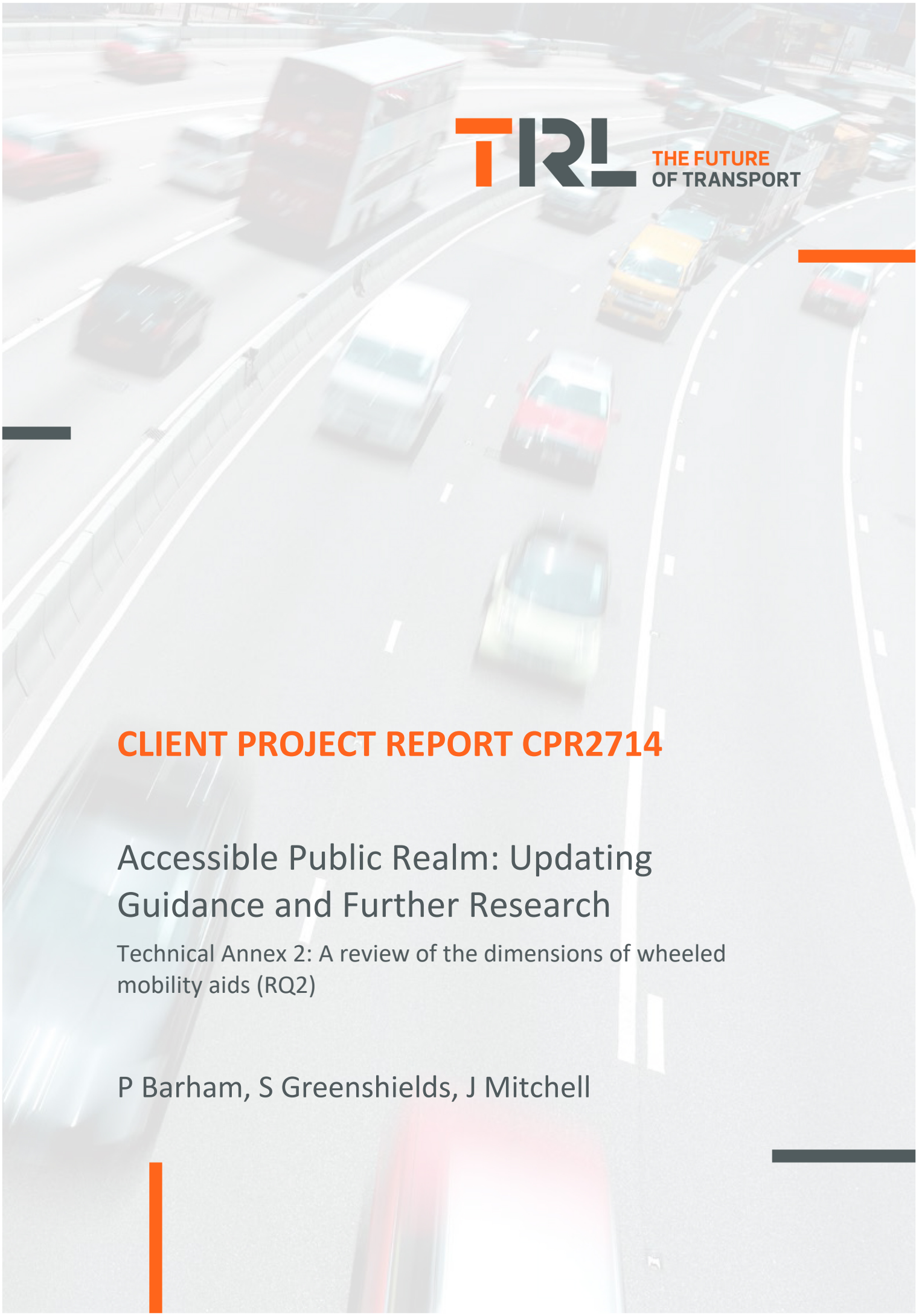

THE FUTURE OF TRANSPORT

CLIENT PROJECT REPORT CPR2714

Accessible Public Realm: Updating Guidance and Further Research

Technical Annex 2: A review of the dimensions of wheeled mobility aids (RQ2)

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Report details

Report prepared for:	Department for Transport		
Copyright:	© TRL Limited		
Report date:	January 2020		
Report status/version:	V5		
Quality approval:			
Anastasia Kounatidou (Project Manager)		Marcus Jones (Technical Reviewer)	

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Executive Summary

This document forms a Technical Annex to the report *Accessible Public Realm: Updating Guidance and Further Research* prepared by TRL for DfT. It reports work undertaken in response to Research Question 2 of the project which investigates the dimensions of wheeled mobility devices.

On the advice of representatives of the wheeled mobility device industry, information on the dimensions of current devices on the UK market was obtained from two key online databases, administered by the British Healthcare Trades Association (BHTA) and the Research Institute for Disabled Consumers (RiDC). These data were supplemented by empirical measurements of the dimensions of occupied wheeled mobility aids, carried out at two mobility-related events. In addition, a review of standards and research reports was undertaken, and the advice of a small sample of wheeled mobility device manufacturers was sought.

The two events at which measurements were made of occupied wheeled mobility devices both took place at the NEC, Birmingham. They were Naidex (March 26-27, 2019) and The Big Event (June 28-29, 2019). Measurements were made using a combination of photogrammetry, using a digital camera mounted on a tripod, and some manual measurements using a tape measure.

The key findings from the empirical measurements and the databases reviewed were that, considering the 95th percentile of wheeled mobility devices currently on the market in the UK:

- There has been an increase in the length
- The width has decreased slightly
- The lap height of occupants has increased slightly
- Evidence for changes in seated height (and hence eye height) is inconclusive.

It is important to bear in mind that these conclusions are based on a combination of surveys at events and industry data. No quantitative evidence was found on the prevalence of wheeled mobility aids of different sizes in the UK nor on the number of trips undertaken or the types of environment where they are used. The increase in length observed is at least in part due to greater availability of electric mobility scooters, some of which are primarily intended for outdoor and on road use. In the absence of data on the frequency of use of each type of mobility device it is not possible to conclude that there is an increase in the number of users who might be disadvantaged by size constraints.

Given the lack of evidence on the prevalence of different categories of mobility devices in the UK, it was concluded that the evidence for increased availability of some larger devices on the market is not currently sufficient to justify recommending changes to the minimum dimensions of public transport infrastructure and pedestrian facilities. Existing evidence suggests that the minimum length specified in *Inclusive Mobility* is still sufficient for attendant-propelled wheelchairs, active wheelchairs, electric wheelchairs and Class 2 mobility scooters. Further research is needed to obtain robust evidence on the prevalence and use of different classes (particularly sizes) of wheeled mobility device.

1 Introduction

1.1 This document

This document forms a Technical Annex to the report *Accessible Public Realm: Updating Guidance and Further Research* prepared by TRL for DfT. It sets out the detailed methodology, findings and recommendations from work undertaken in response to Research Question 2 (RQ2) of the project which investigates the dimensions of wheeled mobility devices.

1.2 Scope of this Research Question

Inclusive Mobility provides design guidance on the basis of specific human factors information on different types of public transport user, including the users of different types of mobility aid. Research Question RQ2 considers whether the human factors information on which the guidance is founded has changed significantly since *Inclusive Mobility* was issued, and, if so, the extent to which important dimensions have changed. If there is evidence for change, then RQ2 will address the issue of the extent to which the design guidance included in the publication should be updated as a result.

A three-pronged approach to collecting evidence to respond to this research question has been used:

- Direct measurement of a sample of occupied wheeled mobility aids
- A review of wheeled mobility aids currently available in the UK, (evidence for any increase in the size of devices in response to market demand being considered to be an indication of changes in the needs of wheeled mobility aid users)
- Consultation with various organisations representing and regulating the medical devices and mobility equipment industry

A limited review of standards and research reports was also undertaken for the purpose of verifying the relevance of the categories of wheeled mobility aids used in *Inclusive Mobility*, and to obtain research results from elsewhere that can be used to corroborate the results of the direct measurement of occupied devices.

2 Categories of wheeled mobility aid

Categories of wheeled mobility aid used in *Inclusive Mobility* are: attendant propelled; electric wheelchairs; new style manual chairs; older style manual chairs; electric scooters. The study investigated whether it would be more appropriate for an alternative set of categories to be used.

In order to gather this information:

- Standards and research reports issued since the publication of *Inclusive Mobility* were consulted, to ascertain the categories of wheeled mobility aid that are currently used

- a small sample of wheeled mobility aid manufacturers was consulted about the appropriateness of the categories used in *Inclusive Mobility*, and for information on the categories they themselves use; information gathered from this source was verified by means of a review of some manufacturers' websites

A wide range of classifications/categories/naming conventions can be found from the following sources:

- TRL Report 470[1]
- CEDS Report from 2005[2]
- The RICA market report on mobility scooters from 2014[3]
- Department for Transport
- ISO TR 13570-2:2014[4]
- Manufacturers

TRL Report 470 (1999) is considered to be a key source for the current project, and the data collection protocols for the current research have been designed so that they are comparable with them. This is so that inferences can be made as to changes in the dimensional characteristics of occupied wheeled mobility aids since the 1990s.

TRL Report 470 used five key mobility aid types:

- Attendant propelled wheelchairs - These chairs have small wheels at the rear and are pushed by an attendant. An example is the NHS model 9L.
- Electric wheelchairs - An electric wheelchair was defined as any four-wheeled chair that was battery powered and controlled by a small joystick or similar device. These included both wheelchairs designed for indoor use, and those designed for outdoor use.
- Older style manual chairs - These are chairs manually driven by the user from the rear wheels and made to an old design, such as the NHS model 8L.
- New style manual chairs - These wheelchairs are manually driven by the user from the rear wheels, and made of a modern, lightweight construction. They are often identified by bright colours, a negative camber on the rear wheels and an adjustable

[1] Stait, R.E., Stone, J. and Savill, T.A., A survey of occupied wheelchairs to determine their overall dimensions and weight: 1999 survey, (TRL Report 470, for the Mobility and Inclusion Unit of the Department of the Environment, Transport and the Regions, 1999).

[2] Hitchcock, D., Hussey, M., Burchill, S. and Galley, M., A survey of occupied wheelchairs and scooters, (CEDS, for the Mobility and Inclusion Unit of the Department for Transport, 2006).

[3] Barton, C., Holmes, J. and Jacobs, C., Mobility scooters: A market study, (RICA (now the Research Institute for Disabled Consumers), May 2014).

[4] ISO/TR 13570-2:2014 Wheelchairs – Part 2: Typical values and recommended limits of dimensions, mass and manoeuvring space as determined in ISO 7176-5, (ISO, Jun. 2014).

wheelbase. Some models of this type of chair, such as those designed for sports, do not have brakes or handles for an attendant to push.

- Electric scooters – Three- or four-wheeled electric powered wheelchairs steered by means of 'handle bars'. These vary from small indoor/outdoor models, to larger outdoor models that can travel on public roads.

Images of wheelchairs used to illustrate these categories in TRL Report 470 are shown in Figure 1

Attendant propelled chair

Electric wheelchair

New style manual chair

Old style manual chair

Electric scooter

Figure 1. Wheelchair categories defined in TRL Report 470

The Survey of Occupied Wheelchairs and Scooters, by CEDS, on behalf of the Mobility Unit of the Department for Transport (2006) used the following four categories of wheeled mobility aid:

- Self-propelled wheelchairs
- Attendant-propelled wheelchairs
- Electric wheelchairs
- Electric scooters

Mobility Scooters: A Market Study, by the Research Institute for Consumer Affairs (RICA) (May 2014) mainly used the regulatory distinction of 'Class 2' and 'Class 3' for mobility scooters, but also quoted the following definitions used within the industry for marketing purposes:

- Class 2 Boot Scooter (for models that are designed to be dismantled or folded so that they fit into a vehicle's boot)
- Class 2 Pavement Scooter (for models that are not designed to fit into a vehicle's boot)
- Class 3 Road Scooter
- The Department for Transport (DfT) lists a number of different mobility aid types, and these are listed with regard to powered mobility units. Rather than a specific type of wheelchair design, this relates to their method of propulsion (human or powered) and maximum speed:
- Class 1 invalid carriages – these are manual wheelchairs intended for use on pavements, and have a maximum permitted speed of 4mph
- Class 2 invalid carriages - these cannot be used on the road (except where there is not a pavement) and have a maximum permitted speed of 4mph
- Class 3 invalid carriages - these can be used on the road, but their speed is limited to 8mph on the road and 4mph on the footway[5]

The DfT also uses the concept of the 'Reference Wheelchair', which is used, for example, to define the dimensions of a wheeled mobility aid that should be able to use all public transport services. These dimensions are 1200mm in length (including extra-long footplates), 700mm in width and 1350mm in height (measured to the top of the user's head), and with a footrest 150mm above the ground.

The standard for wheelchairs, ISO TR 13570-2:2014 Part 2: Typical values and recommended limits of dimensions, mass and manoeuvring space as determined in ISO 7176-5, lists five wheelchair types. Note that the following descriptions have been paraphrased from ISO TR 13570-2:2014:

- Wheelchairs with hand rims = manual (or hand rim activated) rear wheel drive by use of hand rims

[5] *Use of Invalid Carriages on Highways regulations 1988* (Department for Transport).

- Electrically powered wheelchairs of Class A – indoor use electrically powered wheelchairs
- Electrically powered wheelchairs of Class B – indoor and outdoor use electrically powered wheelchairs
- Electrically powered wheelchairs of Class C – largely outdoor use electrically powered wheelchairs
- Electrically powered wheelchairs (scooter design) – electrically powered wheelchairs with tiller steering.

Further, ISO TR 13570-2:2014 splits wheelchair usage by Mass Groups I, II and III. This is a means of categorisation that relates to mannequins designed to simulate individuals of different mass in testing activities.

Two leading manufacturers were contacted for the purpose of discussing this specific issue.

The first of these, unprompted, listed the following categories of wheeled mobility aid from the company's range:

- Attendant-propelled wheelchairs
- Self-propelled manual wheelchairs
- Power-assisted wheelchairs (which the spokesperson described as being "also attendant-propelled")
- Powered wheelchairs
- Powered scooters
- 'Tilt-in-Space' wheelchairs (specialist devices for postural support and comfort)

The spokesperson added that a larger, bariatric version of many of the company's models was available.

The spokesperson for the second of the manufacturers expressed the view that the categories of wheeled mobility aid used in *Inclusive Mobility* were still relevant, but that the company only used the categories: Manual wheelchair, Self-propelled wheelchair, Powered wheelchair and Scooter. However, the company's website uses the following categories:

- Electric powered wheelchairs
- Manual, lightweight wheelchairs
- 'Active' wheelchairs
- 'Sports' wheelchairs
- Mobility scooters

2.1 Discussion of the different categories of wheeled mobility aid

No evidence was found of any modern references to the descriptors 'new style' and 'older style' in relation to manual wheelchairs. There are also a number of reasons for avoiding the use of the term 'invalid carriage'. Although this is a correct legal reference, many people

would associate it with a motor vehicle specifically designed to be driven by a disabled person. Further the word 'invalid' may now carry associations of an offensive or pejorative nature and the term was not found in the marketing literature of wheeled mobility device manufacturers or retailers.

The definition of categories of wheeled mobility aid for the purpose of the current project was based on two further important principles:

1. to define the main types of device (and, by implication, device user) that will influence the detail of guidance on the design of public transport infrastructure and the related pedestrian environment), and
2. to minimise the number of categories used, for statistical purposes, given that the more categories we have, the greater will be the size of the sub-sample population required in order for calculations to be statistically significant.

One implication of "1." was that we did not consider wheeled mobility aids designed for children, given that the focus of design guidance tends to be on the needs of people using devices which are larger, or which have, for example, a larger turning circle. In addition, the data collection activity of measuring the dimensions of occupied wheeled mobility aids was restricted to volunteers aged 18 and over, because the analysis was based on photographic evidence, and unaccompanied children were unable to provide consent for this.

The current research also found that the mobility industry uses terms to target specific markets, such as "sports", "boot scooter", "beach" and "off road". Some such types of mobility aid featured in the sample of measurements taken at the two events held at the NEC, Birmingham, during the course of the project. However, it was decided that, for the purposes of the analysis, these different types should not be defined as separate categories. There is also evidence, from manufacturers' and dealers' product ranges, of a growing tendency for models of device to have a "bariatric"[6] version available.

It should also be acknowledged that some people use bicycles or 'trikes' as a mobility aid, regarding it as being deserving of much the same status as any conventional wheelchair or scooter. Although this detail has received consideration in the wider project, bicycles and trikes were not included as wheeled mobility aids for the purposes of RQ2.

2.2 Description of new or changed categories

Our suggestion is that the categories to be used to describe wheeled mobility aids should have practical implications for guidance on the design of the physical environment. Therefore, they should express how different types of device are used and propelled. In this context, it is felt that the distinction between 'Class 2' and 'Class 3' powered devices is both useful and valid, given that one category of device is designed and permitted to be used on the road, and the other is not. Because *Inclusive Mobility* seeks to ensure that the physical dimensions of the built environment and public transport infrastructure are accessible for all mobility aid users, interest should be focused on those who are most likely to encounter physical barriers. For this reason, there is little value in having a category for smaller devices

[6] 'Bariatric' was originally a medical term used to represent the study and treatment of obesity.

or for devices designed specifically for children. Conversely, the space and turning requirements of an attendant-propelled wheelchair should certainly be of interest.

The suggested amended categories for wheeled mobility aids are shown in Table 1. Note that, generally, Class 3 scooters cannot be used on buses, whereas Class 2 scooters sometimes can (depending on the bus operator, and within the size limits of 600mm width, 1000mm length, a turning radius of no more than 1200mm and a maximum weight of 300kg)[7]. This could have implications for the recommended space requirement in the vicinity of bus stops in *Inclusive Mobility*. Trains are not required to carry mobility scooters, but many will. As with buses, stipulations as to which wheeled mobility aids may be carried on trains vary considerably. This is partly because, currently, not all train carriages are Rail Vehicle Accessibility Regulation (RVAR) compliant, but they should be by 2020. It is therefore prudent that recommendations in *Inclusive Mobility* relating to public transport buildings should match those for trains. The 'reference wheelchair' described in the RVAR Regulations is 1200mm long and 700mm wide, it is assumed that the top of the occupant's head will be at a height of 1350mm, and the footrest is 150mm above floor level.

Table 1. Suggested categories of wheeled mobility aids

Wheelchair type	Key features
Attendant-propelled wheelchairs	Length is important, as the manoeuvring space required includes the attendant
Active wheelchairs[8]	Width is important, as hands will extend beyond the width of the device, in order to drive the hand rims
Electric wheelchairs	Electrically driven, so may be less hindered by inclines than manual chairs
Class 2 mobility scooters	Permitted to be driven at up to 4mph on the footway; also intended for indoor use
Class 3 mobility scooters	Permitted to be driven at up to 8mph on public roads, and at up to 4mph on footways; they are not intended for indoor use

2.3 Other designs of wheeled mobility aid

A wide variety of wheelchair and scooter configurations have been produced in order to cater for the postural, travel and activity needs of users. Some of these have been designed to provide a considerable amount of power, and some are powered not by an electric motor, but by an internal combustion engine. These configurations are relatively low in number, and where their dimensions fall outside of a core range, they might be considered outliers in terms of both categorisation and size. In practice, such devices are eliminated from consideration by design guidelines and standards because of the practice of designing for the 95th percentile of user (note that both ISO TR 13570 and TRL Report 470 use this metric)

[7] This information has been taken from the RiDC's website, in the context of a description of the national scooter permit scheme in the UK: https://www.ridc.org.uk/content/buses

[8] This category refers to wheelchairs that are propelled manually by the user.

– and so it is anticipated that these can be treated as outliers for the purposes of *Inclusive Mobility*.

The concept of design on the basis of the 95th percentile, which is common among design guidelines and standards concerning accessibility, is something that needs to be acknowledged, particularly in the context of aspirations for 'Access for All', 'Inclusive Mobility' and 'Universal Design', all of which imply a desire to include 100% of the population. (Some recommended dimensions for the accessible design of the built environment in Australia have been increased recently due to the decision to focus on the 90th percentile rather than the 80th percentile).

Taking a percentile as a reference point might appear to discriminate against a percentage of potential users, but guidelines and standards should be viewed as containing recommended MINIMUM dimensions etc.; it is not their intention that such minimum dimensions should be translated into the maximum that is provided in practice. A further consideration when considering the nth percentile that is used as a reference point is that there is a compromise to be made between recommending dimensions that include as large a percentage of the travelling population as possible, while still providing realistic guidance that is likely to be both acceptable to those who design and build the public transport environment, and achievable given cost and space constraints. For example, increasing the reference percentile by, say, 5% might have the effect of substantially increasing the dimensions required in order to meet the needs of an additional 5% of the population. Although this would not be contrary to the objectives of the design guidance, the risk is that guidance considered to be unrealistic or impractical by the providers of infrastructure will simply be ignored by them.

Generally, the design principle should be that as much space as possible should be provided for manoeuvring etc., with minimum design requirements being published as a guidance, so that public transport facilities can be made accessible to as many potential users as possible. In this context, with the possible exception of petrol-driven wheeled mobility aids, which might have safety implications for their use in some environments, no device should be dismissed as being totally inappropriate for use on public transport, since it is likely that its user will be reliant on it as a source of mobility.

3 Dimensions of modern wheelchairs for each category

For this Research Question, information on current dimensions of occupied wheelchair was sought by:

- Consulting wheelchair and scooter manufacturers, and various organisations representing and regulating the medical devices and mobility equipment industry, as to the available evidence for current dimensions of wheelchairs and scooters. In effect, this was an attempt to use the dimensions of wheeled mobility devices as a 'proxy' variable for occupied devices, on the grounds that wheelchairs and scooters might have increased in size in response to demand in the market for larger devices. The intention was to both use these data in conjunction with empirical measurements made of occupied wheelchairs at mobility-related events and use

them for the purpose of direct comparison with the data on the dimensions of wheelchairs currently appearing in *Inclusive Mobility*.

- Attendance at 'honeypot' locations for people in wheelchairs and (with their consent) taking direct measurements (excluding weight, which is largely excluded from these documents) using a combination of photogrammetry and measurement using a tape measure to provide as direct a comparison as possible with the data found in TRL Report 470:
    - Naidex (NEC 25th and 26th April)
    - The Big Event (NEC 28th and 29th June)

The purpose of measuring a sample of occupied wheeled mobility devices in this way was to provide a snap-shot of device users at an exhibition that was likely to attract a large number of device-using volunteers. It was expected that the measurements made would be dependent on a number of uncontrollable and unpredictable factors, such as prevailing weather conditions (which might affect volunteers' choice of footwear), etc. The candid and random nature of the sampling process is considered to have been a strength of our approach, and much preferable to attempting to conduct such research under laboratory conditions.

3.1 Mobility aid dimensions

In order to find pertinent information regarding wheelchair users (and largely following TRL Report 470), the information within Figure 1 was collected.

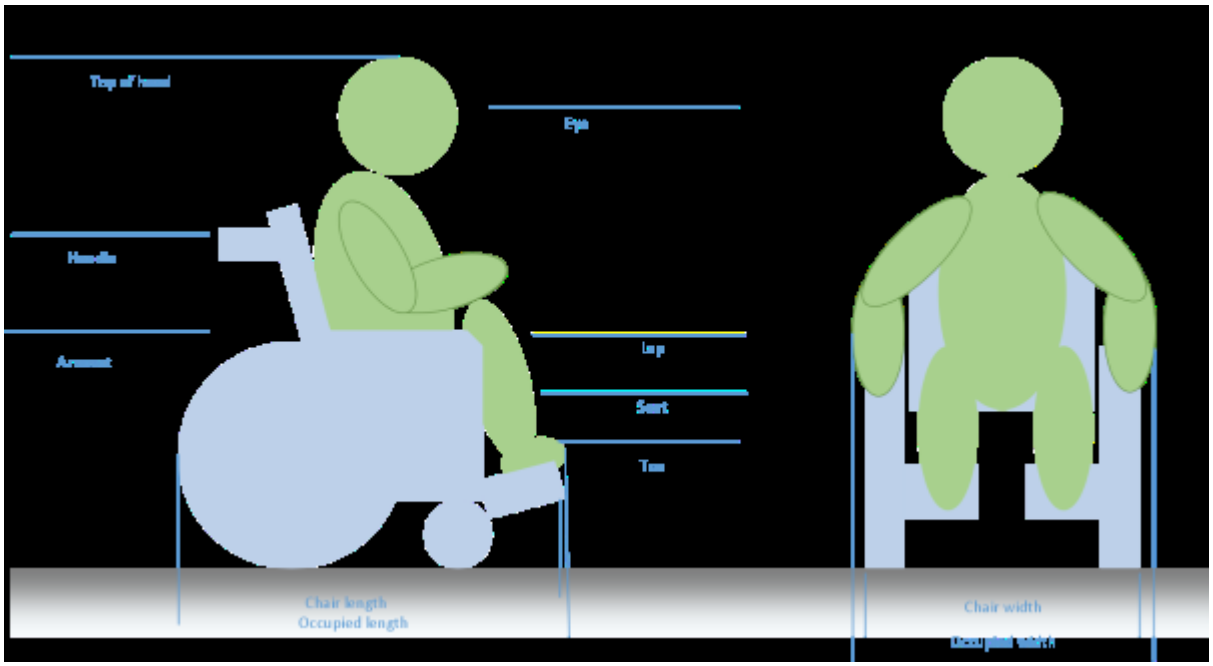

Figure 2. Wheelchair dimensions

3.2 Discussions with medical devices and mobility equipment industry

Initially, enquiries were made to the Association of British HealthTech Industries (ABHI), the British Healthcare Trades Association (BHTA) and the Research Institute for Disabled Consumers (RiDC – formerly RICA, which published Ricability guides). An enquiry email was also sent to CECOPS (an independent standards and certification body for assistive technology services – Comité Europeo de Cooperativas de Producción), although a response was not received.

The result of these enquiries was reference to two databases of current wheeled mobility device dimensions. These were those administered by the RiDC and BHTA, both of which provide online access to a search facility of different models of mobility aid[9]. The RiDC database was the subject of a major update in 2017. The main purpose of the BHTA database is to provide advice on which mobility devices might be suitable for travel by air and other forms of public transport. These sources were used to gather information on the total length, width and height of wheelchairs and scooters, as well as on turning circles and mass (both 'unoccupied weight' and maximum design weight), if available. In some cases, there were discrepancies found in relation to dimensions of devices which were featured in both of these databases, in which case reference was made to the manufacturer's website.

3.3 Data collected on occupied wheeled mobility aids at events

In order to capture these data, researchers attended two mobility-related events - Naidex, in March 2019, and The Big Event, in June 2019, both at the NEC in 2019 – which it was anticipated would be attended would both attract large numbers of wheelchair users. A large part of this exercise relied on photogrammetry as a means of measurement. This involved the taking of two digital photographs of volunteers, one from the front and one from the side, for later analysis in the laboratory. Knowing the height of the camera lens from the floor and its horizontal distance from each volunteer, made it possible to calculate key dimensions such as overall occupied height, width and length, eye height, lap height, etc. Importantly, volunteers were photographed with any bags or other accessories they carried, or which hung on their device, at the time at which they were invited to take part in the research. Eye height was calculated because it has an impact upon the use of modern facilities such as touch screens, on ticket machines and information terminals, for example. Lap height was of interest because it has an impact on the table height required by wheelchair and scooter users, and on the design of counters and kiosks.

All of the volunteers, who were all aged 18 or over, were asked to complete and sign a consent form prior to any photos being taken.

The apparatus used to enable photogrammetric measurements to be made, which included a digital camera, spirit levels and a laser for accurately measuring distance, is shown in Figure 3. For the data collected at The Big Event, each volunteer was photographed from the side only, with unoccupied and occupied width measurements being taken manually, using a tape measure.

[9] https://www.ridc.org.uk/content/scooter-powered-wheelchair-search and http://bhta.com/air-transport-advice/, respectively.

Figure 3. Apparatus used for taking digital photographs

3.4 Comparison of key dimensional data

Table 2. Comparison of dimensions appearing in Inclusive Mobility with alternative sources (all in mm)

	Inclusive Mobility (2002)	**Current market data Class 2 95th percentile (n=53)**	**Current market data Class 3 95th percentile (n=33)**	**TRL survey 1991 95th percentile (n=382)**	**TRL survey 1999 95th percentile (n=745)**	**2019 survey Naidex 95th percentile (n=84)**	**2019 survey The Big Event 95th percentile (n=90)**
Length (unoccupied)	1200-1250	1265	1606			1192.5	1277.5
Length (occupied)	1500[10]			1243	1273	1300	1300
Width (unoccupied)	700[11]	680	718	664	695	617	700
Width (occupied)	800-900[12]					700	755
Overall height (95th percentile)	1374			1377	1374	1392.5	1295.5
Eye height (5th percentile)	960					1020	934.5
Eye height (95th percentile)	1250					1222.5	1185.5
Knee height (5th percentile)	500					600	550
Knee height (95th percentile)	690					720	700

[10] The dimension of 1500mm in *Inclusive Mobility* reflects the 'worst-case scenario' of a wheelchair user having at least one leg extended straight in front of them.

[11] This is an approximate dimension published in *Inclusive Mobility*; the publication quotes its precise source as being the 706mm 95th percentile measurement for "electric wheelchairs", and the 702mm 95th percentile measurement for manual wheelchairs (both taken from the 1999 TRL Report).

[12] Again, this is an estimate, rather than being based on empirical measurement. It uses the rounded-down figure of 700mm for the width of an unoccupied wheelchair and adopts the recommendation of the ISO Standard for wheelchairs (ISO 7193) that there should be an additional allowance of at least 50mm, preferably 100mm, should be allowed on each side of the wheelchair for the user's hands and elbows.

Table 2 provides a comparison of the dimensions for unoccupied and occupied wheelchairs published in Inclusive Mobility, with data obtained through the databases on current wheeled mobility devices on the market, the TRL research findings from 1991 and 1999, and the measurements of occupied wheelchairs carried out at the mobility-related events for the purposes of the current project.

The latter data, from Naidex and The Big Event, have been presented in separate columns. This is because it was felt that the two events might attract visitors with rather different characteristics, so that the samples of wheeled mobility aids measured could not be considered to be from the same population[13]. This hypothesis was tested using the Paired Two Sample t Test, a statistical technique that can be used to establish whether two samples are likely to have been drawn from the same population. The test produces a "p" value; the lower the value of p, the stronger is the evidence that the two samples have been drawn from different populations. The value of p in this instance was calculated to be less than 0.001, strongly indicating that it would be inappropriate to combine the data collected at the two NEC events.

3.4.1 Findings: The length of occupied wheeled mobility aids

Arguably, the most noticeable figure appearing in Table 2 is that of 1606mm as the 95th percentile length of unoccupied Class 3 wheeled mobility devices according to the databases of currently available models consulted. This figure far exceeds that of 1500mm quoted in *Inclusive Mobility*, which is considered to be a 95th percentile length requirement for occupied wheelchairs, because it is considered to be both the length of a manual wheelchair user with a leg extended fully, and the length of the longest mobility scooters. In fact, Inclusive Mobility reports that, of the 745 occupied wheeled mobility aids measured during the TRL's 1999 project, only one was in excess of 1500mm; (this was a manual wheelchair user with a fully-extended leg).

It might be argued that, whilst calculating the 95th percentile of a large dataset is useful in eliminating unusually large and exceptional values, it can be misleading when applied to a dataset containing only 33 observations, (as with the 1606mm figure for Class 3 devices). For this reason, the data on current unoccupied Class 2 and Class 3 wheelchairs were examined more closely, in terms of the mean, median and 85th percentile, and these are shown in Table 3.

[13] "Sample" and "population" are being used here according to their meaning as statistical terms, i.e. "population" refers to the entire set of entities, whilst the "sample" is a sub-set of the population that is used for making inferences about that wider population.

Table 3. Further analysis of the length of current Class 2 and Class 3 wheeled mobility devices (all in mm)

	Class 2 (n=53)	Class 3 (n=33)
Mean	1062	1334
Median	1060	1320
85th percentile	1217	1498
95th percentile	1265	1606

The figures in Table 3 provide a good illustration of the fact that Class 3 wheeled mobility aids are fundamentally larger devices than Class 2 wheelchairs and scooters. Even the mean and median values of Class 3 devices exceed the 95th percentile length for occupied manual wheelchairs (of 1200 to 1250mm) quoted in *Inclusive Mobility*, and the 85th percentile length of current unoccupied Class 3 devices (1498mm) exceeds all of the 95th percentile figures for occupied wheelchairs and scooters recorded by the TRL in 1999: the figure for all types of device measured (1273mm, as shown in Table 2), and also the 95th percentile length of "Electric wheelchairs" (1328mm) and of "Electric scooters" (1402mm).

The issue of longer wheeled mobility devices can be further illustrated with reference to the longest devices measured. It has already been stated that the one occupied mobility device, of the 745 measured by TRL in 1999, that exceeded 1500mm appears to have been rather dismissed, in *Inclusive Mobility*, as an exception, or an 'outlier'. Closer examination of the data collected on current Class 3 devices available reveals that four of the 33 (some 12%) exceeded 1500mm in length unoccupied.

One other aspect of the length data in Table 2 to note is the clear trend for the 95th percentile of all lengths of occupied wheelchair to increase, from 1243mm in 1991, to 1273mm in 1999, to 1300mm in 2019. (However, the 27mm increase in the 20-year period since 1999, which was when the research on which Inclusive Mobility was based had been carried out, might be considered to be 'slight').

3.4.2 Findings: The width of occupied wheeled mobility aids

A finding from both the analysis of databases of current devices available, and the measurement of occupied wheelchairs and scooters, is that the width requirement for wheeled mobility aid users appears to have remained well within even the minimum recommended in *Inclusive Mobility* (i.e. 800mm). The 95th percentile width of an occupied device at Naidex was 700mm, and 755mm at The Big Event, whilst the 95th percentile width of (unoccupied) Class 3 vehicles on the market has been found to be only 718mm.

3.4.3 Findings: The height of occupied wheeled mobility aids

Inconclusive results have been obtained in relation to the total height requirements of occupied wheelchairs and scooters, with a substantial difference between the height figures recorded at Naidex and The Big Event, (although both samples were characterised by a

considerable range of measurements). The data are inconclusive in as much as the 95th percentile height figure obtained at Naidex (1392.5mm) is higher than the equivalent figure recorded during the 1999 TRL study (1374mm), whereas the figure calculated for The Big Event (1295.5mm) was lower. For scooters only in 1999, the 95th percentile height figure was 1438mm, with the largest measurement recorded being 1502mm; at Naidex, the highest recorded for all types of wheeled mobility device was 1450mm, whilst at The Big Event it was only 1370mm.

Similar remarks can be made about the data recorded on eye heights, (and since it is important for information to be displayed at a level that is neither to high, nor too low, the data have been displayed for the 5th percentile as well as the 95th percentile). For the 5th percentile eye height, as with the total height requirement, there is the inconclusive finding that the figure derived from the Naidex data set exceeded the 5th percentile figure appearing in *Inclusive Mobility*, whilst that obtained from The Big Event was lower. The 95th percentile figure used for eye height in *Inclusive Mobility* (1250mm) exceeded the equivalent recorded figure at both Naidex (1222.5mm) and The Big Event (1185.5mm).

There is, however, evidence of an increased height requirement to accommodate wheeled mobility device users' knees. Again, using the 5th and 95th percentile figures to define a range of space requirements, (for the purpose of designing counters and ticket machines, etc.), the range quoted in Inclusive Mobility is 500mm to 690mm. Empirical measurements made at the two mobility-related events held in 2019 all exceed these figures, the most substantial discrepancy being the 600mm 5th percentile figure calculated from the Naidex data set.

3.4.4 Findings: Other key dimensions

Related to the finding of wheeled mobility devices becoming longer (see Sub-section 3.5.1) is the issue of turning circle diameter. The recommendation in *Inclusive Mobility* is that a diameter of at least 1500mm is required for manual wheelchair users. This compares with a 95th percentile turning circle diameter of modern Class 2 devices (as claimed by manufacturers) of 1486mm, suggesting that the current recommended minimum turning circle of 1500mm should be adequate for most Class 2 wheelchair and scooter users. Again, the 95th percentile figure for modern Class 3 devices is considerably higher, at 1968mm, although this turning circle requirement is less than that quoted for similar vehicles in *Inclusive Mobility*, which states that "outdoor electric wheelchairs" have a turning circle diameter of 2420mm, and "electric pavement vehicles" have one of 4350mm. This might be an indication that the design and performance of larger wheeled mobility devices has improved considerably since *Inclusive Mobility* was published, in 2002.

As with data on turning circle diameters, information on the mass of occupied wheelchairs was beyond the scope of the direct data collection exercises carried out for the project during 2019, but some information was gathered from the industry databases on both the unoccupied mass of current wheeled mobility aids and manufacturers' estimates of occupied mass for each model, (the latter figure referring to a maximum 'design weight'). These figures could be compared with the data collected by TRL in 1999 on the overall measured mass of volunteers and their mobility aid. This comparison is, however, rather inconclusive. The 95th percentile unoccupied mass figures calculated for Class 2 and Class 3

devices are, respectively, 136kg and 160kg; the respective occupied 'design weights' are 274kg and 357 kg. It is not surprising that the 95th percentile occupied device mass measured in 1999, of 200kg, lies somewhere in between these figures.

3.4.5 Findings: Discussion

There is evidence from similar work on the dimensions of wheeled mobility aids to suggest that it should not have been a surprise to find that the width of modern mobility aids (see Sub-section 3.5.2) tends to be well within the recommended width allowances recommended in *Inclusive Mobility*. For example, Hitchcock *et al.* (2006) noticed a trend for the width of such devices to decrease when analysing the data that they had collected using a research protocol deliberately designed to mimic the research carried out by the TRL in 1999 so that comparisons could be made:

> "*Comparing measurements of the four principal dimensions of all adult devices measured in the previous (1999) survey, it would appear that overall there have been significant increases in weight, height and length, but a significant reduction in width*."

The study also reported:

> "*….an overall decrease in the average width of devices of 15mm over the six-year period between surveys. The 95th percentile figure has only marginally decreased by 3mm over the period*."[14]

The results obtained during the current research can be compared with research published from elsewhere in the world. For example, D'Souza & Steinfeld (2009) have collected data on behalf of the Anthropometry of Wheeled Mobility Project, at Buffalo University, USA[15]. Their data, for three different categories of wheeled mobility aid, are summarised in Table 4.

Table 4. Data on the key dimensions of wheeled mobility devices (Source: D'Souza & Steinfeld, 2009)

(All figures relate to the 95th percentile, and are in mm)	Manual wheelchairs (n=195)	Powered wheelchairs (n=146)	Electric scooters (n=28)
Unoccupied length	1247	1313	1435
Unoccupied width	740	760	745
Occupied length	1342	1399	1435
Occupied width	780	822	840
Occupied height	1378	1393	1483

[14]

[15] D'Souza & Steinfeld (2009), *The Anthropometry of Wheeled Mobility Project at Buffalo: A comparison of wheelchair dimension values with ISO/CD TR 13570-2*. (Report prepared for: ISO TC173 SC1 WG1).

For the unoccupied length of devices, although there is confirmation, in Table 4, of electric scooters being considerably larger than both manual and powered wheelchairs, the 95th percentile figure of 1435mm for scooters does not approach the equivalent figure of 1606mm, shown in Table 2, for the current UK market. However, it should be borne in mind that the figures contained in Table 4 reflect the market for wheeled mobility aids in the USA of some ten years ago. What is noticeable when comparing Table 2 and Table 4 is that the width and height of occupied wheelchair users is considerably greater in the USA.

Lucero-Duarte (2012), who collected measurement data for wheeled mobility device users in Mexico, reported the results of total seated height separately for male and female volunteers; her 95th percentile figures were 1364.5mm for males and 1311.2mm for females, which lie between the 95th percentile measurements resulting from the data collection exercises at Naidex and The Big Event. Lucero-Duarte's 95th percentile occupied width figure of 731mm is comparable to the equivalent figures for the UK displayed in Table 2, although her figure for total length, of 1096mm, is far below that reported by any of the UK-based studies[16].

It has already been reported that the Australian Building Standards[17] have switched from using the 80th percentile as a basis for defining the dimensions for an occupied manual wheelchair, to the 90th percentile. This has had the effect of changing the 'footprint' of such an occupied device from 1250mm x 740mm, to 1300mm x 800mm. This new space requirement matches the 95th percentile figure for 'occupied length' measured at both Naidex and The Big Event, and the width requirement is not dissimilar to the (95th percentile) figure currently recommended in Inclusive Mobility. The current Australian Building Standards are based on research carried out in 1983[18].

A document making recommendations on the required dimensions for toilets and bathroom facilities in the context of healthcare buildings, which was last updated in March 2017, considers that a "wheelchair turning space" for an active (i.e. user-propelled) wheelchair should be an area of at least 1500 x 1500mm. This document bases its recommendations on "the professional opinion of healthcare planning and design experts and ergonomic research (published and unpublished)"[19].

3.5 Consultation with the mobility aid industry and other stakeholders

A final round of consultations was undertaken for RQ2. This was to obtain the views of the wheeled mobility device industry and related stakeholders on the results reported in this document, before finalising the recommendations. This was carried out through correspondence, based on the following questions:

[16] Lucero-Duarte, K. *et al.* (2012), *Anthropometric data of adult wheelchair users for Mexican population*. Work 41: 5408-5420.

[17] *Australian Standard: Design for access and mobility. Part 1: General requirements for access – new building work*. (AS 1428.1 – 2009).

[18] Bails, J.H., (1983), *Project Report of the field testing of the Australian Standard 1428-1977.* South Australian Department of Housing and Construction).

[19] Health Building Note 00-02. Core elements: Sanitary spaces, (Health Facilities Scotland, 2016).

- To what extent do the findings presented in this report conform to your experience of the nature of wheeled mobility aids currently in use? Are you aware of findings from similar or related research that should be taken into account?
- Do you think that the evidence presented in this report is robust enough, given the sample sizes and the methods employed, to justify recommendations for changes to the design guidance currently contained in *Inclusive Mobility*?
- What do you think should be done, given the research evidence contained in this report, in terms of guidance on the design of public transport infrastructure and the pedestrian environment provided by the Department for Transport?

Consultees were the BHTA, MHRA, NAEP, NHS Supply, NHS England, RiDC (formerly RICA), the Rail Delivery Group, a representative of the committee responsible for redrafting BS8300, and the Anthropometry of Wheeled Mobility Project at Buffalo University.

A response was received from the Research Institute for Disabled Consumers (RiDC), stating that they were unaware of any additional sources of information of the type described in the consultation question. The RiDC added that its own database of wheeled mobility aids was the most comprehensive available, but that this was now not up to date. The one other source referred to in the RiDC's response was the Disabled Living Foundation's "Living Made Easier" website, which provides some information on electric scooters only[20]. This is a resource that may prove useful for any future research into the prevalence of electric scooters in the UK.

In reaction to the research results emerging from the current research, the RiDC offered the observation that users of wheeled mobility devices tend to own more than one, and use those devices for different purposes. (This further complicates the task of building a profile of the prevalence and use of wheeled mobility aids in the UK). The view of the organisation was that it was not aware that mobility aids had increased in length – but indicated that this might be partly due to the fact that the empirical research was carried out in a large exhibition space. (Whilst this might be true, in terms of attracting a sample biased towards an "outdoor type" of mobility device, this does not mean that the sample was untypical of the type of device used for journeys by public transport, and it was important for the sample to be analogous to those used for the TRL's research during the 1990s). The RiDC added that its own experience had been that devices had certainly become heavier, due to a combination of the increased weight of occupants and the trend towards additional mechanical components such as tilting and adjustable height mechanisms.

The MHRA responded to the consultation email but stated that it was unable to provide further information, instead referring the project to the BHTA and manufacturers of wheeled mobility devices. NHS England also responded, similarly referring the project to the BHTA.

[20] https://www.dlf.org.uk/living-made-easy

4 Summary of Key Findings

4.1 Categories of wheeled mobility aid

It is recommended that the categories of wheeled mobility aid to be used should be as follows:

- Attendant-propelled wheelchair
- Active wheelchair
- Electric wheelchair
- Class 2 mobility scooter
- Class 3 mobility scooter

4.2 Changes in the dimensions of wheeled mobility aids

An analysis of wheeled mobility aids currently on the market in the UK, along with a study that has measured the key dimensions of occupied wheelchairs, has indicated that it is the length of these devices that has changed the most since the publication of *Inclusive Mobility*, in 2002. Past studies have provided empirical evidence for the length of occupied wheeled mobility devices to gradually increase over time. From the first TRL survey of occupied wheelchairs and scooters, in 1991, to the repeat survey completed in 1999, the 95th percentile figure for the length of an occupied wheelchair increased by 30mm; the equivalent figure derived from the research carried out for the current project, some 20 years later, suggests an increase in length by a further 27mm.

The clearest evidence of change in the dimensions of wheeled mobility aids has been provided by the review of databases of current devices. *Inclusive Mobility* currently regards 1500mm as being the 95th percentile length that should be considered for a wheeled mobility aid, as this is the figure that is quoted for both the longest electric scooter and the length taken up by a manual wheelchair user with a fully-extended leg. The publication dismisses the longest figure recorded during the TRL's 1999 survey, (1545mm), as being an 'outlier', on the grounds that this observation was the only one, of 745, to have exceeded 1500mm. The review of current devices on the market, however, has revealed that no fewer than four of the 33 Class 3 scooters on the market exceed 1500mm in length. However, although this provides an indication as to the potential for longer wheeled mobility aids to be used by people using public transport and associated pedestrian facilities, no evidence is available as to the prevalence of the use of wheeled mobility aids of different sizes in the UK. It is not therefore possible to draw conclusions on the number of people who use a particular category of device, nor on the number of trips undertaken or the types of environment where they are used. This means that information on availability does not provide a good indicator of the extent to which their users may be disadvantaged by any size constraints. It was therefore concluded that the evidence for increased availability of some larger devices on the market (some of which may be intended primarily for outdoor and on-road use) is not of itself sufficient at this time to justify recommending changes to the minimum dimensions of public transport infrastructure and pedestrian facilities. What is

required, however, is research to obtain robust evidence on the prevalence and use of different classes (particularly sizes) of wheeled mobility device.

As for the other key dimensions of wheeled mobility aids, the width requirement for users appears to have remained well within Inclusive Mobility's 800mm recommended minimum. Inconclusive results were obtained for the height requirements of wheeled mobility aid users, since there was a substantial difference between the occupied height figures recorded at Naidex and The Big Event, with the data from both samples having a considerable range. For example, the 95th percentile occupied height figure obtained at Naidex (1392.5mm) was higher than the equivalent figure recorded during the 1999 TRL study (1374mm), whereas the figure calculated from The Big Event data (1295.5mm) was lower. There were similarly inconclusive findings in relation to eye height measurements.

Updated guidance might be provided for the design of ticket counters and information desks, in the light of evidence for changes in wheeled mobility aid users' knee height range. *Inclusive Mobility* currently quotes a range of 500mm to 690mm, which was based on available 5th percentile and 95th percentile figures. Using the same percentiles to define this range, the evidence gathered from surveys held at Naidex and The Big Event, in 2019, was that the range of knee heights was 600mm to 720mm and 550mm to 700mm, respectively. It is recommended, therefore, that for all design features for which knee height is an important parameter, a range of 550mm to 720mm is considered.

No compelling evidence was found to justify recommending further changes to *Inclusive Mobility* in relation to the width of wheeled mobility aids (slight decrease since 2002), the manoeuvring space required for users of wheeled mobility devices, the overall height or eye height of device users, or the overall mass of devices.

Appendix A Comparative data on wheeled mobility aid dimensions

	Inclusive Mobility	ISO TR 13570 Part 2 - typical for occupant mass group II and III				ISO TR 13570 Part 2 - max limits for occupant mass group II and III				Wheelchair user data		
		Wheelchair with handrims	Class A	Class B	Class C	Wheelchair with handrims	Class A	Class B	Class C	1991 data (95th percentile)	1999 data (95th percentile)	2019 data (95th percentile)
Length (mm)	1500	1040	1100	1170	1150	1200	1200	1200	1200	1243	1267	
Length with any overhang (mm)		1190	1230	1290	1290	1330	1320	1320	1340			
Length with personal assistant (mm)	1750	740	620	680	700	800	700	700	700			
Width of chair (mm)	700	640	620	680	700	700	700	700	700	664	695	
Width of chair with overhang (mm)	800											
Width with personal assistant	1500											
Overall height 95th percentile (mm)	1374	1440	1500	1530	1590	1600	1600	1600	1600	1377	1374	
Eye height range (5th percentile) (mm)	960											
Eye height range (95th percentile) (mm)	1250											
Knee height (5th percentile) (mm)	500											
Knee height (95th percentile) (mm)	690											

Seat height (mm)	460mm to 490mm											
Handgrip height (mm)		900	920	960	960	1090	1090	1090	1090			
Unoccupied mass (kg)		16	65	130	150	20	100	160	200			
Occupied mass (kg)											200	
Turning diameter (mm)	1500	1770	1980	1990	2710	2060	2040	2040	2920			
Minimum ground clearance (mm)						30	40	40	50			
Required width of angled corridor (mm)		880	850	900	980	1030	990	990	1100			
Doorway entry depth (mm)		1190	1230	1290	1380	1670	1590	1590	1590			
Clearance width for two wheelchairs	2000											
Minimum acceptable clearance width	1500											
Absolute minimum clearance width	1000											

Accessible Public Realm: Updating Guidance and Further Research

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CPR2714