Multifunctional Airport Luggage Cart *(The Chariot)*

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Design Challenge: Passenger Experience and Innovations in Airport Terminal Design (*Innovations to accommodate passengers with disabilities and aging passenger demographics at airports*)

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Executive Summary

Aging passengers and persons with disabilities often have difficulties with **handling luggage** and **wayfinding** at airports. This gap motivated the team to propose an innovative design - a Multifunctional Electronic Airport Luggage Cart (*The Chariot*), aiming to address the **ACRP Passenger Experience and Innovations in Airport Terminal Design Challenge**, Problem B- *Innovations to accommodate passengers with disabilities and aging passenger demographics at airports.*

The design team first sought insight from relevant ACRP reports and other literature to learn the needs and challenges of aging passengers and persons with disabilities at airports. Then, the team determined the needed functionalities and modeled the concepts of *The Chariot* with guidance from the faculty advisor and subject matter experts. Featuring a lifting mechanism and interactive tablet computer, *The Chariot* assists aging passengers and persons with disabilities in **handling their luggage** and **wayfinding** at airports. In addition to being used as a luggage cart, *The Chariot* can be attached to a wheelchair, providing **more assistance options** for aging passengers and individuals with disabilities.

The 10-year Benefit-Cost analysis of implementing 100 units of *The Chariot* at a single airport yields a **3.08 to 1** ratio, demonstrating its commercial potential. In order to manage the safety risks of the design, the team followed the FAA standard Safety Risk Management procedure during the design process. The sustainability impact of *The Chariot* was also assessed in terms of economic vitality, operational efficiency, natural resources, and social responsibility using the EONS model. In addition, *The Chariot* contributes directly to three of the 17 United Nations (UN) Sustainable Development Goals (SDGs). Overall, *The Chariot* is an **innovative** and **practical** solution to accommodate aging passengers and persons with disabilities at airports.

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Problem Statement and Background

While the travel experience can be exciting for many, individuals with disabilities and aging passengers often face challenges at airports. The number of aging passengers and travelers with disabilities is increasing. According to the United States Census Bureau, nearly 13% of the U.S. population had a disability in 2021 (Crankshaw, 2023). In addition, it was estimated that around 25% of the U.S. population will be 65 or older by 2030 (Vespa et al., 2018). As the number of aging passengers and travelers with disabilities continues to grow, increasing air travel accessibility for these groups has become more imperative than ever before.

The need for assistance from older passengers and travelers with disabilities varies widely among individuals. Therefore, there is no "one size fits all" service. However, it remains common for many airports to offer only wheelchair assistance (Ryan et al., 2023). The limited availability of assistive facilities could be problematic, as many needs of aging passengers and travelers with disabilities cannot be adequately addressed by wheelchair service (GAO, 2021). In addition, the limited assistance options may result in lower satisfaction levels and a loss of dignity for many aging passengers and persons with disabilities. For instance, many passengers who require communication or navigation assistance cannot access tailored and effective services but are instead greeted by lines of wheelchairs (SHM Group, 2009, as cited in Horn et al., 2020).

Handling heavy luggage and wayfinding at airports are two of the most significant challenges for aging travelers and persons with disabilities (Mein et al., 2014; Ryan et al., 2023). It was found that 20% of these passengers solely requested assistance in carrying luggage and/or wayfinding (British Airways, 2019). It is physically demanding for aging passengers and persons with disabilities to carry heavy or bulky luggage while walking long distances, lifting, and laying

it on conveyor belts (Horn et al., 2020). In addition to dealing with heavy luggage, wayfinding is another major challenge for older passengers and travelers with disabilities (Mein et al., 2014). The hectic airport environment presents complex navigational challenges for these passengers, which can impact their safety and dignity in airport environments (Harding et al., 2017).

Many previous ACRP reports have highlighted the challenges of limited assistance options, luggage handling, and wayfinding for older travelers and individuals with disabilities at airports, providing valuable guidance to the team for developing innovative solutions to address their needs in airports. *ACRP Synthesis* 51 (Mein et al., 2014) provides a comprehensive overview of the challenges for aging passengers at airports. *ACRP Research Report 201* (Horn et al., 2020) offers insights and guidance on innovative solutions to accommodate travelers with disabilities at airports. *ACRP Research Report 239* (Ryan et al., 2023) commented on the needs of aging passengers and persons with disabilities. While each report has a unique focus, they all underscore the importance of developing innovative and practical solutions to accommodate aging travelers and persons with disabilities at airports.

The team was inspired to develop a novel design to address the challenges of limited assistance service, difficulties in handling heavy luggage, and wayfinding challenges at airports. Receiving insights from the faculty advisor, subject matter experts, and previous relevant ACRP reports, the team created *The Chariot*—an innovative proposed design. As a multifunctional electronic airport luggage cart, *The Chariot* aids aging passengers and persons with disabilities in handling heavy and bulky luggage, as well as wayfinding. Additionally, *The Chariot* can operate independently as an airport luggage cart or be attached to a wheelchair, offering more assistance options. *The Chariot* is envisioned as an innovative and practical solution to address the **ACRP Passenger Experience and Innovations in Airport Terminal Design Challenge B**.

Summary of Literature Review

Increasing Number of Older Passengers and Travelers with Diverse Disabilities

Aging Passengers

The U.S. population is currently older than ever before. According to the U.S. Census Bureau (2023), the number of senior citizens is projected to constitute 23% of the total population by 2050. Populations worldwide are also aging. The proportion of older adults is predicted to increase from 12% to 22%, between 2015 to 2050 (World Health Organization, 2022). In addition to the aging trend, as more older adults retire with financial security and air travel becomes more affordable, the number of older travelers has increased dramatically (Ryan et al., 2023). Described as a 'gray boom' by (Burghouwt et al., 2006), the rise in aging passengers represents a notable trend. For airports, the 'gray boom' represents both commercial opportunities and challenges, as older travelers exhibit distinct and different travel characteristics and assistive needs (Graham et al., 2019).

Travelers with Disabilities

The number of travelers with disabilities has been increasing in recent years, fueled by the aging population. It was found that about one-third of adults with disabilities traveled every year (Open Doors Organization, 2015). Before the COVID-19 pandemic, around 27 million persons with disabilities traveled by air in 2019 (U.S. Department of Transportation, 2022). It is important to note that the needs and air travel characteristics for persons with disabilities vary from individual to individual depending on the type and level of disabilities (Horn et al., 2020; Ryan et al., 2023).

Defined by U.S. federal law, disabilities are physical or mental impairments that permanently or temporarily restrict one or more major life activities (The Public Interest Law

Center, 2022). According to the Centers of Disease Control and Prevention (2024), disabilities can be categorized into the following types: (a) Lower body limitation, (b) Upper body limitation, (c) Hearing Loss, (d) Vision Loss, (e) Intellectual or Cognitive Disabilities, (f) Communication Disabilities, (g) Psychiatric Disabilities, and (h) Medical.

The growing number of travelers with disabilities, coupled with the diverse range of disability types, poses challenges for airports in developing practical solutions to accommodate the varying needs of these travelers (Chang & Chen, 2012; GAO, 2022).

Meeting the Needs of Older Passengers and Travelers with Disabilities

The market of travelers with disabilities and older adults is rapidly growing in the aviation industry (Burghouwt et al., 2006). The growing segment of older passengers and travelers with disabilities can become a lucrative niche market for the airports (Chang & Chen, 2012). On the other hand, the increasing number and distinct travel characteristics of this group can pose a number of challenges for airports (Graham et al.,2019). Therefore, to navigate through the challenges and maximize the potential of this passenger segment, it is imperative for airports to understand the demographic of this group and come up with effective solutions to address travelers' unique needs (Mein et al., 2014; Ryan et al., 2023).

Challenges Faced by Persons with Disabilities and Senior Travelers

The Design of Conventional Airport Luggage Cart

Airport luggage carts can generally be categorized into two main types. The conventional luggage cart is typically used landside for both checked and carry-on luggage, while a more portable version is deployed airside, allowing passengers to shop at duty-free stores and transport their carry-on luggage to gates. The former type can further be classified based on whether they have brakes operated by the hand bar. However, *ACRP Synthesis 51* (Mein et al., 2014) indicated

that conventional airport luggage carts are not user-friendly for aging passengers and persons with disabilities. For instance, many of these passenger groups do not have the physical strength to pull down the hand bar to maneuver the luggage cart.

Potential Risks Associated with the Use of Airport Carts.

ACRP *Synthesis 51* (Mein et al., 2014) mentioned that one in three adults aged 65 and older experiences a fall annually. The report noted that while brakes on luggage carts help prevent incidents on ramps, they also pose associated risks, such as abruptly stopping the cart when passengers exit a moving walkway. In addition, lifting luggage onto and off carts can pose hazards for elderly travelers and people with disabilities. Research indicates that lifting heavy objects from the floor can cause spine injuries due to pressure and bending (Desmoulin et al., 2020), particularly affecting older individuals with degenerative spine issues (Oxley et al., 2004; Ning et al., 2012). Additionally, aging passengers and individuals with disabilities can experience higher fatigue from handling heavy or bulky luggage, which could compromise their safety and affect their overall experience and satisfaction level at airports (Cook et al., 2011; Williamson, 2011).

Introducing autonomous technology like the Air Porter at Incheon International Airport can reduce risks associated with carrying luggage for passengers with reduced mobility. (Incheon International Airport Corporation., n.d.). However, implementing such services at the landside area presents challenges, such as accommodating checked luggage sizes and addressing security concerns. Therefore, to enhance satisfaction for older people and persons with disabilities, it is imperative to design new carts that reduce the risk of injuries and facilitate ease of movement, ensuring practical usability in an airport environment.

Possible Discrimination Caused by Uniformed Design of Airport Carts

While airport luggage carts pose challenges and risks for some travelers, their use may be impossible for others, especially wheelchair users. For example, the uniform height of these carts, designed for the average adult, is not suitable for wheelchair users, posing difficulties for them to use the carts independently. The current cart design also presents challenges for assistive personnel who need to push a wheelchair and a luggage cart simultaneously.

Many supermarkets offer a range of shopping carts, including motorized shopping carts and carts with specialized seats for adults or children, designed to meet diverse customer needs. Some retailers even offer carts that can attach to wheelchairs, allowing wheelchair users to shop independently (Forshee, 2004). However, unlike supermarkets, most airports only provide standardized luggage carts, making it nearly impossible for wheelchair users to use them. In addition, the non-wheelchair-friendly design of conventional luggage carts also reduces air travel accessibility for families or groups traveling with members with disabilities. Darcy (2010) indicates high-quality accessibility can greatly boost market occupancy rates. Introducing alternative options to traditional luggage carts can enhance the overall airport experience for individuals with disabilities and their families.

Limited Assistance Option

The limited assistance options at airports create barriers to air travel for aging passengers and travelers with disabilities (GAO, 2021). As the assistance needs of aging passengers and travelers with disabilities vary from individual to individual, there is no 'one-size-fits-all' service. However, at many airports, the only available assistive facilities provided are wheelchairs (Ryan et al., 2023). Therefore, many passengers with other physical limitations, hearing loss, or language barriers often cannot receive tailored assistance beyond wheelchair services. This issue

is underscored by an ironic phenomenon: many travelers with communication difficulties are only provided with a wheelchair service to navigate through airports (Horn et al., 2020).

In addition, the problematic 'one-size-fits-all' wheelchair service can impact air travel satisfaction and dignity for aging passengers and travelers with disabilities. Since the wheelchair service is the only assistance option at many airports, passengers who request assistance have to sit in a wheelchair even if they do not need one (Horn et al., 2020).

Wayfinding Challenges

Wayfinding, defined as a process of ascertaining one's position and following a planned route, can be challenging and stressful for aging passengers and persons with disabilities at airport terminals (Ryan et al., 2023). According to the *ACRP Synthesis 51*, navigating through airport terminals can be challenging for aging passengers (Mein et al., 2014). When entering a terminal, they often feel confused and overwhelmed by overloading visual information, large numbers of people, and unfamiliar terminology on directional signs (Waara et al., 2015). Further, airport wayfinding has been a significant challenge for travelers with disabilities. According to the *ACRP Research Report 177,* travelers with cognitive, sensory, and mobility impairments often face complex navigational challenges at airports. The airport navigation challenge presents a significant obstacle, preventing them from achieving travel independence (Harding et al., 2017).

Easing the wayfinding burden for aging passengers and travelers with disabilities takes innovation, as it is not feasible and practical to provide individual wayfinding services to every passenger with needs (Horn et al., 2020). Many innovative efforts are underway to address the airport navigation challenges. For example, The Intelligent Airport Trolley, introduced in *ACRP Research Report 210* (Horn et al., 2020), is a carry-on luggage cart equipped with a wayfinding

device in the duty-free area. *ACRP Research Report 177* outlines that wayfinding assistive facilities should empower passengers to move independently through an airport rather than simply providing directions at a single point (Harding et al., 2017). Additionally, *ACRP Synthesis 51* indicates the importance of implementing verbal assistance functions, as some older passengers and travelers with disabilities have vision impairments, reading difficulties, or simply prefer to ask for human assistance (Mein et al., 2014).

Legislation and Policies on Air Travelers with Disabilities and Older Adults in the U.S.

The aviation industry in the U.S. is governed by various legislative requirements aimed at accommodating passengers with disabilities and elderly travelers. The Rehabilitation Act of 1974 (Section 504) was the first federal law to prohibit discrimination against individuals with disabilities, paving the way for the Americans with Disabilities Act (ADA) in 1990 (Barkoff, 2023). The ADA aims to provide a clear and comprehensive national mandate for eliminating discrimination against persons with disabilities (U.S. Commission on Civil Rights, 2000); it impacts airports, airlines, and all public facilities (Major & Hubbard, 2019). Notably, airport operators receiving federal financial assistance must adhere to specific accessibility standards prescribed by the ADA.

Certain sections of the ADA exclude aircraft, and the assistance of passengers with disabilities falls under The Air Carrier Access Act (ACAA) (Belles, 2023). Under ACAA, all U.S. and foreign airlines operating flights to or from the U.S. are mandated to provide special assistance to passengers with disabilities. The U.S. government tries to keep enhancing access and accommodation for people with disabilities; for example, the Department of Transportation (DOT) adopted Disability Policy Priorities in July 2022, highlighting four focus areas, including enabling safe and accessible air travel (U.S. DOT, 2022).

Needs for a Fresh Approach to Enhance Airport Service and Accessibility

Airlines are mandated to provide wheelchair service upon request, but statistics show that 10 to 40 percent of these requests are not made in advance. This unpredictability creates challenges in timely assistance due to the limited availability of staffing (GAO, 2021). A survey found that 67% of passengers with disabilities wait 15 minutes or more for wheelchair service upon airport arrival (The Paralyzed Veterans of America, 2022). Consequently, passengers requiring assistance often experience longer wait times for service, leading to operational delays and crowding at airports. Additionally, the lack of information on waiting times contributes to increased complaints about service quality, as noted in *ACRP Research Report 239* (Ryan et al., 2023). Between 2010 and 2018, disability-related complaints surged, with half of them attributed to failures in providing wheelchair assistance (GAO, 2021).

Ryan et al. (2023) suggested that enhancing traveler flexibility and independence could alleviate issues with waiting times. For instance, WHILL Inc. introduced autonomous wheelchairs at airports, allowing elderly individuals and those with reduced mobility to navigate independently (Horn et al., 2020). Some airports also offer electric cart shuttle services to transport passengers directly to their gates, reducing the need for long walks. These approaches demonstrate that various services and research efforts have been directed toward improving wheelchair services. However, beyond wheelchair services, scholarly discussions have paid less attention to other barriers (Martín et al., 2024). It is crucial to recognize that not all older travelers and people with disabilities want or require wheelchair service. In other words, a one-size-fits-all solution does not exist for these populations (Martín et al., 2024; Ryan et al., 2023). Therefore, exploring additional strategies to improve airport accessibility is crucial for accommodating overlooked passenger needs and enhancing service quality.

Problem Solving Approach

Transforming Challenges into Solutions

As a first step, the team established the clear goal of *proposing an innovative design of airport luggage carts to address these challenges and cater to passengers with disabilities and aging travelers*. Based on the clear objective, the team proceeded with a step-by-step approach to developing the proposal. This involved analyzing literature and legislation reviews, attending the Transportation Research Board (TRB) webinar (Rolon, 2024), validating the feasibility, and continuously refining them into the final design through ongoing expert interactions. Figure 1 provides a visual representation of the team's problem-solving approach.

Figure 1

Problem-solving Approach for Innovative Airport Luggage Cart Design

Thorough research on the current state, existing procedures, challenges, and regulatory frameworks led the team to identify four major issues affecting aging travelers and persons with disabilities. These challenges include (a) The limit of assistance services, primarily focusing on wheelchair service, restricts options for individuals who desire independent travel or encounter stigma related to wheelchair use; (b) challenges maneuvering an airport cart that requires power to push along with pressing the handle; (c) difficulties associated with lifting heavy luggage to and from elevated surfaces such as conveyor belts of check-in counters and vehicle trunks; (d)

wayfinding challenges within the crowded and complex airport. Alongside the four challenges, potential consequences for both individuals and airport operations are outlined in Table 1.

Table 1

Challenges and Potential Consequences of Traditional Airport Luggage Carts

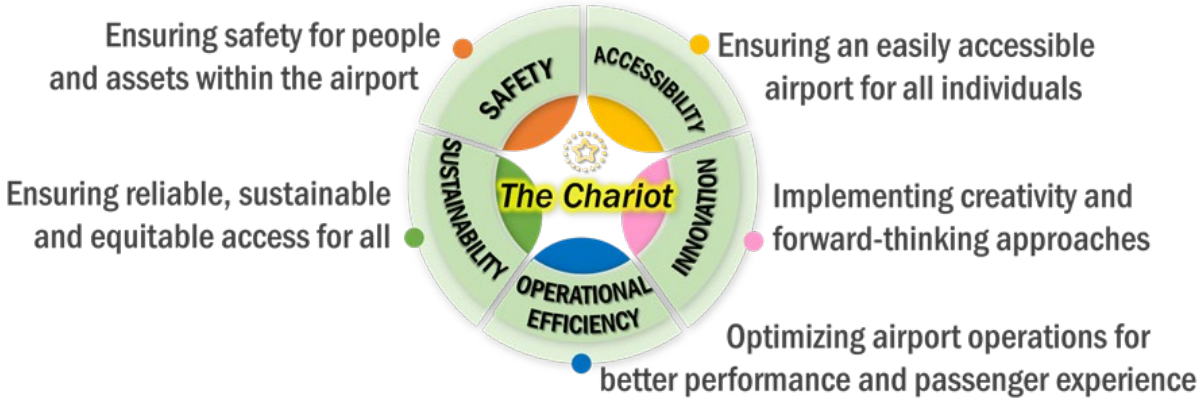
Challenges		Potential Consequences
Limited assistance service options	**Maneuvering an airport cart**	- Risk of injury to oneself/others - Elevating levels of fatigue - Potential damage to airport facilities and luggage - Diminished passenger experience and satisfaction - Influence on airport operations caused by delays in assistance services
Lifting heavy/bulky luggage	**Wayfinding in airports**	

Semi-structured interviews were conducted using tailored questionnaires to gather expert feedback on the proposed design and its effectiveness in addressing the identified issue. These interactions were conducted both virtually and in person with various experts, including airport operators, academia, and industry professionals, as elaborated upon in the following section.

Furthermore, to effectively analyze the initial design in line with project goals and establish a decision-making framework, the team established five core values: Safety, Accessibility, Innovation, Operational Efficiency, and Sustainability. These values are detailed in Figure 2, along with a brief explanation.

Figure 2

Five core values of the team's design



The team conducted a Gap Analysis based on these core values (refer to Table 2), identifying discrepancies between the current state and the desired goal of airport luggage carts and proposing solutions. For instance, the inclusion of electric power and scissor lifting mechanisms aims to mitigate the risks of injury and fatigue associated with handling luggage. Adjustable handle height and wheelchair attachments allow passengers to navigate airports according to their preferences. Additionally, revenue generated through advertisement spaces can benefit airports commercially. This systematic approach facilitated the team to analyze areas for improvement and solution development.

Table 2

Gap Analysis for Airport Luggage Cart Design Improvement

Core Value	Current Status (as-is)	Desired Status (to-be)	Identified Gap	Solution Idea
Safety	- Press the handle for movement - Manual control for movement	- Safe and easy handling - Easy lifting on/off luggage	- Risk of injury - Increased fatigue	**- Electric power source** **- Scissor lifting mechanism for adjustable height levels**
Accessibility	- Fixed handle height - Requires strength to move the handle - Simple functionality	- Easy and independent use for all - User-friendly design	- Difficulty for wheelchair users to use independently - Challenge for guardians to push both a wheelchair and a cart	**- Adjustable handle height** **- Attachment to wheelchair** **- Electronic power for movement** **- Accessories (cup holder and mobile holder)**
Innovation	- Insensitive to trends - Uniformity in design and function	- Innovative and creative cart - leading the trend	- Wayfinding issues in airports - Difficulties in transporting luggage	**- Integration of digital device** **- Electronic-powered movement and lifting** **- Electric device charging ports**
Operational Efficiency	- Cost efficient operation	- Cost-benefit efficient operation	- Initial investment and costs, including operation and maintenance - Increase the return of the cart to designated collection areas	**- Revenue from advertisements on the cart and digital devices** **- Utilizing collected data in airport operations** **- Deposits for using the cart**
Sustain -ability	- None	- Meet UN SDGs and EONS[a] - Reliable, equitable access for all	- Easy to use for all	**- Simple operation method** **- Multilingual voice guidance and user guide on the cart.** **- Gathering user feedback**

Note. [a] UN Sustainable Development Goals (SDGs) and Environmental, Occupational Health, and Safety (EONS) considerations are further detailed in the Sustainability Assessment section.

To ensure the feasibility of the proposed solutions, the team compared *The Chariot* with real-life examples with similar functionalities, as illustrated in Figure 3, demonstrating the practicality and feasibility of the design. For example, the scissor mechanism is commonly used in machinery such as lifting tables and car lifts. Similarly, the adjustable handle height could be implemented using features akin to those found in baby strollers. Attachment to wheelchairs and digital devices on the cart are also realistic technological solutions. Additionally, the solution ideas were evaluated and refined through safety risk assessment, benefit-cost analysis, and sustainability assessment, while ongoing expert feedback was sought.

Figure 3

Proposed Solution Ideas and Similar Real-life Instances

Scissor lifting mechanism	Adjustable handle height	Attachment to wheelchair	Integration of digital device
			

Note. The images were adapted from free-license images sourced from PixelSquid.

Finally, the team chose **'*The Chariot*'** as the branding for the cart, representing its value and identity. Derived from the French word for cart, 'Chariot' represents victory over challenges through will, as symbolized by *the Chariot* card in Tarot (Pollack, 1980, as cited in Dutt, 2013; Bouchard, 2020). Along with its memorable name, the team added the slogan, **'*Your airport, Your Chariot awaits.*'** which can help airports build a positive image for their users.

Through this systematic approach, the team identified the optimal features and operational factors for *The Chariot* to address the challenges faced by persons with disabilities and older travelers. These features are further detailed in the Description of the Idea Section.

Interactions with Airport and Industry Experts

The team conducted semi-structured interviews with eight experts spanning various domains, including airport operations, government, academia, and industry. These experts included disability policy advisors, ADA coordinators, airport managers, and an intelligent cart company representative. Two were presenters at Transportation Research Board (TRB) webinars on the related topic. Attending the TRB webinar not only enhanced the team's understanding of the airport's roles and diverse programs for travelers with disabilities and older adults but also facilitated engagement with a diverse range of experts. Table 3 provides an overview of the interviewed experts.

Table 3

The List of Experts with whom the Team Interacted

Sector	Name	Title	Organization
Airport	Lawrence J. Rolon[a]	ADA Coordinator	Ontario International Airport (ONT)
	Alan Gonzalez	Landside Manager	Dallas Fort Worth International Airport (DFW)
	Junghye Lee	Deputy General Manager	Jeju International Airport (CJU), Korea Airports Corporation
	Adam Baxmeyer	Airport Operations Manager	Purdue University Airport (KLAF)
Government	Kelly Buckland[b]	Disability Policy Advisor	U.S. Department of Transportation
	Wesley Major	Airport Research Specialist	U.S. Federal Aviation Administration (FAA)
Academia	Sarah Hubbard	Associate Professor	Purdue University
Industry	Jens Sehested Krogh	Board Member	Intelligent Track Systems

Note. [a] Presenter at the TRB webinar (Rolon, 2024). [b] Presenter at TRB webinar (Buckland, 2022)

Throughout the design process, the team continuously engaged with experts from various sectors through interviews utilizing tailored questionnaires. The primary focus of the meetings

was to understand accessibility services and procedures in U.S. airports, challenges faced by persons with disabilities and older travelers, airport operators' priorities regarding operational aspects, as well as to collect feedback on the proposed design. The results of these interactions are categorized into three perspectives: operational, functional, and user experience.

Operational Aspects of The Chariot

In interviews with airport experts, the team understood the airport's obligations and responsibilities regarding accessibility services to comply with regulations such as the Americans with Disabilities Act (ADA). The team also recognized the importance of implementing sustainable services for passengers, which involves considerations such as maintenance, luggage cart collection, and operational costs. These interactions led the team to implement additional design ideas, including placing advertisements in three locations on *The Chariot* for revenue generation and introducing a deposit system for cart use to improve collection rates at dispensers. Furthermore, the team learned different strategies for initiating new projects, such as collaborating with other companies or manufacturers to co-develop *The Chariot*, which could reduce the initial investment cost for airports.

Functional Aspects of The Chariot

As included in *The Chariot*'s core values, safety emerged as a primary consideration highlighted by experts. The team received feedback from the experts that measures such as speed limitations and safety barriers around the scissor lift could increase the safety of *The Chariot*. Additionally, from the interviews, the team realized that the height of the current cart poses a challenge for persons with wheelchairs, leading to the concept of an adjustable height handle. Insights were also gained regarding the significance of a simplistic button design akin to that

found in automatic swing door openers. This feature was incorporated into the design of the cart's controller, the interface of the digital device, and the emergency button.

The team also met with an expert from the intelligent airport cart company, introduced in *ACRP Research Report 210* (Horn et al., 2020), which offers a carry-on luggage cart equipped with a wayfinding device for navigating airside areas, including duty-free shopping areas. Through this interaction, the team learned that wayfinding devices can provide navigational assistance and collect operational data to enhance airport operations. For example, airport operators analyze this data for airport planning and layout, including the arrangement of concessions such as retail and dining establishments, which help airports increase revenue. Furthermore, the team understood that the use of such data must adhere to regulations and guidelines to avoid privacy issues.

Perspectives from the user experiences of The Chariot

By interacting with experts knowledgeable about the difficulties faced by persons with disabilities and older travelers, the team better understood these passenger' challenges at the airport. The team recognized the importance of inclusivity in product design and decided to incorporate an attachment feature into *The Chariot*, allowing wheelchair users to enjoy its functionalities.

During interactions, the team recognized that the requirements of The Air Carrier Access Act (ACAA), which mandates assistance services only between the terminal entrance and the aircraft, pose potential challenges for passengers with disabilities and older travelers, especially at parking garages. Therefore, the team learned the importance of selecting appropriate dispensers for the cart locations in convenient areas such as parking garages, ground transportation stations, and curbsides.

Safety Risk Assessment

The team assessed the potential safety risks of the design and outlined corresponding mitigation solutions. As the highest priority in the aviation community, safety is defined as a state in which all risks are controlled to be as low as reasonably practicable (FAA, 2017; ICAO, 2019). Whereas hazard is a condition that can lead to undesirable outcomes, risks are the composite of the severity and likelihood of the associated undesirable outcomes (ICAO, 2017).

Given that the target users of *The Chariot* are aging passengers and persons with disabilities, ensuring the highest possible safety level is essential for this proposed design. To achieve the highest possible safety level, a systematic safety risk management (SRM) procedure is implemented. According to *FAA Advisory Circular 150/5200-37*, SRM is the second pillar of the Safety Management System (SMS), possessing five critical steps depicted in Figure 4 (FAA, 2023a). In addition, as SRM is an ongoing process, the effectiveness of the mitigation approaches needs to be periodically evaluated (FAA, 2022).

Figure 4

Safety Risk Management (SRM) 5-step process

The first two steps of the SRM procedure are system description and hazard identification. To proactively identify potential hazards in the proposed design, the team conducted a what-if analysis, brainstorming possible hazards within each main component of *The Chariot*. Expert interactions further assisted in identifying potential safety hazards related to

the design description. Four potential hazards were identified: (a) Loss of control of the mobility system, (b) Features of the lifting mechanism, (c) Technology failures, and (d) Human factors.

Once hazards are identified, the associated risks need to be analyzed. Risk is the composite measurement of the severity and likelihood of the worst credible outcome of each hazard (ICAO, 2019). To effectively analyze risks, the definitions of severity and likelihood need to be determined based on the specific operational environment (FAA, 2023a). The team determined the definitions for the likelihood and severity levels of *The Chariot* using qualitative and quantitative methods with reference to the FAA AC 150/5200-37A, as depicted in Table 4.

Table 4

Definitions of Likelihood Levels and Severity Levels Tailored to The Chariot

Likelihood Level	**Definition**		
Frequent	Occurs daily or once per 75,000 passengers		
Probable	Occurs weekly or once per 525,000 passengers		
Remote	Occurs monthly or once per 2,100,000 passengers		
Extremely Remote	Occurs annually or once per 28,000,000 passengers		
Extremely Improbable	Occurs every decade or once per 300,000,000 passengers		
Severity Level	**Metric 1**	**Metric 2**	**Metric 3**
	People & Operation	**Assets**	**Reputation**
Catastrophic	1: Fatality 2: Severe Injuries (> 5 persons) 3: Severe interruptions in airport operations for an extended period	1: Over USD 10,000 loss or damage of assets 2: Loss of critical system for more than 5 days	The community loses confidence in using or investing in the airport for an extended period
Hazardous	1: Severe Injuries (<5 persons) 2: Severe interruptions in airport operations for a shorter time	1: Over USD 5,000 loss or damage of assets 2: Loss or damage of critical system for more than 3 days	The community lessens the use of the airport, causing negative financial or operational impacts
Major	1: Minor injury (Requiring medical treatment) 2: Interruption in airport operations for a shorter period	1: Over USD 3,000 loss or damage of assets 2: Damage to airport equipment that can be repaired within 24 hours	The community lessens the use of the airport causing negative financial or operational impacts for a shorter period
Minor	1: Minor injury (Not Requiring medical treatment)	1: Over USD 500 loss or damage of assets 2: Minor damage to equipment	The community questions the reliability of the airport
Minimal	1: No injury 2: None to minimal operational impact	1: Under USD 500 loss or damage of assets	No Impact

Furthermore, risks were assessed and quantified based on severity and likelihood levels after risk analysis. To do this, the team used the Risk Matrix Chart on the FAA Order 5200.11.A. As shown in Table 5, risk level is determined as the product of severity and likelihood levels and is color-coded into High, Medium, and Low categories. While High risk is intolerable and has to be mitigated to at least Medium risk, Medium risk is tolerable but is preferred to be mitigated when resources allow it. Low risk does not require further mitigation (ICAO, 2019; FAA, 2023a).

Table 5

Risk Matrix Chart using FAA Order 5200.11.A

Severity / Likelihood	Minimal (1)	Minor (2)	Major (3)	Hazardous (4)	Catastrophic (5)
Frequently (5)	**5**	**10**	**15**	**20**	**25**
Probable (4)	**4**	**8**	**12**	**16**	**20**
Remote (3)	**3**	**6**	**9**	**12**	**15**
Extremely Remote (2)	**2**	**4**	**6**	**8**	**10**
Extremely Improbable (1)	**1**	**2**	**3**	**4**	▲
LOW (Acceptable)		**MEDIUM (Tolerable)**		**HIGH (Intolerable)**	

Note. The polygon means the Risk is deemed unacceptable with Common Cause Failure or Single Point.

Finally, as the initial risks were assessed using the Risk Matrix Chart, unacceptable risks must be mitigated. Given risk is measured based on the likelihood and severity of undesirable consequences, risk can be controlled by reducing these two parameters (ICAO, 2019; FAA, 2023a). Based on the guidance provided in the *ICAO Safety Management Manual* (SMM) and the *FAA AC 150/5200-37A*, the team formulated various risk mitigation strategies to control the initial risks to an acceptable level. These strategies, along with the initial risk level and the resulting residual risk values, are detailed in Table 6.

Table 6

Potential Risks and Mitigation Strategies, FAA AC 150/5200-37A.

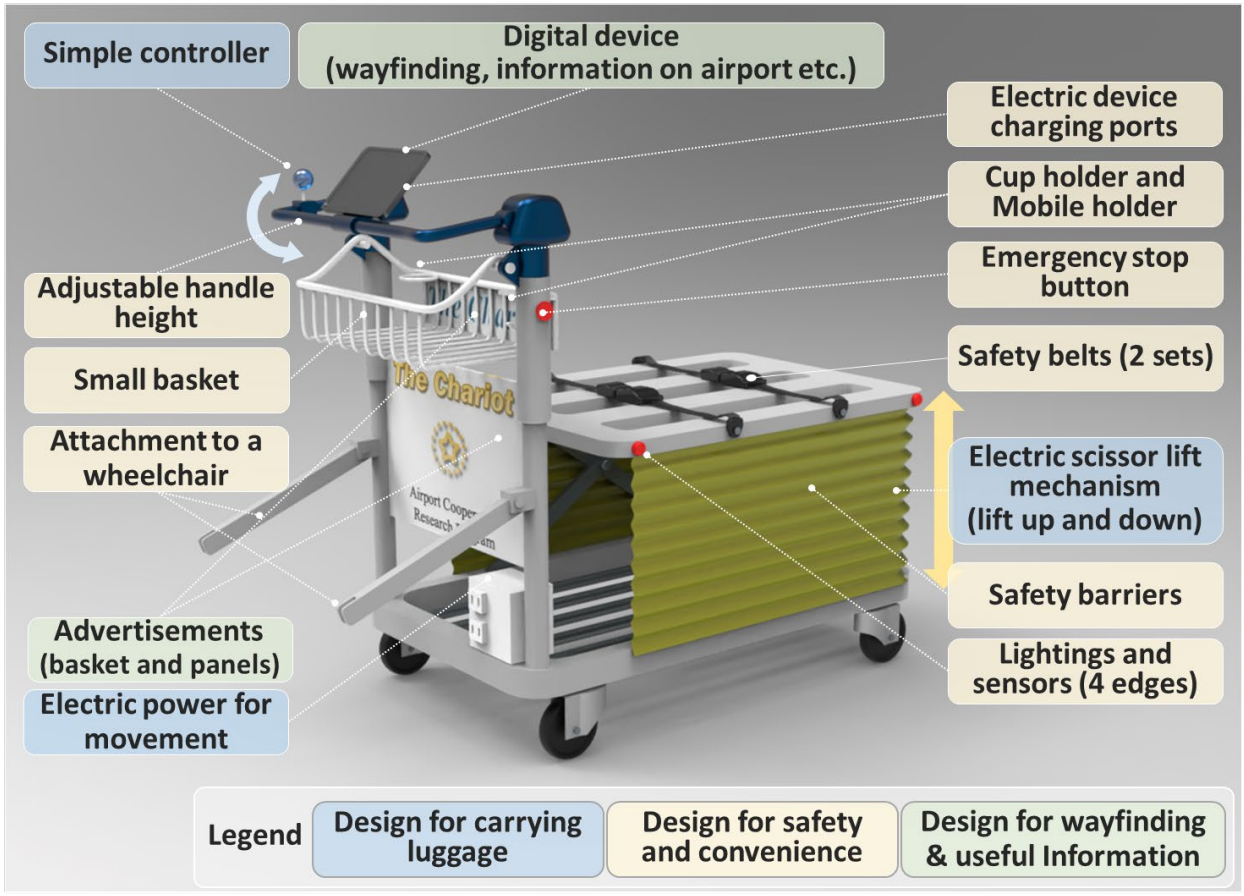
Hazards and Potential Consequence	Likelihood (L)	Severity (S)	Initial Risk	Mitigation	Residual Risk
Loss of Control					
- Injury to oneself or others - Damage to facilities or luggage	4	5	High 20	- Install detection sensors and conduct regular inspections of the cart [(L) to 2] - Implement speed restriction [(S) to 3]	**Medium** **6**
Feature of Lifting Mechanism					
- Be caught objects or body parts between moving components	4	4	High 16	- Install safety barriers around moving parts; - Mark hazardous areas with warning labels and lighting [(L) to 2] - Install emergency stop button [(S) to 3]	**Medium** **6**
- Injury of oneself or others and/or damage to facilities or luggage caused by falling luggage	4	3	High 12	- Implement safety belts to secure luggage; - Conduct routine inspections [(L) to 3] - Implement speed restriction for lifting feature [(S) to 2]	**Medium** **6**
Technical Failures or Issues					
- Cyber-attack on digital devices - Privacy concerns with data collection	3	3	Medium 9	- Follow legal frameworks and guidelines; - Implement cybersecurity measures [(L) to 2] - Utilize only anonymous data [(S) to 2]	**Low** **4**
- Cart malfunction or power outage	3	3	Medium 9	- Conduct routine inspections - Increase cart collection efficiency by implementing a deposit system [(L) to 2] - Emergency call button on the digital device [(S) to 2]	**Low** **4**
- Malfunction or outdated information of digital device	3	2	Medium 6	- Update information regularly; - Conduct routine checks at the charging area [(L) to 2]	**Low** **4**
Human Factors					
- Digital barriers - Challenges related to language and literacy	3	2	Medium 6	- Incorporate an emergency call button on the digital device for assistance; - Provide multilingual instructions and audio guidance [(L) to 1]	**Low** **2**

Description of Idea

Through the design process, the team developed innovative features and functions for the airport luggage cart named *The Chariot* to accommodate persons with disabilities and aging travelers. *The Chariot* is easy to maneuver with electric power, and its lifting surface can assist users in lifting their heavy and bulky luggage. Safety measures such as an emergency button and safety belts are incorporated to control the potential safety risks of the proposed design. Additionally, the digital device provides benefits beyond navigational assistance. For example, the calling function on the digital device allows passengers to access remote assistance. Refer to Figures 5 and 6 for *The Chariot*'s design details outlined in subsequent sections.

Figure 5

The Prototype Design of The Chariot (a)

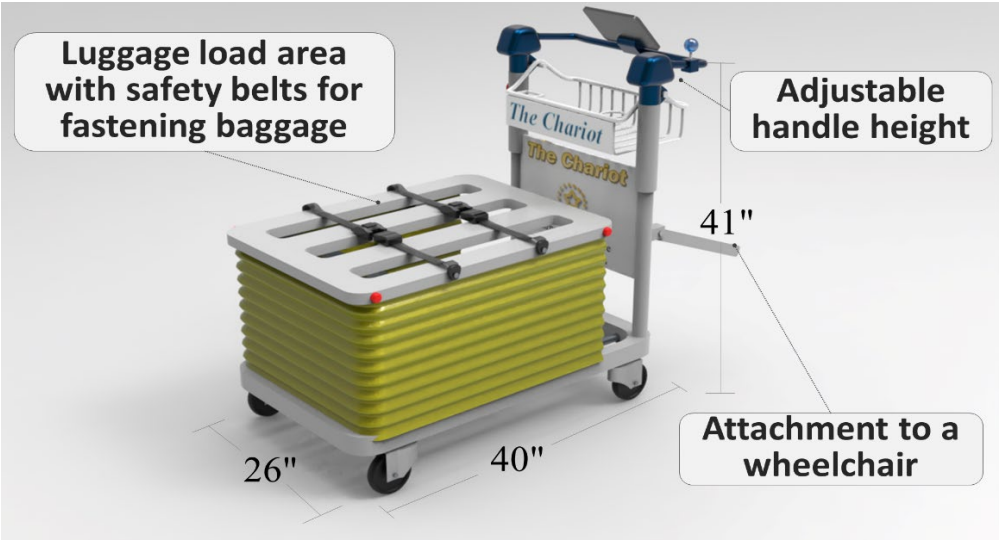


Enhanced Functions of the Cart for Carrying Luggage

The Chariot has several innovative features to address the challenges faced by persons with disabilities and aging travelers when maneuvering airport luggage carts and handling heavy or bulky luggage. *The Chariot* facilitates easy movement by integrating electric power assistance, enhancing the fundamental purpose of the cart. It is designed to be operated manually or automatically, accommodating both electric and manual wheelchair users. Swivel wheels at the front enable effortless directional changes. Furthermore, a scissor table mechanism is incorporated to assist in lifting luggage to and from elevated surfaces such as check-in counters and vehicle trunks. All these functions are managed through a simple controller and buttons integrated into the cart's handle. Additionally, to optimize storage space by stacking carts, the front of the cart could be designed with an upward slope from the ground.

Figure 6

The Prototype Design of The Chariot (b)



Additional Functions to Enhance Safety and Convenience

Safety is a core value of the team's approach, and to enhance safety and convenience, the team conducted a Safety Risk Assessment and engaged with experts. The speed of *The Chariot* is

capped at 2 MPH, equivalent to a slow adult walking speed (Murtagh et al., 2020), which is lower than the minimum requirement for powered vehicles (Centers for Medicare & Medicaid Services, 2015). In addition, safety measures include safety barriers around the scissor lift, safety belts to secure luggage to the cart, and an emergency stop button to halt lifting and movement functions if necessary. Laser Distance Sensors (LDS), which measure distance using radiated light properties (Hutabarat et al., 2019), are integrated to monitor distances and prevent collisions. Motion-activated lights warn users and those nearby during operation. Furthermore, caution signs that comply with safety standards are strategically placed on moving parts and near controllers to alert passengers to potential hazards (Occupational Safety and Health Administration, 1996). These measures ensure that users are aware of safety precautions and can operate *The Chariot* safely and effectively.

In addition to safety considerations, *The Chariot* incorporates several convenient features to enhance user experience. The handle height is adjustable to accommodate both wheelchair users and non-users, and attachments ensure a stable connection between *The Chariot* and wheelchairs. Simple additions such as a cup holder, mobile holder, small basket, and electric device charging ports enhance user convenience significantly.

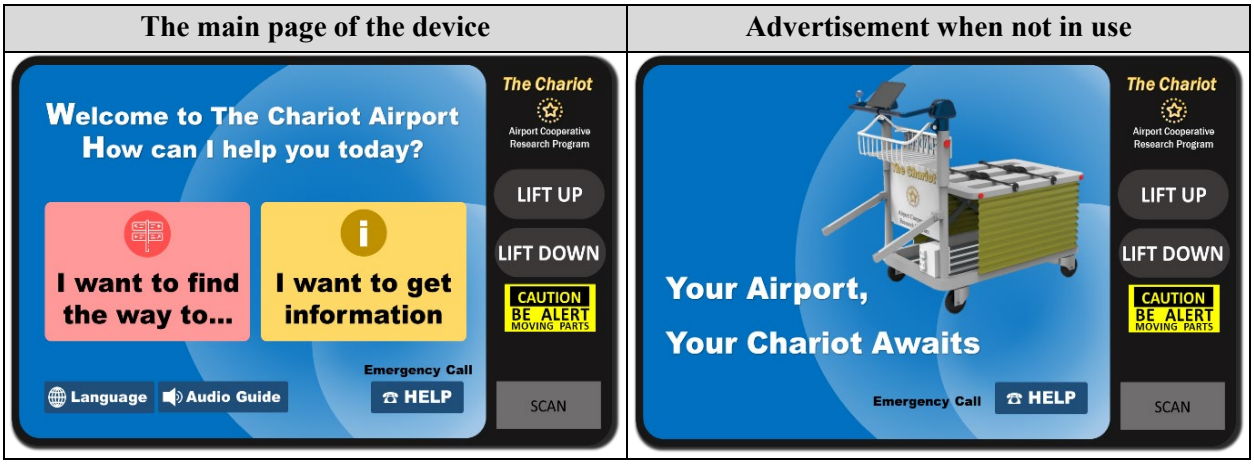
Digital Device for Wayfinding and Useful Information

To address wayfinding challenges at the airport, *The Chariot* is equipped with a digital device that assists passengers in wayfinding at airports. Users can easily search for destinations like check-in counters, restrooms, or restaurants with touch buttons and scan their tickets for tailored wayfinding and flight information. This device also provides other helpful airport information, including services for passengers with disabilities and older travelers, coupons for airport restaurants and shops, and details about airport events.

The digital device is designed for simplicity to ensure ease of use for all passengers, supporting multiple languages and offering audio guidance to overcome language and literacy barriers. In addition, passengers can use the device's emergency call function to get immediate assistance. The advertisements displayed on the device generate revenue for the airport and provide other helpful information to passengers about airport services and amenities. Figure 7 illustrates the main page design, displaying its user interface and functionality, along with an example of an advertisement on the right.

Figure 7

The main page and an example advertisement on the digital device



Additionally, as mentioned in the *ACRP Legal Research Digest 42* (Zoufal et al., 2021) and learned from expert interaction, using digital devices would benefit airport operators by serving as a platform for data collection. Operators can leverage this data, such as passenger movement, to improve airport facilities and operations. In addition, privacy and legal requirements, such as anonymization techniques, should be considered when collecting passenger data to reduce privacy risks (Zoufal et al., 2021). The NIST Privacy Framework can improve privacy by conducting a risk-based approach that addresses privacy risks associated with data processing (National Institute of Standards and Technology, 2024).

Projected Impacts of the Design

The Chariot is envisioned as an innovative and practical solution that airports of any size can implement to aid aging passengers and travelers with disabilities in luggage handling and wayfinding. Featured with a lifting mechanism, *The Chariot* can assist in carrying and lifting heavy and bulky luggage. Equipped with an interactive device, *The Chariot* provides wayfinding information to aid aging passengers and persons with disabilities in wayfinding at airports. The luggage handling and wayfinding assistance provided by *The Chariot* would significantly increase the safety level and reduce air travel barriers for aging passengers and travelers with disabilities. Further, *The Chariot* can function independently as a multifunctional luggage cart or be attached to a wheelchair, offering more autonomy to passengers. The various assistance options would significantly increase the satisfaction level and dignity of aging passengers and travelers with disabilities, as they could decide their ideal way to get through airports instead of receiving the 'one size fits all' wheelchair service.

Alignment with ACRP goals

The Chariot directly responds to the luggage handling and wayfinding challenges reported by *ACRP Synthesis 51* (Mein et al., 2014) and *ACRP Research Report 177* (Harding et al., 2017). In addition, the concepts of *The Chariot* were inspired and developed with knowledge learned from ACRP *Research Report 201* (Horn et al., 2020) and ACRP *Research Report 239* (Ryan et al., 2023). Overall, *The Chariot* aims to function as an innovative and practical design solution to address the **ACRP Passenger Experience and Innovations in Airport Terminal Design Challenge, Problem B-** *Innovations to accommodate passengers with disabilities and aging passenger demographics at airports.*

Through preparing for the ACRP University Design Competition, the team is more aware of the significance of reducing air travel barriers for aging passengers and persons with disabilities at airports. In addition, from interacting with industry experts, the team gained real-world knowledge of creating a more accommodating airport environment for aging passengers and travelers with disabilities. Furthermore, the team acquired valuable skills in safety assessment, suitability analysis, and benefit-cost analysis, empowering the team to conduct research and address challenges in a robust, reliable, and comprehensive manner.

Benefit - Cost Analysis

The commercial potential of the proposed design is addressed through a benefit-cost analysis to ensure *The Chariot* is a practical, realistic, and affordable solution for accommodating passengers with disabilities and aging passengers at airports. The team estimated and quantified the tangible and intangible benefits of implementing 100 units of *The Chariot* through brainstorming sessions and referencing real-world data. A comprehensive assessment of the costs of designing, implementing, and operating 100 units of *The Chariot* was conducted. The 10-year benefit-cost ratio amounts to **3.08**. Detailed benefit and cost estimations are provided below.

Benefit Assessment

The team analyzed both the tangible and intangible benefits of operating 100 units of *The Chariot* over 10 years. Using quantitative and qualitative methods, the team estimated and quantified the potential benefit of the proposed design through brainstorming, researching real-world data, and expert guidance.

Tangible Benefits

The proposed design offers significant tangible financial benefits through reduced labor costs, advertisement revenue, and increased operational safety. By implementing 100 units of The Chariot, it is assumed that airports can save labor costs by 72 hours per day, with the assumption of reducing three eight-hour shifts for three staff members per day. This results in annual savings of $525,600. Additionally, each cart offers three advertisement spaces with different prices based on location, size, and visibility. Using the 'variable pricing' strategy, 100 units of *The Chariot* can generate $780,000 in advertisement revenue annually.

Furthermore, despite improved safety not directly generating revenue, it can help airports save costs. According to the ACRP guidance on its website, the monetary compensation for a severe injury is $955,000 (Byers, 2021). Assuming that 100 units of *The Chariot* can prevent one serious injury related to carrying and lifting luggage over 10 years, the airport could save $95,500 annually. The tangible benefits from reduced labor costs, advertisement revenue, and enhanced safety level add up to $1,401,100 annually, as detailed in Table 7.

Intangible Benefits

In addition to tangible financial benefits, the proposed design offers many intangible benefits. Increased air travel accessibility could further unlock the economic potential of the lucrative niche market of aging passengers and individuals with disabilities (Chang & Chen, 2012). As *The Chariot* accommodates the needs of aging passengers and travelers with disabilities, these passengers and their families may be more inclined to spend time and money at airports. Additionally, implementing innovative solutions such as *The Chariot* can reflect airports' initiatives and determinations to accommodate aging passengers and individuals with disabilities, strengthening airports' brand value.

While the intangible benefits cannot be directly assessed, a sensible assumption was developed to quantify the potential financial benefit of these intangible assets. The team assumed that all these intangible improvements could help airports increase concession revenue by 0.01% per year. The concession revenue used in this assessment is the average of the concession revenue of LAX airport and SFO airport in the fiscal year 2022 (Los Angeles International Airport, 2022; San Francisco International Airport, 2023). The estimated intangible benefits of one unit of *The Chariot* amount to $35,030 annually, as illustrated in Table 7.

10-Year Total Benefit

The Chariot's total tangible and intangible benefit adds up to **$1,436,130** annually. As all these benefits persist over time, the total benefit over 10 years was derived by multiplying the annual benefit by 10. The total 10-year benefits amount to **$14,361,300**, as depicted in Table 7.

Table 7

The Chariot's Benefits to Airports (100 units over 10 years)

Item		Rate	Multiplier	Quantity	Subtotal	Note
Tangible Benefit						
Reduce labor costs		$ 20/labor hours	72 labor hours	365 days	$ 525,600	Reduce labor hours by 72 hours per day (3 staffs×8 hrs.×3 shifts)
Revenue from Advertisements	**Small Basket**	$ 100/unit	100 units	12 months	$ 780,000	Use variable pricing for ads. based on location, size, etc.
	Back Panel	$ 250/unit				
	Digital Device	$ 300/unit				
Reduce potential injury from heavy luggage		$ 955,000/ injured passenger	1 seriously injured passenger /10 years	1 year	$ 95,500	Estimated 10% reduction in serious injury rate
Subtotal Tangible Benefit					$1,401,100	
Intangible Benefit						
Increase concession revenue by improving passenger experience		$350,300,000 /year	0.01%	1 year	$ 35,030	Based on average concession revenue at LAX and SFO in 2022
Yearly Subtotal Benefit					**$1,436,130**	
10 Years Total Benefit					**$14,361,300**	

Cost Assessment

The cost analysis of this proposed design comprises four phases: Alpha (Research & Concept development), Beta (Prototype and Testing), Charlie (Production, Marketing & Distribution), and Delta (Operation and Maintenance), as depicted in Figure 8.

Figure 8

Cost Allocation from Design to Operation

Note: Inspired by the ACRP Cost-Benefit Analysis Resource Video (Byers, 2021).

The Alpha phase encompasses the cost of researching and modeling the concept of *The Chariot.* In this phase, the team first researched relevant ACRP Reports and other literature to gain a better understanding of the challenges that aging passengers and travelers with disabilities are facing. With the knowledge gained, the team conducted several brainstorming sessions with the faculty advisor and developed the idea of *The Chariot*. With guidance and input from airport experts, the team further decided on *The Chariot's* detailed design and functionalities. The team then used modeling tools (Autodesk Maya, AutoCAD) to deliver the 3D visual design of *The Chariot*. The cost of phase Alpha totals $27,500, with a detailed breakdown in Table 8.

Table 8

Cost for Design and Research – Alpha Phase (3 months)

Item	Rate	Operators	Quantity	Subtotal	Notes
Graduate Student	$ 21.5/hr.	2 Students	360 hrs.	$ 15,480	12 weeks, 30hrs./week
Concept modeling	$ 55/hr.	1 Designer	18 hrs.	$ 990	Assist in idea modeling
Airport Expert	$ 40/hr.	1 Expert	48 hrs.	$ 1,920	Safety test, consultancy
Faculty Advisor	$ 55/hr.	1 Advisor	36 hrs.	$ 1,980	Project advisor
Subtotal Cost				$ 20,370	-
Overhead Expenses				$ 7,130	35% of project cost
Total Cost of the Alpha phase				**$ 27,500**	-

A pre-production model needs to be constructed and tested in the Beta phase. The team first estimated the cost of building the pre-production model, considering expenses for labor, materials, reliability tests, and specialized equipment expenses. Additionally, the team estimated the costs associated with the prototype testing, including administration and user recruitment fees. The team also factored in the ADA expert consultation fee and intellectual property protection fee with reference to real-world data—the total costs of the Beta phase amount to $127,818, with details provided in Table 9.

Table 9

Cost for Prototype and Testing – Beta Phase (4 months)

Item	Rate	Multiplier	Quantity	Subtotal	Notes
Graduate Student	$ 21.5/hour	2 students	480 hours	$ 20,640	16 weeks, 30 hrs./week
Physical Prototype Construction	$ 55/hour	2 engineers	200 hours	$ 48,500	1 Software, 1 Hardware
	$ 30/hour	2 personnel	200 hours		Executing construction tasks
	$ 150/hour	1 set	50 hours		Specialized equipment rental
	$ 2,000/unit	1 set	1 unit		Prototype construction Materials
	$ 5,000/test	Reliability Test	1 test		Conducting reliability tests
Airport Manager	$ 40/hour	1 manager	35 hours	$ 1,400	Managing logistics
ADA Expert	$ 40/hour	1 expert	35 hours	$ 1,400	Consultation and assessment
User Recruitment	$ 16/hour	30 users	0.5 hours	$ 240	Incentives for participation
Travel & Administration	$ 1,000	-	-	$ 1,000	Field survey, testing, etc.
Faculty Advisor	$ 55/hour	1 advisor	300 hours	$ 16,500	Project advisor
Property Protection	$ 5,000	-	-	$ 5,000	Patenting & Licensing (if applicable)
Subtotal Cost				$ 94,680	-
Overhead Expenses				$ 33,138	35% of project cost
Total Cost of the Beta phase				**$ 127,818**	-

Once the Beta model is constructed and tested, the next step is to launch the product in the market. With guidance from the faculty advisor and reference to real-world data, the team estimated the cost of introducing *The Chariot* into the market by considering three aspects: Cost of Production, Cost of Marketing, and Cost of Distribution. The cost of production includes

expenses for materials and labor, while the marketing costs encompass compensation for two market researchers and a sales representative who works on a commission basis. Additionally, the cost of distribution includes shipping and warehousing expenses. The total production, marketing, and distribution cost for 100 units of *The Chariot* amounts to $385,425, with a detailed breakdown illustrated in Table 10.

Table 10

Cost for Production & Marketing & Distribution of 100 units of The Chariot

Item	Rate	Multiplier	Quantity	Subtotal	Notes
Cost of Production - Material Costs & Labor cost & Overhead cost					
Material Costs	$ 2,000/unit	100 units	-	$ 200,000	Including frames, electronic, and mechanical components
Labor Cost	$ 50/hour	60 personnel	15 hours	$ 45,000	Wages for fabrication, assembly, and quality control
Subtotal Cost of *Production*				**$ 245,000**	-
Cost of Marketing- Market Research & Sales Support					
Market Research	$ 30/hour	2 researchers	200 hours	$ 12,000	Conducting market studies, trend analyzing, and forecasting
Sales rep.	-	1 sales rep.	-	$ 18,000	Commission-based
Subtotal Cost of *Marketing*				**$ 30,000**	-
Costs of Distribution- Shipping & Warehousing					
Shipping	$ 75/unit	100 units	-	$ 7,500	Costs for shipping the carts to customer airports
Warehousing	$ 3,000/year	1 year	-	$ 3,000	To hold inventory before distribution
Subtotal Cost of Distribution				**$ 10,500**	-
Subtotal Cost of Production, Marketing & Distribution				$ 285,500	-
Overhead Expenses				$ 99,925	35% of project cost
Total Cost of Production & Marketing & Distribution				**$ 385,425**	-

Finally, the team assessed the operational and maintenance expenses for *The Chariot* over 10 years. To gain a sensible estimation, the team evaluated the initial year investment and the recurring years separately, recognizing the ongoing nature of these activities. In the initial year, a more in-depth training session would be conducted to ensure a smooth implementation. Additionally, the need for labor hours for maintenance and the frequency of preventative

maintenance and routine inspections would be higher in the initial year compared to recurring years. The total 10-year cost of operation and maintenance for one unit of *The Chariot* (100 carts) amounts to $4,109,759. Table 11 presents the breakdown of the operational and maintenance expenses.

Table 11

Cost for Operation & Maintenance for 100 units of The Chariot

Item	Rate	Multiplier	Quantity	Subtotal	Notes
Cost of the initial year					
Initial Training [a]	$ 700/session	1 session	1 year	$ 700	Initial training
Preventative Maintenance	$ 75/unit	100 units	12 months	$ 90,000	Once a month
Routine Inspections	$ 500/visit	6 visits/year	1 year	$ 3,000	Every two months
Operators' Personnel [b]	$ 18/hour [c]	48 labor hours	365 days	$ 315,360	Labor cost
Insurance	$ 15/unit	100 units/month	12 months	$ 18,000	Property insurance
Electricity Cost	$ 0.0035/mile	100 units	13,150 miles	$ 4,603	Annual cost
Year 1 Subtotal Cost				$ 431,663	-
Overhead Expenses (35% of project cost)				$ 151,082	-
Year 1 Total Cost of Operation & Maintenance				**$ 582,745**	-
Cost of the recurring years (Year 2 – 10)					
Recurring Training [a]	$ 500/session	1session/3 years	9 years	$ 1,500	Every 3 years
Routine Inspections	$ 500/year	2 visits/year	9 years	$ 9,000	Twice a year
Preventative Maintenance	$ 75/unit	100 units	36 times	$ 270,000	Every three months
Insurance	$ 15/unit	100 units/month	108 months	$ 162,000	Property insurance
Operators' Personnel [b]	$ 18/hour [c]	36 labor hours	3,285 days	$ 2,128,680	Labor cost
Electricity Cost	$ 0.0035/mile	100 units	118,350 miles	$ 41,423	Cost for 9 years
Recurring Years (Year 2-10) Subtotal Cost				$ 2,612,603	-
Overhead Expenses (35% of project cost)				$ 914,411	-
Year 2-10 Total Cost of Operation & Maintenance				**$ 3,527,014**	-
10 Years Total Cost of Operation & Maintenance				**$ 4,109,759**	-

Note. [a] Includes instructor fees, venue rental, administrative, and miscellaneous expenses. [b] Labor hours required for introducing and collecting *The Chariot.* [c] Customer service average wage is around $18/hour (U.S. Bureau of Labor Statistics, 2023)

10-Year Total Cost

Whereas the cost of operation and maintenance is ongoing, all other costs can be considered as the initial investment. Therefore, the 10-year total cost was derived by summing all initial investments and the 10-year operation and maintenance cost. The 10-year total cost of implementing 100 units of *The Chariot* adds up to **$4,650,502**, as detailed in Table 12.

Table 12

10-year Cost for 100 units of The Chariot

Item	10 Years Subtotal Cost	Note
Cost of Alpha Phase	$ 27,500	Table 8
Cost of Beta Phase	$ 127,818	Table 9
Cost of Production & Marketing & Distribution	$ 385,425	Table 10
Cost of Operation & Maintenance	$ 4,109,759	Table 11
10-year Total Cost for 1 unit (100 Carts)	**$ 4,650,502**	

Benefit-cost Ratio

The 10-year benefit-cost ratio resulted in **3.08** for one airport implementing 100 units of *The Chariot*, as shown in Table 13. While some assumptions were made to estimate and quantify the associated benefits and expenses, this ratio demonstrates *The Chariot's* commercial potential.

Table 13

10-year Benefit/Cost Ratio for 100 units of The Chariot

10-Year Total Benefit	**$ 14,361,300**
10-Year Total Cost	**$ 4,650,502**
Benefit/Cost Ratio	***3.08***

Sustainability Assessment

Sustainability has gained increasing global interest over time, and many now consider it an essential component for business success. While sustainability is often associated primarily with environmental preservation, it encompasses a broader concept. The 'Our Common Future' report by the World Commission on Environment and Development (Brundtland Report) in 1987 defined sustainable development as "Meeting the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987, p. 41). The Federal Aviation Administration (FAA) encourages airports nationwide to create detailed sustainability plans that encompass strategies for reducing environmental impact, fostering economic growth, and advancing social progress by collaborating with local communities (FAA, 2023b).

According to ACRP *Report Synthesis 66* (Martin-Nagle & Kluber, 2015), the airport community has adopted the EONS framework to define sustainability. EONS represents Economic vitality, Operational efficiency, Natural resources, and social responsibility (Sustainable Aviation Guidance Alliance, n.d.). By embracing sustainability as a continuous improvement strategy, airports can enhance various aspects of their operations and facilitate future growth (Martin-Nagle & Kluber, 2015).

The team conducted a Sustainability Evaluation of *The Chariot* using the EONS Model, as depicted in Table 14. The results demonstrate that *The Chariot* enhances not only the social responsibility of the airport but also contributes to revenue generation and passenger flow while promoting environmental sustainability. For instance, utilizing *The Chariot* at airports can attract more investment and services and reduce the likelihood of legal action resulting from injuries caused by conventional luggage carts. Additionally, it enhances the efficiency of the check-in

process to reduce queuing time and establishes an inclusive environment for independent air travel for all individuals.

Table 14

Sustainability Evaluation Using the EONS Model for The Chariot

EONS	Sustainable Impacts of the Design (Effects on Airport)	
Economic Vitality	Attract more investment and services to airports and increase demand through innovative change	(+)
	Enhance airport and tenant revenue through improved reputation, increased concession sales, and enhanced passenger experience	(+)
	Reduce the likelihood of legal action resulting from injuries caused by conventional luggage carts, leading to cost savings	(+)
	Introduce a new assistant service option and decrease complaints about accessibility services, resulting in cost savings	(+)
Operational Efficiency	Optimize passenger flow within the airport terminal to reduce travel time for elderly and disabled passengers	(+)
	Enhance the efficiency of the check-in process to reduce queuing time and improve passenger movement	(+)
	Decrease the waiting time for wheelchair services and contribute to on-time flight performance	(+)
	The use of digital devices may pose a potential challenge for some persons	(-)
Natural Resources	Utilize recyclable and sustainable materials for manufacturing	(+)
	Compatible energy consumption equal to or less than current energy use	(+)
	Implement a stackable design to utilize airport space efficiently	(+)
	Potential generation of electronic waste due to battery usage	(-)
Social Responsibility	Establish an inclusive environment for independent air travel for all individuals	(+)
	Promote equality and reduce travel stigma for aging travelers and persons with disabilities	(+)
	Enhance convenience and accessibility through multifunctionality, offering comprehensive services	(+)
	Provide a positive airport experience, reducing stress, fatigue, and potential injuries	(+)

The 2030 Agenda for Sustainable Development, developed by the United Nations in 2015, contains 17 SDGs representing urgent sectors requiring action by all countries. To further assess *The Chariot*'s sustainability from different perspectives, the team conducted another

sustainability assessment using the United Nations (UN) Sustainable Development Goals (SDGs). Initially, the team identified three SDGs to which *The Chariot* can contribute: SDG 9 (Industry, Innovation, and Infrastructure), SDG 10 (Reduced Inequalities), and SDG 11 (Sustainable Cities and Communities). These SDGs were selected along with specific targets set by the UN. Table 15 describes how *The Chariot* contributes to achieving these SDGs.

Table 15

The Chariot's Impact on the UN Sustainable Development Goals

SDGs	Target met	How to achieve
9 Industry, Innovation, and Infrastructure 	9.1 **Develop quality, reliable, sustainable and resilient infrastructure**, including regional and transborder infrastructure, **to support economic development and human well-being**, with a focus on affordable and equitable access for all (U.N., n.d.)	*The Chariot* attracts more investment and enhances the passenger experience by providing an accessible airport environment for all, ensuring inclusivity and convenience.
	9.4 By 2030, **upgrade infrastructure and retrofit industries to make them sustainable**, with increased **resource-use efficiency** and greater adoption of **clean and environmentally** sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities (U.N., n.d.)	*The Chariot* optimizes airport efficiency by reducing travel time for users and promoting eco-friendly operations by utilizing sustainable energy resources
10 Reduced Inequalities 	10.2 By 2030, **empower and promote the social, economic and political inclusion of all**, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status (U.N., n.d.)	*The Chariot* provides an inclusive environment for persons with disabilities and aging travelers, offering independent air travel options and assisting with wayfinding
	10.3 **Ensure equal opportunity and reduce inequalities** of outcome, including by eliminating discriminatory laws, policies and practices and promoting appropriate legislation, policies and action in this regard (U.N., n.d.)	*The Chariot* breaks the stereotype of airport cart and fosters equality by integrating innovative multi-functional features tailored to the users, ensuring equal opportunities for all travelers
11 Sustainable Cities and Communities 	11.2 By 2030, **provide access to safe, affordable, accessible and sustainable transport systems for all**, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons (U.N., n.d.)	*The Chariot* reduces the risk of injury, fatigue, and stress for passengers, particularly those with disabilities and aging travelers, thus enhancing safety and convenience during their airport experience
	11.7 By 2030, **provide universal access** to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities (U.N., n.d.)	*The Chariot* enables independent travel for its target users, promoting inclusivity and creating a more accommodating environment

Conclusion

The limited assistance options pose difficulties for aging passengers and travelers with disabilities in receiving practical and effective assistance in luggage handling and wayfinding at many airports. Inspired to address these limitations, the team proposed an innovative design – a multifunctional electronic airport luggage Cart (*The Chariot*), aiming to tackle the **ACRP Passenger Experience and Innovations in Airport Terminal Design Challenge**, Problem B- *Innovations to accommodate passengers with disabilities and aging passenger demographics at airports.*

The concept for *The Chariot* was developed after seeking insights from relevant ACRP reports and other literature. Subsequently, the team modeled the concepts together through internal brainstorming sessions and interactions with industry experts. Equipped with an interactive device and a lifting feature, *The Chariot* is designed to assist aging passengers and travelers with disabilities in **luggage handling** and **wayfinding at airports**. Furthermore, *The Chariot* can function independently as a multifunctional cart or be attached to a wheelchair, allowing passengers with **more assistance options** to get around airports.

For a single airport, the 10-year benefit-cost of implementing 100 units of *The Chariot* yields a **3.08 to 1** ratio, illustrating the commercial potential of *The Chariot*. Safety risks were identified and controlled under the *FAA Advisory Circular 150/5200-37*. Additionally, the sustainability analysis results show that *The Chariot* is a sustainable design that responds to three goals of the *17 UN SDGs*. Overall, *The Chariot* is an innovative and practical solution to increase air travel accessibility for aging passengers and travelers with disabilities.

Appendix A: Contact Information

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Appendix B: Description of The University

Purdue University

Purdue University is a public university founded in 1869 and named for John Purdue, a leading benefactor in establishing Purdue University as Indiana's land grant college. The School of Aviation and Transportation Technology (SATT) is located at the airport on the system's flagship campus in West Lafayette, Indiana. Founded in 1934, the Purdue University Airport (KLAF) is the first university-owned airport in the US. Our aviation programs have over a thousand undergraduates enrolled in Bachelor's degree programs and over 150 graduate students seeking Master's and Doctoral degrees. The mission of SATT is to prepare the next generation of leaders and change agents for the transportation sector. SATT is one of six academic departments in the college, known as the Purdue Polytechnic Institute. (Purdue University Polytechnic Institute, n.d.)

There are over 200 undergraduate programs, 11 colleges, and over 2,000 faculty and staff at Purdue. Over 50,000 students from over 135 countries study in West Lafayette. Over 100,000 students study in West Lafayette, around Indiana, and globally. Purdue University is highly ranked in several factors. These include being ranked 5th for most STEM graduates in the US according to Forbes, 2022; ranked 4th as the Most Trusted Public University in the U.S., as reported by Morning Consult's 2022 survey; recognized as a Top 10 Public University and ranked 7th as the Best Value School in the U.S., according to The Wall Street Journal and Times Higher Education, 2022 (Purdue University, n.d.).

Appendix C: Description of Airport and Industry Experts

Lawrence J. Rolon serves as the ADA Coordinator at Ontario International Airport (ONT), California. Previously, he held the position of ADA Coordinator at Los Angeles World Airport (LAWA) for over 21 years before transitioning to Ontario International Airport. He was a speaker at the TRB Webinar titled "Assessing Airport Programs for Travelers with Disabilities and Older Adults" held in 2024. During the webinar, he highlighted the role of airports and provided real-world examples of efforts to implement accessibility services for travelers with disabilities and older adults. Lawrence Rolon holds a Master of Public Administration and a Master of Science in Library Science from the University of Southern California.

Alan Gonzalez is the Landside Manager at Dallas Fort Worth International Airport (DFW), Texas. With over 10 years of experience in airport operations, he previously held positions as Guest Transportation Assistant Manager and Ground Transportation Supervisor at DFW. Alan Gonzalez holds a Master of Science in Aviation and Aerospace Management from Purdue University and a Bachelor of Business Administration from the University of Texas. Furthermore, he is a Certified Member (CM) of the American Association of Airport Executives (AAAE) and certified in the Safety Management System of AAAE

Junghye Lee is the Deputy General Manager of the Security Management Team at Jeju International Airport, Korea Airports Corporation. With over 15 years of experience in airport operations, she has led several projects related to service development for passengers with reduced mobility, airport sustainability, and landside operations enhancement at airports throughout South Korea. Junghye Lee holds a Master of Science in Aviation and Aerospace Management from Purdue University and a Bachelor of Science in Air Transport from Korea Aerospace University.

Adam Baxmeyer serves as the Airport Operations Manager at Purdue University Airport with nearly 25 years of experience in the aviation industry, encompassing both commercial and general aviation airports. Before assuming his current role in 2016, he held the position of Deputy Director of Operations and Facilities at Bloomington Normal Airport Authority (BNAA). He served as the Airport Operations Supervisor at Cherry Capital Airport. Adam Baxmeyer holds a Master of Public Administration from Purdue Global and a Bachelor's in Aviation Administration from Purdue University.

Kelly Buckland has been actively involved in disability issues since 1979. His extensive work experience in this field includes serving as Executive Director at the National Council on Independent Living (NCIL), Living Independent Network Corporation, and the Idaho State Independent Living Council for over 20 years. He has actively advocated for disability rights through direct service and systemic changes and has provided testimony before Congress on a range of relevant matters. Moreover, Kelly Buckland has received state and national awards, such as the University of Idaho President’s Medallion and the Hewlett-Packard Distinguished Achievement in Human Rights Award. He presented at the TRB Webinar "Enhancing Wheelchair Accessibility on Commercial Service Aircraft" in 2023, addressing Disability Policy Priorities at the Department of Transportation related to air travel accessibility. Kelly Buckland holds a Master's degree in Rehabilitation Counseling from Drake University and a Bachelor of Arts in Social Work from Boise State University.

Dr. Wesley Major is an Airport Research Specialist at the FAA William J Hughes Technical Center, where he explores and examines various aviation-related topics based on his knowledge and experience. Wesley holds a Bachelor of Science in Organizational and Community Leadership from the University of Delaware and a Master's in Aviation and Aerospace

Management from Purdue University. He further concentrated on aviation and earned a Doctor of Philosophy in Aviation and Transportation Technology, with his thesis focused on improving the airline experience for people with disabilities.

Dr. Sarah Hubbard is an Associate Professor of Aviation Management in the School of Aviation and Transportation Technology at Purdue University. Her professional interests span various areas within aviation and transportation, including airport operations, multimodal planning, and safety. She is a licensed civil engineer and has conducted research projects focusing on integrating emerging technologies and sustainability into airport and transportation operations, as well as safeguarding vulnerable system users. Dr. Hubbard serves on the Research, Engineering, and Development Advisory Committee (REDAC) for Airports to assist the Federal Aviation Administration (FAA) in its research endeavors. Additionally, she serves as a member of the Standing Committees of the Transportation Research Board (TRB) on AV060 (Airfield and Airspace Capacity and Delay) and AV095 (New Users of Shared Airspace).

Jens Sehested Krogh serves as a Board Member of Intelligent Track Systems (ITS), a Danish company specializing in intelligent shopping trolleys with digital devices, particularly in airport duty-free areas. Additionally, he holds the position of Managing Director for group sales and Executive Vice President of CPHI-Holdings, which comprises three intelligent technology subsidiaries: BBHS (an intelligent baggage handling solutions company), Exruptive (an innovative X-ray screening technology development company), and ITS (an intelligent trolley development company). Jens Sehested Krogh plays a crucial role in guiding the strategic direction and fostering business development within these subsidiary groups, leveraging his expertise in business strategy and international sales.

Appendix E: Evaluation of the Educational Experience Provided by the Project

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

The ACRP University Design Competition provided a valuable learning experience for our team. By addressing airport-related issues, we gained insights not only from the perspective of airport operators but also from passengers with disabilities and older travelers—perspectives we had not previously considered. Engaging with airport and industry experts provided invaluable experience learning about the aviation industry and professional work practices, offering perspectives that cannot be gleaned from textbooks alone. Moreover, collaborating as a team through a step-by-step process allowed us to proceed systematically, enhance our critical thinking skills, and bolster our confidence for future endeavors.

2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?

The team encountered two major challenges. Firstly, we needed to specify the feasible mechanical mechanism and the applicable area of the proposed airport luggage cart. These challenges were addressed through a thorough literature review and guidance from the faculty advisor, as well as interactions with airport and industry experts. Secondly, we aimed to gain a deeper understanding of the difficulties faced by persons with disabilities and older travelers. Based on the literature review conducted, we engaged with experts to understand the challenges of persons with disabilities and aging individuals. Specifically, interactions with various experts

who deeply understand these challenges provided valuable insights into the difficulties faced by passengers with disabilities and aging travelers.

3. Describe the process you or your team used for developing your hypothesis.

In the initial step, the team examined the entire boarding process, from arrival at the airport to boarding the aircraft, disembarking from the aircraft, and leaving the airport. Among the identified challenges, the team recognized that current luggage carts may have limitations in accommodating older people and persons with disabilities compared to shopping carts at major supermarkets. Conducting literature and legislation reviews, the team identified four major issues related to conventional luggage carts for persons with disabilities and older travelers. Additionally, interactions with faculty and experts, along with a clear goal and five core values of the team's design, enabled the team to proceed to the design process.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Industry participation in the project was precious and beneficial. The team engaged with airport and industry experts through in-person and virtual meetings, receiving meaningful feedback that enriched the project. By connecting with experts from diverse fields and sectors, the team gained various perspectives and insights from different professional experiences. Arranging and conducting these meetings facilitated practical learning and gave the team valuable hands-on experience and knowledge. Despite their busy schedules, the experts generously allocated their time to share real industry issues and insights, contributing significantly to the project's depth and relevance. The interactions with these experts were

instrumental in shaping the project's direction and ensuring its alignment with industry needs and challenges.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

This competition project helped the team to the next level. It provided the team with valuable industry-related knowledge and emphasized the significance of collaboration with others. Furthermore, the process enhanced the team's critical thinking skills and provided practical experience in tackling industry challenges. Ultimately, the team's aspirations grew, fueling a desire to work as airport experts in the future and contribute to the industry.

Faculty

l. Describe the value of the educational experience for your student(s) participating in this competition submission.

The value of this educational experience is three-fold. First is there the team's response to a Request for Proposal (RFP). Few students leave university who have developed a concept to improve a real airport problem, estimated the cost and benefits, described and mitigated the safety risks, and determined the categories of sustainability analysis. The second is the teaming with those who have different viewpoints than your own: educational, cultural, experiential, and so on. Third, is completing a project on-time and the necessary reassessments of how much is left to do, how much resource do we have left, how many calendar days are left, and how are we going to get to a completed idea and proposal given what we have left.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

This is a graduate class in aviation and aerospace sustainability. One way to fulfill the research and design requirement is to enter the ACRP airport design competition.

3. What challenges did the students face and overcome?

The first challenge is the challenge that many teams face, and that is to right-size the challenge and the solution. Given that the teams form in late January and deliver in late April, the team members must get to know each other, their strengths and weaknesses, develop the concept in an iterative fashion, speak with experts, and then size, resize, and right size the processes to be improved and the techniques to improve them. The teams complete the analyses and report in 3 months total time. This team struggled with the intended end users – are they aging, are they differently abled (physical or otherwise), are they families with children or others in their traveling party that require extra visual vigilance…exactly who are the end users? What do they need? How do we know? What would be best? These are very real challenges in real world design, too.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

I plan to continue to use this competition as an educational vehicle. Like most students, learning becomes more fun, engaging, and meaningful when they can learn, do, and compete.

5. Are there changes to the competition that you would suggest for future years?

I really like the new arrangement of the categories this year. In addition, I would add a required sustainability analysis in the airport design competition because sustainability has become important to airport stakeholders.

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