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RESEARCH PAPER

Design of built environments to accommodate mobility scooter users: part II

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Abstract

Purpose. Accessibility standards for wheeled mobility devices currently use a 1.5 m turning circle, designed to accommodate manual wheelchairs. Scooters are less manoeuvrable than wheelchairs, so allowing a full turning circle would require too much space. Instead, we propose using a rectangle that provides space for a three-point turn. Here, we determine the area requirements of this approach.

Method. For rectangular 'rooms' of varying aspect ratios, we measured the minimum dimensions in which two four-wheeled scooters (the Celebrity-X and Fortress-1700), which combine good outdoor performance with reasonable indoor manoeuvrability, could enter the space, perform a three-point turn and exit. Moveable Styrofoam walls defined each 'room', and a doorway was located either near the corner of the space or in the middle of one wall. 'Room' size was decreased until our expert driver could no longer perform the manoeuvre.

Results. Compared to the area required for a turning circle, 42–54% savings were achieved. Relative to existing requirements, 53–95% more space is required to accommodate the Celebrity-X; 173–223% increases are necessary for the Fortress-1700.

Conclusions. When accommodating four-wheeled scooters, our proposed three-point turn definition would require more space than the current standards, but considerably less than if a full turning circle were used.

Keywords: *Architectural accessibility, assistive technology, disabled persons, mobility limitation, mobility scooter*

Introduction

Scooters are a class of powered wheeled assistive mobility devices designed for people who have good upper body control but difficulty in walking [1,2]. While many of these users can walk short distances, they need their scooters to overcome distance limitations and conserve energy for desired activities.

Scooters are far less expensive than powered wheelchairs, the other major class of powered wheeled assistive mobility device. Perhaps as a result of this, scooters are becoming an increasingly popular mode of transport [3–5]. It is projected that 'powered scooter use will soon exceed power wheelchair use' in the US and UK [6].

Whereas existing access standards are typically based on the requirements of the manual wheelchair, there is increasing recognition that other mobility devices must be considered as standards are updated. In Canada, the Province of Ontario has expressed interest in modifying its indoor built environment accessibility standards to allow access for users of mobility scooters that are also designed to allow adequate outdoor mobility [7].

Scooters tend to be larger and less manoeuvrable than wheelchairs. This is particularly true of those providing safe outdoor performance in rural environments and locations which experience colder winter weather. Unless space savings can be found in other areas, a move to accommodate scooters in the indoor built environment would therefore come

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at a cost to builders, since the costs of a building are generally proportional to its floor area. There is an ongoing debate about the balance that should be struck between affordability and access in accommodating scooter users in the built environment.

To inform the development of new built environment access standards, there is a limited but growing body of literature describing the size [8–13] and manoeuvrability [11–13] of both powered wheelchairs and mobility scooters. Two of these studies, by the Universal Design Institute (UDI) in Manitoba [11] and the IDeA Centre in Buffalo, NY [12], have collectively measured the turning space required by 147 participants driving their usual powered mobility devices. Only 24 of these participants were scooter users. The turning diameters measured by Ringaert at the UDI (n=14) ranged from 1186 to 3622 mm, averaging 2107 mm for clockwise and 2128 mm for counter clockwise turns. The range of turning diameters measured by Steinfeld and the IDeA Centre was smaller (1900–2500 mm, n=10), but the average was quite similar, at 2020 mm. While the sample sizes are low, it is worth noting that very few of the tested scooters would be accommodated within the 1500 mm turning circle currently allowed by the Canadian and US accessibility standards [14,15]. Allowing turning space for even the 'average' scooter in these studies would require more than doubling the turning space allowances, while the largest scooters would require three times (IDeA Centre) to six times (UDI) the existing space. A previous study at Toronto Rehabilitation Institute [13] used an expert driver to test the manoeuvrability of five scooter models, each of which was identified by the manufacturers as having a good combination of manoeuvrability and outdoor performance. The turning diameters of these scooters ranged from 2080 to 3940 mm, requiring turning space increases ranging from two to seven times the existing allowance. Clearly, the upper bounds of these ranges are prohibitive.

Here, we propose that as an alternative to providing a full turning circle for scooters, a more reasonable requirement would be that a scooter could be driven forward into a space, perform a three-point turn, and drive out facing in the direction of travel. Our pilot testing indicated that a three-point turn would not be prohibitively difficult or time-consuming for drivers, whereas greater difficulty and frustration would be likely if the space were sized only to accommodate multi-point turns that require more than three manoeuvres (e.g., five, seven or nine points). Since scooter users typically have some mobility (although this is frequently limited) it is not always necessary to be able to access all parts of the room while seated on the scooter. In cases where that are desirable, it may still be appropriate to provide space for a full turning circle; however, in spaces in other cases where turning space is required by accessibility guidelines, such as court rooms and locker rooms, the approach we propose may provide adequate accessibility without being prohibitive.

The goal of this study is to determine the areas and aspect ratios of rectangles that would allow just enough space for each of our selected scooters to enter, be driven through the three-point turn manoeuvre and exit. Of particular interest are the dimensions which allow the manoeuvre to be completed in the minimum area for each scooter, and comparisons of the resulting areas to both the existing standards and to the areas required to accommodate full turning circles.

Methods

Scooter selection

We used two scooter models for this study: the four-wheeled Celebrity X (CX; Figure 1a; Pride Mobility Products Corporation, Exeter, Pennsylvania) and the four-wheeled Fortress 1700 (F4; Figure 1b; Handicare, Moss, Norway). These scooters were chosen from a larger set of five scooters that were used in our first study [13] and were identified as the two which offered the best compromise between

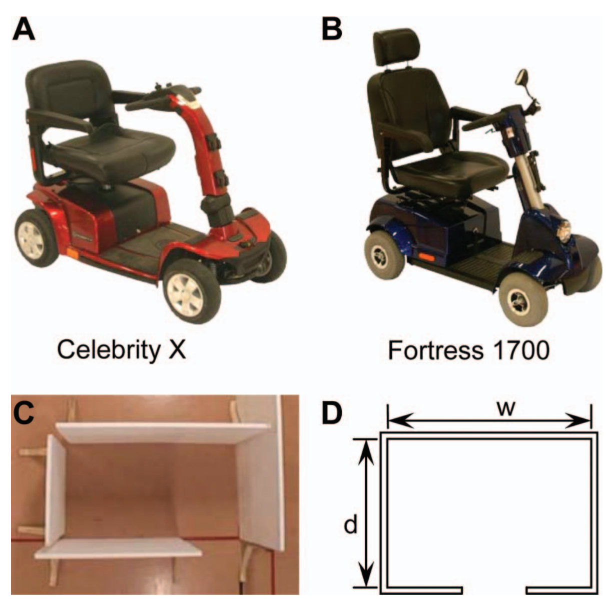

Figure 1. Photographs of the four-wheeled models of the Celebrity X (CX; panel A) and Fortress 1700 (F4; panel B). Panel C is a photograph of one of the rectangular 'rooms', taken by our overhead camera. In this example, the doorway is located near the corner of the space. A schematic of a 'room' with a doorway in the middle of the wall is given in panel D. The width w (dimension containing the doorway) and depth d are identified for reference.

manoeuvrability and performance. Our selection process was as follows:

1. Shoppers Home Health Care (Shoppers), the largest retailer of scooters in Ontario, Canada, approached scooter manufacturers on our behalf and asked them to recommend the scooters that they felt had the best combination of indoor mobility and outdoor performance. In total, five scooter models were provided for testing: the four-wheeled Fortress Winner and the three- and four-wheeled versions of the Fortress 1700 from Handicare (Moss, Norway), and the Victory Twin and four-wheeled Celebrity X from Pride Mobility Products Corporation (Exeter, Pennsylvania).
2. Based on the results of our first study [13], we were able to rank the manoeuvrability of these scooters as follows: Victory Twin (most manoeuvrable), three-wheeled Fortress 1700, Celebrity X, four-wheeled Fortress 1700 and Fortress Winner (least manoeuvrable).
3. A survey approach was used to determine which scooters would offer acceptable year-round mobility in small communities in Ontario. Telephone surveys were conducted with the managers of eight Shoppers stores in rural and northern Ontario to determine which of the five scooters would represent acceptable mobility solutions in their sales areas. The results indicated a universal preference for four-wheeled scooters. In most of the surveyed areas (6/8), mid-sized scooters similar to the F4 were preferred, although for three of these communities the CX was also considered acceptable. In the wide but sparsely populated sales areas served by the Timmins and Dryden stores, larger scooters such as the Fortress Winner were considered necessary. However, store managers reported that scooters were often used to replace cars in these areas, rather than as a substitute for walking.

Based on our previous performance testing [13] and the limited survey data, it appears that, depending on the community, either the CX or the F4 represents the minimum acceptable performance level to provide reasonable outdoor mobility. Both are tested to broaden the applicability of our findings.

Scooter configurations

Both scooters were rear-wheel driven, and both were tested with their factory-set acceleration/deceleration controls. Their dimensions and turning diameters are given in Table I. To ensure that our measurements reflected the basic capabilities of each scooter, we removed their baskets and tucked in the F4's rear-view mirror for all of our measurements and testing sessions. These aspects of the scooter setup can easily be modified or redesigned to minimise their impact on the scooter's manoeuvring space requirements.

Scooter driver

All driving for this study was performed by the same expert driver who drove for the companion study (male, age 25, seven years of scooter driving experience using two scooters: the four-wheeled Fortress 1700 and the four-wheeled Golden Companion) [13]. He was referred to us by Shoppers, and selected because he had won their scooter driving skills competition. The competition consisted of an all-terrain obstacle course (over bumps, gravel and a teeter-totter) and a test of the contestants' ability to manoeuvre through tight spaces without contacting a boundary marked by pylons. All contestants used the same scooter, provided by the contest organisers. Our driver finished first overall in the contest, having competed against over 100 other scooter users, including a number of professional scooter sales agents. Our expert driver provided informed consent to participate in the study, which was approved by the institutional research ethics board.

Protocol

We performed our testing using the same equipment and general protocol as in Part I, where it is described in detail [13]. Briefly, we constructed rectangular 'rooms' using tall (1830 mm [6] high), freestanding, moveable Styrofoam walls (Figure 1c), similar to those used in other accessibility studies [16]. Our goal was to determine the minimum dimensions in which the required manoeuvre could be performed for rectangles with a range of aspect ratios, in addition to determining the dimensions and that would minimise overall space usage. To do this, we fixed one dimension (either the depth or width), then incrementally reduced the other dimension until it was no longer possible for our driver to complete the three-point turn and exit through the doorway. We would then adjust the primary dimension and repeat the procedure. For each combination of dimensions, our driver was allowed up to three attempts to successfully complete the manoeuvre. At the beginning of a testing session and whenever the primary dimension was adjusted, a practice round

Table I. Basic measurements of scooter dimensions and turning diameters.

Scooter	Length (mm)	Width (mm)	Turning diameter (mm, measured) [13]		Area for full turning circle (m^2)*
			Left	Right	
Celebrity X (CX)	1260	700	2620	2740	5.9
Fortress 1700 (F4)	1290	710	3510	3660	10.5

*Based on the larger of the left or right turning diameter.

was added in which the driver was allowed four attempts to complete the first manoeuvre, rather than the usual three. We deemed a manoeuvre to have been completed successfully if the entry, three-point turn and exit were completed without moving any of the walls (as determined by visual observation and confirmed by reviewing overhead video footage), a similar criterion to the one used by Steinfeld et al. in the IDeA Center study [17]. Testing for this study was completed over 3 days, with each testing session lasting approximately 4 h. A 15-min break was provided after the first 2 h.

Pilot testing clearly showed that the entry and exit points to a space, such as doorways, have a substantial impact on the dimensions necessary to complete the required three-point turn. We, therefore, performed our testing using the two most extreme access points: close to the corner (Figure 1c) and in the middle of one wall (Figure 1d). Gaps measuring 865 mm (34″) were left in the wall to represent these 'doorways'. This dimension has been selected as the new minimum clear doorway width by the Province of Ontario [18].

During testing, all dimensions were measured using a tape measure to within an accuracy of ±25 mm (1″). We video-recorded all trials using a Sony Handycam HDR-SR1 camcorder mounted overhead (sample view shown in Figure 1c). These video-recordings were used to examine the paths travelled by the scooter driver and to verify the results for each condition.

Results

The minimum dimensional requirements for each doorway location and a wide range of aspect ratios for each scooter are shown in Figure 2. The resulting areas are shown in Figure 3. Minimum area requirements were also computed for each scooter in each condition. These results are summarised in Table II, where they are compared to the area requirements of the current standard. The space savings of this approach over using the full turning circle of the scooters are also calculated.

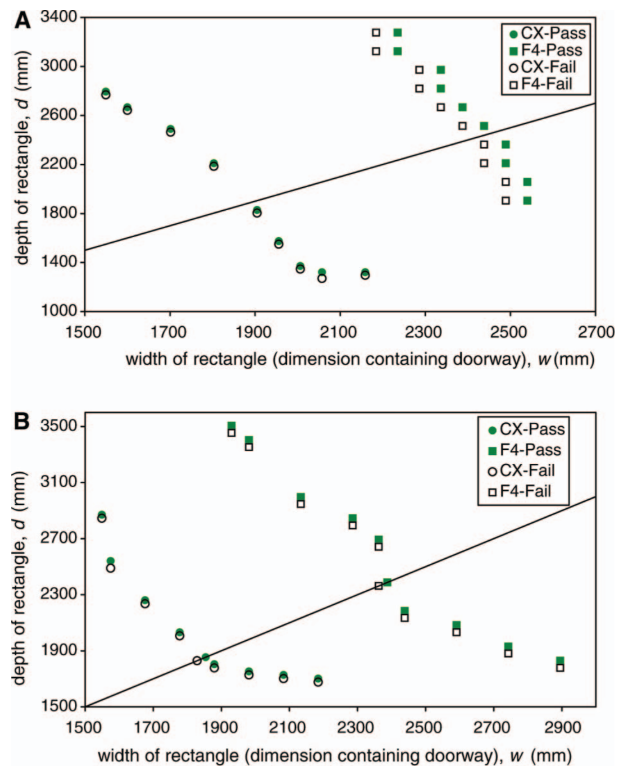

Figure 2. Minimum rectangle dimensions achieved by our driver for rectangles accessed from a corner 'doorway' (panel A) and in the middle (panel B) of the entry wall. Lines indicating the

Corner doorway

With the doorway near the corner of the space, the relationship between depth and width varied similarly for the CX and the F4 (Figure 2a), with the required depth, *d*, declining steadily with increases in the width, *w* (see Figure 1d for labelling convention).

For the CX, *d* declined with increases in *w* at a ratio of about 3:1 until a value of 2060 mm (81″), after which no further reduction in *d* could be gained, regardless of how far *w* was increased. The other bound of the plot is at the lower limit of *w* for which the three-point turn was possible. This value, 1550 mm (61″), corresponds to the minimum corridor width in which a three-point turn can be performed [13]. The minimum area requirement was found at the point where the dimensions were 2060 mm × 1320 mm (81″ × 52″) – giving an area of 2.7 m^2 (29 sq ft), an increase of only 56% over the area required by the current standard.

In testing the F4, we started with *d* set to the minimum corridor width in which a three-point turn could be performed (1900 mm [75″]) [13], and continued to increase *d* incrementally through the range of interest. The dimensional changes followed a similar trend to those of the CX, although the slope of the curve was steeper at approximately 4:1 (Figure 2a). Over the range tested, the minimum area requirement for the F4 was found at the dimensions 2540 mm × 1900 mm (100″ × 75″), requiring an increase in area of 173% over the current standard.

Despite trying other strategies in early or failed trials, our scooter driver used the same basic strategy for all of his manoeuvres in successful minimum dimension trials. Examples of the paths driven for this condition are shown in Figure 4a & 4b.

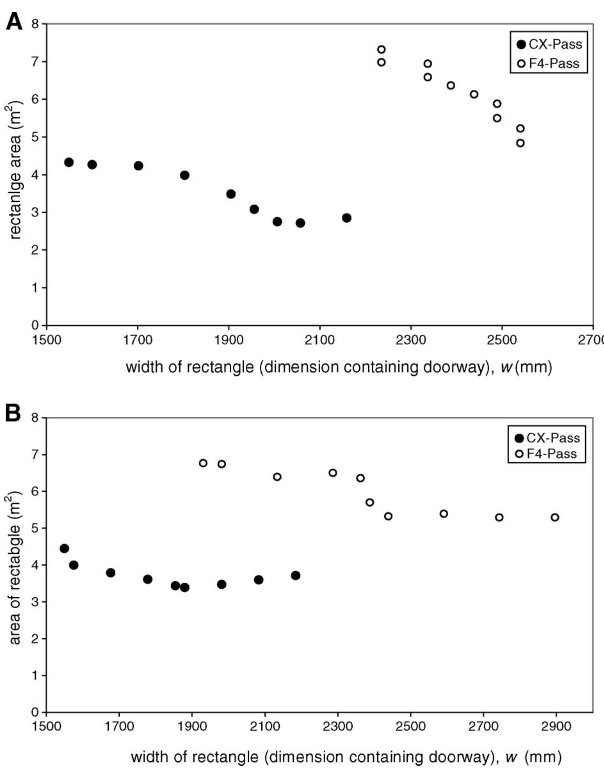

Figure 3. Areas corresponding to measured minimum dimensions (from Figure 2) in which the driver could complete the required manoeuvre. With the doorway near the corner, the areas required were lowest in wide, shallow spaces. When the doorway was in the middle of one wall, the minimum was achieved when a square space was used.

Middle doorway

When the doorway was in the middle of the entry wall, the lower bound of dimension *w* for each scooter corresponds to the minimum corridor width in which a three-point turn can be completed successfully [13]. While this might be expected to provide the minimum dimension for *d* as well, the paths driven are such that the additional space required to get into position for the three-point turn within the space would require increasing dimension *w* impractically. We finished testing for this condition when it was clear that no major gains in *d* would be found for a given increase in *w*.

For both scooters, the minimum areas were achieved when a square space was used for the manoeuvre. The minimum area points were found for squares with sides 1850 mm (73″) and 2390 mm (94″) long for the CX and F4, respectively. These dimensions require increases in area over the current standard of 94% (CX) and 223% (F4), but both represent considerable savings when compared to a full turning circle – for both scooters, the savings in area are greater than 40%.

The progression of minimum depths at each width varied less consistently between the two scooters than when the doorway was near the corner of the space (Figure 2b). The main difference is the appearance of a bulge in the graph for the F4 when the rectangle is a little deeper than it is wide. The reasons for this become clearer with a more detailed look at the paths driven (Figure 4). The limiting factor in this case is in the third leg of the manoeuvre. When the space is narrow (as in Figure 4c), the driver must turn through more than a quarter of a circle in order to exit through the doorway. This

Table II. Minimum area requirements using the proposed 3-point-turn criterion.

	Width	Depth	Area	% Increase *vs.* current standard	% Savings *vs.* full turning circle*
Celebrity X					
Corner doorway	2060 mm (81″)	1320 mm (52″)	2.7 m^2 (29 sq ft)	53%	54%
Middle doorway	1850 mm (73″)	1850 mm (73″)	3.4 m^2 (37 sq ft)	94%	42%
Fortress 1700					
Corner doorway	2540 mm (100″)	1900 mm (75″)	4.8 m^2 (52 sq ft)	173%	54%
Middle doorway	2390 mm (94″)	2390 mm (94″)	5.7 m^2 (61 sq ft)	223%	46%

*Comparison based on the larger of the left or right turning diameter.

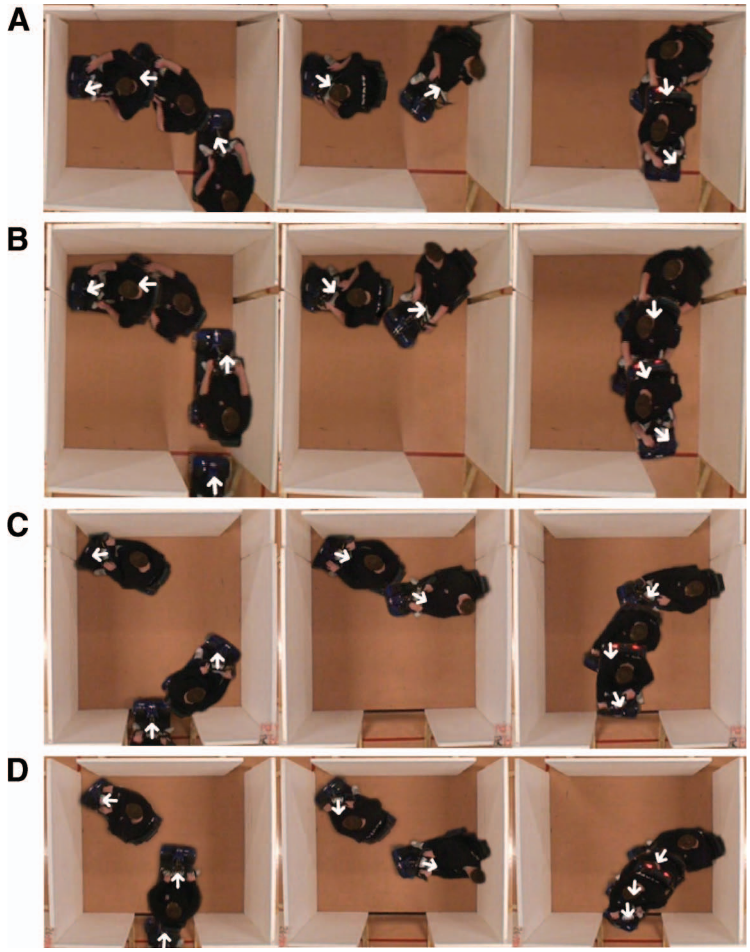

Figure 4. Examples of the paths driven by our expert driver, separated into the three 'legs' of the three-point turn manoeuvre (from left to right: entry, reverse, exit). The white arrows indicate the direction of travel, perpendicular to the steering column. The same driving strategy was used with each scooter, and there was a smooth progression in driving strategy as the spaces transitioned from narrow and deep to wide and shallow. Panels A and B show the driving strategies used for wider and narrower rectangles, respectively, when the doorway was near the corner; panels C and D show this with the doorway in the middle of one wall. Note that in panel C, the scooter needs to 'double-back' slightly over the width of the space in order to exit through the middle doorway, whereas this is unnecessary for the path driven in panel D. All examples show the F4 scooter.

causes a small doubling-back across the width of the space, leading to noticeable increases in the required depth for given widths. When this doubling-back is no longer necessary (as in Figure 4d), the rectangle depth required for a given width decreases sharply. The same phenomenon is present for the CX, but is less pronounced because the turning radius of the CX is much lower compared to the length and width of the scooter than is the case for the F4.

Discussion

We began by proposing a definition of an accessible turning space for a scooter based on a clear rectangle which would allow a scooter to drive in facing forward, perform a three-point turn, and exit facing in the direction of travel. For the two scooters tested, we have found the minimum dimensions required to accommodate this definition over a wide range of aspect ratios. While increases over the current area requirements for accommodating wheeled mobility devices will still be necessary, the increases required to accommodate our proposed definition are far lower than would be necessary if the current standards were extended directly to require a full turning circle.

Existing space allowances for turning around are based on the 1.5 m turning circle (area 1.8 m^2) required by occupied manual wheelchairs in the 1970s [6,16]. Based on our proposed definitions, scooters with the turning characteristics of the CX would require increases in this floor area of 54–94% over the current requirement, depending on doorway location, as opposed to an area increase of 234% (more than triple the existing floor space requirement) if the traditional turning circle definitions were used. Accommodation of the F4 would require increasing floor area allowances by 173–223%, as opposed to the increase of 495% (six times) that would be required by the turning circle definition.

In addition to finding the dimensions which minimise additional space usage, we have also tested and reported the minimum dimensions which would provide adequate access for rectangles of a wide range of aspect ratios. We report them because while they do add some complexity, these shapes may, in some cases, be easier or cheaper for built-environment designers to incorporate into their plans.

We deliberately tested only two doorway locations in the interests of supporting a clear, easily understood guideline. We propose that for instances in which building designs require an access point which is not at either the middle or end of one of the bounding walls, the requirement should be that the clear turning space include one of the 'accessible rectangles', anchored at the doorway or other access point. For example, if a doorway were offset slightly from the nearest side wall, the corner doorway space allowance requirement would still apply. This would make the guideline easy to understand and apply.

It is interesting to note that despite similar size, the four-wheeled models of the Celebrity X and Fortress 1700 have very different turning diameters and hence very different space requirements for manoeuvring. The turning radius of a scooter affects how accessible built environments are for the driver, and should be given careful consideration when designing or purchasing a scooter. However, it should also be noted that while three-wheeled scooters generally have far tighter turning radii than those with four wheels, they also have less inherent stability. In Canada, Veterans Affairs has adopted a policy that 'As a safety consideration ... only four-wheeled models will normally be approved [for funding]. Three-wheeled scooters will only be considered in exceptional circumstances' [19]. Safety, performance and manoeuvrability considerations must be balanced by both manufacturers and consumers to provide optimal mobility assistance.

Study limitations

Those interested in providing accessibility and setting standards should note that our intent in this study is to demonstrate a concept, rather than specifying actual dimensions: we performed this study using two currently available four-wheeled scooters designed to provide a good combination of manoeuvrability and outdoor mobility. These scooters were identified as such by the manufacturers and retailers. Verification of the acceptability of these scooters for outdoor use in challenging conditions is still in progress.

Our focus on scooters with good outdoor performance was based on the Ontario environment. For regions with less demanding outdoor environments, the minimum performance required for adequate outdoor mobility may permit the selection of a smaller scooter, or one with better manoeuvring characteristics. However, the concept described in this report may still provide a means of minimising any required changes to the turning space allowances specified by wheeled mobility device access guidelines.

A further point to emphasise is that the driving was performed under conditions which tested the best possible manoeuvring characteristics of the scooter. The driving was performed by an expert with good upper-body mobility, and we allowed him to take his time in performing each manoeuvre. Small increases in dimensions would be necessary to allow for differences in driver skill levels, differing driver body sizes and capabilities, and the need to accomplish the manoeuvre in a reasonably short time. Further study will be required to establish what allowances should to be made for these factors.

During our testing, we also chose to level the playing field for the scooters by removing their baskets and tucking in rear-view mirrors, since these elements are easy to modify. While this showcases the optimal mobility characteristics of each scooter, it should be taken into account that most scooter users do carry baskets, backpacks, oxygen tanks, canes or other accoutrements which increase the footprint of their scooters [12,20]. Further space allowances may be necessary to accommodate these customisations, but manufacturers and consumers should also bear in mind the effects on manoeuvring characteristics when designing and installing these additional elements.

In this series of tests, we used representative doorway openings rather than full doors. In applying the concept demonstrated in this article, it will be important to ensure that clear manoeuvring space is provided in the 'accessible rectangles', and that this are not obstructed by doors.

Conclusion

When extending accessibility guidelines to accommodate four-wheeled scooters, use of the proposed three-point turn rectangle as an alternative to the traditional turning circle would provide considerable space savings, although increases will still be required over the current space allowances. For spaces entered through a doorway near the corner of the long side of the rectangle, we found a 54% space saving for both scooters using the proposed definition; for rectangles with doorways in the middle of the wall or at the end of the short side, space savings of 42–46% were possible. We expect these trends to generalise to other 4-wheeled scooter models.

Our hope is that the adoption of accessibility standards based on the minimum rectangles which permit three-point turning will be feasible in contrast to a requirement to accommodate the full turning circle, which we anticipate may be rejected on the grounds of impractical cost. We also hope that scooter manufacturers will be able to advertise their products with reference to their ability to operate within such new standard rectangular dimensions.

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