparation," "children are different," " parents' support for emergencies."

According to the essential labels, further categorized and five main themes were identified: "insights about technology," "learning ability," "needs," "challenges," and "diversity issues." However, upon careful examination of the data within the context of these themes, while factors such as "learning ability" and "diversity issues" were relevant to this research question, it was challenging to formulate solid and definitive ideas based solely on these factors. Thus, three main themes were identified and grouped similar data into several sub-themes. The main themes are **Challenges**, **Needs**, and **Insights from caregivers about technology**.

5.6 Findings

The results of study two revealed the challenges experienced by children with mild cognitive impairment when using autonomous buses during their trips, as well as the caregivers' perspectives regarding their needs and reactions of cognitively impaired children to technology.

5.6.1 Challenges

According to the caregivers' experiences, the main challenges faced by children with mild cognitive impairments vary at different stages of their trip. The following quotes show the caregiver reflecting before the trip.

> *"They need to know exactly what is going to happen when they are going to do this activity (...) Otherwise, they will say, no, I'm not going to do that."- P1*

The above quotes express that the main challenges for children with mild cognitive impairments before the trip are the fear of unknown travel; these children lack the motivation and confidence to leave their familiar environment. They may refuse participation in outings unless they perceive a sufficient level of safety. Therefore, the **Challenge before a trip** is Children with cognitive impairments experience insecurity and a lack of trust when faced with unfamiliar trips, resulting in a loss of motivation and confidence in traveling.

Waiting at the station often poses big trouble for those children, as things may not go as planned. Caregivers explained it in the following way.

> *"Buses usually are not on time (...) They can't communicate their frustration (...) So waiting is very difficult. They don't know what to do in 10 minutes, what do I manage to make and do in 10 minutes? "- P1*

> *"Some buses don't come to the right place. For these children is very big challenges"- P2*

> *"If there are some unexpected situations. They don't know how to do how to deal with that."- P4*

Children with cognitive impairments often struggle to understand unexpected events or deviations from their understood plans. The inability to grasp why things are not going as expected can upset them. These phenomena are primarily attributed to the unpredictable and unpunctual operation of buses. Thus, the **challenge at stations is** the unpredictable bus operation schedule, and incorrect bus stop locations contribute to the challenges faced by children with intellectual disabilities in locating the bus stations. Moreover, the prolonged waiting periods during this process can lead to heightened emotional anxiety.

When asked about the challenges faced by these children on the buses, caregivers showed more concerns about emotional challenges and social interaction issues with the following quotes.

> *" They just have difficult to accept each other's behavior"- P5*

> *"When we look after autonomous buses, the seats, all of them. to the middle, facing each other. They are always facing each other. And as we said before, some of the kids are really difficult and social. (...) Maybe we have some children*

are difficult to ride the same bus with other children if they could be a possibility to have a one seat a little bit more."- P1

The significant challenge experienced on the buses involves children with intellectual disabilities who also have social disorders. These children encounter difficulties in accepting the behaviors of others and interpreting their emotions, which places a substantial cognitive burden on them. Riding alongside other passengers can consequently evoke stress, fear, and anxiety. Moreover, while on a trip, these children face obstacles in seeking assistance from others and expressing their thoughts and needs effectively. Hence, the **Challenge on the buses** is that Cognitively impaired children encounter heightened psychological and emotional pressure from other passengers during bus rides due to social disorders. The current design of autonomous buses, particularly the arrangement of open spaces and seats facing each other, further exacerbates this issue.

5.6.2 Needs for encouraging children to travel

Caregivers also mentioned several solutions for encouraging children to travel. The following quotes show how they encourage children to travel.

"We have a strict and precise structured preparation before we do an activity (...) so they're gonna follow a checklist."- P2

"A precise bus operation time and stop place that's helpful for the people we work with"- P3

Detailed and thorough travel plans play a crucial role in boosting the confidence of children with cognitive impairments, fostering a sense of trust and security, and ultimately encouraging their active participation in traveling. Similarly, precise bus operation ensures smoother travel experiences for these children. Both aspects highlight the necessity of **precision** in creating conditions that support independent travel.

Caregivers argued that those children struggle with accepting new situations, and any deviations from routine can cause them to feel insecure. They need consistent surroundings; for instance, having a consistent driver, vehicle, time, and location can provide comfort. Repetitive daily routines can also help them feel more at ease when going out. The following quotes prove that.

"If it's the driver that I've driven the child many times (...) the child knows the driver, they feel more safe and can get on."- P1

"If they take same bus (...) going same way to bus station every day (...), that is helpful."- P3

Accordingly, maintaining **consistency** in various factors can help reduce cognitive loads for children with cognitive impairments, thereby making their travel experience more accessible.

When asked how they coped with the emergencies, caregivers said parents are often the most effective source of comfort for these children, and speaking with their parents can help them feel secure.

> *“I think it's bigger chance that a phone to phone your parents or something of the calm down.”- P4*
>
> *“If something happens, it would be good if they can call their parents or someone they trust. (...) help them to become calm down.”- P2*

Thus, **Parental support** is the most effective way, taking various forms, including providing reassurance, offering guidance and assistance, and actively participating in the travel planning process. Having parents involved makes children feel more secure, confident, and supported, reducing their cognitive burden and facilitating smoother travel experiences.

5.6.3 Insights from caregivers about technology

Caregivers strongly believed in **technology's potential to assist children with cognitive impairments**, including autonomous buses.

> *“The automatically bus will do the same thing over and over again and that's helpful for us.”- P6*
>
> *“I think automatic buses becomes more predictable (...) they know what will happen every time, the same thing.”- P2*
>
> *“I have such high hopes for technology. (...) the bus would stop right place and then will inform you should go out, go get off the bus now.”- P4*

The **feasibility of using robots instead of humans** was also discussed, with caregivers expressing confidence in its viability.

> *“In Denmark, a robot has been tested in teaching at schools with children with special needs. And it worked out very well, because the children didn't need to read different emotional states of the teacher all the time. They could focus on what they were going to learn instead. So I think it's a good idea.”- P6*
>
> *“A robot is more predictable and you need that. He's going to interact at the same way every time.”- P2*

Caregivers provided positive feedback when asked about **other technological products** like GPS and navigation systems. They believed that children could use these tools effectively, and they highlighted the potential for children to receive notifications on their phones about when to get on and off the bus, enabling them to complete these tasks independently. Caregivers also expressed great interest and confidence in future AI and big data development, envisioning possibilities such as using smartwatches to sense adrenaline and detect children's emotions in advance.

6. Discussion

This section will integrate the findings from two studies datasets, along with the context of prior studies, to answer **RQ1** and **RQ2.**

RQ1: *What are the challenges for cognitively impaired children related to travel*？and **RQ2:** *What are the potential solutions for cognitively impaired children based on autonomous buses through caregivers' perspective lens*？

By doing that, the research question can be addressed- *How can autonomous buses be designed and used to support children with mild cognitive disabilities in achieving greater independence during their travel?*

6.1 Answering RQ1:

The findings of study one, derived from the observation of external behaviors, prominently highlight the visible challenges encountered by children utilizing autonomous buses. On the other hand, the challenges identified in study two, stemming from the experiences and insights of caregivers, primarily shed light on the less apparent but significant challenge relating to motivation, emotion, and cognitive impairments. By integrating these two sets of findings, a comprehensive understanding of the challenges experienced at different stages throughout the travel process can be attained.

- **Before a trip:** According to Risser et al. (2015), the challenges and barriers faced by individuals with cognitive disabilities are not solely due to the inaccessible external context. Instead, they also stem from internal factors such as motivation and attitudes. Children with cognitive impairments frequently struggle with motivation and confidence regarding independent travel due to feeling insecure and lacking trust in unfamiliar situations. Consequently, they may exhibit reluctance to start travel, let alone embark on journeys individually without assistance or guidance.
- **Go to and arrive at the station trip:** The primary obstacle impeding children's independent travel lies in the occurrence of unforeseen events out of their plans. Inaccurate placement of bus stops enables children with cognitive impairments hard to reach the designated bus stations. Moreover, the unpredictability of bus schedules results in prolonged waiting periods, intensifying emotional anxiety and undermining their confidence in independent travel. In addition to our research findings, prior studies have also demonstrated that inadequate design of transportation-related

facilities and complex environments impose burdens on children with cognitive impairments during their journeys (Carmien et al., 2005).

- **On the buses:** Onboard autonomous buses, children with cognitive impairments face challenges that can be attributed to two primary sources: their physical and cognitive abilities (Rosenkvist, 2008). Firstly, the design of autonomous buses often lacks adequate support for children with cognitive impairments, particularly those with physical disabilities, making it difficult for them to complete travel tasks independently. Further details on this topic were provided in study one. Secondly, the presence of other passengers on buses can contribute to internal emotional issues experienced by children with social disorders.

6.2 Answering RQ2:

Before answering the questions of this study, it is worth discussing the possibility of independence during traveling for children with cognitive impairments firstly.

6.2.1 The possibility of independence during traveling for children with cognitive impairments

When asking caregivers if these children could travel independently, such as finding their way to the station and reaching their destination, they showed confidence in these children. They believe these children can find their way independently with enough patience and time to teach them to identify objects with persistent landmark properties (Courbois et al., 2012). Kubiak (2015) emphasized that repeated learning helps preserve what is being learned, meaning that through consistent repetition and practice, individuals with cognitive disability are more likely to retain and maintain the knowledge or skills they have acquired. That was proved by video; a researcher taught a child how to open the car door during observations in study one. After two to three demonstrations, the child could open the door independently. They also emphasized that strict structure plans and less social interaction are prerequisites for those children's independent traveling. Children can follow their plans to travel independently. However, caregivers emphasize the importance of assessing a child's ability to complete a task and handle unexpected situations before allowing them to do something independently. They prioritize the child's safety and well-being above all else. If a child is deemed incapable of completing a task independently, caregivers will not permit them to do so.

6.2.2 Design insights

Based on the preceding description, it is evident that caregivers' perspective in addressing the challenges experienced by children with cognitive impairments during travel is centered around the fundamental concepts of precision, consistency, and parental support. To elaborate, the concept of precision involves developing a well-defined plan, ensuring well-organized bus operations, and providing accurate information to reduce uncertainty-related stress and cognitive load experienced by the children. Consistency pertains to maintaining a consistent plan, information, and external environment, which can significantly alleviate the children's cognitive load and feelings of confusion. Additionally, parental support plays a crucial role in providing emotional encouragement, instilling confidence, and offering reassurance to the children during emergencies, thereby facilitating the successful completion of their trips.

On the other hand, facing the challenge of those children using autonomous buses, they cannot independently complete tasks due to cognitive or physical limitations; it is beneficial to embrace proactive design principles rather than relying solely on accessible design. The emergence of artificial intelligence (AI)-driven interactive systems has led to the development of the concept of proactive human-computer interaction. In this approach, AI systems initiate and drive user interactions rather than solely relying on human input. (van Berkel, Skov, & Kjeldskov, 2021). By taking a proactive approach, these children can complete specific tasks with the assistance and support of automated systems without being solely responsible for the entire operation, ultimately promoting their independence and autonomy.

Given the above considerations, four design insights were identified: **proactive design**, **precision**, **consistency**, and **parental support** to assist children with mild cognitive impairments in achieving greater independence during their travel.

6.2.3 Design Implementation

These design insights can be applied across the entire travel process, encompassing both human support and technological products, including autonomous buses. The implementation of these design suggestions aims to provide greater support for children with cognitive impairments, enabling them to travel more independently and with increased confidence.

Proactive design: It involves both visible physical interactions and invisible information interactions to assist children with cognitive impairments by anticipating and addressing their needs proactively. This approach aims to reduce their reliance on others and promote greater independence in their travel.

Previous research has highlighted the impact of self-driving technology on the internal space of buses, leading to increased diversity in interactions. Therefore, interaction and experience design should be considered across various aspects, and the design of automated and accessible interfaces is of utmost importance (Moreno et al., 2023).To support the independence of children with cognitive impairments, designers can incorporate proactive interaction for certain functions to reduce the difficulty of completing tasks. That can be achieved through sensor-based technology for automatic seat belts, wheelchair ramps, and an automatic door control system. Furthermore, to enhance information accessibility and compensate for cognitive deficits, multimodal interfaces can be utilized (Tolba, 2019). For example, autonomous buses can actively notify children about their route, estimated arrival time, and emergency notifications through displays and sound prompts, thereby reducing passenger anxiety and uncertainty.

Similarly, the design of external interactions should also be considered when the bus enters the station, actively displaying its route to help children confirm that they are boarding the correct bus. Moreover, compared to traditional buses, dynamic design aspects and elements such as seating and space can be adjusted to improve attention and reduce cognitive workload (Pollmann et al., 2019). For instance, autonomous buses can dynamically create private spaces within small and medium-sized public transportation systems, providing a secure and comfortable environment for children with social stress (Fröhlich et al., 2018).

Consistency: Keep consistency is proposed to use consistent design elements and experiences throughout the entire system or product, ensuring that the design is tailored to the needs of children with cognitive impairments, considering their cognitive abilities, attention spans, and sensory processing. By doing so, unexpected changes can be minimized, promoting familiarity and reducing the cognitive load and sense of confusion for users.

In all components of the public transportation system, including vehicles, stations, information display systems, and interactive devices, consistent design elements and experiences should be maintained, including factors such as color, font, iconography, and interface layout. Research conducted by Janebäck and Jonsson (2020) on design usability for individuals with cognitive impairments emphasizes the importance of considering these factors in user interface (UI) design, adhering to established standards and using familiar icons, terminology, and symbols can improve the comprehensibility of the UI and facilitate ease of use. In addition, voice interaction is an emerging method of interaction, and careful consideration must be given to the choice of language to ensure cultural appropriateness for the user (Law et al., 2019; Al Mahmud and Soysa, 2020). However, it should be noted that designing audio interfaces presents challenges and may require users to rely on memory and mental agility to make interaction decisions. That can be difficult for individuals with cognitive impairments and may introduce new usability barriers.(Castilla et al., 2020).Based on the suggestions provided by caregivers, providing consistent and less emotionally charged feedback is recommended, as this can enhance interaction with individuals with cognitive impairments. Predictability and controlled feedback are beneficial for children in particular. Similarly, information display systems and interactive devices in public transportation should follow the same operating procedures and interaction methods to avoid inconsistent operations and prompts in different contexts. Inconsistencies can increase confusion and cognitive load for users.

In addition to ensuring consistency in design elements and experiences, it is advisable to have consistent and familiar staff members working on autonomous buses. That can significantly benefit children with cognitive impairments as it helps them feel more secure and confident in the presence of familiar individuals and within familiar situations. Furthermore, building a trusting relationship with these staff members enables children to rely on their assistance, ultimately enhancing their sense of security and promoting their independence.

Precision: Precise design and experiences are crucial in reducing uncertainty-related stress and cognitive load, promoting confidence and security for children with mild cognitive impairments during travel. Designers should prioritize precision in their transportation services, ensuring accurate information such as vehicle arrival times, driving routes, and stop locations. This information can be effectively conveyed through various mediums such as screens, voice prompts, or mobile apps, enabling children to plan their trips better and avoid anxiety and confusion. Enhancing the travel experience is essential for autonomous buses to adhere to on-time arrival and departure schedules, minimizing long waiting times and accurately stopping at designated pickup and drop-off points. Consistency in bus arrival, parking, and operation further contributes to a comfortable and predictable travel experience. In the event of delays or cancellations, it is essential for public transport systems to promptly notify children and parents, providing alternative travel options to mitigate any disruptions to their journeys.

Support from parents: Based on the recognized significance of parental support for children with cognitive impairments during travel, designers can incorporate a remote parental support system into autonomous buses. This system allows parents to monitor their child's journey in real-time through a mobile app or other interfaces, providing updates and encouragement throughout the trip. The app can also serve as a platform for parents to communicate with their children during the journey, offering reassurance and support when needed. By integrating a remote parental support system into the autonomous driving system, children with cognitive impairments can benefit from the stability and assistance of their parents, which promotes emotional well-being, confidence, and independence during their travels.

In summary, precision is crucial in designing autonomous bus operational services to reduce uncertainty and increase the confidence and sense of security in children with cognitive impairments. Consistency in interaction, experience, and functional autonomy should be prioritized when designing autonomous buses to assist children in completing their travel tasks. Additionally, parental support can be integrated as a remote assistance system, providing encouragement and practical help to reduce anxiety and negative emotions, thereby promoting a more positive travel experience for children. These positive experiences can significantly enhance the trust and confidence of children with cognitive impairments, fostering a greater willingness to venture out before their trips. When these children have successful and empowering travel experiences, trust in the process and their own capabilities increases. That, in turn, motivates them to engage in independent travel and explore new environments with greater enthusiasm and confidence. Thus, through human and technology collaborative efforts, autonomous buses can potentially enhance the independence of children with cognitive impairments in the future.

6.3 Other considerations

While offering design suggestions for using autonomous buses to support independent travel for children with cognitive impairments, it is essential to consider other relevant factors. Two significant considerations are the diversity of these children and the potential opportunities for designing a service ecosystem tailored to their needs.

6.3.1 Individual differences

In line with the findings of Fischer(2001), the results of this research also indicated that children with cognitive impairments have complex and diverse responses and needs. Caregivers also emphasized the uniqueness of each child's needs, highlighting the importance of considering individual differences. These variations in needs were further evident in observations of different reactions and responses among the children during autonomous bus rides. Some children remained quiet and unresponsive, while others displayed curiosity and engaged in conversations with the safety staff. Some children sought companionship and communication, while others struggled with social interaction. Regarding the support needed for independent travel, the focus group discussions provided insights that precision planning, consistent context, limited social interaction, and parental support can facilitate independent travel for children with some learning abilities. However, observations also revealed that some children might require assistance for specific tasks, such as fastening safety belts or boarding the bus. Moreover, while some children can become independent through learning, others may require lifelong support. These findings underscore the complexity of promoting independence during trips for children with mild cognitive impairment, presenting a challenge for designing human-computer interaction (HCI) based on user-centered design principles. Furthermore, establishing universally applicable standards that address this group's diverse needs and preferences is difficult (Carmien et al., 2005). It is important to note that these research findings are based on current data and previous research, providing valuable insights into common phenomena rather than strict standards.

6.3.2 The roles of caregivers and safety staff

Caregivers and safety staff are essential in ensuring cognitively impaired children's safe and comfortable travel on autonomous buses. Caregivers, as primary guardians, are responsible for providing additional care and support for these children during the journey, such as assisting them with fastening seat belts and boarding or alighting the bus. Moreover, caregivers need to monitor the emotions and behavior of the children closely, offering appropriate care and support whenever necessary to address any anxiety or fear they may experience. On the other hand, safety staff has various responsibilities, including managing the boarding and alighting of passengers, initiating the bus's operation, monitoring traffic conditions and vehicle status, and overseeing takeovers when needed to ensure passenger safety. They also serve as a guide for caregivers and children, answering their questions about autonomous buses and helping them understand and adapt to this new mode of transportation. Safety staff provides support and assistance to caregivers and children, ensuring the safety and comfort of intellectually disabled children during their autonomous bus travel.

These findings align with the research conducted by Schuß et al. (2022) on the changing responsibilities of drivers. As the transition to autonomous bus systems progresses, there is a potential for safe staff to assume new roles, including potentially taking on caregivers' responsibilities. This shift in responsibilities could shape the future of autonomous bus transportation, introducing a new dynamic and redefining the role of safe staff.

6.3.3 Transportation service system

As Carmien et al.(2005) highlighted, establishing a supportive platform system for public transportation use by individuals with cognitive impairments requires a socio-technical approach. In the future, designers can leverage the potential power of AI data and IoT to integrate various devices, such as virtual and hands-on training tools, personal trackers/locators, and GPS/audio-visual cue devices. These devices have proven effective in improving the independent bus travel of children with cognitive impairments, enhancing their confidence and ability to use public transportation independently (Stock et al., 2011). Integrating these devices with autonomous bus systems can create a more comprehensive and user-friendly service chain. By enabling data sharing among these devices and the bus system, the accuracy and effectiveness of these services can be improved, ultimately promoting these children's independence and quality of life. An integrated system can also provide parents with a sense of security, knowing their children can access reliable and safe transportation with assistance.

Additionally, while the goal of this study is to promote independence, it is essential to recognize the crucial role of human factors. For example, additional assistance and supervision from safe staff or caregivers may be necessary for children with cognitive impairment to ensure their safety and comfort during transportation. Furthermore, even if caregivers are not physically present, they remain an integral part of the service design system in the back end, as previous studies have demonstrated.

In summary, by combining the efforts of technology, safe staff, and caregivers, an integrated transportation service system can be developed to provide a comprehensive and sustainable service chain for children with cognitive impairments, ultimately promoting their independence and enhancing their overall quality of life.

6.4 Limitations and future work

6.4.1 Limitations

Despite the valuable insights gained from this research, it is essential to acknowledge the study's limitations and consider their potential impact on interpreting the results.

Firstly, the presence of caregivers throughout the observation to ensure the safety of cognitively impaired children could have influenced the observed behaviors. These behaviors may have been performed under supervision rather than independently, potentially impacting the generalizability of the findings. Additionally, using semi-structured questions during focus group interviews may have constrained the discussion and omitted essential points. Moreover, the issue of "proxy design" arises as the caregivers, rather than the children themselves, represent their wishes, introducing the possibility of caregiver bias or misinterpretation of the children's needs and preferences.

Secondly, it is crucial to recognize that the experience of autonomous buses provided to participants occurred in a controlled experimental setting, which may not fully replicate the complexities of real-world environments. The bus environment can be seen as a mobile laboratory where researchers provide maximum support to ensure the comfort and safety of intellectually disabled children. Factors such as the absence of other passengers on the bus and the lack of real-world scenarios involving stops and pickups make it challenging to assess the impact of other passengers' emotions and behaviors on the children's independence. The study's limitations in capturing data related to the influence of other passengers may affect the applicability of the findings to real-world situations.

Finally, to achieve this research goal, two studies were conducted, employing different sources and methods to collect and analyze data, requiring extensive research experience or sufficient time to analyze data repeatedly. However, it is essential to acknowledge that the timeline of this study was relatively short, which may have limited rigor of the data. On the other hand, The independence and psychology of children with cognitive impairments require long-term observation and analysis to understand fully. Therefore, this study may have only captured a limited snapshot of a specific phenomenon, potentially resulting in incomplete or biased conclusions.

6.4.2 Future work

As innovative technology continues to evolve, further research is needed to address the limitations and gaps in the current study and explore new avenues for advancing understanding of the topic at hand.

Firstly, various research methods can be explored to obtain richer data and conduct real-world experiments. However, it is crucial to carefully consider ethical considerations to prevent any negative impact on the experiences of children, such as those caused by negative emotions or behaviors of other passengers. Additionally, conducting long-term longitudinal studies can offer a more comprehensive understanding of the challenges and opportunities faced by children with cognitive impairments in autonomous transportation systems, including potential changes that may occur over time.

In addition to the inherent challenges and needs faced by children with cognitive impairments, various other factors can significantly impact their level of independence. One such factor is the perception of autonomous buses among these children, as it can affect their willingness and ability to utilize this mode of transportation. Another crucial aspect is their learning ability, which influences their capacity to adapt to new environments and tasks and ultimately determines their level of independence within an autonomous transportation system. Furthermore, the influence of peers and caregivers can also shape their willingness to use transportation and their overall experiences while doing so. Therefore, delving into the interplay between these factors and children's independence could be a promising research direction, providing valuable insights for future design and development.

Finally, building upon this paper's findings and recommendations, several specific design considerations can be explored to enhance the independent travel capabilities of children with cognitive impairments in autonomous buses. These design considerations encompass both physical and information interactions within the autonomous bus environment. Additionally, there is potential for developing a comprehensive autonomous bus service system specifically tailored to support independent travel for children with cognitive impairments. Such a system would involve the collaboration of safety officers, self-driving vehicles, and other electronic devices to provide a complete range of solutions for independent travel. With time, the reliance on caregivers and safety officers can gradually diminish until their assistance is no longer necessary.

7. Conclusion

This study sheds light on the potential of autonomous buses to enhance the independence of children with mild cognitive impairments during travel. By examining their experiences and challenges in interacting with others on autonomous buses, the study identifies the crucial design insights: proactive design, precision, consistency, and parental support, as well as provides recommendations for implementing the design of autonomous buses. Additionally, the study underscores the importance of collaboration between technology and human support, emphasizing the need to account for human factors in transportation systems. Finally, caregivers expressed a positive attitude towards various technology products for children with cognitive impairments, perceiving them as predictable, accurate, controllable, consistent, and devoid of emotions, which they found beneficial. These insights can guide the design and development of technological products catering to individuals with cognitive impairments, extending beyond transportation applications.

This study makes contributions to the field of human-computer interaction, both regarding knowledge advancement and practical implications. It offers insights into user experience understanding and design implementation, particularly concerning autonomous transportation systems and their support for individuals with cognitive disabilities. The findings and recommendations of this study have the potential to enhance understanding of how to design future autonomous transportation systems that better cater to the needs of these individuals, promoting inclusivity and accessibility. Additionally, the design insights gained from studying individuals with cognitive impairments can also be generally applied to the elderly population, as cognitive abilities naturally decline with age. In summary, this study emphasizes the importance of considering the unique needs and perspectives of marginalized user groups and advocates for advancing accessibility and inclusion in human-computer interaction.

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Appendix A:

An Example about Transcribed data from Videos

Åktur 1
The first group of children:
Three children. The older boy is referred to as "F," the younger boy as "little M," and the girl as "MM." All three have mild intellectual disabilities but are physically healthy and have full independent mobility. They have some capacity for independent decision-making and can communicate with the outside world, including people and objects.

"Åktur 1 Påstigning" -Getting on
The researcher and caregiver accompanied the child to the bus station and, on the way, asked if the child was interested in riding the bus. The child showed curiosity and excitement. They run to the bus and get on the bus by themselves. The first group of children, who had mild mental handicaps but were physically able, could board the bus and find seats on their own.
To ensure the safety of the children, the safety officer rearranged their seating arrangement. The safety officer sat in the back row between two children, "little M" and "MM," while the "F" sat in the front row with the researcher. The child sitting in the back did not actively fasten the seat belt; carers helped two children to fasten the seat belt.

"Åktur 1 Kamera bakåt" - Rear-facing camera & Kamera framåt-back camera
Event1: get on the bus
Buses: There is an audible alert when the door is closed. Audible alert before the vehicle starts
Children: The children found seats and sat down but did not have the sense to put on their seat belts.
Carers: Caregiver did not initially put on her seat belt until prompted by a safety officer. After being prompted, she assisted the children and themselves in putting on their seat belts and sat between them.
Safety staff: The safety officer emphasized the need for seat belts in the rear and asked that they be worn in the back.
Event2: bus starts
Buses: After two beeps first, relatively slow start-up
Children: Curious and Relax.
Safety staff: close the door
Event3: When an obstacle appears
Buses: hard brake suddenly
Children: Due to the brakes, the back row of the child's body appeared to sway back and forth. However, there was no significant safety hazard since the children were wearing seat

belts, and the car was not moving quickly. The front row, where "F" was seated, did not seem affected as much.

Carers: Take care of your children and talk to them as a way to dissipate their nerves

Safety staff: explain the situation-The bus detects an obstacle, so it stops

Event4: Gradual acceleration

Children: feel the bus become faster

Event5: Sudden emergency stop

Environment: There is a faster car driving by the side。

Children: The child was shocked. MM opened her mouth. The other two boys reacted relatively little.

Carers: Calming the child,

Safety staff: explain the situation

Event6: Loud and constant

Children: No curiosity about sound

Event7 :stop

Buses: After emitting two prompt sounds, the bus stopped smoothly.

Safety staff: When the car stops, the driver opens the door

Children: The children in the back seat can unbuckle their seat belts and get off the bus alone.

Summaries:

The child expressed curiosity and excitement about the driverless car during the ride. MM constantly looked out the window and asked if she could spot puppies or hide from them. She even suggested to the safety driver, who was standing during the ride, to sit down as well.

The child could comprehend that the bus was driving without a driver and found it very cool. During conversations with the safety officer, they described the bus as a box and even discussed games.

MM was more willing to engage and communicate throughout the drive, while the other little boy, "little M," remained quiet and looked out the window. "F" felt thrilled with the acceleration but didn't interact much, apart from giving a thumbs up when asked if everything was okay. All three children appeared to be relatively relaxed during the ride.

"Åktur 1- Avstigning Getting off

The bus closed the station, slowing down the speed

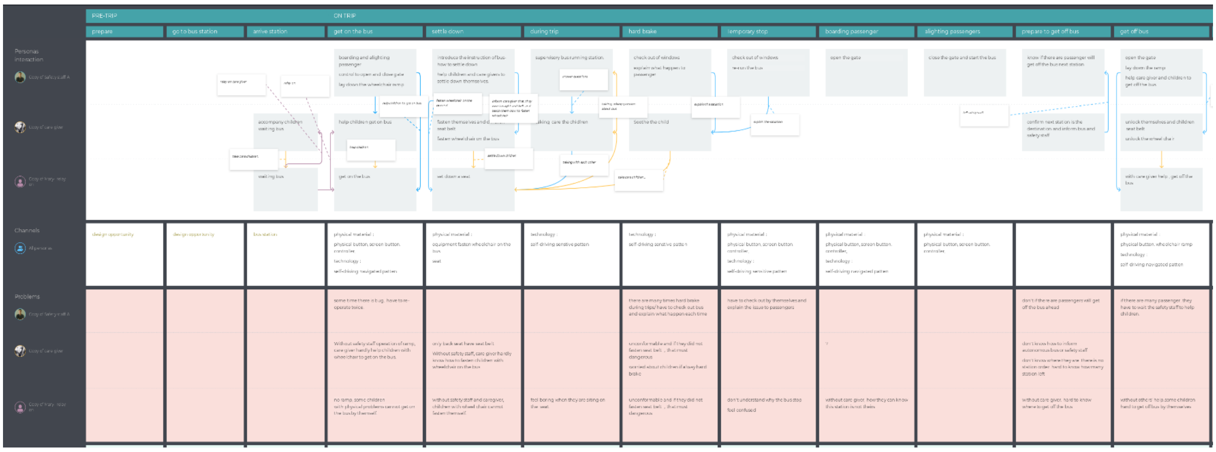
Bus: two "ding ding" sound alert

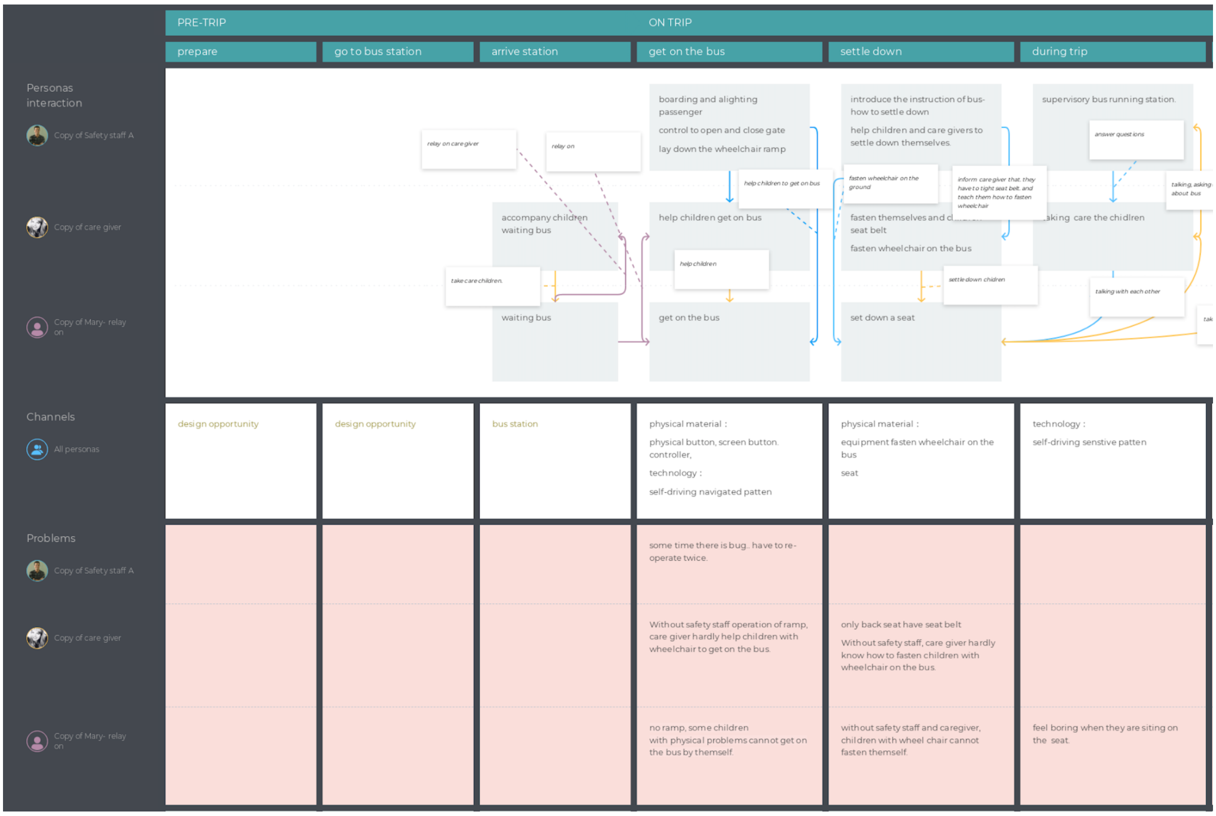
Children: get off the bus by themself, looks happy

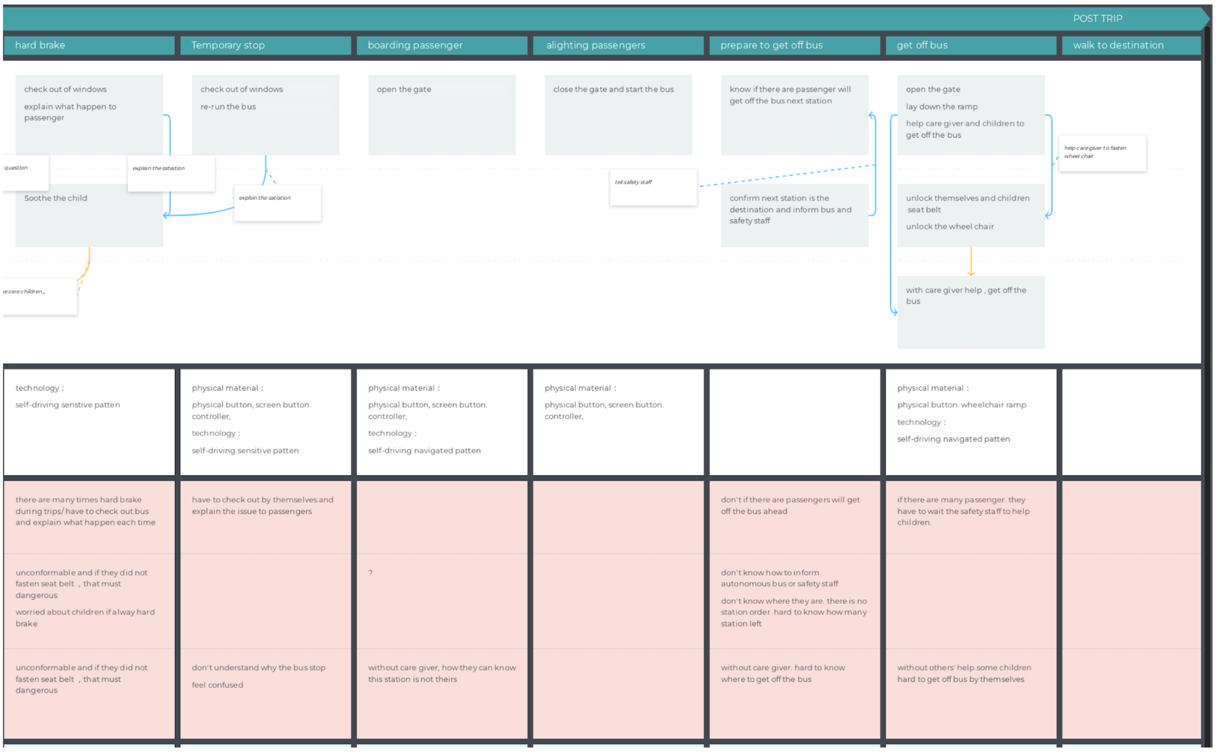
Carers: The caregiver will keep an eye on the child's movement, safety status

Appendix B:

Customer Journey mapping



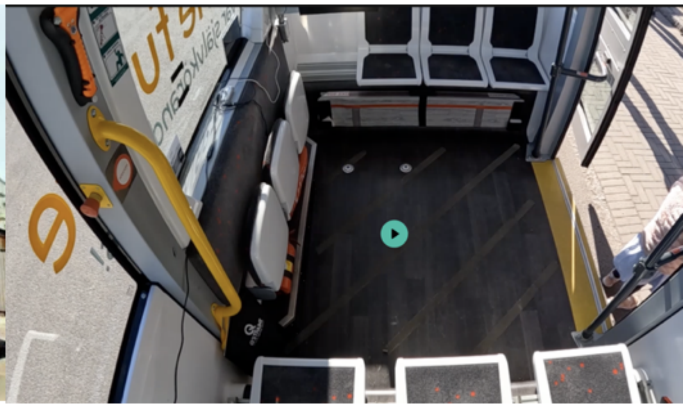



POST TRIP
hard brake
Temporary stop
boarding passenger
alighting passengers
prepare to get off bus
get off bus
walk to destination
check out of windows
explain what happen to passenger
question
explain the satiation
Soothe the child
care children ,
check out of windows
re-run the bus
explain the satiation
open the gate
close the gate and start the bus
tell safety staff
know if there are passenger will get off the bus next station
confirm next station is the destination and inform bus and safety staff
open the gate
lay down the ramp
help care giver and children to get off the bus
unlock themselves and children seat belt
unlock the wheel chair
with care giver help , get off the bus
help care giver to fasten wheel chair
technology :
self-driving senstive patten
physical material :
physical button, screen button. controller,
technology :
self-driving sensitive patten
physical material :
physical button, screen button. controller,
technology :
self-driving navigated patten
physical material :
physical button, screen button. controller,
physical material :
physical button. wheelchair ramp
technology :
self-driving navigated patten
there are many times hard brake during trips/ have to check out bus and explain what happen each time
have to check out by themselves.and explain the issue to passengers
don't if there are passengers will get off the bus ahead
if there are many passenger. they have to wait the safety staff to help children.
unconformable and if they did not fasten seat belt , that must dangerous
worried about children if alway hard brake
?
don't know how to inform autonomous bus or safety staff
don't know where they are. there is no station order. hard to know how many station left
unconformable and if they did not fasten seat belt , that must dangerous
don't understand why the bus stop
feel confused
without care giver, how they can know this station is not theirs
without care giver. hard to know where to get off the bus
without others' help.some children hard to get off bus by themselves

Appendix C:

Discussion guideline for a study two

Discussion main focus:
How to use self-driving buses to enhance independent travel for children with intellectual disabilities.
First phase: **Introduce the autonomous bus:**
During this phase two tasks, we can learn: How the autonomous buses work and the interaction technology.



The autonomous buses: www.ridethefuture.se
There are nine seats, only back seats with seat belts.
Low speed around 45 km, operate during 3-5 km long—commute buses around the campus.
Safety staff partly control the buses: gate, get on /off buses, wheelchair ramp, emergency.
Buses drive automatically, but leaving the station should wait for the commands from safety staff. If any accident happens, safety staff will take over the control, confirm the condition, and restart the buses.
Alarm when coming in/out station, brake, stop.
Free to ride
Buses (digital interaction & Physical design): screen, voice interaction. Button, big data. (see another PDF-Interaction way)
Second phase: discussion
During this phase, we will discuss following the trip chain, from plan trip, go to the station, get on the bus, on the bus, get off the bus, and go to the destination.
In each section, we will first discuss caregivers' challenges when traveling with cognitively impaired children and their vital role. Then, we will discuss how we can combine the efforts of caregivers, safety staff, and the design of the bus (both digital and physical) to improve the travel experience.

General questions :

What has been your biggest challenge in caring for children with intellectual disabilities during their travels, for example, getting on the buses? On the buses or get off the buses?

Have you ever experienced problems or unexpected situations during a child's trip? For example, if a child gets lost or injured on the road. If not, how do you think you would handle such situations?

Questions and discussion following the trip chain:

Planning trip phase:

Questions:

Who decides where to go? Children? Or caregivers?

Do children know where they're going and why they're taking the trip？

How could you explain travel plans to children？

Have you faced any problems when planning a trip? Like kids not wanting to go

Discussion：

Do you think it is possible for children to know they will go someplace? Do you have any idea if we want to train them to understand?

Go to station phase:

Discussion：

Can a child with an intellectual disability find the right station or location for transportation on their own?

Can an APP or some intelligent device(GPRS) be used?

Do you think there is (or can be) a difference between regular and autonomous buses regarding

Getting on the buses phase:

Questions*:*

When you and your children get on or off the bus, do you have experience talking to the driver or other passengers? For example, asking for help? Will they help you?

Did you or the person you care for have any special needs when getting in and out of the vehicle? Did the driver or other passengers help you?

Do you think Can a child with an intellectual disability get on suitable buses by themselves？

Discussion：

Besides the above, do you have any ideas about the roles of safety staff? Can they do more to help children?

Do you have any ideas to help children get on suitable buses, and settle down, fasten seat belts only with the help of safety staff or autonomous buses?

Riding on the buses phase:

Questions:

What do you and the person you care for usually do to pass the time on the Buses?

What difficulties do you and the person you care for face while traveling on the buses? For example, if it's a crowded, noisy, or long journey.

Does a child with intellectual disabilities feel uncomfortable or anxious when traveling?

Do you need to make special arrangements to meet the child's needs, such as providing a quiet place to sit or a toy that the child likes?

Discussion：

Besides the above, do you have any ideas about the roles of safety staff? Can they do more to help children?

Do you think it is possible for the children to ride buses by themselves, facing some "issue," like hard braking, feeling bored, or scared?

Do you think safety staff can think instead of caregivers on the buses（trust/emotion）

Do you have any ideas to help children ride the buses independently? Only with the help of safety staff or autonomous buses?

Getting off the buses phase:

Questions:

Could children with intellectual disabilities understand when to get off the bus?

Can children press the "stop" to get off the bus's next stop?

Discussion：

Do you have any ideas to help children get off the buses independently? Only with the help of safety staff or autonomous buses?

Arrival at destination stage:

Discussion

Do you believe children with intellectual disabilities can comprehend how to walk to their destination?

Free Discussions about potential some ideas