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Rail Safety IDEA Program

Modeling and Validation of Standards for a Sleeping Compartment on Accessible Passenger Rail Vehicles

Final Report for
Rail Safety IDEA Project 31

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Modeling and validation of standards for a sleeping compartment on accessible passenger rail vehicles

IDEA Program Final Report /Rail Safety Project 31

Prepared for the IDEA Program Transportation Research Board
The National Academies

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EXECUTIVE SUMMARY

The main outcome of the project are designs for accessible sleeping compartments on single level and bi-level intercity trains that accommodate up to four passengers traveling together including two passengers who may have reduced mobility. The objective of this IDEA project was to extend the 2D and 3-D digital modeling of a passenger rail accessible restroom to include the design of a complete accessible sleeping compartment, and to build a full-scale soft mock-up of the proposed sleeper compartment design that contains a restroom with a shower for evaluation by people with disabilities. These activities also validated many of the proposed accessible rail standards that accommodate large wheeled mobility devices than current standards. 3-D modeling of the previously designed accessible restroom for passenger rail was extended to include a shower. A full-scale soft mock-up of the sleeping compartment containing a restroom with a shower was built and evaluated by people with reduced mobility and members of the general public. The study also included an online survey that was disseminated, and 173 people with and without reduced mobility in North America and Europe provided responses. At the conclusion of this study, the team developed new designs for accessible sleeping compartments for intercity passenger rail that were verified and evaluated and showed that a low cost soft mock up enhances design visualization and provides an opportunity to obtain valuable feedback from the general public including people with reduced mobility.

The key concept of the design innovation for the sleeping compartment is the inclusion of two sleeping berths at a lower level. This design feature is not available on any accessible sleeper bedrooms currently in operation in the US or Canada. The project balanced two competing objectives: (1) providing improved access for passengers with reduced mobility and (2) addressing passenger rail economics by managing spatial consumption by increasing occupancy to up to four passengers. On advice from the project advisory committee, the detailed design was for a bi-level car, with the expectation that the accessible sleeping compartment would be located on the sightseer-lounge car and co-located by a vestibule equipped with an onboard lift for access to the train from the platform and an onboard elevator for access to the upper level. All these considerations together would enable passengers with reduced mobility to access the sightseer-lounge car and improve the train travel experience. The bi-level refers to the Amtrak *Superliner*/California *Surfliner* type of bi-level car with two distinct levels this is sometimes called the "High level". The bi-level sleeper spans the full width of the train and permits a full 360^{o} rotation of a large wheeled mobility device in the sitting/sleeping area. The restroom includes a fully accessible shower that is equipped with a fold-down seat and adjustable height shower head. The restroom permits a fully assisted transfer from a large wheeled mobility device to the toilet and also space for a securement device for an unoccupied wheelchair.

Concepts designs were developed for an accessible sleeper on a single level train car. There is a need to retain a passage way through the train and consequently this impacts the amount of space available for an accessible sleeper. The objective of two lower level sleeping berths were maintained, but there were other compromises. The accessible restroom still accommodates a fully assisted transfer from a wheeled mobility device to the toilet and there is space to secure an unoccupied wheeled mobility device. However, there is no space to accommodate mobility of the wheeled mobility device outside of a one-directional movement or a 360^{o} turn in the sitting/sleeping area and the shower is not included in the restroom.

The IDEA project also applied Digital Human Modeling (DHM) in the 3-D Computer-Aided Design (CAD) environment to assist with visualization, comfort assessment and analysis of accessibility preferences between people with reduced mobility and people without mobility restrictions. The soft mock-up provided some surprising results that had not been captured in either the survey or DHM and this included recommendations to include railing and grab bar on the lower berths. The IDEA project also demonstrated the economic value of using a soft mock-up as part of the design tools. Soft mock-ups are relatively inexpensive and very adaptable. The soft mock-up for the bi-level sleeper design cost less than $1,000 for materials and construction costs and provided an opportunity to gather feedback from the general public including people with reduced mobility. Next steps in development include; installing and testing the soft mock up on both a single level and bi-level rail cars that can travel to different locations across the US for more evaluation by people with reduced mobility, and design of a separate accessible shower compartment that can be used by other passengers and located adjacent to the accessible sleeping compartment on a single level train.

The IDEA project showed that it is possible to develop new accessible sleeping compartments with two lower berths that will increase access and occupancy, and improve the train travel experience of travelers with reduced mobility.

DESCRIPTION OF PROJECT:

The IDEA project developed new designs for an accessible sleeping compartment that were verified and evaluated using 2-D and 3-D digital modeling and a soft mock-up as shown in Figure 1. The project extended the 3-D modeling of the previously designed accessible restroom for passenger rail and built a full-scale soft mock-up of the sleeping compartment that contains a restroom with a shower for evaluation by people with disabilities. The soft mock-up permitted evaluation of several different amenities by people with and without disabilities. An online survey was also implemented to gather feedback from people who are unable to visit the soft mock up. Representatives of the passenger rail industry and advocates for people with mobility disabilities are involved throughout the project.

Figure 1 Images of the constructed full-scale soft mock-up shown with a 50th percentile male manikin in a manual wheelchair.

SCOPE OF PROJECT

INTRODUCTION

Design specifications of accessible spaces often follow the minimum design standards as regulated by the Americans with Disabilities Act[1]. These standards, however, do not account for more recent changes in population age and size as well as the size of wheeled mobility devices [2]–[7]. Seating, sleeping, and restroom accommodations are important aspects of overnight passenger rail travel, and validation of the recommendations to industry is a crucial step in determining final design criteria. Current practice for accessible design consists of human subject testing and 2-D and 3-D spatial footprint analysis. A key insight that motivated this work is the successful application of computer-aided design (CAD) and digital human modeling (DHM) as time- and cost-efficient tools that enable consideration of human factors and ergonomic aspects early in the design process [3]–[9]. The addition of these tools into the methodology of design for accessibility in the context of passenger rail has the potential to reduce time and cost required in the design process while outputting an appropriate design that considers the comfort and well-being of users. For the accessible restrooms in the sleeping compartment, prior research conducted on spatial occupancy analysis that was used for the design of lavatories in the passenger aircraft environment was adapted to passenger rail [2], [9]. In a dependent wheelchair-toilet transfer study, aggregated motion capture was used to determine spatial consumption during the task with results suggesting that accessible designs created with preferential design to safe transfer angles may minimize on-board spatial consumption

There are very few published findings on accessibility on-board passenger rail, however previous work has recommended improvements to accessibility in part by accounting for the changes in population and advancements in technology [10], [11] Independent mobility, safe performance of tasks such as transfers and reaches, and safe securement were factors considered in the current work.

A number of recommendations towards improvement of accessibility and related design criteria are discussed in the report. These are in accordance to the Americans with Disabilities Act. (ADA), Rail Vehicle Access Advisory Committee (RVAAC), the Canadian Code of Practice for passenger rail, the final summary report to the Federal Railroad Administration on the Accessible Design of the next generation of passenger cars, and also previous publications from the design team including the recommendations for Passenger Rail Investment and Improvement Act (PRIIA) specifications [1], [10]–[13]

Goals and Objectives

The accessible sleeping compartment design is based on several existing sleeping and accessible restroom designs that were studied as a reference base[14]. 3-D models of the restroom were created from the 2-D floor plans in part based on dimensions received from Amtrak's Acela lavatory (toilet, sink, grab bars); these were modified to improve accessibility needs of larger wheeled mobility devices and included recommendations for accessible restrooms in the built environment [10].

The 3-D models of the sleeping area were created with modified versions of convertible flatbed seats obtained from aerospace seating manufacturers and generic placeholders for amenities. These 3-D models of the sleeping compartment that included 95th percentile male human models were created and sent to the Project Advisory Committee for additional feedback on amenities and spatial allocation. The Project Advisory Committee consists of stakeholders from both the user population and rail industry. Feedback was received with regards to spatial consumption, reach, inclusion of amenities, and accessibility. At the project kick off meeting the Project Advisory Committee strongly recommended that the shower and toilet area be incorporated into the sleeping compartment and that a bi-level car be the base design. A detailed design for the single level car has not been developed or validated as part of this IDEA project, but consideration of some of the design attributes are discussed in the report. Additional design objectives are to create designs that maximize accessibility and meet user needs while being conscious of revenue and real estate on the car. Figure 2 is a 2-D layout of the proposed mock up. This version is designed to accommodate up to four passengers with two sleeping berths at floor level and two upper berths.

The discussion provided is based on the most preferred design that were presented in an interim report to the Project Advisory Committee. This report detailed all the designs and summarized the positive and negative attributes of each design. In all the designs that were developed, the accessible space accommodates four passengers, two of which may have reduced mobility and require an accessible sleeping compartment, however only one large wheeled mobility device can be accommodated comfortably. This design requirement accounts for such situations as older passengers and individuals with disabilities traveling in pairs or a small group.

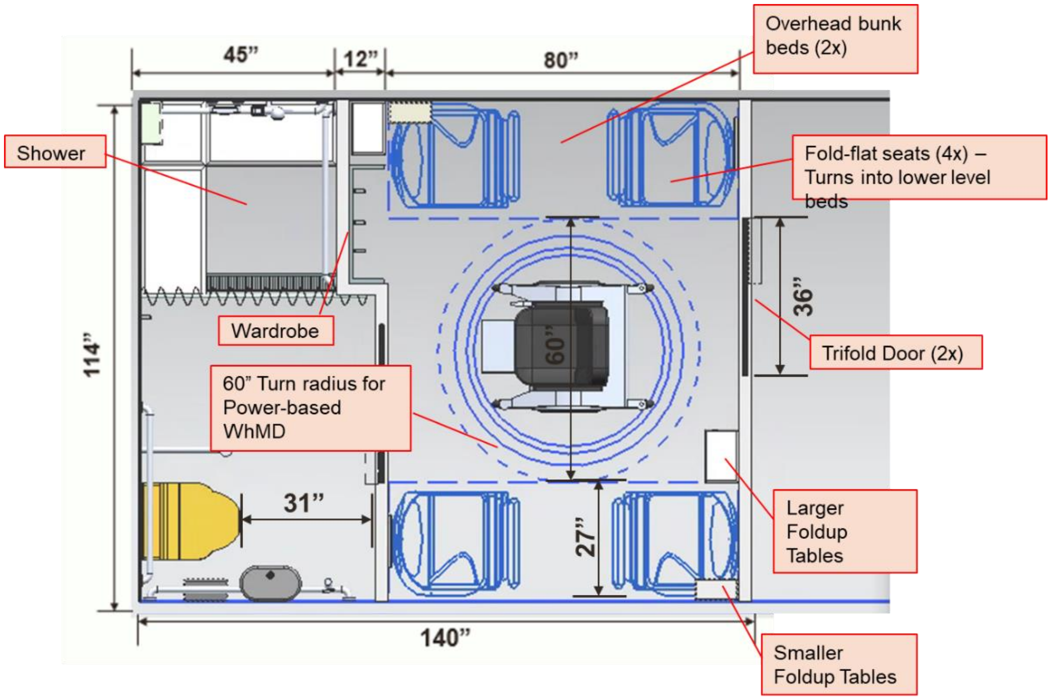

Figure 2: An overhead view of the 2-D model of the bi-level car design with notes and limited dimensions

Concept and Innovation:

The accessible sleeping compartment has two areas; the sitting room that converts into a four berth sleeping area at night, and the restroom that consists of both a toilet area and shower area in the bi-level car. The key feature of the accessible sleeping compartment designs, that are currently not available, include two lower sleeping berths to accommodate two people with limited mobility and/or older travelers and a separate shower area. The two lower sleeping berths are 17-18 inches high from the floor to facilitate access and transfers to and from wheeled mobility devices. The seating configuration allows two or more passengers to see out of the window. On the bi-level car, all the passengers will be able to see out of the windows, potentially when the berths are lowered. The designs also include upper berths accessed by a ladder. The designs recommend multiple power outlets throughout the sitting area as well as space for CPAP machines and power outlets adjacent to the lower berths. A number of amenities such as power outlets and call for assistance are included in the detailed design. Following the current trend in air travel, it is anticipated that passengers will use their own devices for on board entertainment, so no specific screens are provided.

It is recommended that the accessible sleeping compartment be located adjacent to the entry vestibule that includes an on board train lift or ramp to access the platform in stations and also an elevator for access to the upper level. The user requirements include a person who uses a large wheeled mobility device that can fit on a platform lift or ramps and access the train. There is wheeled mobility device access into the restroom, however full 360° rotation of a wheeled mobility device within the seating/sleeping area is only possible in the bi–level design where the full width of the car is available. Both the bi-level and single level designs accommodate assisted transfers to and from large powerbase wheeled mobility devices and the toilet, as well as the seats/berths. The spatial design analysis includes the range between a 95th percentile Caucasian male and a 5th percentile Asian female.

For both the bi-level and single-level designs, the overall length of the accessible sleeping compartment is optimized to minimize the impact on revenue seating and other sleeping accommodation. The constraining dimension are the sleeping berth lengths, based on anthropometric height of 95th percentile males, and transfer space requirement in the restroom. Stowage of wheeled mobility device is proposed to be available within the dry area of the restroom. It is not possible to have a private accessible shower area in the accessible sleeping compartment on the single level car, however it is possible to have an accessible communal shower on the single level car.

Spatial Requirements

Recommendations for minimum spatial requirements were investigated in order to consider the value of passenger rail vehicle real estate. A power-based wheelchair was used as a representative wheeled mobility device in accessible areas [14]. A turn radius of 60 inches is recommended to be available for complete mobility of wheeled mobility devices, and this is feasible within the bi-level design where the full width of the car is available. In the single-level car design, a 360^{o} turn radius is not possible as the room is narrower due to the need for a train passage way outside of the sleeping compartment. In the single level design, a 32-inch aisle within the sleeping compartment will allow for one-directional movement of the wheeled mobility device through the compartment. The current design includes a 25-inch wide passage way outside the sleeping compartment which is not accessible and may not meet all the passenger rail operational criteria. The imposed requirement for two lower berths provides significant design compromises for the single level design.

Clearance provided in the seating/sleeping area and restroom are based on recommendations that were previously published and were updated, in particular for the single-level design, which is spatially compromised [11], [15]. Minimum spatial requirement of at least 26 inches at the front of the toilet is recommended, but 31 inches improves overall accessibility to accommodate assisted transfers to the toilet with the presence of a sink that is accessible from a seated position on the toilet [15]. Model posture was determined from ergonomic transfer posture and angles [15]. Grab bars and their respective positions are in accordance with current regulations.

Figure 3 shows a rendering of an assisted transfer by at 95th percentile male of a 95th percentile male from a large wheeled mobility device.

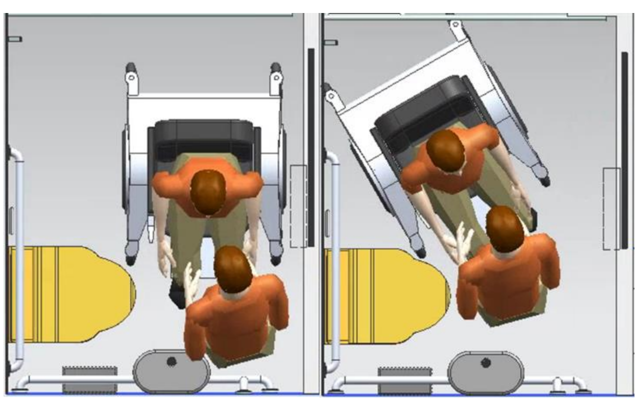

Figure 3 Assisted transfer study with 95th percentile manikins. 31 inches is shown in front of the toilet here.

Transfer space in the seating/sleeping area is constrained by the width of the in-compartment aisle available. In the bi-level car, more than required space is available, however only a parallel transfer is possible in the single-level car. A spatial study was also performed for the shower area in the bi-level design, and the full width of the car provided more than required space for transfers.

Minimum reach requirements from the toilet determined the locations of the sink and amenities from a seated position on the toilet. Figure 4 shows a reach study with a 5th percentile female. The heights of these amenities are in accordance with current accessible building regulations and no recommendations for changes are made based on digital results. Results from the soft mock-up suggest that the height of the upper berth is not able to accommodate an individual with reduced mobility, therefore two berths at the lower level need to be provided in all the accessible sleeping compartment. In addition, results and comments received suggest that the upper limit of allowable heights for grab bars and controls in the ADA regulations may be inaccessible to some individuals and a range of heights or a lower height are needed; additional investigation is needed to determine if a lower height for amenities would compromise accessibility. Digital results were able to estimate the soft mock-up results. Spatial requirements for future design of accessible spaces may be expedited to include less extensive physical testing.

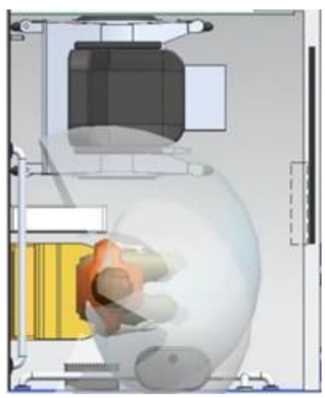

Figure 4 Reach study with 5th percentile manikin

The toilet area in both the single-level and bi-level cars includes the design elements for an accessible restroom. Specifically, the toilet is oriented parallel to the line of travel of the car and includes an elongated bowl, a split toilet seat, toilet seat at a height of 17-18 inches above the floor. Around the toilet the clear space of at least 32 inches available adjacent to the toilet for lateral transfers, and at least 31 inches available in front of toilet to accommodate assisted transfers. The toilet area includes pivoting assist support arms adjacent to toilet to assist getting on and off toilet. The restroom will permit assisted transfers to and from the toilet and wheeled mobility device[14].

Bi-Level Design

The bi-level design is intended for long distance passenger cars with two levels and spans the full width of the car. The accessible sleeping compartment would be located on the lower level adjacent to vestibule where the elevator to the upper level is located.

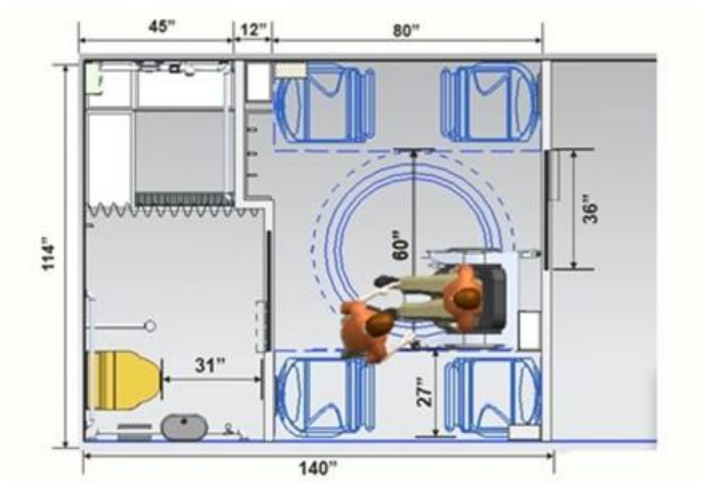

Figure 5 shows a schematic of the accessible sleeping compartment for the bi-level car. It is recommended that the accessible sleeping compartment be located in the sightseer- lounge and that this car be adjacent to the dining car to enhance the travel experience of people with disabilities and minimize the impact of the elevator on revenue seating.

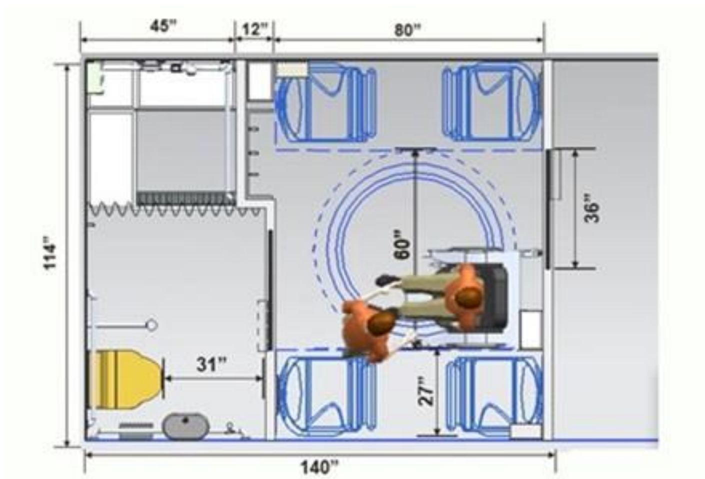

Figure 5 Schematic accessible sleeper design for Bi-level Car with 95th percentile male human models positioned representative of a transfer from a large power-base wheelchair.

For the bi-level car, the restroom area includes a dry toilet area that is apart from the wet shower area. A “cattle guard” type drain is proposed to keep the wet and dry areas separate in order to eliminate the ledge that is common on accessible showers and potentially can create a tripping hazard.

The shower for the bi-level design includes a portable shower chair and a hand held and extendable showerhead. This is based on current online survey results and also will allow for a smaller shower module, especially in the single-level scenario. There are mixed results on the use of a portable shower chair or a fold down seats between the survey and visits to the soft mockup. Figure 6 shows the reach range of a 5th percentile female in the shower area.

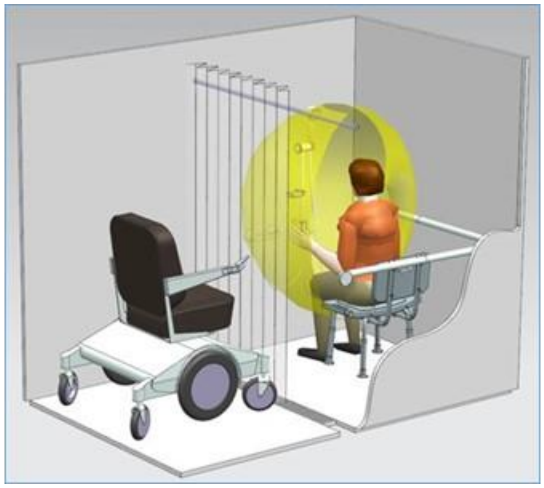

Figure 6 Reach study with 5th percentile female manikin using a shower chair in bi-level shower.

The length dimension of the shower may be lower than the generalized one shown, however the length of the dimension is constrained by the transfer space required in front of the toilet area. The toilet must be oriented in line of travel of the car. Feedback from members of the PRIIA accessible working group do not recommend corner toilets even though these are installed on some commuter trains.

Single Level Design

In addition to the bi-level design, the team is developing a version for the single-level cars that are used in the Northeast area of the United States. The available real estate for the single-level car is narrower than for the bi-level car since there is a need for a passageway through the full length of the single-level car. The discussion will focus on the difference in elements from the bi-level designs.

The single-level design is much more constrained than the bi-level design while still accommodating four passengers. The need for a passage way extending the full length of the car constrains the space available in the single-level design. In the single-level car, it is not possible to have a clear 60 inch turning circle, however it is possible with multiple turning maneuvers for a larger mobility device to turn. This configration design only contains one window directly to the outside, although a second window onto the aisle could be considered and modeled in 3-D. In the single-level design, it is difficult to include a shower that includes separated wet and dry areas without a large impact on space. The narrow design limits the transfer space available within the seating/sleeping area of the compartment and also restricts the movement of a wheeled mobility device to one-directional travel. The wheeled mobility device clearance and turn radius in the seating/sleeping area was compromised to fit the compartment in a single-level car [11]. Some space may be available underneath the seats/berths, however 3-D manikin studies performed showed that a taller individual with limited mobility of their legs may be unable to perform any degree of turn in this space. The 32-inch dimension shown would not allow for a larger wheeled mobility device to be used in the space. Storage area may be provided in the restroom, and two upper berths are still available. Figure 7 shows a very spatially constrained 2-D diagram of the single level car design.

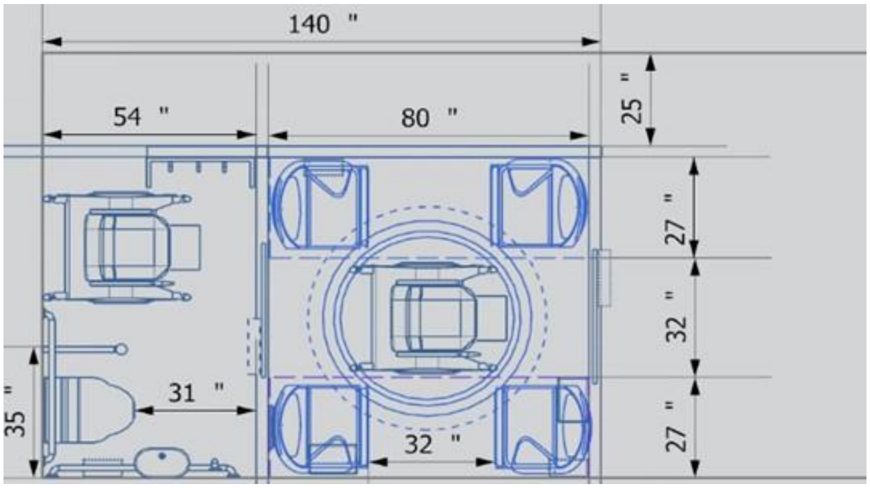

Figure 7 2-D Single-level schematic of accessible sleeping compartment with large power-base wheelchairs for visualization

The initial design for the single level car does not include a shower area, the preliminary results from the online survey whose respondents included people with reduced mobility and who also traveled by rail indicated the preference to have a shower as part of the accessible sleeping area. However, the option for a common use accessible shower was more ambiguous. The preliminary results also indicate that most people would use a shower if it was available.

Design criteria for the accessible sleeping compartment was developed in conjunction with the Project Advisory Committee consisting of members from the passenger rail industry and members of the population of individuals with disabilities and was also based upon customer feedback as provided by passenger rail industry representatives. The design criteria recommend that the design must accommodate two passengers with reduced mobility as well as a representative wheeled mobility device within the sleeping area; these requirements are based on passenger feedback to the passenger rail industry and reflect a need to improve accessible accommodations. A key design criterion is that two of the berths must be at a lower level. In the current accessible sleeping compartments in AMTRAK service there is only one lower berth, and this is a problem when two people who both have reduced mobility are travelling together. The accessible restroom design must accommodate a larger and more representative type wheeled mobility device and allow for assisted transfers to and from both the toilet area and shower if the shower is co-located in restroom. Accommodations such as grab bars, other amenities, and operational constraints onboard cars are also considered. Both single- and bi-level cars are considered.

In the design process, 2-D models consisting of floor plans with placeholders for expected and required spatial consumption of furnishings and amenities were constructed. Dimensions used were in accordance to the Rail Vehicle Access Advisory Committee (RVAAC) recommendations, and the Americans with Disabilities Act (ADA), Canadian Code of Practice, and the final summary report to the Federal Railroad Administration on the Accessible Design of the next generation of passenger cars[1], [10], [12], [13].

The vehicle's real estate and overall economic impact for rail service providers are reflected in the proposed minimum dimensions. A number of designs were provided to the Project Advisory Committee for discussion in the project's interim report. Computer-generated design concept images facilitated the discussion among subject matter experts from different backgrounds and areas of expertise. The most preferred configurations were selected for further development and study in 3-D.

Design Validation

In the 3-D design phase, spatial requirements were explored in greater detail with the additional of 3-D anthropometric human models. The 95th percentile Caucasian male models were used to explore minimum spatial requirements in static situations and minimum assisted transfer spatial requirements were assumed based on previous work [14], [15]. The anthropometric models were also used to model transfers in static postures. The 5th percentile Asian female models were used to explore minimum reach requirements of amenities and furnishings. Caucasian anthropometric parameters are obtained through ANSUR, anthropometric survey of U.S. Personnel, and the Asian anthropometric parameters are obtained through Japanese_2006 as specified by International Standard. The range used allow the design to account for the diverse population seen within the U.S. Computer-generated images were again used to demonstrate the determined requirements visually to the Committee for a number of iterations. During the digital design phases, no physical prototyping was performed.

There is a gap in research for population-specific digital human models that represent people with disabilities that can be used for accessible design. Existing digital human models are used for digital verification of accessible design considerations. The soft mock up provides the opportunity at a relatively low cost, to increase the degree of fidelity for accessible spaces. Similar to the selection of the 2-D models, 3-D models were selected for the next phase in consultation with the Project Advisory Committee and based on compromises between economic impact and accessibility.

A full-scale soft mock-up based on an "adjustable" design for the bi-level designs was built and used for the human subject evaluation phase. Renderings from the computer-generated 3-D design are used to fill the space in order to more readily manipulate the mock-up. Spatial and reach requirements, as well as availability of amenities are evaluated by participants. A survey, that is available at the soft mock-up or online, is used to determine the target population's needs, values, and opinions on passenger rail and accessibility. Responses are considered in the final design recommendations.

The protocol for human subjects was approved by the Oregon State University (OSU) Institutional Review Board, and participants provided informed consent prior to their participation. The recommended model and its variations was constructed as a full-scale soft mock-up. The mock-up represents an adjustable design for single- and bi-level designs but analysis was only conducted on the bi-level design. Renderings of the mocked-up space from the 3-D computer-aided models, as shown in 3D in Figure 8, were used to fill the space and create a more readily manipulated mock-up. The soft mock-up includes the seating and sleeping space, the toilet and sink area, and the shower area. This was intended to determine the target population's needs, values, and opinions on passenger rail and accessibility as well as to observe spatial consumption of individuals as they traversed the space within the soft mock-up. Additionally, an online survey was distributed.

Figure 8 Generated 3D renderings from the created CAD models used in communication with potential participants, stakeholders, and the Technical Advisory Committee.

(Top) Rendering of a concept for a bi-level seating/sleeping area. (Bottom) Rendering of a concept for an accessible shower module.

Participants were invited to evaluate the mock-up via flyers and community outreach to local organizations relating to accessibility. Evaluations include subjective responses and opinions to different aspects of the space. Responses were gathered with regards to spatial dimensions such as door width, turning and maneuvering space, size of berths, transfer space availability, and storage space; also, height dimensions of berths, toilet, and sink were addressed. Concerns regarding privacy and specific needs (use of continuous positive airway pressure (CPAP), specialized mattress toppers, etc.), seat and bed padding, toiletries and disposals needs, and others were addressed and transcribed from the video and audio recording.

Participants were permitted to freely explore the built space soft mock-up either completely or in part in their own wheeled mobility device, or a manual wheelchair and were under supervision of a researcher to ensure their safety and to remind them not to place weight on non-loadbearing parts. A manual wheelchair takes up a smaller spatial footprint than a representative power-based wheelchair, however for safety, the manual wheelchair was selected over a power-based wheelchair [2], [14]. Two cameras were used to capture the movement of participants as they explored the space and their ability to maneuver within. The cameras were placed at both front-end corners of the mock-up and were adjusted when participants entered the restroom area in order to capture their footprint while in that space. Audio recordings were also collected.

In addition, participants performed simple reaching tasks within the mock-up shower area to validate digital human modeling outcomes. Visual recording was used to gather data pertaining to (i) spatial consumption during movement, maneuvering, and use of the mock-up environment, positioning in preparation of transfers, reaching, and opening/closing doors, and (ii) communication of customer needs through gestures. Audio recording was transcribed for comments and communication of customer needs. Comments pertaining to spatial requirements and comfort were noted for evaluation of the DHM analyses. Transcribed comments will not be discussed in full detail but are included at the end of the report. It was hypothesized that design recommendations will be improved with the incorporation of DHM to depict the spatial needs of users.

Two cameras, one in the sagittal plane and one diagonally between the sagittal and transverse plane, were used to record the participant's posture. Participants were asked to sit in a shower seat or maneuver into the shower space if they require use of a wheelchair. The 15-inch shower seat is positioned 36 inches from the front wall to reflect the current minimum length of a fold-down shower seat in a maximally sized accessible shower in a grounded facility [16]. Participants were then asked to perform a two-hand reach to the mock grab bar located in front of them. Positioning of the grab bar is likewise according to current standards; the mock grab bar was 3-dimensional however it was not load bearing, and participants were informed of this. Participants were then asked to rate their comfort for the motion on a 5-point scale. Then, participants were asked to perform 1-hand reaches with their dominant hand to mock shower controls in front of them; these were positioned at 33 inches, 40 inches, and 48 inches above the floor level, reflecting the minimum, median, and maximum heights for shower control locations [17]. Participants again provided a rating on their comfort on a 5-point scale ranging from very uncomfortable/impossible to very comfortable.

Following their physical exploration of the soft mock-up, participants were asked to complete a short questionnaire rating their opinion of the space provided. In responding, participants provided a scale rating of the availability of space for movement, transfers, storage and the provision of grab bars. Ratings were based on a Likert-type scale chosen to capture subjective opinion in levels of intensity to inform design recommendations [18].

Application of DHM Analysis

Anthropometric digital human models from the ANSUR database were used to match the static posture of each set of reaches in Siemens Jack and NX [19]. Figure 9 shows a representative image of this process. Models were generated to match the sex and height of the participant; weight was regressed from the height. The physical appearance of the models' stature was altered to best match the appearance of the participant based on the recording. For each participant, one generated digital human model was used for all analyses.

The generated model was placed in a wheeled mobility device, either manual or power-based depending on the device they used during their visit to the soft mock-up. The seated model was placed into the digital space and consumption of space based on visual recordings was observed. The generated models were aligned with a circular footprint on the digital floor space based on turn radii of each participant for visualization. Scenes were captured to communicate with the Project Advisory Committee in comparison to the recordings.

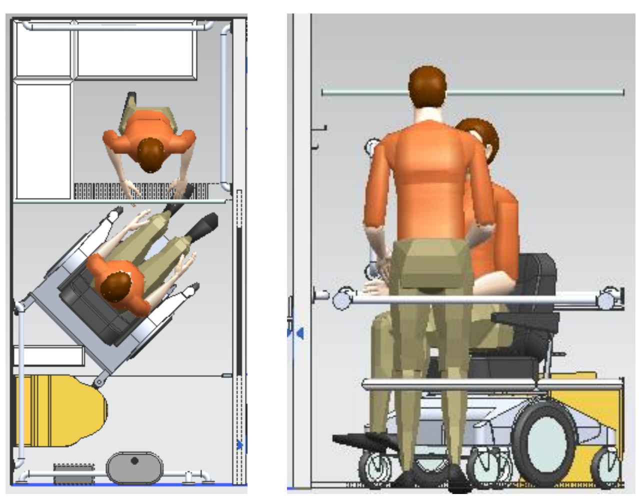

Figure 9 Images created with the CAD and DHM tools representing postures for a dependent transfer from a representative wheeled mobility device to a potential design for an accessible shower viewed from two camera perspectives.

Reaching Comfort Assessment

Static reach postures of participants as they performed the reach tasks to the grab bar and the three shower control heights within the mock-up shower were obtained from the visual recording. For these postures, participants using manual wheeled mobility devices were seated at between 17 inches - 18 inches height while participants in power-based wheeled mobility device were at a height depending on their specific device. A number of participants also expressed preferences for heights and locations of grab bars and shower amenities with physical reaches and gestures beyond what was prompted. These additional reaches were obtained from the recording as static postures to represent a potentially preferred posture.

From the static posture, a reach envelope was generated about the dominant hand the participant selected in performing their reach. A comfort assessment was performed for static reach postures with focus on shoulder and lower back. Assessment output was compared to the Likert-scale rating reported by participants. The CAD environment of the shower and controls were not required in order to perform the posture-dependent analyses however the CAD was imported into Jack to include in scene-captured images. Postures, spatial consumption, and reach were also presented and compared visually with 5th percentile Asian female manikins and 95th percentile Caucasian male manikins. Subjective rating and comfort assessment outputs are classified as "uncomfortable", "neutral", or "comfortable" and compared with the two sample Mann-Whitney U-test for unpaired, independent samples in R. This statistical test is a non-parametric test of the null hypothesis by comparing two independent samples with ordinal responses. It is hypothesized that the DHM comfort assessment output will be representative of the subjective assessment of individuals who may use accessible accommodations.

Human Validation Results

The recommendations for accessibility derived from prior studies were used for the 2D and 3D designs that were constructed in Siemens NX [2], [11], [14]. Digital renderings of the design space with computer-aided designs replaced some of the physical prototyping and digital human models used to incorporate human factors in the early phases of design, thereby saving potentially costly design iterations [3], [5], [20].

A total of 27 visits were made to the full-scale soft mock-up. Out of the 27 total, 17 explored the space in a wheeled mobility device, 14 in a manual wheelchair and 3 in a power-based wheelchair. Footage of soft mock-up exploration as well as verbal and/or written comments were obtained for all visits. Participants' stature was used to generate a digital human model. The DHM model was placed in a model of a wheeled mobility device (either manual or power-based) and moved to traverse the 3D model of the mock-up space. The model was manipulated to best match the posture of the participant via overlaying the DHM model with the video recordings. Static image frames from the recording were compared to renderings of the 3D spatial analysis in specific locations such as at the center of the seating/sleeping area, near the seat/berth in preparation for a transfer, and near the toilet in preparation for a transfer or using the mock-up sink. Images of this analysis is shown in Figure 10.

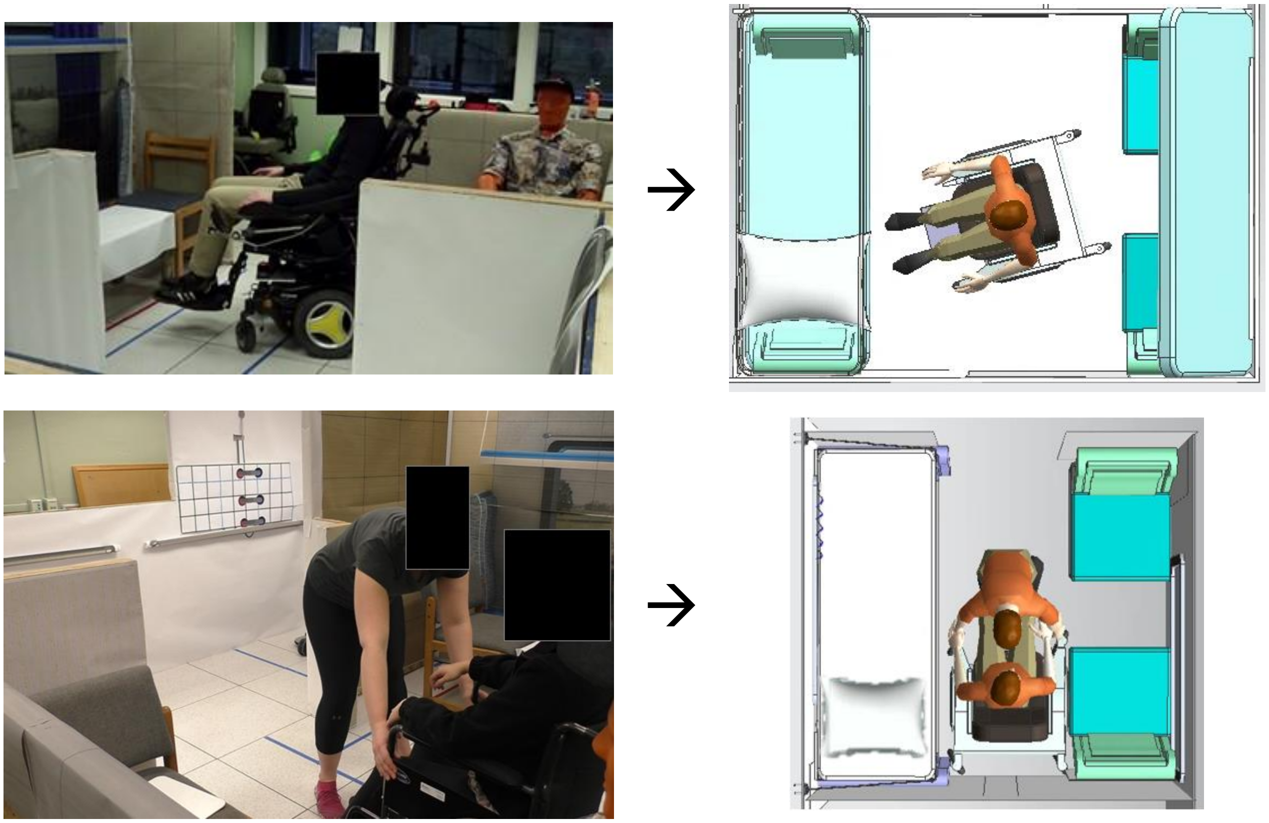

Figure 10: Comparison of static floor space consumption in the soft mock-up vs. the digital human model in the digital space.

Top image shown in the bi-level configuration; bottom image shown in the single-level configuration to represent multiple design scenarios and alternatives.

Participants' postures observed during their visits were recreated in 3D with DHM in Jack software by modeling static posture and location along their paths of motion. It was observed that depending on the experience and level of expertise of the participant, the required space for maneuvering and tasks such as turning or repositioning took a greater amount of space. These differences are highlighted in the turning radii recreated in Figure 11.

Following the exploration of the soft mock-up, participants were able to rate the availability of space within the seating/sleeping area in the space depicted in Figure 11 . From a 1-5 scale where 1 is insufficient, 3 is neutral, and 5 is too much space, the average rating was found to be 3.57.

In addition, during exploration, upper body gestures such as reaching for a "door" in the soft mock-up or gesturing towards a storage location was captured in the video recording. Other gestures acted out use of amenities such as sinks or grab bars. Footprints were generated with DHM in the digital environment similar to the turn radius footprints shown in Figure 11. Images to compare the digital recreation of the posture to the participant posture were created and shown in Figure 12. Within the generated images, camera angles may be selected by the designer.

Unlike the video recordings collected, the DHM images provide a design evaluation with a range of camera angles with no camera obscuration. (Top) The participant is gesturing a reach for a grab bar next to the sink in order to shift their body. (Middle) The participant acts out a dependent transfer for a spinal-related disability. The single-level space is shown insufficient for this posture as it obstructs the required space. (Bottom) The participant is shown tracking the space in the doorway as they move their power-based wheeled mobility device through. Camera obscuration blocks the view of their feet however this is not the case in the DHM.

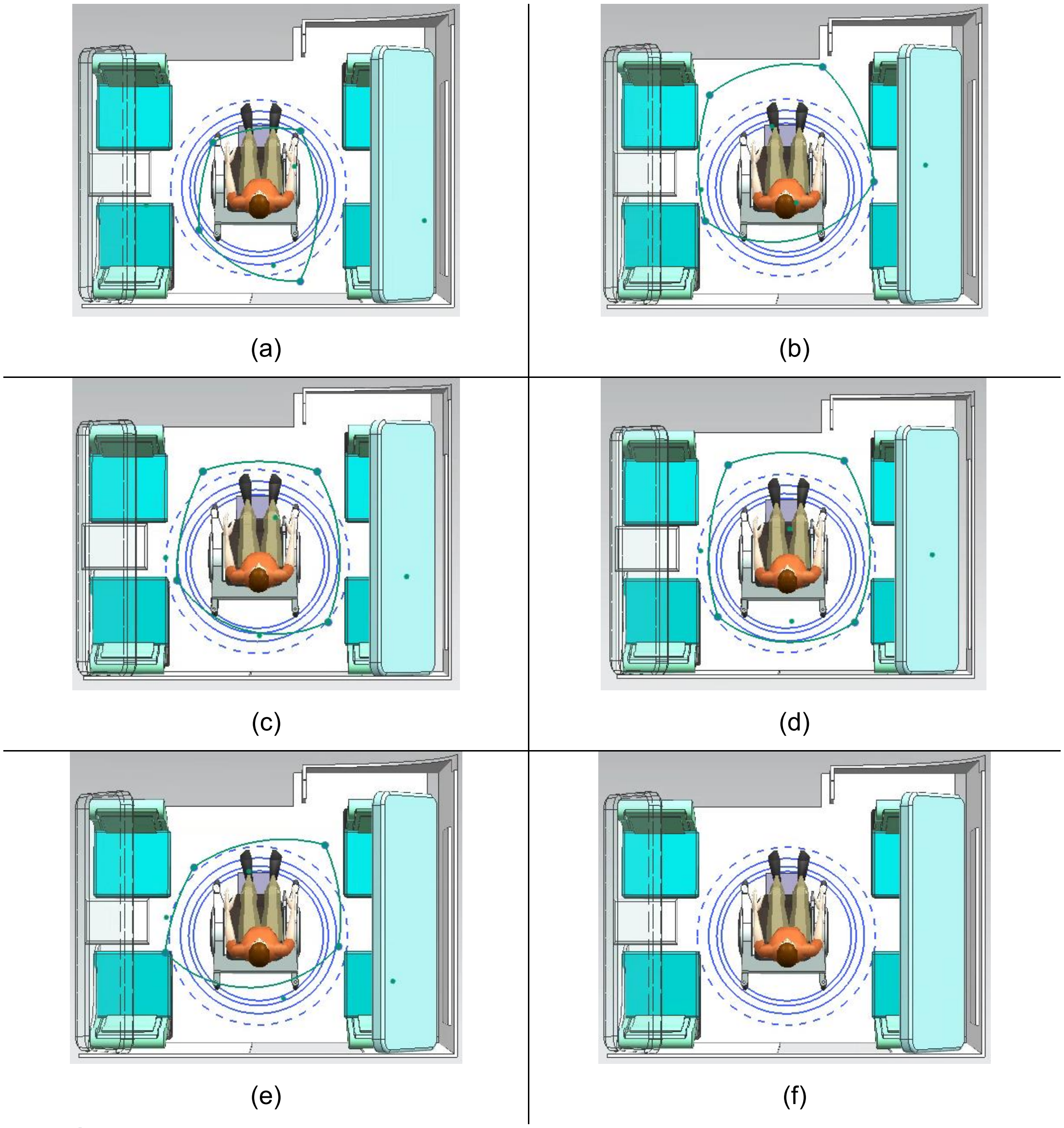

Figure 11 95th ANSUR male in a manual wheeled mobility device showing (a-e) several representative turning radius based on participants' movement vs. (f) the assumed 60" turn radius. (a) shows the smallest turn observed and (b) shows the largest. Footprints shown in the bi-level car design.

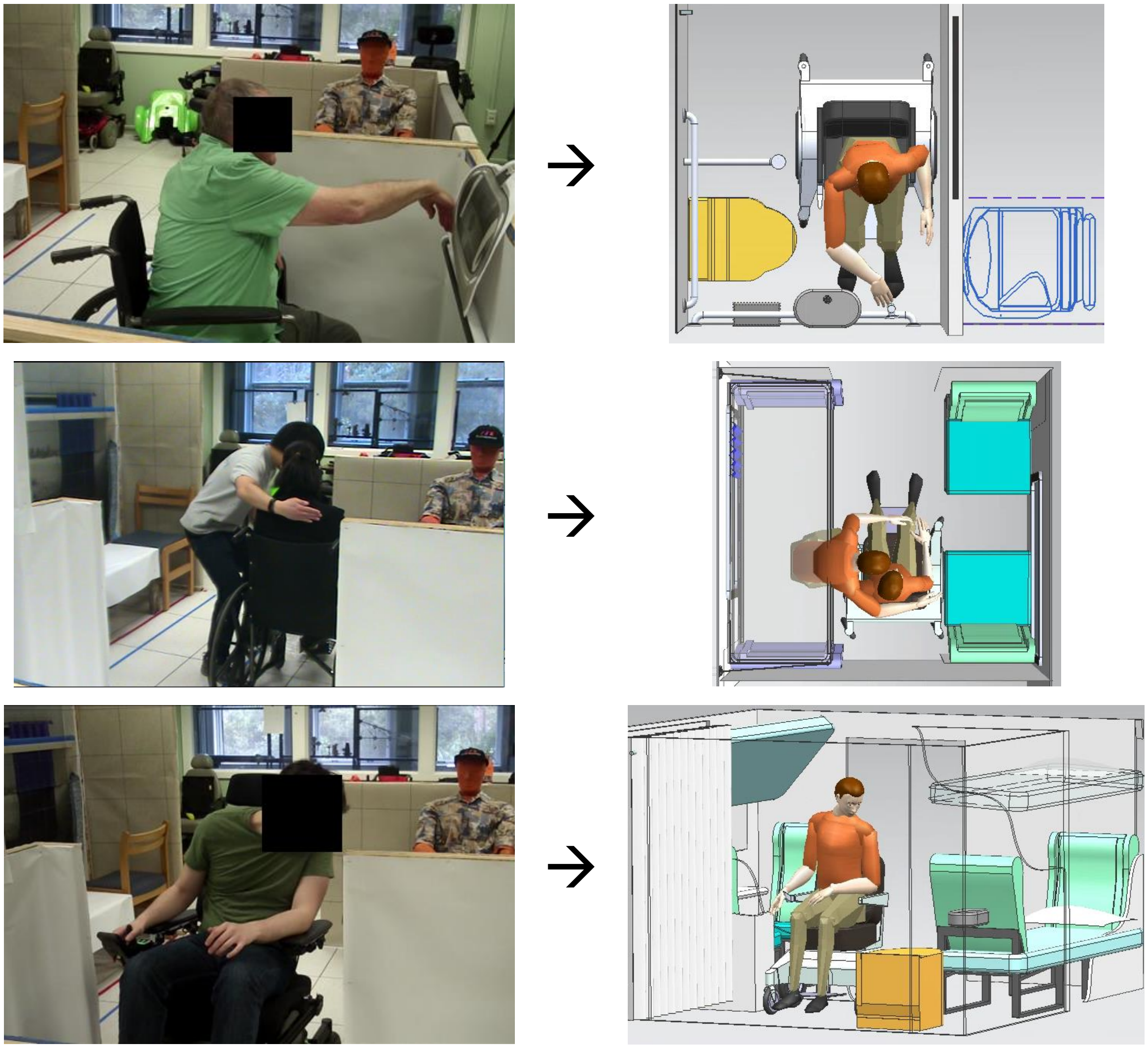

Figure 12: Comparison of participant gesturing or acting out of tasks in the soft mock-up vs. the digital human model in the digital space.

A compilation of common postures, reaches, and comments was created using the recordings from the visits. Ranges of motion and spatial consumption were drawn from these and used to inform design decisions. For example, a participant who identified as being less experienced in their wheeled mobility device made more movements in repositioning themselves to reach the "door" and therefore required more space in front of the doorway. In the early phases of design, the turn radius for the wheeled mobility device users were assumed to be the radius of the extended footrest and constant between users, and this assumption was corrected as a recommendation towards accessible design standards.

Reaching tasks were executed in the shower area of the soft mock-up. Reach tasks consisted of a two-hand reach to the grab bar at 33 inches and one-handed reaches to alternative design heights for shower controls at 33 inches, 40 inches, and 48 inches about the ground, representing the range of permissible shower controls in grounded facilities [16]. Comfort ratings were given on a 1-5 scale where 1 is "very uncomfortable or impossible", 3 is "neutral", and 5 is "very comfortable". The heights listed in Table 1 shows the height stature of the digital human model used for subsequent analyses.

A comfort assessment in Jack was performed for manikins in the static reach posture at all reach task heights [21]. Output from this assessment is defined in the Jack toolkit as "comfortable" or "uncomfortable", and the output for the dominant arm reach (flexion angle) is compared to the subjective rating where 1-2 is defined as “uncomfortable” and 4-5 is defined as “comfortable” while 3 is neutral. Neutral is defined in the assessment output as the value at the threshold between comfort and discomfort. Results for 14 participants is shown in Table 1. The group of participants included both individuals who both may or may not be confined to their wheeled mobility device. Figure 13 shows an image of the reach task and corresponding DHM.

Table 1 Height and sex of the anthropometric manikin used for each participant who performed the reach tasks. Weights were regressed from the heights.

Participant subjective ratings from the 1-5 scale shown; 1 = uncomfortable/impossible, 3 = neutral, 5 = very comfortable. The mean for all ratings is 3.7**.**

Participant	DHM Height Used (in)	DHM Sex Used	Subjective Rating Raw		
			33”	40”	48”
1	72	Male	5	5	5
2	70	Male	5	5	5
3	65	Male	5	5	4
4	69	Female	5	4	2
5	70	Male	5	5	3
6	66	Female	4.5	5	2.5
7	75	Male	3	3	3
8	75	Male	3	4	3
9	74	Male	3	3	2.5
10	66	Male	3	3	3
11	70	Male	4	4	2
12	66	Female	5	5	4.5
13	70	Male	4	4	4
14	68	Male	1	1	1
Mean	69.7 in	Mean	4.0	4.0	3.1

The comfort assessment toolkit Jack was used to provide comfort ratings for participants performing the reach task for shower controls. The comfort assessment in Jack provides a graphical representation of postures as “comfortable” or “uncomfortable” depending on the joint angles. An image of a created reach posture is shown in Figure 9. These graphical research envelopes are based on the statistical studies done by Porter (1998) and investigate the comfort of the shoulder and elbow joints individually [21], [22]. In addition, the subjective ratings based on the 1-5 scale as previously defined were used with the joint angles to provide a further understanding about the comfort level of the subjects. Thus, the 1-5 scale ratings were defined as “comfortable”, “uncomfortable”, or “neutral”. Comfort ratings from the subjective rating and the DHM assessment output are listed as “C”, uncomfortable ratings are listed as “U”, and neutral ratings are listed as “N” in TableError! No text of specified style in document.2. Neutral ratings were defined as comfort assessment outputs that were on the threshold between the comfortable and uncomfortable ratings.

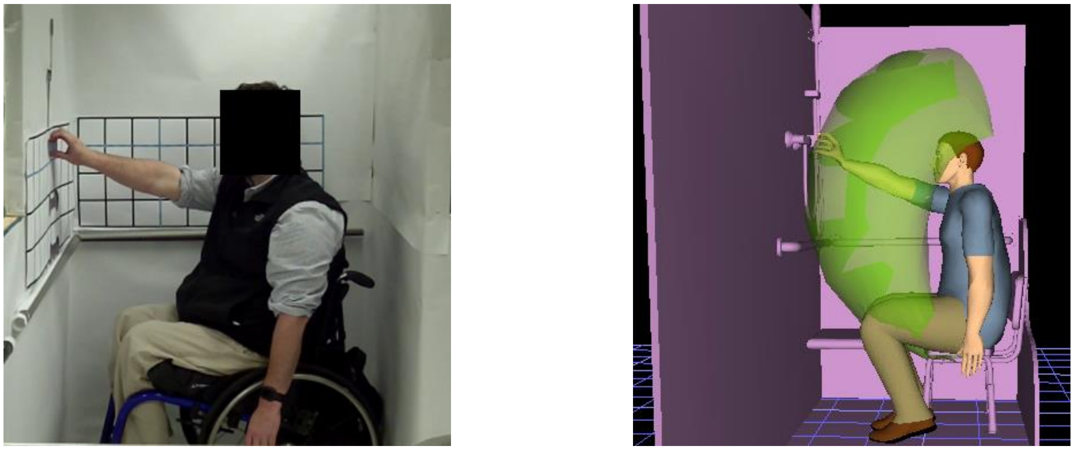

Figure 13 Image of participant performing the reach task for shower controls and the digital human model created to represent their posture.

A reach envelope was generated to illustrate the range of reach. The controls located at 48 inches from the ground represent the highest possible location for shower controls following grounded facility standards.

TableError! No text of specified style in document.**2 Subjective ratings comparted to comfort assessment outputs.**

"C" = Comfortable, "U" = Uncomfortable, and "N" = Neutral.

Participant	Subjective Rating			Comfort Assessment Output – Shoulder			Comfort Assessment Output – Elbow		
	33"	40"	48"	33"	40"	48"	33"	40"	48"
1	C	C	C	U	U	U	U	U	U
2	C	C	C	U	U	U	U	U	U
3	C	C	C	C	C	U	C	U	U
4	C	C	U	C	C	U	C	U	C
5	C	C	N	C	C	U	C	U	N
6	C	C	U	U	U	U	C	U	U
7	N	N	N	U	U	U	U	U	U
8	N	C	N	N	C	U	C	U	C
9	N	N	U	C	C	U	C	U	U
10	N	N	U	U	U	U	U	U	U
11	C	C	U	C	C	U	C	U	C
12	C	C	C	C	U	U	U	U	C
13	C	C	C	C	C	U	C	U	U
14	U	U	U	C	C	U	U	U	U

The Mann-Whitney U-test for non-parametric samples was used. Shoulder and elbow postures were investigated and compared individually. Table 3 presents the statistical summaries and note that p-values < 0.05 indicate a significant difference between subjective rating from participants without upper-body mobility limitations and the comfort assessment output for that the reach height using able-bodied digital human models. Comparisons were made at each individual reach height 33 inches, 40 inches, and 48 inches from the floor as well as all the combined heights. For all heights of reach, the comfort assessment output from the elbow joint were representative of the subjective rating given by the 14 participants.

This was the case for only the 33-inch height in the shoulder comfort assessment. The results show that 33 inches is more comfortable.

Table 3 Mean ratings and outputs are shown with statistical results.

Assessment outputs were compared for dominant arm shoulder and elbow. U-values are expected for the sample size.

Height of Reach	Mean Subjective Rating	Shoulder			Elbow		
		Mean Comfort Assessment Output	U-Value	p-Value	Mean Comfort Assessment Output	U-Value	p-Value
33”	C	C	81.5	0.3996	C	88	0.6076
40”	C	U	7	< 0.001 *	C	75	0.2226
48”	N	U	42	0.001308 *	U	80.5	0.3858
All heights	C	U	385	< 0.001 *	C	723	0.1145

* Significance p-value <0.05

Discussion of DHM

One limitation of this study was the sample size. A total of 27 visits to the full-scale soft mock-up were made, and a total of 14 participants performed the reach tasks during their visit. Video and audio recordings were collected during all visits. One direct result of the limited sample size is the range of needs and experiences captured within the set of participants. In recreating the postures of participants within DHM, the range of postures and gestures performed were also limited by the sample size.

CAD and DHM were used to recreate the recorded postures and gestures to insert in-use scenarios to the 3D CAD environment. The digital human models and scenes generated suggest that DHM may be used to show in-use scenarios for accessible spaces comparably to human subject data collections. There are aspects of DHM in need of improvement, including the range of mobility of manikins to reflect members of the accessibility needs in a specific population. While default ranges are adjustable, there is currently no preset to help designers account specifically for this target population in the available software.

It has been suggested that using human models may aid in the accessible design process, however it is unclear whether the nature of being an onboard space with elements such as vibration is affected by the context presented in the digital environment [4]. Feedback was received from members of the Project Advisory Committee regarding the computer-generated images and renderings; the effectiveness of the images as a means of communication was reflected in the expedited early design phase. Comments were also received from visitors of the soft mock-up indicating that the use of renderings in place of physical mock-up amenities was helpful for visualization of the space.

Figure 10 shows the digital human models in two alternative designs, one with more clear space provided than the other. Participants acted out postures, gestures, and tasks in the soft mock-up that had a larger amount of clear space, however the digital human postures could be applied to different alternative designs. Incorporating 3D models of design alternatives could potentially decrease the need for numerous physical prototype iterations since designs that do not safely accommodate the digital humans could be eliminated from the design space. For example, in Figure 12, the middle pair of images depicts the posture at the beginning of one type of dependent transfer. The CAD/DHM model generated shows that the more constrained design alternative would not provide enough room for this action. Applying the transfer posture to a 3D model of the space during the early design phase would reveal to the designer that this space would not meet user requirements. However, in this case, during the initial design iterations with the Project Advisory Committee, only assisted 0 degree, 45 degree, and 90 degree transfers were considered in recommending minimum spatial requirements. The inclusion of space for more types of transfers would increase the inclusive accessibility in the sleeping compartment.

Economic impact of design assumptions

In the ADA requirements for buildings, a 60-inch turn radius is recommended as a minimum representative footprint for maneuvering a wheeled mobility device [11]. Rating results regarding the space available in the seating/sleeping area suggest that the 60-inch turn radius was able to represent the space needed, however how the space was used by each participant in maneuvering the mock-up varied. Results of the DHM seem to reflect this. Figure 11 shows the range of the estimated movement of participants when asked to "turn in a circle" within the soft mock-up. Power-based wheelchairs were able to turn in relatively tight circles compared to manual wheelchairs. A number of participants took up more floor space on one "half-circle" of the turn and less on the other; this was because in their physical motion, some tended to stop their turn upon reaching 180 degrees then choosing instead to back their wheeled mobility device up for the remainder of the turn. This suggests that a potential economic impact compromise that could be made would be to adjust the 60-inch turn circle to a half-circle with a slightly larger radius. However, reducing the turn circle may restrict the maneuverability for some people, and more research is needed to determine an optimal compromise. In evaluating the assumption of a 60-inch turn radius, the results suggest this is an appropriate compromise that provided sufficient space for participants. A skewed turn circle may also be proposed as a new representative turn footprint.

Another design assumption used in the early phases of design with the Project Advisory Committee was the reach and postures involved in operating doors. Following the human subject data collection, it was revealed that a redesign in the doors provided may be needed to remove a potential barrier to accessibility. For design tools such as DHM, initial human subject data collection in built environments is needed to inform design decisions, however the postures recreated in DHM within this work may be compiled as a database that may aid in providing inclusivity into accessible design assumptions. The sample size of this study limited the postures available, however a continuation of this research may better populate this proposed database.

Reach tasks consisting of three heights within the allowable range for shower controls was used with a subjective rating system to evaluate the DHM comfort assessment toolkit. For two of the three reach task heights, the comfort assessment toolkit output for the shoulder joint were significantly different from the subjective responses of participants. No significant difference was found in the elbow joint comfort assessment. While this suggests that there are limitations in applying the statistic-based toolkit to this application and to accessibility, the average comfort assessment output did not overestimate comfort. That is, while subjective responses indicated a comfortable posture, the assessment output indicated an uncomfortable one. This suggests that while the assessment output may be significantly different from the collected set of responses, it may result in safe designs. Further, one limitation of this study was the sample size. Future work with a greater sample size would be needed to fully assess the DHM toolkits.

In addition to the video recording, the audio recording was transcribed for key comments and insight. The comments and feedback received from members of the target population at visits of the soft mock-up were important in influencing the next stage of the design process in completion of TRB IDEA Project-31. Comments included insight that elaborated on subjective responses but also extended to other aspects of design. A non-comprehensive list of topics is as follows:

- The availability of railings or securement provided on the berths.
- The widths of the berths.
- The clear space to accommodate assisted transfers in front of the toilet and sink.
- The doors and door types that best accommodate accessibility needs.
- The availability of grab bars, non-slip surfaces, and cushioning.

Survey Results

Survey comments received, highlight and reveal that there are barriers in accessible accommodations that are currently available. Within responses, it was stated that accessible seating, sleeping, and restroom accommodations were not fully accessible, and there was difficulty associated with boarding and disembarking the train car. Respondents identified the gaps between the platform and the car as well as the steep ramp located on some cares make it difficult or impossible to board independently. In addition, comments regarding the availability of accessible storage reveal that space should be provided at lower heights or at heights reachable from a seated position. Accessible surfaces for placing items such as medication or assistive devices may also be accessible from both the seat in the day and the folded-down berth at night. A large range of limitations and accessibility needs is reflected within the results, and further investigation is needed in order to define an optimal to direct account for in the design.

PLANS FOR IMPLEMENTATION

The Safety IDEA project-31 addressed the design for an accessible sleeping compartment. In addition, the project studied the use of DHM and soft mock ups as a cost-effective tool to enable design visualization. One limitation of the soft mock-up visits in this study was the sample size, especially those who regularly used larger wheeled mobility devices (power-based or scooters). It is suggested that soft mock ups of the sleeping compartments be installed on bi-level and single trains and evaluated in different parts of the US. In evaluating spatial consumption. The online survey provided an additional source of input from the general public including people with reduced mobility. Additional research is also needed to evaluate if DHM can accurately represent the motions and postures of persons with accessibility needs pertaining to sensory disorders, obesity, or older age in the context of accessible spaces. Following the findings of this project, additional research is also needed on how the perception of participants in accessible spaces may be affected by the fidelity of the mock-up or prototype used. The potential of incorporating augmented or virtual reality may also be explored.

Results also indicate that accessibility of entry and exit of the train car, accessibility of the aisles/vestibule, and accessibility of bi-level upper decks are current gaps in accessibility and may be addressed in the future.

Although costs may be mitigated by using digital methods such as those presented in this Safety IDEA project, further research is needed in order to optimize the means of capturing user requirements from a representative target population. The inclusion of images or a digital means to explore potential designs and their respective effectiveness may also be explored.

The next phase of the project includes; the design of an accessible shower compartment for the single level car, and the construction of a full-scale mock ups on bi-level and single level trains that can be moved to different locations and evaluated by rail crew and people with disabilities in different parts of the country.

CONCLUSIONS

This project confirmed the need to develop accessible sleeping compartments with two lower level berths, and an accessible restroom. The analysis showed that an accessible restroom that includes a shower is only possible on the Bi-level train. Additional evaluation of the space constrained design for the single level train is required. This design includes the sleeping/seating area, and a new accessible restroom/shower compartment.

This project used CAD and DHM in the early design process of an accessible sleeping compartment within a next generation passenger car. The inclusion of DHM allows designer to consider a range of human users and their human factors and comfort even prior to collecting human subject data. The soft mock-up and online survey are in expensive validation tools that provided important feedback from stakeholders. The project results show that there is a need to study the applicability of using building code standards in the design of passenger rail vehicles, where vehicle real estate is very valuable. The use of new design and analysis tools assist in the design of accessible space, but these tools need to be calibrated to reflect the needs of people with reduced mobility and other physical challenges.

Results from the on line survey suggest that in designing for accessibility, obtaining user requirements from a general representation of the population with accessibility needs may not fully reflect the needs or magnitude of the needs of all members. There is a need to develop design tools that inclusively and effectively represent the population of those with accessibility needs is needed within the accessible design process. From the online survey, it is shown that even within the target population, individuals who identified as having reduced mobility have different preferences to accessibility than those who did not likewise identify. Design aspects related to privacy were more strongly rated as important within the sub-group with reduced mobility. Other design aspects the sub-group more strongly rated as important were related to the accessibility of the sink and the height of the beds in the sleeping compartment. Having the beds at the same height off the floor at 17 inches would eliminate the need to be limited to one bottom berth and one upper berths in accessible compartments. On the other hand, both sub-groups were in agreement on design aspects pertaining to mobility on-board the train and increasing the general accessibility, suggesting that user needs relating to general accessibility of passenger rail may be addressed using a general sample of the target population.

Continued research is needed in order to improve accessible design and accessible design methodology. A streamlined methodology with the inclusion of effective tools for communication and evaluation of design is expected to encourage more inclusively accessible designs.

GLOSSARY AND REFERENCES

Single-level car: A car of a trainset that has only one level where passengers are accommodated for travel.

Bi-level car: A car of a trainset that has two levels where passengers are accommodated for travel.

Wheeled Mobility Device: Wheeled mobility devices (wheeled mobility device), include manual wheelchairs, three and four wheeled scooters, power wheeled mobility devices, wheeled walkers, and other wheeled devices. Of primary concern herein is the power-based wheelchair.

Footprint: The static two-dimensional floor area occupied by a wheeled mobility device.

Accessible Restroom: The enclosed space where a person, with a wheeled mobility device can use the toilet, vanity and hygiene facilities. This also includes sufficient space for an attendant to perform an assisted transfer from the mobility device to the toilet.

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APPENDIX A: COMMENTS RECEIVED FROM PARTICIPANTS OF THE SOFT MOCK-UP AND ONLINE SURVEY

Key comments and feedback were transcribed from the human data subject collection and during conversation with subject matter experts and members of the target population during recruitment for visits. Some commenters identified as customers of passenger and some identified as not current customers due to the existence of barriers to accessibility. Comments and customer experience are important to industry service providers. Comments in Table A.1 are categorized based on aspects of the train; repeated comments are comments that apply to multiple aspects with the relevant information underlined. Phrasing and sentence structure of comments are exactly as they were provided with some corrections to spellings. This is intended to avoid including any designer bias or misinterpretation of data.

Table A 1 Comments from participants in soft mock up and on line survey

Seating

Power plug ins while in a seat

I wish the sleeper cars were more cost effective instead of sitting in a recliner chair for an overnight trip.

Making sure there is space nearby if traveling with a family member in a wheelchair.

Sit during the day; sleep at night. Would appreciate rooms large enough for families 4-6.

It needs to be affordable. People should have the capability to use oxygen for COPD if needed.

I may want to stay in my wheelchair. I would like a way to park my wheelchair in the space the seat would be.

If I transfer from the wheelchair, I prefer it closer to me so I can move to it when I need if I am by myself.

Sleeping Area

- Wide beds are needed.
- Providing a rail or means to attach a personal rail or grab bar to the bed would be helpful.
- Railing on the bed should be provided on both upper and lower beds.
- Currently, it's very difficult to get into the upper bunk, but still possible. I have two artificial hips and a spinal fusion so I'm less flexible than I used to be. Two beds on the same level would be great!
- Some means of 'securing' the side of the bed to minimize the risk of falls. Not bedrails, necessarily, but something that could be available as needed.
- My experience is mostly European. Very tight sleeping quarters make it difficult even for able- bodied. I would pay more for better designed space.

Storage

- Room to store electric GoGo
- Like to have space for a small piece of luggage by my seat
- As a small, short older woman, I don't want to store my luggage overhead in a compartment. I would like to have storage for a suitcase available under the bed or under a table, for example. I would also want grab bars in any restroom or shower as a safety feature if I'm in there while the train is moving. Moving between train cars can also be tricky for balance issues. Ease of opening the doors at the end of the train cars would be important to me. A number of years ago we took the train between Albany, OR and Seattle several times and found we really appreciated the "quiet" car - so we could hold a quiet, personal conversation (hear ourselves over the noise of the train) and not have to endure people talking loudly on their cell phones.
- Storage under the seat is preferred. I want my items close to me.
- What if I need my luggage at night and I cannot move to get it because I do not have my chair? I want to be able to reach it.

Aisles

- Being able to turn in the seating area increases safety for both myself and others.
- Wider aisles, aisle next to row of windows so no compartment is across from another, a window that opens part way
- Adequate room to move around with the use of two canes. Also, minimal tripping hazards such as steps. raised thresholds, etc. Those of us with radiculopathy have little to no feeling in our feet and consequently trip

- I am a light sleeper, so any sleeping compartment has to be as quiet as possible
- Sit during the day; sleep at night. Would appreciate rooms large enough for families 4-6.
- Climbing to an upper bunk is difficult and would not be an option...
- Width of the berth would also be important. I can't sleep on super skinny beds. Slightly smaller than the width of a twin would be okay but significantly smaller would be difficult to sleep
- In 2014 I took my mother from Portland to Hudson, NY via train. She was 89 at the time & used a walker or cane. We had a compartment which was OK, however the shower was too tight & we only used it one time. She had a lot of problems going from car to car to reach the cafe car, especially between cars. I think the rocking from side to side made it hard to keep her balance. I had the top bunk & it was extremely difficult to climb in/out of & while you are there it's hard to turn over. Because oil trains have preference over other trains we were 6 hrs. late getting to our final destination & had to take a taxi to get our rental car. Being late made us anxious, but, the train staff did a fairly good job of making sure we made connections.
- Good mattress for sleep so you feel refreshed at journey's end
- The biggest barrier for sleeping accommodations you have apparently already identified which is accessing a top bunk. And not an accessibility problem but a problem that makes sleep very difficult is the condition of the tracks. I was traveling in a sleeper from Denver to Chicago and was unable to sleep as the train was shaking and bouncing around due to the poor condition of the tracks.
- Bunk beds are not a problem for me now, but I can see that they might be in the future. Maneuvering about the train could be difficult for handicapped travelers.
- If it is necessary for someone with accessible needs to use the top bed, provide plenty of space to maneuver and rails on the bed.
- Have a storage place for mattress toppers.

Restroom/Shower

- As a small, short older woman, I don't want to store my luggage overhead in a compartment. I would like to have storage for a suitcase available under the bed or under a table, for example. I would also want grab bars in any restroom or shower as a safety feature if I'm in there while the train is moving. Moving between train cars can also be tricky for balance issues. Ease of opening the doors at the end of the train cars would be important to me. A number of years ago we took the train between Albany, OR and Seattle several times and found we really appreciated the "quiet" car - so we could hold a quiet, personal conversation (hear ourselves easily and have little to no balance because of loss of feeling in lower legs and toes.
- I don't know this but am wondering if aisles are wide enough for wheelchairs/walkers? And some way for a disabled person to get to the upper decks is important
- aisle needs to be wide enough so that one can get past a wheelchair
- Wider walking spaces (aisles, etc.) are necessary. I have neuropathy in my feet, so my gait is sometimes labored in that I move from side to side. Even shopping in stores with narrow aisles is challenging.
- As a small, short older woman, I don't want to store my luggage overhead in a compartment. I would like to have storage for a suitcase available under the bed or under a table, for example. I would also want grab bars in any restroom or shower as a safety feature if I'm in there while the train is moving. Moving between train cars can also be tricky for balance issues. Ease of opening the doors at the end of the train cars would be important to me. A number of years ago we took the train between Albany, OR and Seattle several times and found we really appreciated the "quiet" car - so we could hold a quiet, personal conversation (hear ourselves over the noise of the train) and not have to endure people talking loudly on their cell phones.

Elevator

- I like elevator idea. I find it difficult to get up and down stairs, especially with carry-on items. The sleeper chair would be a good option in a section like airlines have for long trips. This would be good for poor circulation and issues to keep legs up.
- Some stairs to get onto train cars are very steep and not very deep making footing precarious
- I like the lifts on the Alaska Rail Road. This made my trip truly accessible because I could join my friends on the upper and lower levels.

General

- The train has to be wheelchair accessible
- Fall risk; legally blind; use C-pap machine; walk w/cane; may need assistance to dining car, etc.
- I'm fully mobile at the moment but bought a single level home 10 yrs. ago to plan for possible mobility issues as I age. Thus, I would like accommodations to be available both for these in need now and in the future.
- What about access to food vendors? Help getting self and luggage on and off a train?
- A public assistant in getting from car to car if not traveling with a companion

over the noise of the train) and not have to endure people talking loudly on their cell phones.

- I have not had opportunity to travel long-distance by train. Don't have disability except like need to use bathroom often.
- I was in trains abroad last year, have not been on Amtrak for years - but bathrooms must be self-cleaning and have things like hand-sanitizer and room to wash without making a mess for others
- Comfort height toilets are important; grab rails in the shower and next to the toilets; ample legroom in seating areas.
- Just wanted to be clear on the last question. I would prefer a more sturdy attached shower chair rather than portable. I've found that portable chairs slip a lot during my transfers.

Entry/Exit of train

- Entering and exiting the train is a bit tricky for able-bodied people. I wonder how those in wheelchairs or using crutches get on?
- ease of entering and exiting the cars
- You didn't ask how hard it is to get ONTO the train! When you have hip or knee injuries/changes/pain, it can be darn hard.
- Entering and exiting the train can be challenging
- Ramps cannot be too steep. Lifts are needed, and they must accommodate heavy wheelchairs.
- I can foresee that one of the major problems is getting onto the train. Since I have no mobility issues, it is hard for me to determine what I would like if I did have such problems.
- Someday I may need to use extra accommodations for train travel. It's a good idea to help those who do right now.
- Would love to use more often if they would be more on time
- We use the point system for shopping; which we normally repay monthly thus we have been traveling for years in first class bedrooms and private bathroom, and free excellent meals. We have traveled all over the US that way for many years. We never use the Amtrak card for luxuries we don't need so we never pay interest on this card.
- Service animals for blind or paralyzed individuals ONLY.
- Improving accessibility for long-distance train travel is a worthy endeavor. I wish you great success!
- I love trains and I would travel by train for every trip if they were more affordable.
- I am not limited in mobility and answered accordingly, but I help others regularly and think that none of them could take a train at present.
- More accommodation will be welcome for all those who have challenges with access. Thank you for addressing these issues!
- we need many more of them in the U.S.[23]
- I currently have a mobility impairment, but it will improve. My time traveling on long-distance trains did not coincide with my impairment. However, I am familiar with accessibility features and can attest that greater accessibility is needed.

Overall, the comments reflected a need to address a number of barriers to accessibility both on-board the train and in boarding or disembarking the train. These comments will be used to influence the recommendations made at the final stage of this TRB IDEA Project-31 and also in moving forward to future projects.