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VOLUNTEER EVALUATION OF WHEELCHAIR ACCESSIBILITY IN VEHICLES

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16. Abstract

Transportation for people with mobility impairments who use wheelchairs depends on vehicle environments that accommodate their needs for safe and easy-to-use vehicle spaces. Our team created a document titled "Design Guidelines for Accessible Automated Vehicles: Mobility Focus", which provides design guidelines on how to make passenger vehicles, and particularly autonomous vehicles, accessible for people in wheelchairs. The vehicle aspects addressed include doorways, ramps, lifts, handholds, interior access routes, wheelchair spaces, wheelchair securement, occupant protection for people in wheelchairs, floor surfaces, and operable parts. For each area, we identified good, better, and best recommendations. The volunteer study described in this report was conducted to assess whether the better and best recommendations provided improved accessibility and comfort compared to the good recommendations. Testing results generally did not show significant differences between conditions, which may be due to small sample size and limitations from the combinations of factor available on the test vehicles. However, participant feedback and data on belt fit provide useful information for accessible vehicle design.

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Introduction

Background

Transportation for people with mobility impairments who use wheelchairs depends on vehicle environments that accommodate their needs for safe and easy-to-use vehicle spaces. One challenge in ensuring accessibility of autonomous vehicles (AVs) is that multiple organizations and entities have developed relevant test procedures and recommended practices, but they generally have been generated independently and without coordination. Historically, vehicle manufacturers have traditionally not designed their passenger vehicles to be accessible, although this is changing. Instead, a limited number of vehicle models can be modified (by enlarging door openings, adding ramps/lifts, dropping the floor or raising the roof, and adding hardware to secure wheelchairs) so they can be used by people seated in wheelchairs during travel.

The Americans with Disabilities Act of 1990 (ADA, Department of Justice, 1990) and the ensuing American with Disabilities Act Accessibility Guidelines (ADAAG, Architectural and Transportation Barriers Compliance Board, 2016) issued by the US Access Board are intended to ensure that vehicles used for public transportation are usable and accessible to people with disabilities. While ADA accessible transportation requirements have been implemented most commonly by placing wheelchair seating stations on large buses, an AV intended for a shared-services transportation model will also need to comply. The dimensional requirements in the current ADA guidelines are based on wheelchair dimensions from decades ago. While the scientific literature contains studies and associated recommendations for accommodating the greater range of wheelchair designs currently available, ADA regulations have not yet been updated to reflect the current fleet. However, AV manufacturers hoping to meet the transportation needs of a greater number of people using wheelchairs may be interested in designing their vehicles to include more recently proposed requirements.

To facilitate this task for AV manufacturers, researchers at the University of Michigan Transportation Research Institute (UMTRI) have developed a document entitled “Design Guidelines for Accessible Automated Vehicles: Mobility Focus”, which provides design guidelines on how to make passenger vehicles, and particularly autonomous vehicles, accessible for people in wheelchairs. The vehicle aspects addressed include doorways, ramps, lifts, handholds, interior access routes, wheelchair spaces, wheelchair securement, occupant protection for people in wheelchairs, floor surfaces, and operable parts. For each topic, the guidelines include recommendations for good, better, and best practices. The recommendations were derived from the literature and precedents set by the ADA, where applicable.

This report describes findings from a study performed to determine whether wheelchair users found vehicles set up with different levels of accessibility (as specified by the document) easier or harder to use. Results have been used to update the final version of the guidelines published in August 2022.

Objective

The purpose of this study is to evaluate whether the good, better, and best accessibility recommendations documented in our design guidelines document for automated vehicles agree with volunteer experience using wheelchairs in vehicles with different ratings. Specifically, we aimed to:

Evaluate volunteer experience and feedback when navigating

- Wheelchair ramps with different incline angles
- Wheelchair ramps with different height edge guards
- Wheelchair ramps with different apron configurations
- Vehicles with different door widths and heights
- Vehicles with different configurations of wheelchair seating stations.

Evaluate volunteer experience and feedback when using different types of wheelchair docking and restraint systems

- 4-point strap tiedown
- UDIG
- Standard and automated seatbelt systems

Evaluate volunteer comfort and feedback

- Comfort and fit of belt systems
- Control locations

Methods

All research protocols were approved by the University of Michigan Institutional Review Board. Appendix A contains copies of the flier, screening questionnaire, and consent form.

Participant Pool

The key criteria for participating: the subjects are 18 or older, are regular wheelchair users, are not pregnant, and would be able to transfer to manual and power wheelchairs with special features for use in the study. Test sessions lasted up to 2 hours and subjects were paid $40 to participate. Subjects were primarily recruited through the University of Michigan volunteer site, umhealthresearch.org. In addition, we contacted past study participants who had given us permission to contact them for future studies. Fliers were also posted at the Ann Arbor Center for Independent Living (AACIL), as well as Michigan Medicine locations, and numerous Facebook groups and websites.

After a potential participant contacted us by phone or email, we used the screening questionnaire (provided in Appendix A) to determine their eligibility by phone or email based on their preferred contact method. Upon arrival at UMTRI, the experimenter reviewed what the study involves and asked the participant to sign the form giving their consent.

Test Conditions

Overview

All testing occurred using stationary accessible vehicles/fixtures parked in an UMTRI high bay lab. Condition A was a Ford Transit equipped with a lift, plus an automated docking station and seatbelt donning system. Condition B was a Pacifica equipped with a ramp, 4-point strap tiedown securement, vehicle-mounted outboard anchor, and a floor-mounted buckle stalk. The wheelchair station for condition B was in the center of the 2nd row. Conditions C and D were a body-in-white (BIW) equipped with a ramp, an automated docking station, and floor-mounted buckle stalks. Condition C used a baseline ramp edge guard height, while condition D used a higher ramp edge guard. Conditions E and F were a Chrysler Town Country equipped with a ramp, 4-point strap tiedown securement, vehicle-mounted outboard anchor, and buckle stalk-mounted inboard anchor. The wheelchair station for conditions E and F were located behind the driver seat in the 2nd row of the vehicle. Condition E used the baseline ramp configuration, while Condition F added aprons to the end of the ramp that allowed the person to approach the ramp from an angle rather than straight on. The two setups with an automated docking system were also equipped with hardware to allow securement of volunteers' own wheelchairs with 4-point strap tiedowns.

Ingress/Egress

Table 1 summarizes the differences between the ramps and doorways across the test conditions, while photos of each setup are shown in Figure 1 through Figure 3. Recommendations for good, better, or best recommendations described in the Design Guidelines are also included in the table, and all cells are shaded to indicate which level they would meet.

Table 1. Summary of ingress/egress details across conditions

Condition	Vehicle	Ramp Angle (deg)	Ramp Width (in)	Ramp features	Door width (in)	Door height (in)
A	Transit	NA Lift		NA Lift	52	62
B	Pacifica	9.5	30	Standard	33	56.5
C	BIW	4.8	48	2 in edge	31.5	52
D	BIW	4.8	48	4 in edge	31.5	52
E	Town & Country	6	31	Standard	32	57
F	Town & Country	6	31	Apron	32	57
Good		9.5	30	2 in edge	32	56
Better		6	34	>2” edge	34	60
Best		4.8	36	Apron?	36	65

Figure 1. Lift in condition A (left and ramp in condition B (right).

Figure 2. Baseline low edge guard C (left) and high edge guard D (right) ramp conditions.

Figure 3. Baseline E (left) and F apron (right) ramp conditions.

Interior Layout

Details of interior layouts are shown in Table 2. Conditions B and EF were both set up with the minimum wheelchair station layout size of 30 inches wide by 48 inches long, but the station was centered in Condition B and shifted as far as possible to the left in Condition EF as shown in Figure 4. Both A and CD had a larger station footprint, but the station was shifted as far as possible to the left in the A and centered in the CD as shown in Figure 5. Based on the fit of the UMTRI circular accessibility template, Conditions B, C, and D had the largest amount of maneuvering space, followed by Conditions EF and then A. Conditions A and CD both have an automated wheelchair docking station that can be used by wheelchairs with compatible attachment hardware, as well as 4-point strap tiedown anchors for use with the volunteers' own wheelchairs.

Table 2. Summary of vehicle interior and seatbelt details across conditions

Condition	Vehicle	Station location	Station width (in)	Station length (in)	WC Secure type	Seatbelt
A	Transit	Left	30	60	UDIG/4-pt	Automated, optimal geometry
B	Pacifica	Center	30	48	4-pt	Vehicle geometry
CD	BIW	Center	34	60	UDIG/4-pt	Manual, optimal geometry
EF	Town & Country	Left	30	48	4-pt	Vehicle geometry
Good			30	48		
Better			32	54		
Best			34	60		

Figure 4. Comparison of station location and size in condition B (left) and EF (right)

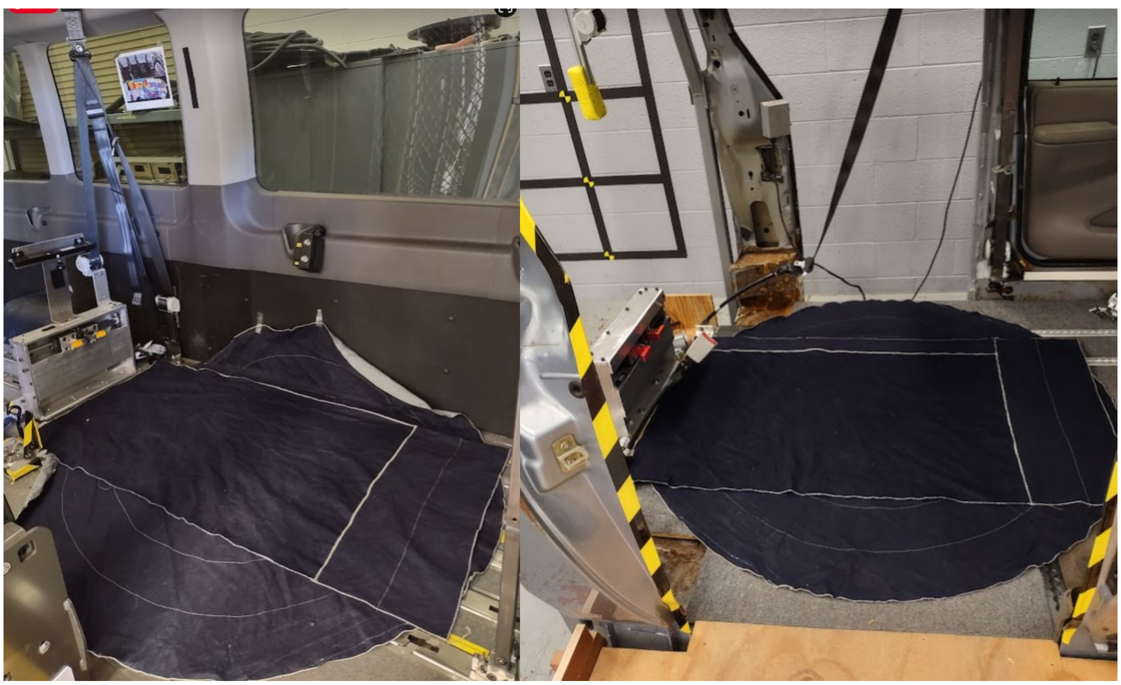


Figure 5. Comparison of station size and location in condition A (left) and CD (right).

Details of each wheelchair station, securement system, and belt anchorages are shown in Figure 6. All stations have the centerline marked with contrasting tape, and Configuration A also has the edges of the station marked. Conditions A and CD both have similar styles of UDIG-compatible vehicle anchors available for docking. For Condition A, the hardware on top of the anchors holds an overhead camera that is displayed in front of the station to assist the passenger in lining up with the anchors. Four-point strap tiedown hardware is attached to the floor on either side of the

UDIG anchors to allow installation of the volunteers' own wheelchairs. This hardware is also visible in Conditions B and EF, mounted to a rear floor track running across the width of the vehicle. Condition A has an automatic belt donning arm (Figure 7) that can deploy the seatbelt once the wheelchair is secured. The other three vehicles required the participant or experimenter to don the seatbelt. Conditions B and EF used the outboard vehicle-mounted lap belt anchor and D-ring anchor. The inboard anchors, and both lap anchors in Conditions CD, were mounted on flexible buckle stalks secured to the floor tracks. Customized adjustable hardware was used to locate the D-ring anchor for Conditions CD.

Figure 6. Wheelchair station, docking, and lap belt hardware for Configuration A (left), B, (left center), CD (right center) and EF (right.)

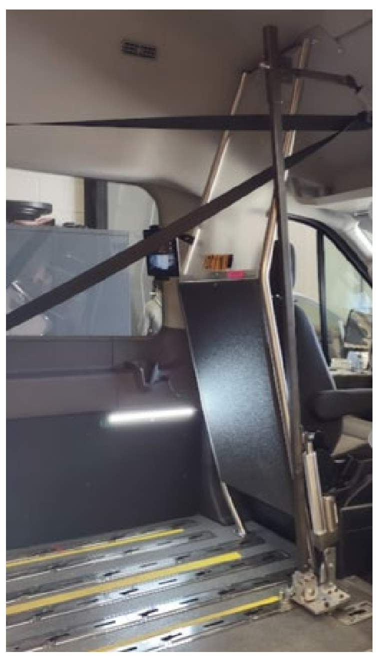


Figure 7. Automated donning arm used in Condition A.

For seatbelt geometry, both A and CD were set up to have belt geometry close to the configuration determined from a past NHTSA study (Klinich et al. 2022). However, Condition A uses an automated belt donning arm to apply the belt, while CD require the person and/or experimenter to deploy the belt. Table 4 shows examples of belt fit across each condition using the three study wheelchairs for one exemplar person, while Figure 9 through Figure 11 show plots of the seatbelt geometry in the four vehicles, with the origin at the rear center of the wheelchair station. The graphs illustrate the anchor points, and do not necessarily capture the locations of the buckle for the conditions where the lap belt hardware is mounted on flexible stalks that can rotate to align with the contact point on the passenger.

Figure 8. Example belt fit across vehicles and wheelchairs for exemplar person.

Condition	Manual WC 1	Manual WC 2	Power WC
A			
B			
CD			
EF			

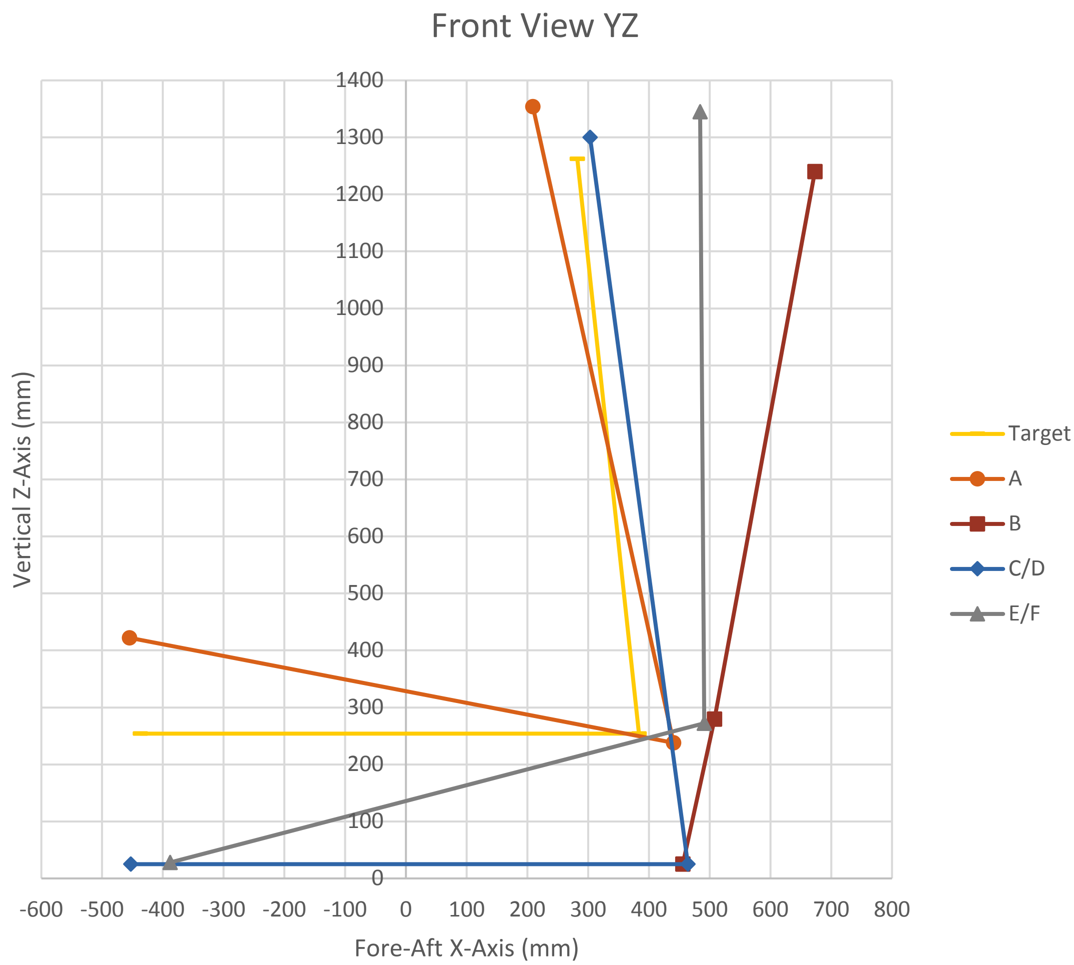


Figure 9. Front view (y-z) of belt geometry across conditions, compared to recommended.

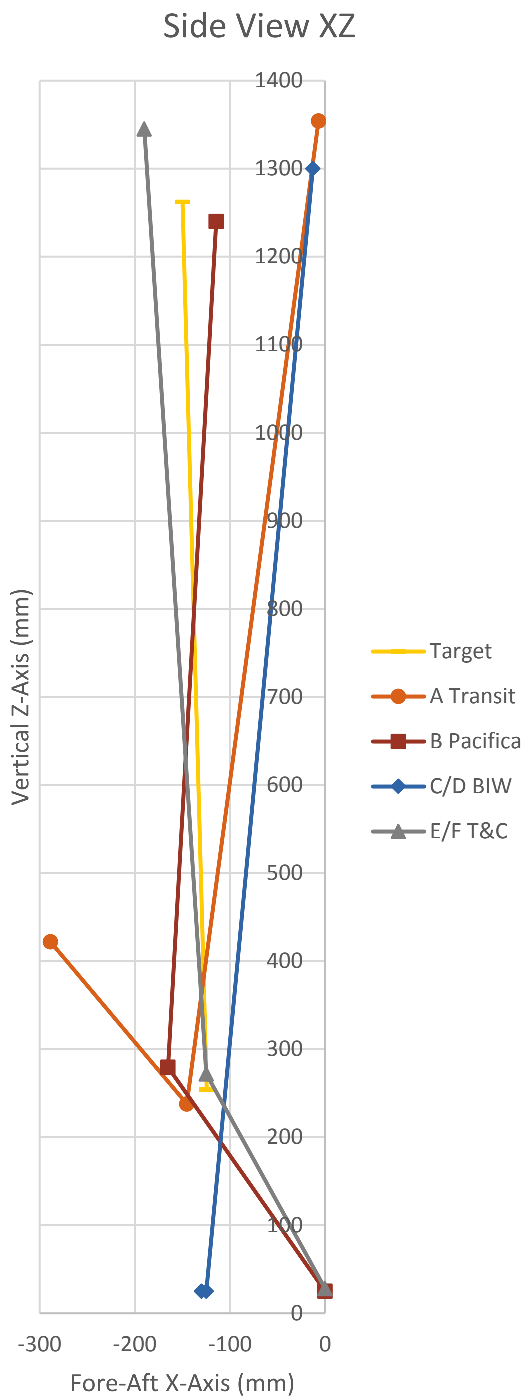


Figure 10. Side view (x-z) of gelt geometry across conditions, compared to recommended.

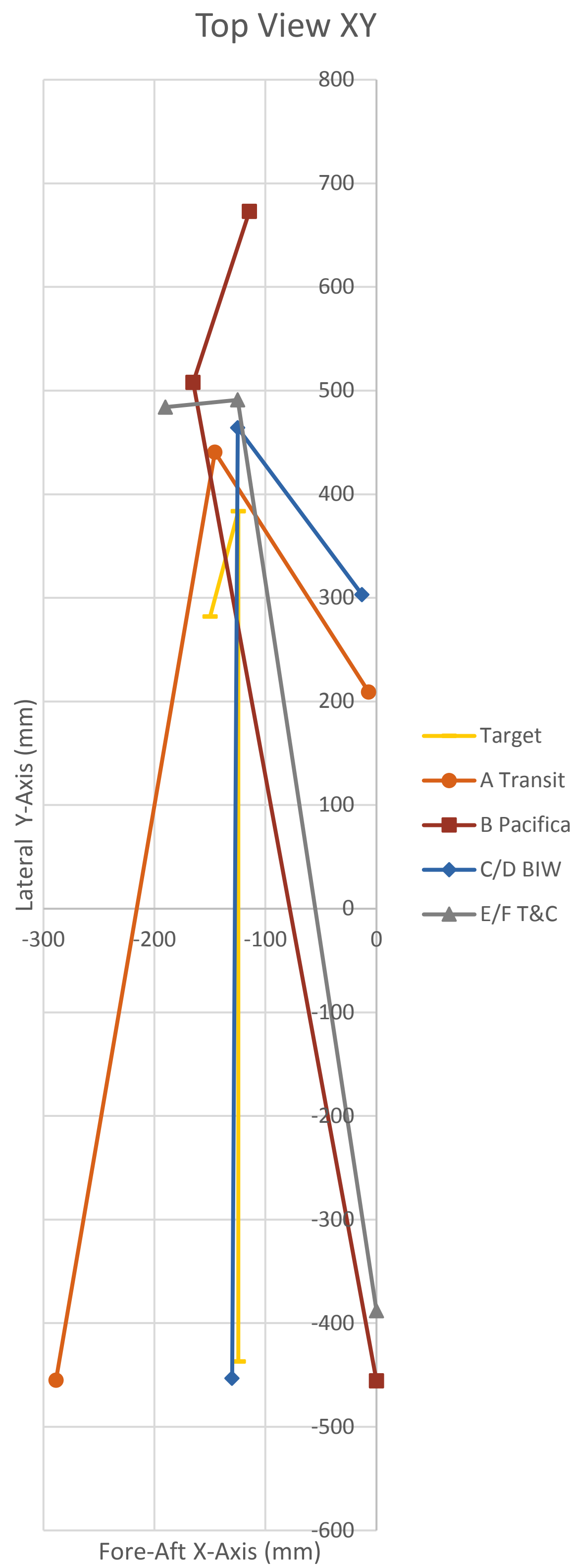


Figure 11. Top view (x-y) of belt geometry across conditions, compared to recommended.

In addition to the trials conducted in the volunteer's own wheelchair, three study wheelchairs were equipped with UDIG-compatible attachments so usability could be assessed in conditions A and CD. Photos of the attachments created for each wheelchair are shown in Figure 12.

Figure 12. Manual wheelchair 1, a Sunrise Quickie 2 (left), Manual wheelchair 2, a Helio (center), Power wheelchair, a Permobil F3 Corpus (right), each equipped with custom UDIG-compatible attachments.

The planned matrix for twelve volunteers is shown in Table 3. Unfortunately, because of multiple volunteer cancellations, COVID complications, and availability of equipment, only five participants were tested.

Table 3. Planned trial matrix.

Volunteer	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8
ADG01	AV1	BV1	CV1	FV1	**DP**	CM2	AM2	EM1
ADG02	CV2	AV2	FV2	BV2	FM2	DM1	**BP**	**EP**
ADG03	BV3	FV3	AV3	CV3	**CP**	**FP**	EM1	DM2
ADG04	FV4	CV4	BV4	AV4	DM1	AM1	FM2	**CP**
ADG05	AV5	FV5	CV5	BV5	**EP**	DM2	CM2	FM1
ADG06	FV6	AV6	BV8	CV6	CM1	EM2	**DP**	**FP**
ADG07	BV6	DV7	AV7	EV7	**AP**	**CP**	EM2	BM1
ADG08	DV8	BV7	EV8	AV8	DM2	FM1	CM1	**EP**
ADG09	AV9	EV9	BV9	DV9	**FP**	**DP**	EM1	CM2
ADG10	BV10	AV10	DV10	EV10	FM1	BM2	**CP**	**AP**
ADG11	EV11	DV11	AV11	BV11	**BP**	**EP**	DM1	FM2
ADG12	DV12	BV12	EV12	AV12	EM2	CM1	**FP**	**DP**

Protocol

The experimenter first instructed the volunteer on where to apply reference target stickers to the visible portions of their body to display approximate locations of the sternum, clavicles, hips, knees, chin. This was done to help determine anatomical landmarks when estimating posture using photos and scans of the volunteer. They were shown a video demonstrating how to use the prototype docking station and automated belt donning arm used in some of the test conditions. Next, we took front and sideview photos of the volunteer in front of a reference grid and recorded their 3D posture with a Kinect camera measurement tool. The photographs and scans allow estimation of key body dimensions while minimizing close contact.

Figure 13. Examples of reference photos to estimate dimensions and posture of person and their wheelchair.

The volunteer began the test matrix using their own wheelchair. For each vehicle, the volunteer entered using the ramp or lift and navigated to the wheelchair station. They secured the wheelchair and put on the seatbelt using traditional or automated systems, depending on the particular vehicle configuration. The participants were videotaped throughout the process. The experimenter took photos of the volunteer in each condition, and also recorded their 3D posture using a handheld Sense measurement tool.

The remaining trials were conducted with the study wheelchairs (two manual and one power), equipped with special attachments that will allow the person to use an automated docking station. The volunteer transferred to one of the study wheelchairs and performed trials under one or two conditions. This process was repeated with the two other study wheelchairs. For the trials in Conditions A and CD, they used the UDIG system to secure the wheelchair. For the other conditions, 4-point strap tiedowns were used.

Throughout the study, participants filled out survey responses using Qualtrics software on a tablet. After each trial, the volunteer exited the vehicle, and filled out a survey regarding their experience. Questions include ease of use of the securement system, comfort of seatbelt, and feeling of security. The survey also includes questions about ease of use regarding the ramp or lift, the size of the door, and the space available in the vehicle to maneuver. The purpose of this survey was to identify how each volunteer thinks the system is working, and how accessible each vehicle configuration is.

After completing all trials, the volunteer filled out a different survey regarding their general travel experiences and a race/ethnicity form. The general survey asks about their modes of transportation, whether they travel while seated in their wheelchair, and the types of problems they experience while traveling. The purpose is to identify different conditions where the systems being evaluated in the study might be useful for making transportation easier, and issues to consider when designing accessible vehicles. The race/ethnicity form allows us to determine if our sample of participants is representative of the US population.

They then transferred back to their own wheelchair and filled out the forms to receive payment. The experimenter then escorted the participant back to their own vehicle.

Data Analysis and Statistical Design

For each trial, video cameras were used to record volunteers' activities. Videos were analyzed to calculate the time it takes to board and alight from the vehicle, dock and undock the wheelchair, and don and doff the belt system. Potential issues in using the systems were also be evaluated with the videos, such as the number of attempts needed to dock, any challenges using the ramps or lifts, and whether the seatbelt got stuck on anything while donning. Photos and 3D measurement data were analyzed to assess lap and shoulder belt fit under each condition. Survey data collected were processed to evaluate the relative ease and comfort for each configuration. Data were processed to eliminate responses that did not apply to the test condition (i.e. UDIG ease for tiedown installations.)

Results were used to help determine whether the initial design guidelines recommendations for "best" accessibility designs are actually better than the conditions described as "better" or "good". In addition to providing the range of responses for each factor, where possible, mean values were compared using ANOVA tests to determine significant differences.

Results

Volunteer Characteristics

Although we had eleven volunteers scheduled to participate, we were only able to collect data on five volunteers because of cancellations due to participant illness. We were not able to extend the time to collect volunteer data because some equipment was no longer available. Table 4 contains data on the participant characteristics. BMI for Volunteer 2 is low likely because of her amputation.

Table 4. Summary of participant characteristics.

ID	Gender	Age	Height	Weight	BMI	Type of wheelchair	Reason for wheelchair use
ADG01	W	41	63	153	27.1	Manual	Spinal cord injury
ADG02	W	73	59	97	20.3	Manual	Left leg amputee
ADG05	W	52	68	146	23.6	Power	Spinal cord injury
ADG07	W	66	64	120	20.6	Manual	Spinal stenosis
ADG08	M	70	72	206	37.7	Manual	Foot operations on both feet

Task Duration

One way to assess usability is to measure how long it takes to perform each task. Figure 14 shows the mean duration of four entry tasks: entering the vehicle by ramp or lift, navigating to the wheelchair station, docking the wheelchair, and donning the seatbelt. The only task that was statistically different by condition was entry time ($p=0.006$), where condition A with the lift took longer than any of the ramp conditions. Figure 15 shows how these tasks varied with the wheelchair used. The only task that was of significantly different duration was navigation from the door to the station ($p=0.005$), which was longest for the power wheelchair and shortest with the volunteers' own wheelchairs. There were no significant differences in entry task duration between trials that used UDIG docking vs. 4-point strap tiedown, or between trial numbers. The only entry task that differed significantly between participants was belt donning ($p=0.008$); mean times for each participant were 17, 36, 50, 22, and 23 s.

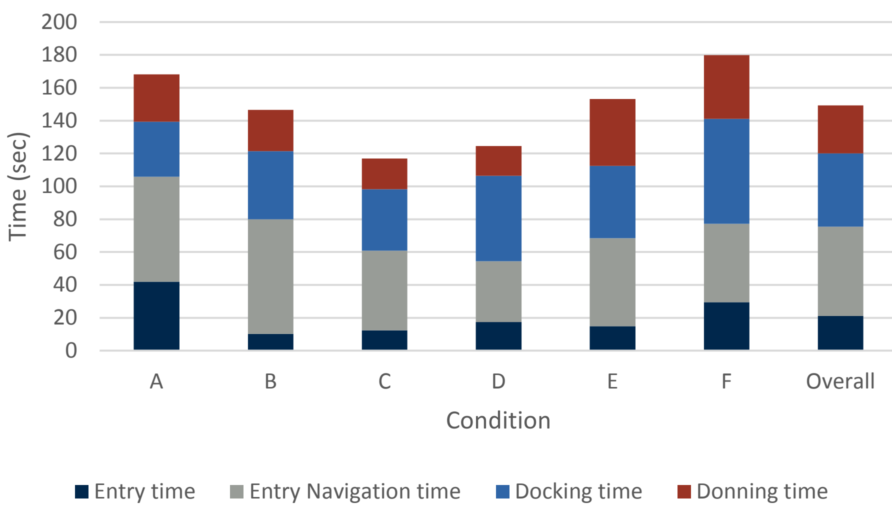


Figure 14. Mean entry task duration by condition.

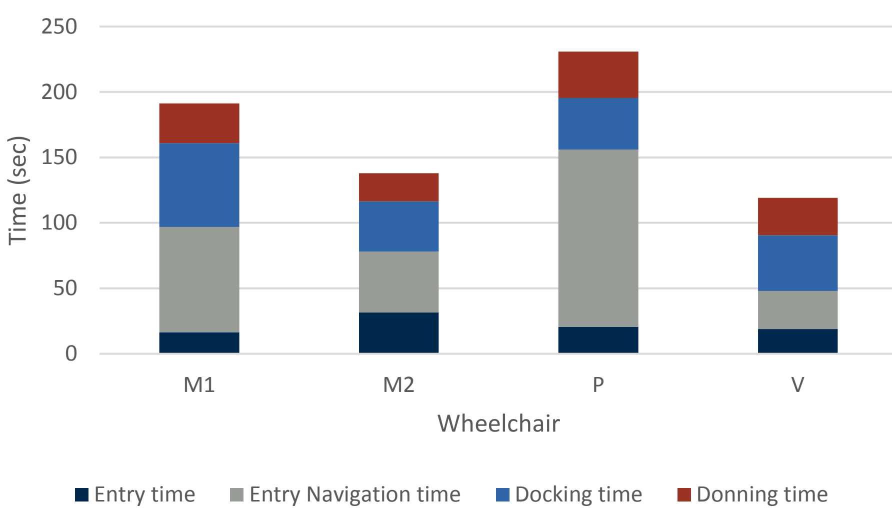


Figure 15. Mean entry task duration by wheelchair.

Mean duration for each exit task by condition is shown in Figure 16. For these results, both doffing time and exit time were significantly different ($p<0.001$), with condition A that used the automated donning arm and the lift taking longer than other conditions. When comparing results by wheelchair in Figure 17, differences in mean undocking time and mean exit navigation were significantly different ($p<0.02$). The volunteers' wheelchairs had the longest undocking time, and the volunteers and M1 trials had the shortest exit navigation times. The mean undocking time with UDIG trials (11 s) was significantly shorter than the mean undocking time with 4-point strap tiedown trials (19 s, $p=0.02$). The exit navigation time by volunteer was also statistically significant ($p=0.014$), with a range of values from 5 to 15 s.

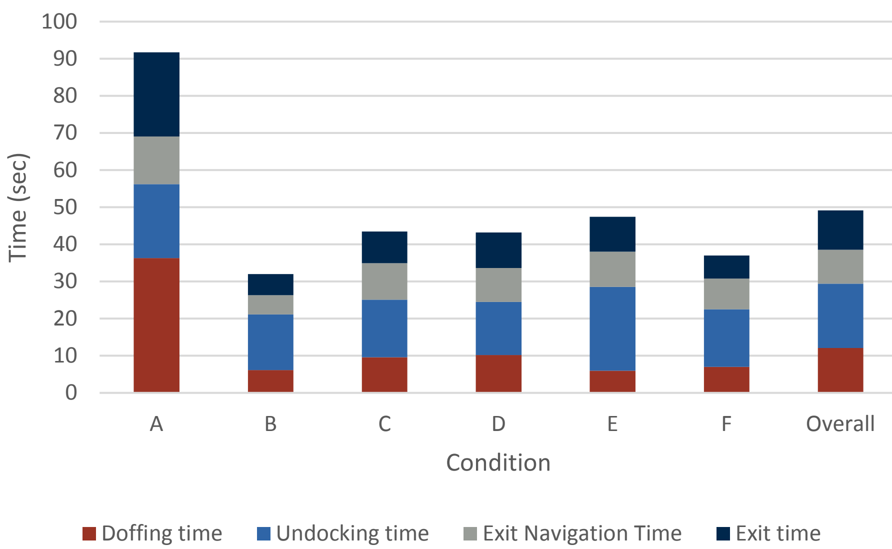


Figure 16. Mean exit task duration by condition.

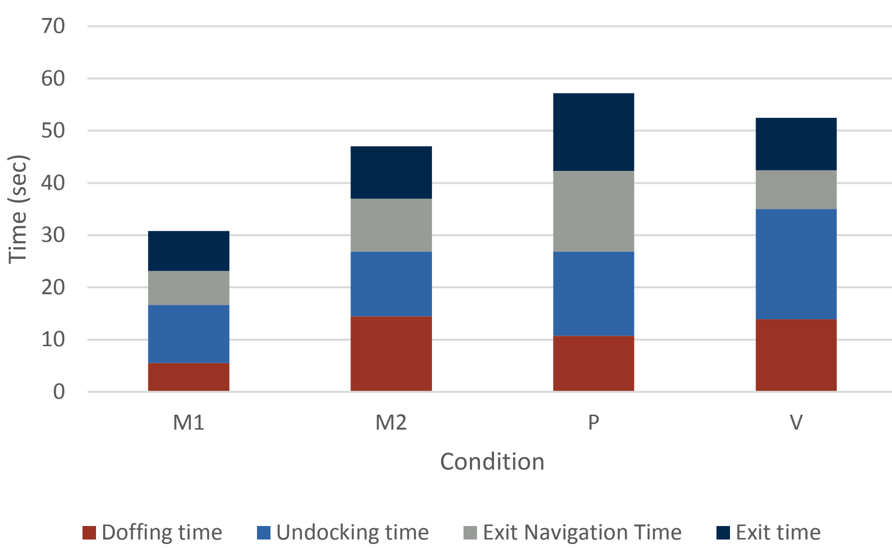


Figure 17. Mean exit task duration by wheelchair.

Doorways

Volunteers did not record any comments specifically related to door width or height. For width, using a scale of 1: Extremely Difficult to 4: Extremely Easy, mean results by width are shown in Figure 14. There is no apparent trend for ease of use based on doorway width (p=0.641), and while the shortest doorway had lower average rating than the taller ones, results were not significant (p=0.173). Participants often ducked their head down when entering the doorway, particularly in the CD condition.

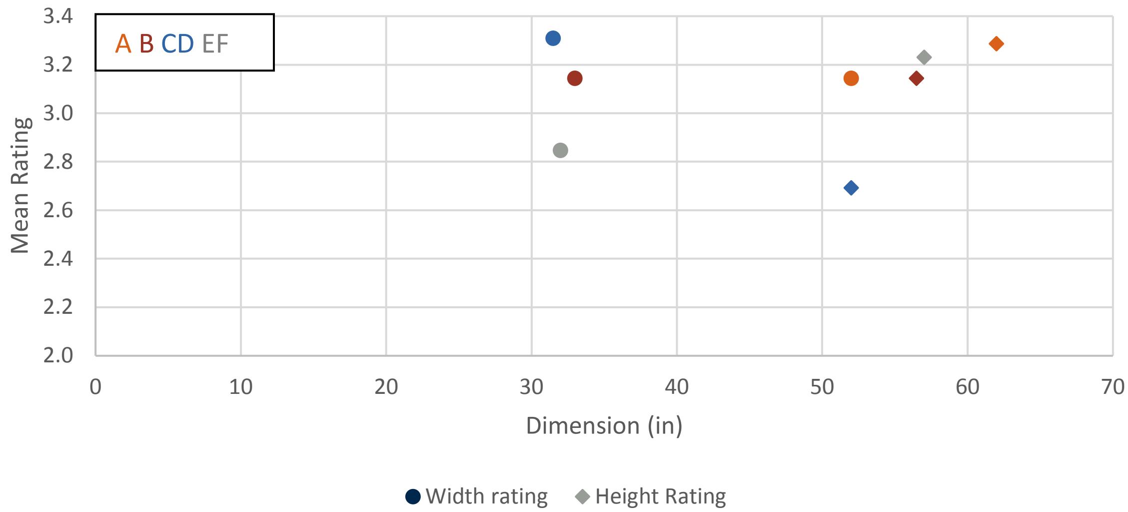


Figure 18. Mean ease of use ratings for doorway width and height for the four vehicle conditions.

Ramps/Lifts

For conditions C, D, and E, all volunteers approached the vehicle from the forward direction. In conditions B and F, in one of seven and two of six trials, respectively, the volunteer entered from the rearward direction. In condition A with the lift, the volunteer entered forward in three trials and rearward (as recommended by lift instructions) in four trials.

The average ratings on how easy it was to use each ramp/lift condition on entry and exit are shown in Figure 19. While there is some variation in ratings, none were statistically different. One participant commented that for vehicle A, going backwards on the lift and positioning was tricky. Three volunteers commented that ramp B was steep and they might need assistance in a manual wheelchair. Another volunteer commented that ramp EF was also too steep, and they needed assistance with the manual wheelchair. In general, volunteers found the ramps and lift easiest to use while in their own wheelchair or using the test power wheelchair.

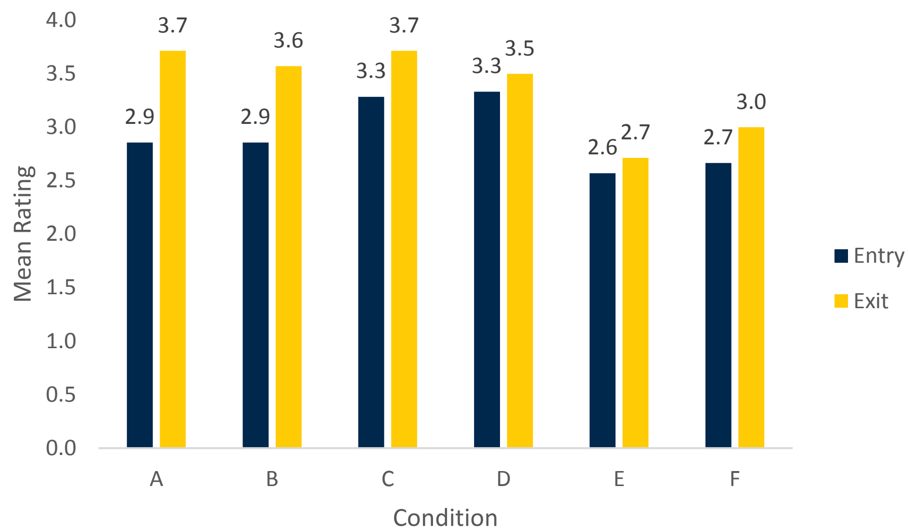


Figure 19. Mean ratings of ease of ramp/lift use to enter and exit.

Passenger Access/Wheelchair Space

The average number of forward movements to align the wheelchair is shown in Figure 20 for each condition and wheelchair. Although condition EF (positioned close to the left side of the vehicle and with the minimum wheelchair station length) has a higher mean value, results were not statistically different from the three other conditions with either longer station lengths and/or a center location in the vehicle. Several participants experienced knee or other lower extremity contact with the driver seat during maneuvering, particularly when using the power wheelchair. Condition results may be confounded by the statistically significant differences ($p=0.013$) in number of alignments by wheelchair type, where the volunteers needed the fewest number of forward movements in their own wheelchairs. On exit, the volunteers were able to move forward to exit the vehicle without backing up in all but four trials.

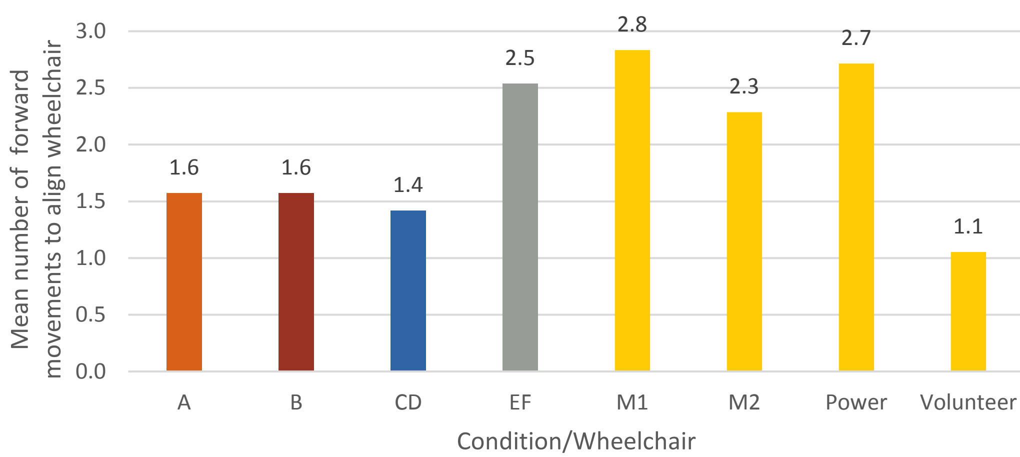


Figure 20. Mean number of forward movements to align wheelchair with the securement system broken down by wheelchair type and test condition (Conditions A, B, CD, EF, wheelchairs).

The survey responses regarding ease of maneuvering agree with this assessment as shown below in Figure 21. Condition EF had the worst ratings in terms of ease of positioning the wheelchair in the wheelchair space.

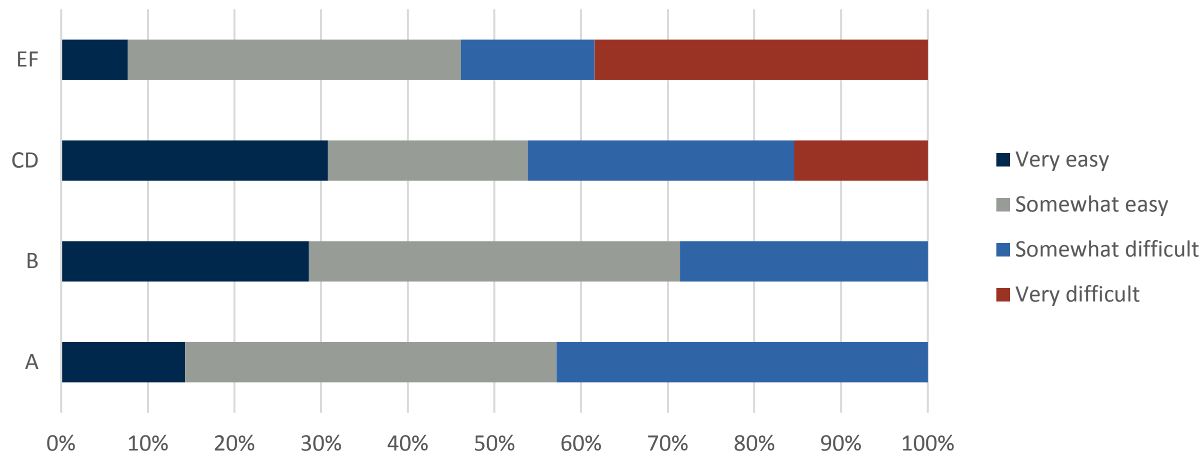


Figure 21. Average level of difficulty involved in positioning the wheelchair in the wheelchair space compared to other securement systems per condition.

The wheelchair type being used influenced the ease of entering and maneuvering into the vehicle wheelchair space. As shown in Figure 20, the power and manual M1 test wheelchairs required the greatest number of forward movements on average to align with the passenger space centerline. These two wheelchairs had the longest and widest footprints, which did affect the turning radius and maneuverability. The volunteers were asked to rate the difficulty of maneuvering the test wheelchairs compared to their personal wheelchair and the results are shown below in Figure 22.

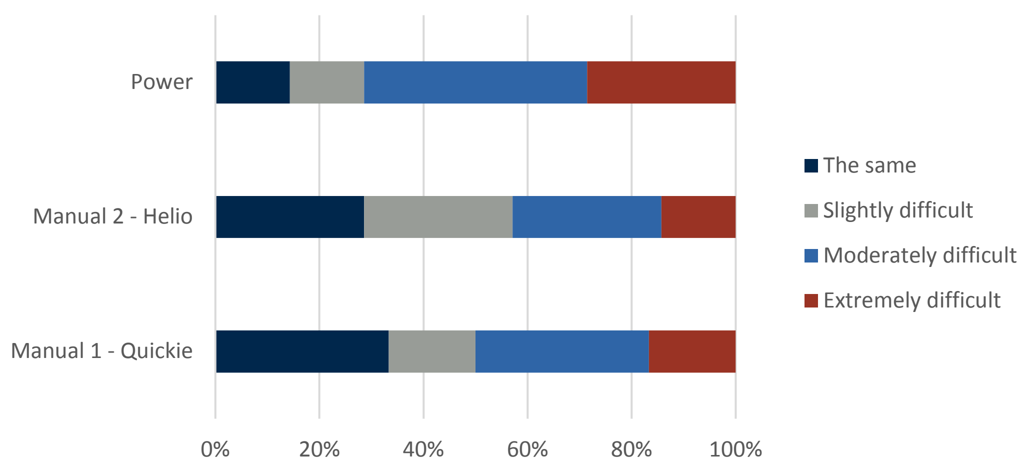


Figure 22. Level of difficulty ratings for maneuvering the test wheelchair compared to the volunteer’s own wheelchair by test wheelchair.

In six trials, there was interference between the seatbelt and wheelchair as the volunteer was navigating into the wheelchair station. Two were in condition A, two in E, one in B, and one in C. Two were in the power chair, two in M2, one in M1, and one in the volunteer's chair. When exiting there were four trials where the seatbelt got stuck on the volunteer or the wheelchair, one each in conditions A, B, C, and D. Two were in the power chair, one in M1, and one in the volunteer's chair.

Wheelchair Securement

Figure 23 shows volunteer ratings of the ease of lining up their wheelchair for the trials that used tiedown securement. The two conditions with the wheelchair station in the center had the best ratings. For the two conditions with the wheelchair station along the left side of the vehicle, condition A with the longer wheelchair station length had better ratings than condition EF with the minimum required wheelchair station dimension.

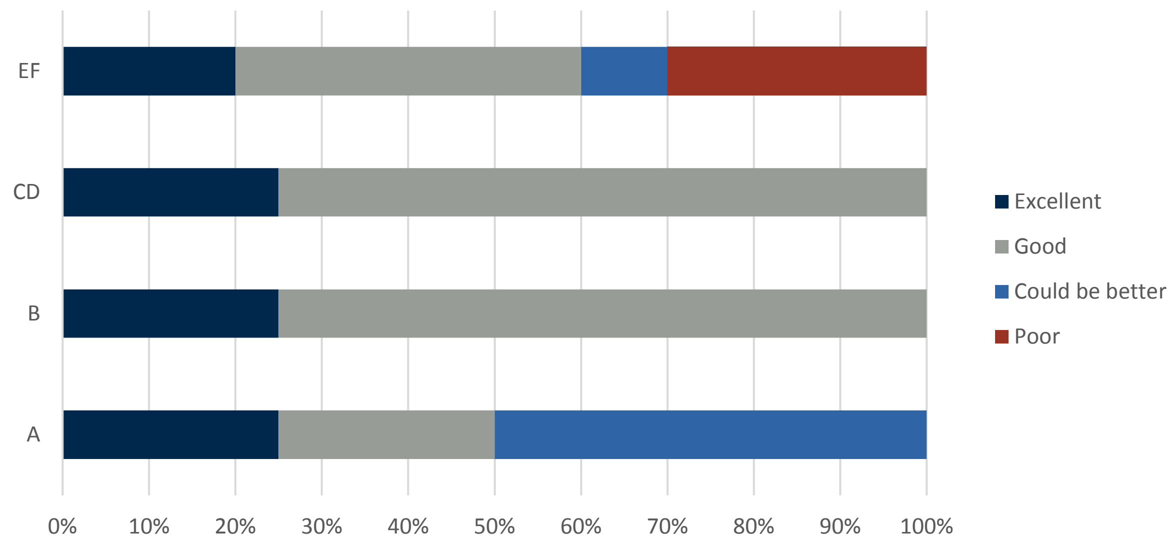


Figure 23. Ease of lining up wheelchairs for tiedown securement.

In the ten trials involving UDIG securement, the volunteers needed to realign their wheelchair after the first docking attempt in half of the trials. The realignment rate was 50% in both conditions A and CD. As shown by volunteer ratings in Figure 24, it was easier to align with the anchors in condition A. Given that CD had more space to maneuver, and the better ratings of CD compared to A for the 4-point tiedown securement, we hypothesize that this finding reflects a wider dimension between the two UDIG anchor hooks in the CD installation compared to the A installation.

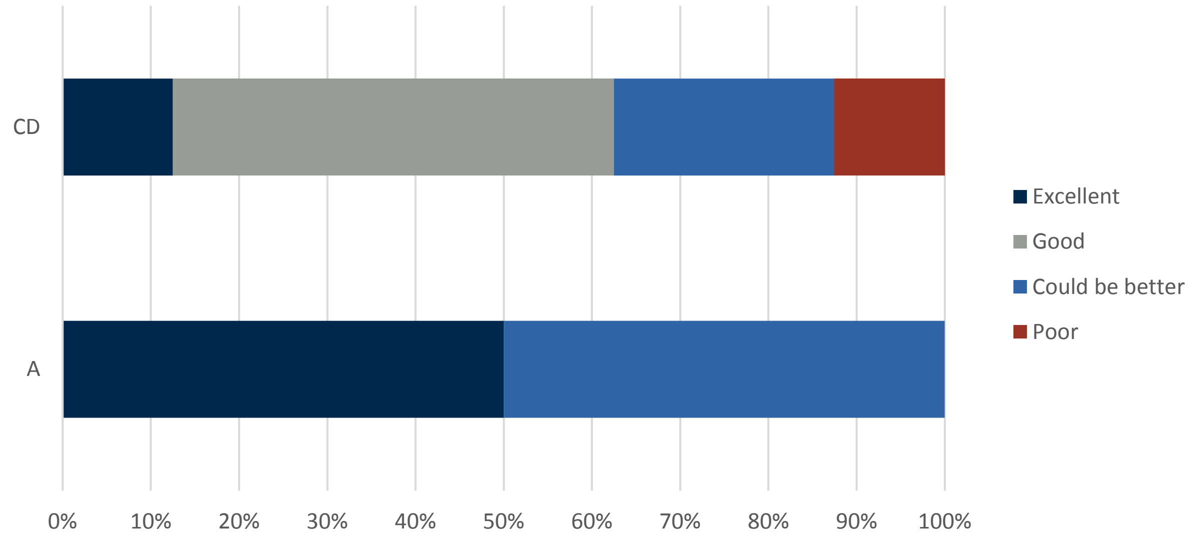


Figure 24. Ease of lining up wheelchairs with UDIG anchors.

Conditions B, C and D required an assistant to anchor the wheelchair with the 4-point tiedown straps. The retractable tiedown straps were either manually tightened by the tester or automatically retracted to snug, resulting in stable wheelchair securement. Survey feedback, summarized in Figure 25, indicates that the volunteers felt very secure in these conditions. The volunteers also thought the UDIG provided an excellent or good feeling of security, averaging slightly better than with the 4-point tiedowns. When asked to rate the ability to use the UDIG docking system without help, volunteers thought the independence was excellent in 30% of the trials, good in 50% of the trials and they thought it could be better in 20%.

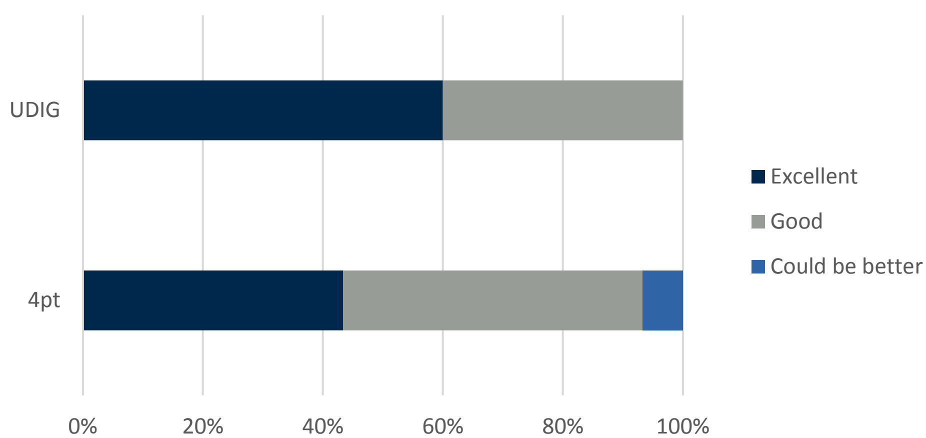


Figure 25. Ratings for feeling of security once docked or tied down.

Occupant Restraint Systems

Mean ratings of seatbelt related survey questions are shown in Figure 26. Although the plot shows some variations, the only statistically significant difference (p=0.02) was the lower score in EF for being able to use the seatbelt without help. For condition EF, the inboard buckle stalk was located slightly too far rearward in the passenger space and prevented some of the volunteers from buckling the belt themselves due to their limited range of motion.

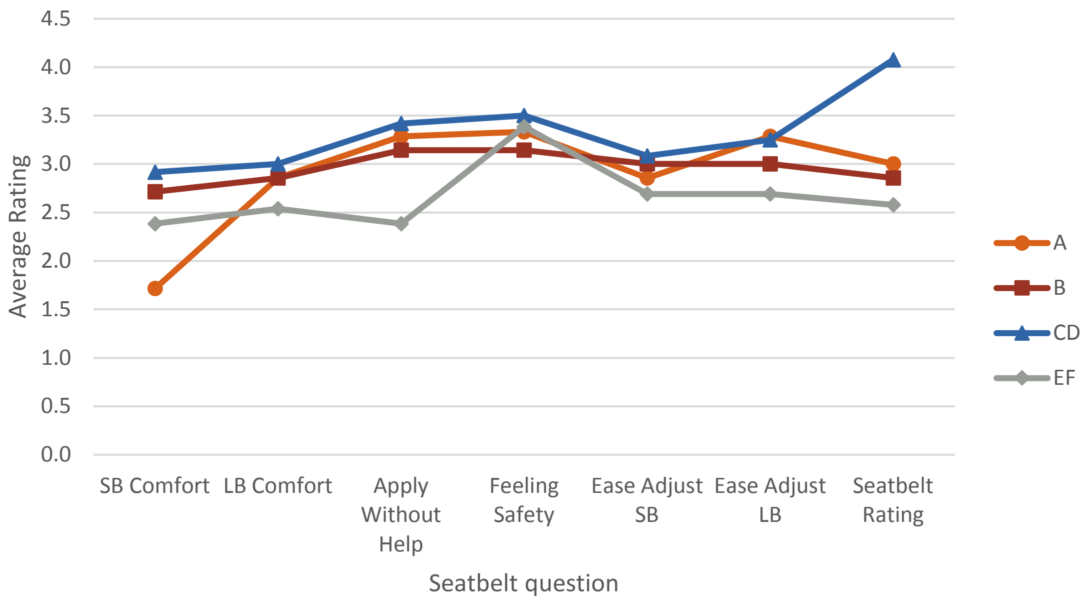


Figure 26. Mean answers of belt survey questions by condition.

Appendix B shows photos of each trial to illustrate the seatbelt fit. Volunteer 1 had reasonable lap belt fit in all conditions, possibly because her personal manual wheelchair did not have armrests. Her shoulder belt fit in conditions A and D was consistent with the overall mean trends. Volunteer 2 had similar fits to volunteer 1, although her manual wheelchair did have cantilevered armrests. Volunteer 5 used a power wheelchair with cantilevered armrests as her personal wheelchair. Partly because of her posture, her shoulder belt seems to be located closer to the neck in each condition, compared to Volunteers 1 and 2. Lap belt fit was the worst in trial 8, as shown in Figure 27 (left) where the lap belt was improperly routed over the armrest and was also twisted. Volunteer 7 had more trials with poor lap belt fit. In trial 7 (Figure 27, center), she held the shoulder belt away from her neck. Volunteer 8's wheelchair had closed armrests that prevented the belt from being routed alongside the hips (Figure 27, right); ideally, the belt should have been routed through a gap in the armrest.

Figure 27. Belt fit challenges: poor lap belt fit caused by improper routing and belt twisting (left), discomfort leading to volunteer holding belt away from shoulder (center), closed armrest on volunteer wheelchair leading to suboptimal belt routing (right).

Table 5 shows the mean belt fit scores and belt angles across conditions. All belt fit scores significantly different ($p<0.02$) with condition. For shoulder belt fit, condition A had scores placing the belt closest to the neck, while condition B had the belt closest to the arm. This is consistent with the mean shoulder belt angle measured from the front view photos. For lap belt fit scores, condition CD had the best placement with the lowest mean scores, while condition EF had the highest. The mean lap belt angle was closest to the optimal target in conditions B and CD. When reviewing belt fit by wheelchair, there were no significant differences ($p>0.19$).

Table 5. Summary of mean belt fit scores and belt angles.

Condition	SBS (mm)	LBF (1-5)	SB Angle	LB Angle
A	-8.3	2.6	56	50
B	118.4	2.1	39	45
CD	15.4	1.6	52	42
EF	16.5	3.2	49	36

Distribution of lap belt comfort and shoulder belt comfort are shown in Figure 27 and Figure 28, respectively. For lap belt comfort, condition CD had the highest proportion of positive responses, but also had some negative concerns. For shoulder belt fit, CD also had the highest proportion of positive responses, with condition A the worst, followed by EF.

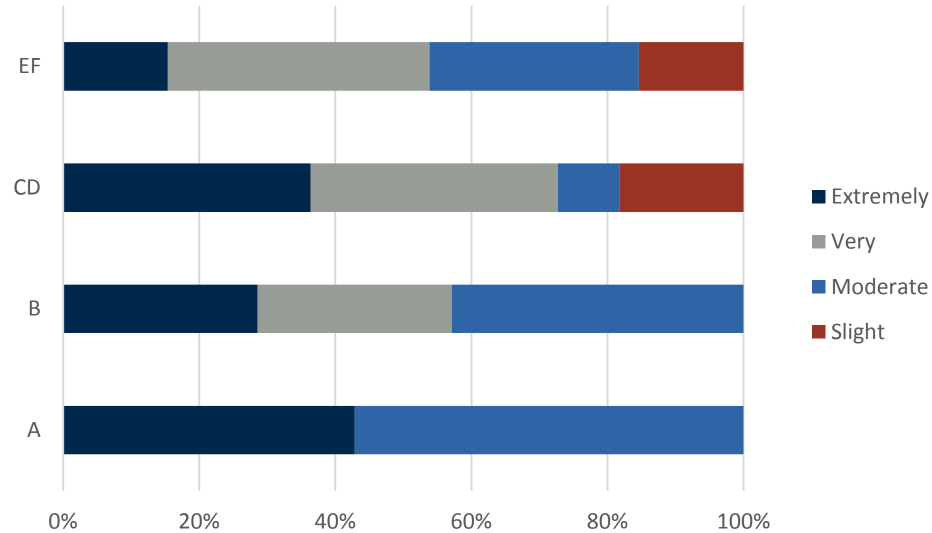


Figure 28. Ratings of comfort for the lap belt per vehicle condition.

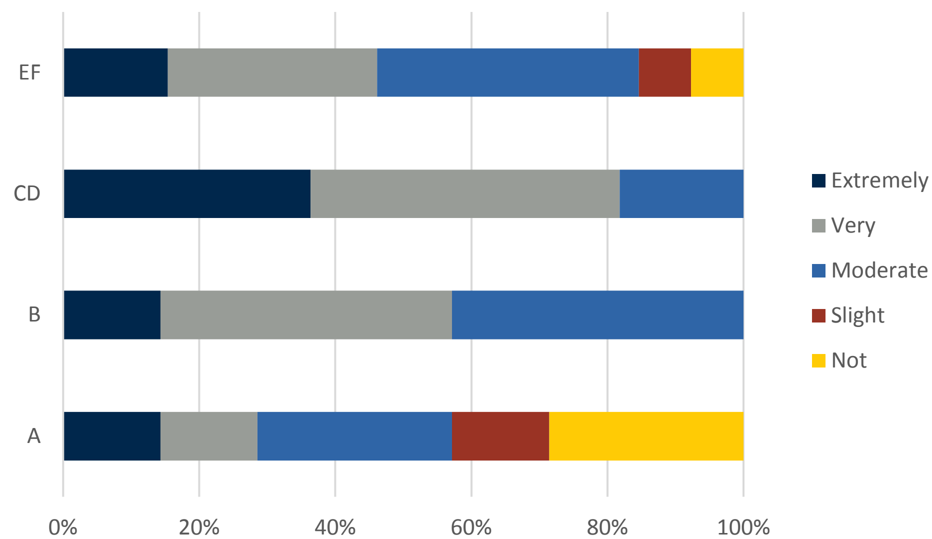


Figure 29. Ratings of comfort for the shoulder belt per vehicle condition.

When reviewing the videos of each trial, during donning the seatbelt caught on the armrest in just one trial using M1 in condition E. During doffing, the belt caught on the armrest in one trial in A with the power wheelchair and in another in condition B with the volunteer's chair. The volunteer helped position the seatbelt on themselves in all but three trials. Figure 27 shows the percentage of trials in each condition where the volunteer adjusted the shoulder belt fit, lap belt fit, or placed the belt under the wheelchair armrests.

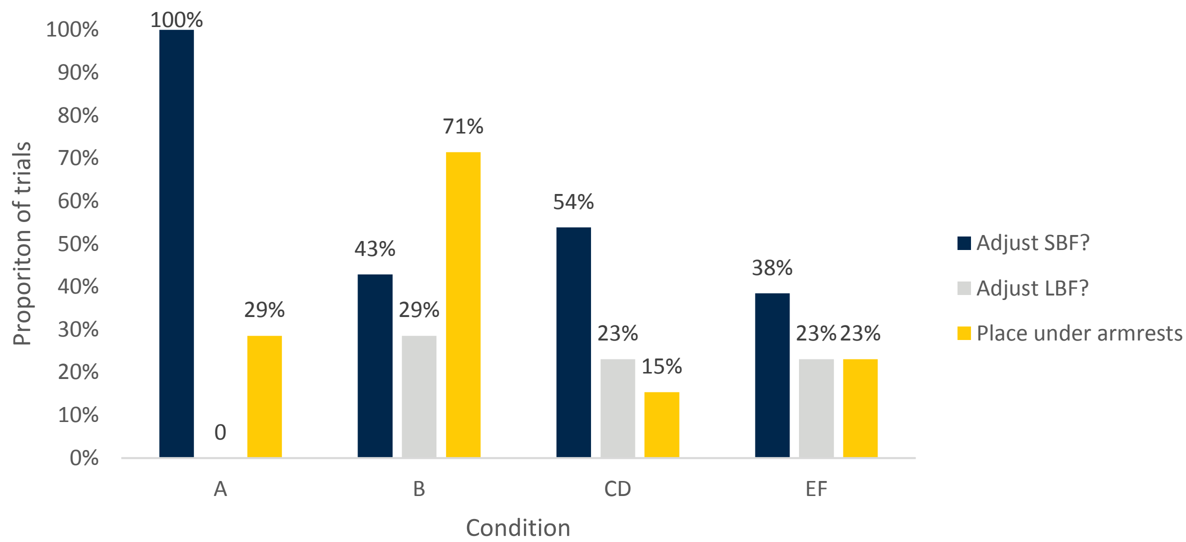


Figure 30. Percentage of trials by condition where volunteer adjusted shoulder belt fit, lap belt fit, or placed the belt under the wheelchair armrests.

Volunteers were asked to rate the ease of positioning the lap portion of the seatbelt on their body. Figure 20 below shows that the ratings were better for condition A that used an automatic donning lap and shoulder belt than the other vehicle conditions that required the volunteer to manually buckle and place the belt system on their body.

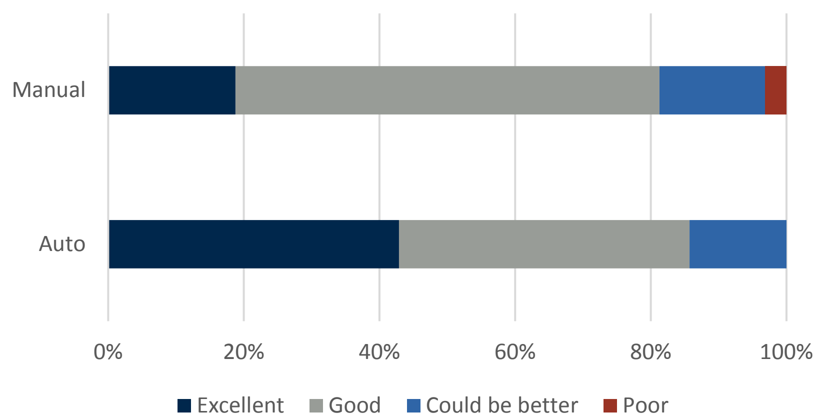


Figure 31. Ratings for ease of positioning the lap belt on the body.

When asked the same question about the ease of positioning the shoulder belt on the body, the volunteers responded as shown in Figure 21. Some poor responses were received likely due to the shoulder belt contacting the neck of the volunteer when using the automatic donning belt system. In other cases, the shoulder belt needed to be routed under the wheelchair armrest for good fit, which made positioning slightly more difficult. All but one of the volunteers rated the feeling of security once belted to be excellent or good.

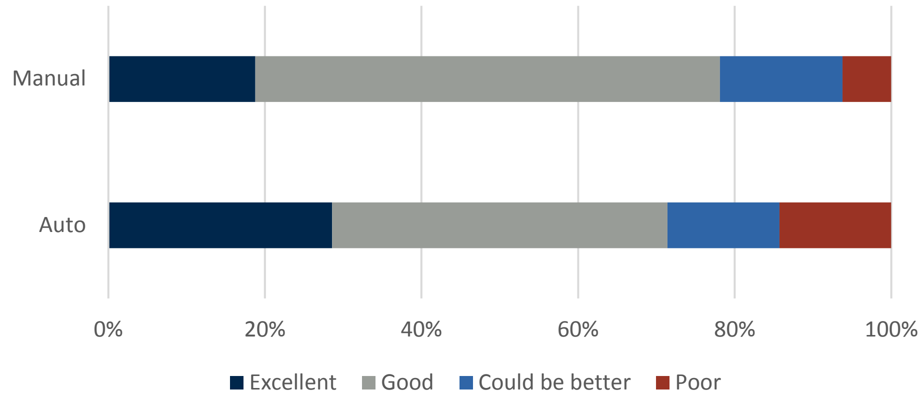


Figure 32. Ratings for ease of positioning the shoulder belt on the body.

In general, the seatbelt systems setup across the conditions were rated well on the ability to use independently as shown in Figure 33. As mentioned earlier, the rearward location of the belt stalk in condition EF did not allow some participants to apply the belt without assistance.

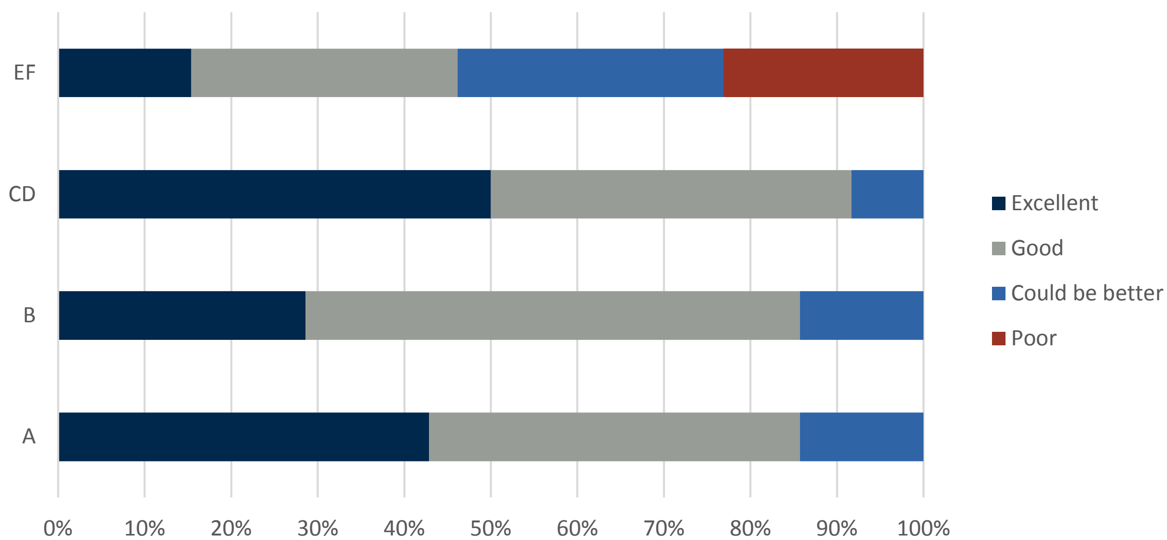


Figure 33. Ratings for the ability to use the seatbelt system without help

Operable Parts

Only ten trials involved the UDIG docking system, two in A and the rest in CD. To engage the UDIG anchors with the wheelchair UDIG attachments, two buttons needed to be pushed that independently control the left and right-side hooks. Several people inadvertently pressed the buttons more than once and some were confused about whether or not the buttons had to be pushed simultaneously. The iPad in front of the volunteer provided a view of the UDIG hooks so that they could determine if engagement was successful. In the BIW for conditions CD, LED lights turned on when the UDIG hook engaged with the attachment on each side. In the Transit, there were LED lights mounted on top of the UDIG anchor device in the vehicle that turned off when the hooks successfully engaged with the attachments. The volunteers rated the level of difficulty using and understanding the UDIG docking system controls while engaging/locking the UDIG mechanism compared to other securement systems they had used previously. The controls were rated very easy in 30% and somewhat easy in 60% of the trials, with an even split between the two vehicles. One volunteer did not provide a rating. Results were similar for using the controls to exit the UDIG anchor.

Discussion

Our four interior layouts illustrated the challenge in providing accessible floor space while maintaining good belt fit for people using wheelchair stations. In condition B with the with the D-ring mounted to the vehicle's C-pillar but the wheelchair station centered in the vehicle, shoulder belt fit tended to be outboard across all participants. While the shoulder belt anchorage location in condition A was based on optimizing belt effectiveness in simulations, it placed the belt too close to the neck in many trials, leading to discomfort.

We were able to modify baseline ramps so they demonstrated the range of angles included in the design guidelines. However, the shallow ramp in conditions E and F is so long (to achieve the target angle) that implementing them in an AV using traditional ramp construction and storage techniques would likely not be feasible. In addition, the potential benefits from a shallower ramp angle were offset by the extra effort needed to navigate the longer ramp length. The fourth vehicle used was equipped with a lift because its sill height is too high to allow installation of a ramp meeting minimum angle requirements. Entry times with the lift took longer than with the ramps as well. Past studies (Klinich et al. 2022, Frost et al. 2012) indicated that wheelchair users prefer ramps to lifts, and risk of adverse events is lower when using ramps. Kneeling mechanisms available in large buses to facilitate easier ingress/egress of wheelchair users might be an option for achieving lower sill heights and easier ramp navigation in AVs.

This study evaluated two potential ramp improvements that have been previously suggested in the literature but not previously evaluated. One was the presence of higher edge guards, constructed to be 4 in rather than the required 2 in. Unfortunately, we evaluated the higher edge guard height using the widest ramp width, where it would probably have the most limited benefit compared to a narrower ramp. In addition, the long ramp length (that would be impractical in an actual vehicle) seemed to offset the potential benefits of shallower angle and taller edge guard. The other was the addition of an apron to the bottom of the ramp, which would allow the wheelchair user to approach the ramp from an angle, rather than having to line up completely straight before approaching. However, review of the videos showed that none of the participants tried to use the extra apron sections at the base of the ramp.

This study had several limitations. The first is that we were only able to test five participants, despite having eleven scheduled at one point. People had to cancel because of illness and/or exposure to COVID. The study could not be extended because two of the wheelchairs were being crash tested for another research program and could no longer be used with volunteers. While this resulted in forty trials and provided some insight on how usability varied with conditions, we were not able to support or oppose the guidelines with statistical significantly statistic results. In the few cases where results may have differed, they may be confounded by differences in wheelchair usability; because of the reduced number of volunteers tested compared to planned, we did not have the same number of trials with each wheelchair in each condition. Since volunteers were able to maneuver their own wheelchairs much more easily than the study wheelchairs, ratings of conditions were likely somewhat affected by the wheelchairs used.

Another limitation of the study was that we were not able to assess all combinations of good, better, and best because we needed to work with the vehicle characteristics available for testing. Thus we were limited to the door height/width combinations available in our four vehicles, and only one ramp angle was tested with each door entry size.

Overall, this limited volunteer testing supported the recommendations in the design guidelines to provide larger wheelchair seating stations and space around them to maneuver. The seatbelt geometry used in condition CD was the easiest to use and most comfortable. We did not add to the guidelines a recommendation to the base of the ramp to allow approach from an angle greater than 90 degrees, since none of the volunteers used this feature when it was available. For the remainder of the items evaluated, there was not sufficient sample size to determine whether the better and best recommendations are better than the good requirements. As a result, we have included them in the design guidelines as a preliminary recommendation until more research is available to determine whether they are appropriate goals for improving accessibility.

References

Architectural and Transportation Barriers Compliance Board, Dec. 14, 2016, Americans with Disabilities Act (ADA) Accessibility Guidelines for Transportation Vehicles, 36 CFR Part 1192 [Docket No. ATBCB 2010–0004] RIN 3014–AA38.

Department of Justice. 2010. 2010 ADA Standards for Accessible Design.

Frost KL, van Roosmalen L, Bertocci G, Cross DJ. (2012) Wheeled mobility device transportation safety in fixed route and demand-responsive public transit vehicles within the United States. Assist Technol. 24(2):87-101.

Klinich KD, Orton NR, Manary MA (2022) Design Guidelines for Accessible Automated Vehicles: Mobility Focus. UMTRI 2022-8. University of Michigan Transportation Research Institute.

Appendix A: Recruitment Documents

Flyer

Screening Script

Consent Form

Study ID: HUM00212535 IRB: Health Sciences and Behavioral Sciences Date Approved: 3/10/2022

VOLUNTEERS NEEDED

For a study on wheelchair transportation accessibility and safety.

If you are 18 or older, use a wheelchair, and can transfer to other seating, we invite you to participate in a research study with the University of Michigan Transportation Research Institute.

You will receive $40 for participation in a single 2-hour session.

For more information, email carsafety@umich.edu
or call 734-763-3463

Participant Screening Script: Phone version

Volunteer Participant ADG Study
Thank you for volunteering for this study about accessible vehicles for people using wheelchairs. I need to ask you several questions to see if you qualify for our study. How old are you?

Reject if less than 18

Are you pregnant?

Reject if pregnant

Do you use a wheelchair regularly?

Reject if they are not a wheelchair user.

Can you and are you comfortable transferring from your wheelchair into another wheelchair independently or with minimal assistance?

Reject if no.

Let me tell you a little more about the study. You would need to come to our lab at UMTRI, which is near the corner of Huron Parkway and Plymouth Road in Ann Arbor. We will have several wheelchair accessible vehicles set up. We will ask you to enter each vehicle using the ramp or lift, navigate to the wheelchair station, dock your wheelchair, and put on your seatbelt. We will take videos, pictures, and measurements of you in each configuration, and then ask you some questions about each setup. Some trials will be in your own wheelchair, and other trials will be in a manual or power wheelchair that we have at UMTRI. Do you think you will be able to transfer into two different wheelchairs and enter and exit different vehicles over the course of two hours?

If interested:

We will be scheduling sessions for morning or afternoon weekdays the weeks of XX and XX. Can you please let me know some times you would be available?

Participant Screening Script: Email version

Volunteer Participant ADG Study
Recruiting email #1:
Thank you for volunteering for this study about accessible vehicles for people who use wheelchairs. Please answer the following questions so we can see if you can be in our study.
How old are you?
Are you pregnant?
Do you use a wheelchair regularly?

Can you and are you comfortable transferring from your wheelchair into another wheelchair independently or with minimal assistance?
Once you send me these answers, I will let you know if you can participate and send more details about the study.

Recruiting email #2:

Thank you for your responses, you are able to be in our study. Here are some more details:

You would need to come to our lab at UMTRI, which is near the corner of Huron Parkway and Plymouth Road in Ann Arbor. We will have several wheelchair accessible vehicles set up. We will ask you to enter each vehicle using the ramp or lift, navigate to the wheelchair station, dock your wheelchair, and put on your seatbelt. We will take videos, pictures, and measurements of you in each configuration, and then ask you some questions about each setup. Some trials will be in your own wheelchair, and other trials will be in a manual or power wheelchair that we have at UMTRI. Do you think you will be able to transfer into two different wheelchairs and enter and exit different vehicles over the course of two hours?

And are you interested in participating?

If so, we will be scheduling sessions for morning or afternoon weekdays the weeks of XX and XX. Can you please let me know some times you would be available?

UNIVERSITY OF MICHIGAN

CONSENT TO BE PART OF A RESEARCH STUDY

1. KEY INFORMATION ABOUT THE RESEARCHERS AND THIS STUDY

Study title: *Evaluation of Design Guidelines for Accessible Vehicles*

Principal Investigator: Kathleen D. Klinich, PhD, University of Michigan Transportation Research Institute

Study Sponsor: MCity

You are invited to take part in a research study. This form contains information that will help you decide whether to join the study.

1.1 Key Information

Things you should know:

- The purpose of the study is to evaluate different configurations of wheelchair-accessible vehicles to understand which features make the vehicles easier and more comfortable to use.
- If you choose to participate, testing would be in our lab at UMTRI where we will have several different wheelchair accessible vehicles. We will ask you to enter each vehicle using the ramp or lift, navigate to the wheelchair station, dock your wheelchair, and put on your seatbelt. Some trials will be in your own wheelchair; for other trials you would need to transfer to our manual or power wheelchair with special attachments. We will take photos, videos, and three-dimensional measurements during these trials. You will also fill out a survey after each trial. We will ask you about your experience in your own wheelchair. At the end of the session, you will fill out a survey regarding your transportation experiences. The test session will take up to two hours.
- Risks or discomforts from this research include frustration when trying out different hardware designs, or discomfort from using a seatbelt that might not fit well. There is a risk of falling from the wheelchair during transfer or as you maneuver in our test vehicle. Breach of confidentiality is also a risk.
- There are no direct benefits for you to participate in this study.

Taking part in this research project is voluntary. You do not have to participate and you can stop at any time. Please take time to read this entire form and ask questions before deciding whether to take part in this research project.

2. PURPOSE OF THIS STUDY

Vehicle manufacturers are designing automated vehicles with integrated wheelchair stations. The project’s goal is to create Design Guidelines for Accessible Automated Vehicles, where we have gathered recommendations from different sources into one document. The purpose of the volunteer testing is to check that our recommendations for different features are beneficial for wheelchair users.

3. WHO CAN PARTICIPATE IN THE STUDY

3.1 Who can take part in this study? People 18 and older who regularly use a wheelchair, but are able to transfer to one of our study wheelchairs, are eligible to participate. You cannot participate if you are pregnant.

3.2 How many people are expected to take part in this study? Up to 24 people will participate in this study.

4. INFORMATION ABOUT STUDY PARTICIPATION

4.1 What will happen to me in this study?

- Testing will occur in our lab at UMTRI.
- We will tell you about the study and obtain your consent.
- You can fill out surveys using a tablet, paper, or verbally. You do not have to answer any questions you don’t want to answer.
- We will make sure you can safely transfer to our study wheelchairs, and that you are comfortable using them.
- We will show you where to put stickers on different parts of your body.
- We will take some photos and scans to document your body dimensions.
- We will show you a video of how prototype wheelchair docking stations and automatic belt systems work.
- We will have you enter one of the vehicles using the lift or ramp. You will secure your wheelchair and put on the seatbelt. Photos and video and will be recorded during this process.
- Then we will document your posture and position using a 3D measurement tool and photos.
- Then you will remove the seatbelt, undock the wheelchair, and exit the vehicle. Photos and video and will be recorded during this process. You will fill out a form about the trial.
- We will repeat the process up to 10 times using different vehicle setups. Some trials will be in our manual wheelchair, some will be in our power wheelchair, and some will be in your own wheelchair.
- You will fill out a survey about your personal travel experiences and a race/ethnicity form.

4.2 How much of my time will be needed to take part in this study? Up to 2 hours.

5. INFORMATION ABOUT STUDY RISKS AND BENEFITS

5.1 What risks will I face by taking part in the study? What will the researchers do to protect me against these risks?

The highest risk is being frustrated if hardware is difficult to use or the vehicle is hard to maneuver in. There may also be risk of discomfort if our seatbelt system doesn’t fit you well. There is also a risk of you falling out of the wheelchair as you transfer or maneuver in and out of the vehicle. The researchers will try to minimize these risks by padding surfaces and having an experimenter close by to help if needed.

Because this study collects information about you, one of the risks of this research is a loss of confidentiality. See Section 8 of this document for more information on how the study team will protect your confidentiality and privacy.

5.2 How could I benefit if I take part in this study? How could others benefit?

You may not receive any personal benefits from being in this study. Results from the study will be used to vehicles that should make it easier and safer to travel while seated in a wheelchair.

6. ENDING THE STUDY

6.1 If I want to stop participating in the study, what should I do?

You are free to leave the study at any time. If you leave the study before it is finished, there will be no penalty to you. If you decide to leave the study before it is finished, please tell one of the persons listed in Section 9. “Contact Information”. If you choose to tell the researchers why you are leaving the study, your reasons may be kept as part of the study record. The researchers will keep the information collected about you for the research unless you ask us to delete it from our records. If the researchers have already used your information in a research analysis it will not be possible to remove your information.

If you are unable to use the test wheelchairs safely, we will end your participation in the study.

7. FINANCIAL INFORMATION

7.1 Will I be paid or given anything for taking part in this study? You will receive $40 for your participation in the study. If you decide to withdraw from the study early, we will pay you $12/hour, rounded to the nearest 15 minutes. You will be responsible for arranging transportation to and from the UMTRI lab. There will be no charge for parking.

8. PROTECTING AND SHARING RESEARCH INFORMATION

8.1 How will the researchers protect my information?

We will give you a subject code number. All of your data will only be identified with this code. Information with your name on it, such as recruitment and payment forms, will be stored separately and destroyed after 3 years. All of your data, photos, and video recordings collected at UMTRI will be stored on a password-protected server. If you give consent on this form and we use pictures or videos of you in a report or presentation, we will blur the images whenever possible.

8.2 Who will have access to my research records?

There are reasons why information about you may be used or seen by the researchers or others during or after this study. Examples include:

- University, government officials, study sponsors or funders, auditors, and/or the Institutional Review Board (IRB) may need the information to make sure that the study is done in a safe and proper manner.

8.3 What will happen to the information collected in this study?

We will keep the information we collect about you during the research for future research projects. Information, video, and photos will be saved locally and will be shared with collaborators to guide future design improvements. Your name and other information that can directly identify you will be stored securely and separately from the research information we collected from you.

The results of this study could be published in an article or presentation, but will not include your name that would let others know who you are. We will blur your face in photos and videos where possible, but people might be able to recognize you from videos in presentations.

We will not keep your name or other information that can identify you directly, unless you agree that we can contact you for future studies.

8.4 Will my information be used for future research or shared with others?

We may use or share your research information for future research studies. Future research may be similar to this study or completely different. We will not ask for your additional informed consent for these studies.

If we share your measurement and survey information with other researchers it will be de-identified, which means that it will not contain your name or other information that can directly identify you. We would like to share your identifiable information (photos and videos) with other researchers for future research. We will ask for your consent to do so at the end of this form. We will only try to blur your face in photos and videos (when possible) in presentations and reports. Because the photos and videos are a main part of our data collection, you cannot be a part of this current research project without agreeing to this future use of your identifiable information.

9. CONTACT INFORMATION

Who can I contact about this study?

Please contact the researchers listed below to:

- Obtain more information about the study
- Ask a question about the study procedures
- Report an illness, injury, or other problem (you may also need to tell your regular doctors)
- Leave the study before it is finished
- Express a concern about the study

Principal Investigator: Kathleen D. Klinich, PhD

Email: kklinich@umich.edu

Phone: (734) 936-1113

Study Coordinator: Nichole Orton

Email: nritchie@umich.edu

Phone: (734) 936-1107

If you have questions about your rights as a research participant, or wish to obtain information, ask questions or discuss any concerns about this study with someone other than the researcher(s), please contact the following:

University of Michigan

Health Sciences and Behavioral Sciences Institutional Review Board (IRB-HSBS)
2800 Plymouth Road
Building 520, Room 1169Ann Arbor, MI 48109-2800
Telephone: 734-936-0933 or toll free (866) 936-0933 Fax: 734-936-1852

E-mail: irbhsbs@umich.edu

You can also contact the University of Michigan Compliance Hotline at 1-866-990-0111.

10. YOUR CONSENT

Consent to Participate in the Research Study

By signing this document, you are agreeing to be in this study. Make sure you understand what the study is about before you sign. We will give you a copy of this document for your records and we will keep a copy with the study records. If you have any questions about the study after you sign this document, you can contact the study team using the information in Section 9 provided above.

I understand what the study is about and my questions so far have been answered. I agree to take part in this study.

Print Legal Name: ____

Signature: ____

Date of Signature (mm/dd/yy): ______________________________________

11. OPTIONAL CONSENT

Consent to use of video recordings, audio recordings or photographs for publications, presentations or for educational purposes.
I give permission for audio recordings/video recordings/photographs made of me as part the research to be used in publications, presentations or for educational purposes. I understand that photos and videos used in reports and presentations will be blurred when possible, but that I may be recognizable.

_____

_____ Yes

_____ No

Print Legal Name: ____

Signature: ____

Date of Signature (mm/dd/yy): ____________________________________

Consent to use and/or share your identifiable information for future research
The researchers would like to use your identifiable information for future research that may be similar to or completely different from this research project. Identifiable means that the data will contain information that can be used to directly identify you. The study team will not contact you for additional consent to this future research. We may also share your identifiable information with other researchers. You can contact us at any time to ask us to stop using your information. However, we will not be able to take back your information from research projects that have already used it.

_____ Yes, I agree to let the researcher(s) use or share my personally identifiable information for future research.

_____ No, I do not agree to let the researcher(s) use or share my personally identifiable information for future research.

Print Legal Name: ____

Signature: ____

Date of Signature (mm/dd/yy): ____________________________________

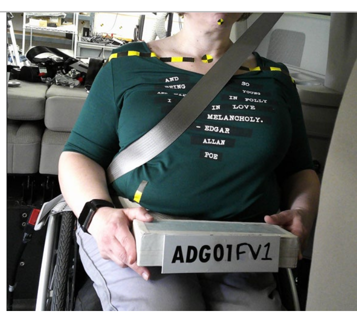
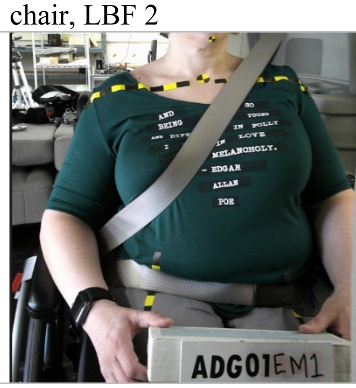
Consent to be Contacted for Participation in Future Research

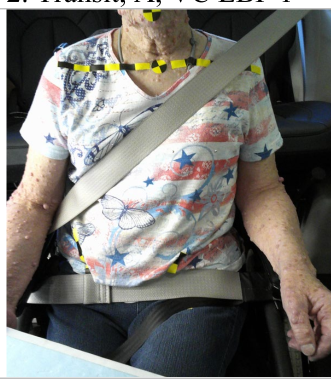
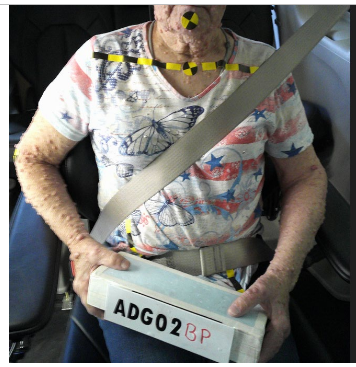
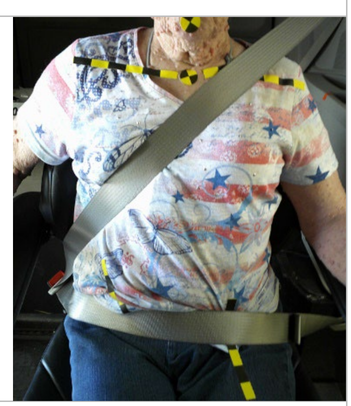
Researchers may wish to keep your contact information to invite you to be in future research projects that may be similar to or completely different from this research project.

_____ Yes, I agree for the researchers to contact me for future research projects.

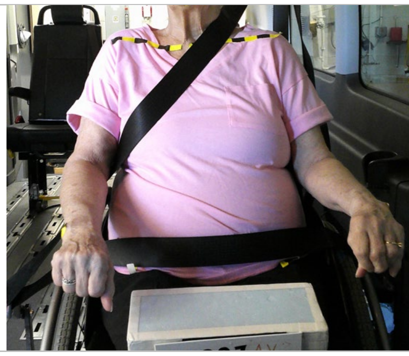
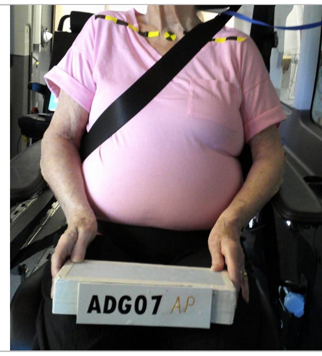
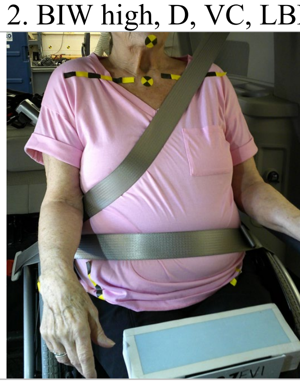
_____ No, I do not agree for the researchers to contact me for future research projects.

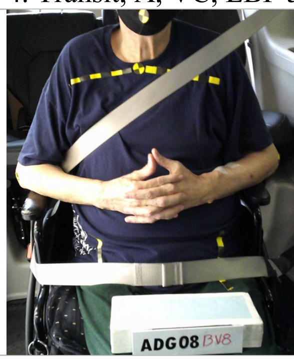
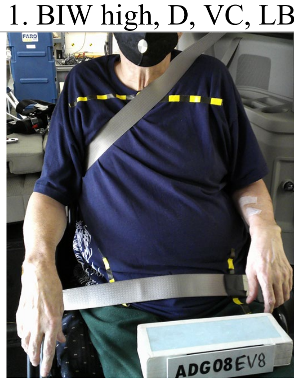
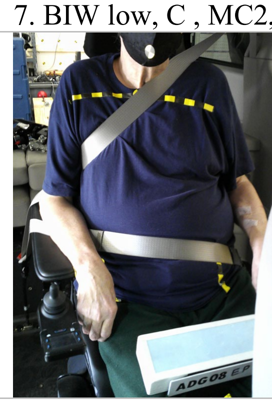
Appendix B: Photos of volunteers in each condition

Cond	ADG01 Trials 1-4	ADG01 Trials 5&8	ADG01 Trials 6&7
A			
	1. Transit, A, VC, LBF 2		7. Transit, A, MC2, LBF 1
B			
	2. Pacifica, B, VC, LBF 2		
CD			
	3. BIW low, C, VC, LBF 2	5. BIW high, D , Power chair, LBF 2	6. BIW low, C, MC2, LBF 1
EF			
	4. T&C apron, F, VC, LBF 3	8. T&C baseline, E, MC1, LBF	

Cond	ADG02 Trials 1-4	ADG02 Trials 5, 6, &7	ADG02 Trial 8
A			
	2. Transit, A, VC LBF 1		
B			
	4. Pacifica, B, VC, LBF 1	7. Pacifica, B, PW, LBF 2	
CD			
	1. BIW low, C, VC, LBF 2	6. BIW high, D , MC1, LBF 1	
EF			
	3. T&C apron, F, VC, LBF 1	5. T&C apron, F, MC2, LBF 2	8. T&C baseline, E, PW, LBF 2

Cond	ADG05 Trials 1-4	ADG05 Trials 5 & 6	ADG05 Trials 7& 8
A			
	1. Transit, A, VC, LBF 3		
B			
	4. Pacifica, B, VC, LBF 2		
CD			
	3. BIW low, C, VC, LBF 2	6. BIW high, D , MC2, LBF 1	7. BIW low, C , MC2, LBF 1
EF			
	2. T&C apron, F, VC, LBF 2	5. T&C baseline, E, PW, LBF 2	8. T&C apron, F, MC1, LBF 5

Cond	ADG07 Trials 1-4	ADG07 Trials 5-8	
A			
	3. Transit, A, VC, LBF3	5. Transit, A, Power Chair, LBF 2	
B			
	1. Pacifica, B, VC, LBF 2	8. Pacifica, B, MC1, LBF 2	
CD			
	2. BIW high, D, VC, LBF 2	6. BIW low, C , Power Chair, LBF 2	
EF			
	4. T&C baseline, E, VC, LBF 5	7. T&C baseline, E, MC2, LBF 3	

Cond	ADG08 Trials 1-4.	ADG08 Trials 5 &6	ADG08 Trials 7 & 8
A			
	4. Transit, A, VC, LBF 5		
B			
	2. Pacifica, B, VC, LBF 2		
CD			
	1. BIW high, D, VC, LBF 1	5. BIW high, D , MC2, LBF 2	7. BIW low, C , MC2, LBF 1
EF			
	3. T&C baseline, E, VC, LBF 2	6. T&C apron, F, MC1, LBF 5	8. T&C baseline, E, PW, LBF 5