A Survey of Occupied Wheelchairs and Scooters

Conducted in 2005

Research conducted on behalf of
Mobility and Inclusion Unit of the Department for Transport

Research conducted by
CEDS, 2A Hotel Street, Coalville, Leicestershire LE67 3EP
Tel. 01530 5125959, Fax. 01530 839841, www.ceds-research.org

Report prepared by
David Hitchcock, Michael Hussey, Stephen Burchill and Magdalen Galley

CONTENTS

EXECUTIVE SUMMARY

This report details the findings of a survey of occupied wheelchairs and scooters to determine their overall masses and dimensions, conducted in 2005 by The Centre for Employment and Disadvantage Studies (CEDS). This study was the third in a series to identify and report on trends in wheelchair and scooter designs. For the first time, in addition to adult devices, specific effort was made to include children's wheelchairs. Information provided by the survey enables policy makers, architects and designers of transport systems to ensure accessibility to transport, buildings and equipment.

Nine dimensions of occupied devices are presented in this report, together with findings about the nature of wheelchair and scooter use and the results of some exploratory research into the dynamic stability of a sample of devices. Data were collected at two specialist exhibitions and 12 site visits around the UK. A total of 1356 occupants and devices were included in the sample. Dimensions were determined, using multi-image photogrammetry. Device and occupant weights were recorded with portable beam wheelchair scales and custom-made flat bed scales.

The total sample comprised 48% females and 52% males; 82% of the participants were adults and 18% children. Self-Propelled Wheelchairs formed 42% of the sample, Attendant-Propelled Wheelchairs 13%, Electric Wheelchairs 27% and Electric Scooters 18%.

The nine dimensions collected were: Height of device and occupant; Length of device and occupant; Width of device; Weight of device and occupant; Wheelbase of device; Height of armrest or device controls; Distance between device handles; Angle of the front wheel to the front of the device (wheelchairs only); Angle of the rear wheel to the rear of the device (wheelchairs only). Mean (50^{th} percentile), minimum, maximum, 5^{th} and 95^{th} percentile values are presented for each dimension, as well as comparative data for like for like measurements from the 1999 survey to highlight any trends.

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 height, weight and length but a significant decrease in width.

Looking at a comparison of the same dimensions for all of the child devices between the two surveys suggests that in contrast to the adult figures, average measurements of height, width and length are significantly lower than the corresponding measurements for 1999. Only the height figure demonstrates no significant change. However, it should be noted that significance comparisons may be less reliable for children as the average values for the 1999 data are based on small sample sizes.

The project also considered some fundamental aspects of device stability in relation to the use of ramps on vehicles and in the built environment; not as a formal compliance test, but to review the performance of different devices at different angles. A brief overview of other work in the area of wheelchair measurement is presented, together with the results of a user needs survey involving 43 stakeholders, to identify how data are used by end-users and how future surveys might be shaped.

1.0 INTRODUCTION

The Centre for Employment and Disadvantage Studies (CEDS) is the research division of yes2work, a social firm working with those who have disabilities or are otherwise disadvantaged. CEDS was commissioned by the Mobility and Inclusion Unit of the Department for Transport (DfT) to conduct the 2005 survey of occupied wheelchairs and scooters to determine their overall masses and dimensions.

This study was the third in a series (previous studies were conducted in 1991[1] and 1999[2]) to identify and report on trends in wheelchair and scooter designs. Information provided by the surveys enables policy makers, architects and designers of transport systems to ensure accessibility to transport, buildings and equipment.

The two previous studies concentrated on adult devices and collected data principally at the Mobility Roadshow, a regular and well attended event which provides the opportunity to try out mobility products, drive adapted vehicles and find out the latest information from a wide variety of charities, interest and research groups. CEDS was given a broader remit to include children's wheelchairs and to collect data at the Mobility Roadshow and through a number of site visits around the UK.

To facilitate comparison with the earlier (1999) survey, devices were assigned to one of four categories in this latest survey:

Self-Propelled Wheelchairs
These wheelchairs are manually driven by the user from the rear wheels. Unlike the 1999 survey, there was no longer a need to distinguish between 'older' and 'newer' style designs.

Attendant-Propelled Wheelchairs
These wheelchairs have small rear wheels and are pushed by an attendant.

Electric Wheelchairs
These wheelchairs have four (or sometimes six) wheels, powered by battery and operated by means of a control joystick or similar.

Electric Scooters
These are three or four wheeled electric powered devices steered by means of 'handlebars'.

---

[1] Stait R E, and Savill T A. 1995. A survey of occupied wheelchairs to determine their overall dimensions and characteristics. TRL Report 150.

[2] Stait, R.E., Stone, J. and Savill, T.A., 2000, *A survey of occupied wheelchairs to determine their overall dimensions and weight : 1999 Survey*, TRL Report 470.

An example of each of these device types is presented in Figure 1 below.

Self-Propelled Wheelchair

Attendant-Propelled Wheelchair[3]

Electric Wheelchair

Electric Scooter

Figure 1: Examples of the device categorisation used in this survey

Nine dimensions of occupied devices are presented in this report, along with survey findings about the nature of wheelchair and scooter use and the results of some exploratory research into the dynamic stability of a sample of devices.

[3] Electric Wheelchairs can look similar to Attendant-Propelled Wheelchairs or of a more modern design like the one shown in Figure 1 above.

2.0 THE SURVEY DEMOGRAPHICS

2.1 Venues

In common with the two previous surveys carried out for DfT, this investigation took the opportunity of interviewing and measuring the devices of users attending the Mobility Roadshow (held in 2005 at Castle Donington).

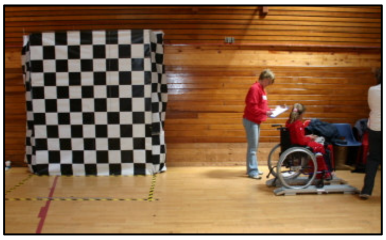
It may be argued that those attending the Mobility Roadshow demonstrate an ability to use transport (private and public) that may not be representative of all wheelchair and scooter users. Therefore, to increase representation and, hopefully, make any generalisations of the sample survey data more reliable, the survey was extended to include 12 site visits to retail centres and schools around the UK. A stand similar to that set up at the Mobility Roadshow was also used at another exhibition, the specialist event for disabled children, ‘Kidz up North’, held in Bolton in November 2005. Table 1 shows the number of devices measured at each type of venue.

Venue Type	Total	%
Kidz up North	56	4%
Mobility Roadshow	962	71%
Retail	203	15%
School	135	10%
Grand Totals	**1356**	**100%**

Table 1: Number of devices measured at each venue type

Exhibition

Retail



School

Figure 2: Examples of the venues

For a variety of reasons, not every dimension described in Section 4.0 (Sizes Data) is based on the total number of devices measured. For example, there are weights for 964 adults but only 526 readings for the distance between handles. The reason for this, of course, is that not all wheelchair devices have handles. Another example of discrepancy arose from not being able to weigh certain designs of devices on the portable ramps at site visits.

2.2 Participants

The total sample of 1356 device users who took part in this survey is made up of 48% females and 52% males. This corresponds exactly to the gender breakdown in the 1999 Survey. From Table 2 below it can be observed that while the number of participating adults (aged 16 and over) is almost a complete match between males and females, the gender split for children is skewed in the direction of males (58%) to females (42%).

The age breakdown reveals that 82% of the participants were adults and 18% children. Figures for the 1999 survey reflect a breakdown of 90% adults and 10% children, so there has been a very real increase in the representation of children in this latest study.

	Female	Male	Not Recorded	Totals
Adult	549	548	1	1098
Child	103	143	1	247
No Reply	3	6	2	11
Grand Totals	**655**	**697**	**4**	**1356**

Table 2: Age category and gender of survey participants

The average age of adult males participating in the survey was 49.9 years and the average age of adult females was statistically marginally higher at 51.9 years ($Z = 1.86$, Significance = 0.03, 1TT). For the children's age group, the average ages for males and females are 9.6 years and 10.1 years respectively – not a significant difference.

2.3 Devices

Table 3 below shows the distribution of devices measured in the survey. This describes a very different profile to that of the 1999 survey. The proportion of Electric Scooters has doubled from 9% in 1999 to 18% in 2005. The amount of Attendant-Propelled Wheelchairs has almost doubled from 7% to 13%. The percentage of Electric Wheelchairs has remained nearly constant; 25% in the 1999 study verses 27% in 2005. Although still very much the most popular type of chair, the Self-Propelled Wheelchair now only accounts for 42% of the total sample size as compared with the 1999 figure of 59%.

Device	Total	%
Self-Propelled Wheelchair	568	42%
Attendant-Propelled Wheelchair	182	13%
Electric Wheelchair	363	27%
Electric Scooter	243	18%
Grand Totals	**1356**	**100%**

Table 3: Devices measured in the survey

Table 4 below presents the number of males and females that used different types of device. Performing a chi-square test on these data reveals that there is a strong association between gender and the type of device used. (Chi(3)[4] = 33.14, Significance = 0.000). Electric Wheelchairs and Electric Scooters accounted for roughly equal proportions of users from the different genders, but more females (17.6%) than men (9.6%) used Attendant-Propelled Wheelchairs. Conversely, more of the Self-Propelled Wheelchairs surveyed were occupied by males (47%) than females (37%).

	Female	**Male**	**No Reply**	**Totals**
Self-Propelled Wheelchair	241	326	-	567
Attendant-Propelled Wheelchair	115	67	-	182
Electric Wheelchair	186	177	3	366
Electric Scooter	113	127	1	241
Grand Totals	**655**	**697**	**4**	**1356**

Table 4: Gender of users of each device type

Chi-square analysis also reveals an association between age and the kind of device used. (Chi(3) = 114.318, Significance = 0.000). Here the proportions of children and adults who used Self-Propelled Wheelchairs is about the same, as is the proportion of children and adults who used Electric Wheelchairs. However, only 10% of adult devices were propelled by an attendant whilst the corresponding figure for children was 30%.

	Adult	**Child**	**No Reply**	**Totals**
Self-Propelled Wheelchair	458	109	1	568
Attendant-Propelled Wheelchair	106	74	2	182
Electric Wheelchair	294	63	6	363
Electric Scooter[5]	240	1	2	243
Grand Totals	**1098**	**247**	**11**	**1356**

Table 5: Age category of users of each device type

[4] Chi(3) is used in preference to Chi(6) when the 'No Reply's are excluded from the calculation.

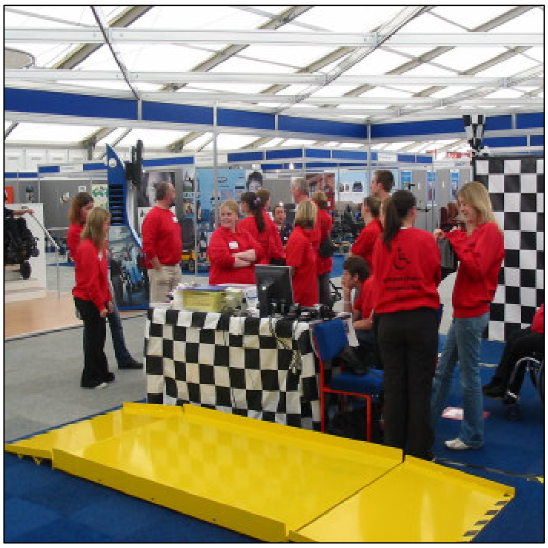
[5] Children are not permitted to use Class 3 devices – the electric scooters – and, therefore, the response of 1 is clearly an error, although it has no impact on the statistical analysis.

3.0 METHOD

3.1 General Approach

At all sites, including the Mobility Roadshow, wheelchair users or their attendants if appropriate were approached and asked if they would participate in the survey. Almost without exception people were happy to take part, and the majority expressed interest in the work.

The method and intentions of the survey were explained before each participant or attendant was asked a brief series of questions about the device and the way in which it was used. Following this, seven photographs were taken around their device – these would be used to extract the sizes data. Finally, the device was manoeuvred onto scales to record the weight of the device and its occupant (portable beam wheelchair scales were used at the site visits, and custom-made flat bed scales for the Mobility Roadshow and Kidz up North event).



Mobility Roadshow Arrangement

Site Visits Arrangement

Figure 3: Typical equipment arrangements used in the survey

3.2 Photogrammetry

This survey, like its predecessors, required efficient data collection in order to capture a high number of representative devices and their occupants with the minimum of inconvenience. In all three cases photographs were taken of each participant for subsequent analysis.

The 1991 and 1999 studies used single-image photogrammetry. In the 1991 survey each wheelchair user was required to manoeuvre into a right angle formed by two checkerboards in order for a side profile and a front profile photograph to be taken.

Because some users found it difficult to make the necessary manoeuvre this technique was slightly revised for the 1999 survey so that the wheelchair only needed to be positioned alongside a single white and black checkerboard, while the same profiles were photographed. Each of the photographs taken was used to manually calculate the various dimensions such as height, length and width. The previous researchers reported that using the two photographs of each subject, measurements were taken directly from the prints and the dimensions were calculated by scaling from the checkerboards and using trigonometry. To validate this method, photographs were taken of a person in a wheelchair and then actual measurements were taken in situ.

For this 2005 survey, it was decided that an alternative use of photography was desirable which enabled greater portability for the site visits and was not reliant on accurately positioned checkerboards or devices and provided opportunity to extract a wider range of measurements. The most appropriate technique selected was that of multi-image photogrammetry, which is reputably more accurate and flexible than the single-image method used previously.

A process for taking the photographs was developed to ensure that sufficient images for data extraction could be taken in the minimum of time; throughput rate of participants needed to be one per minute to meet target numbers. The minimum number of images was found to be seven, using the camera arrangement shown in Figure 4. In order to ensure that both the markings of the 'wheelchair zone' (needed for scaling) and all of the pertinent wheelchair features were captured in each image, the minimum distance between the zone and the camera needed to be at least 1.6m. All photographs were taken from a standing position except in positions 1 and 7 which required the photographer to squat in order to achieve sufficient angular separation.

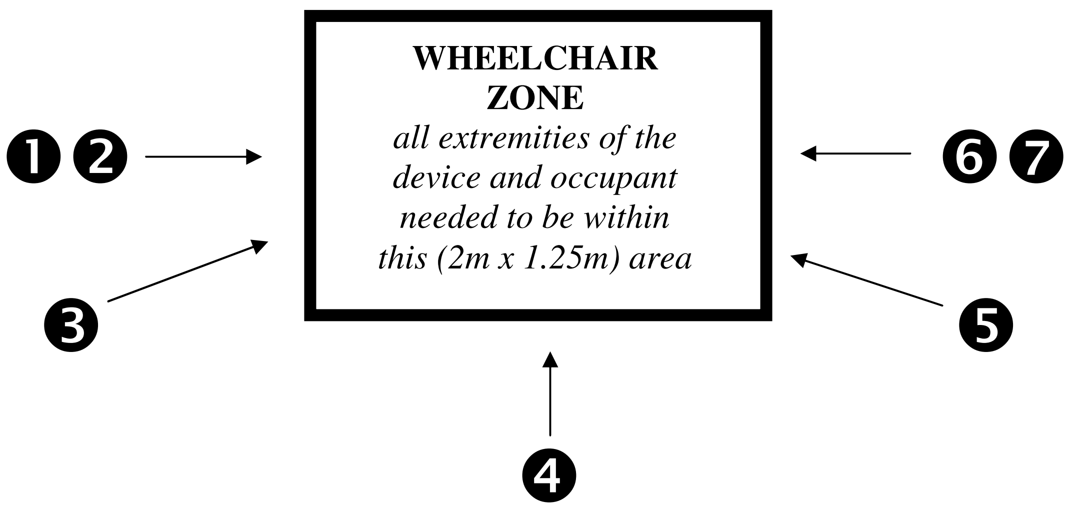


Figure 4: The seven camera positions to capture rear, front and side profiles

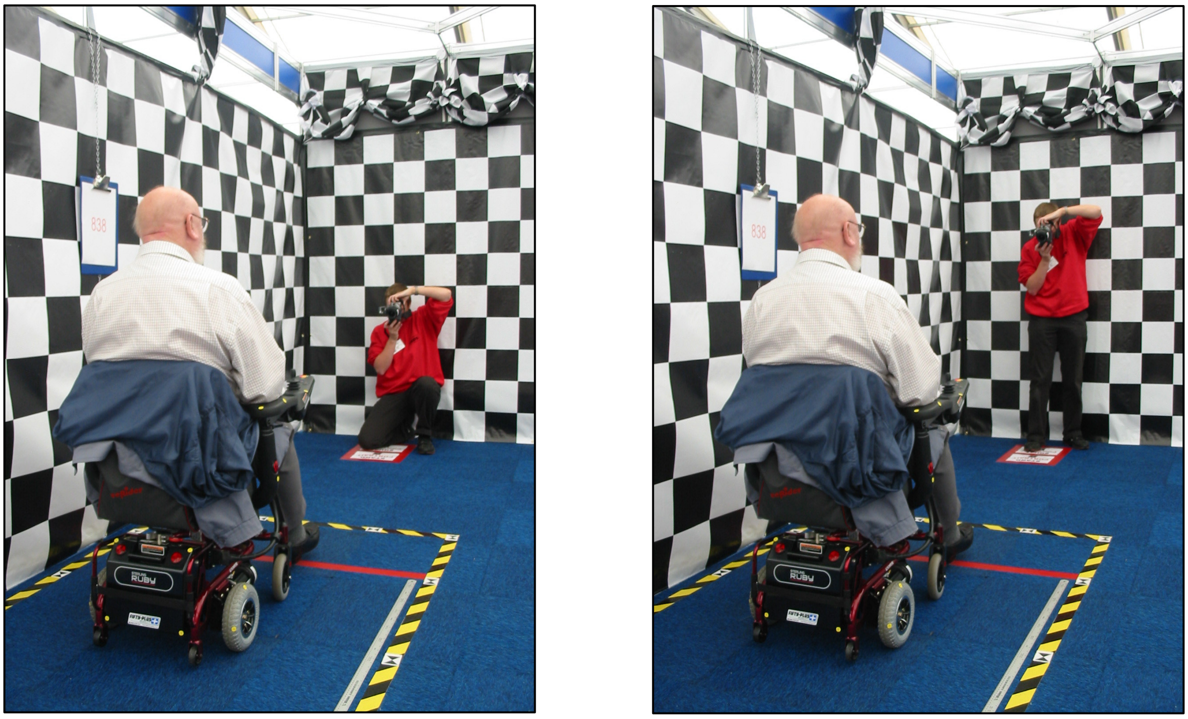


Figure 5: Different camera positions (heights) used to achieve angular separation

Because of the practical nature of the intended application of the data resulting from this survey, devices were typically photographed and weighed without the removal of luggage and other carried items, unless they were clearly exceptional such as a proliferation of Mobility Roadshow bags and promotional gifts.

Every effort was made to ensure that the same device and occupant were not duplicated at the same or subsequent events and that matching 'Shopmobility' (or similar devices, including loan wheelchairs at the Mobility Roadshow) were not repeated.

The multi-image photogrammetry technique made it possible to adopt an iterative approach to data extraction; selecting new or additional dimensions to be attained as the project progressed. Future needs from manufacturers or other researchers may also be satisfied as all the photographs are catalogued and processed ready for further dimensions to be acquired as necessary.

3.3 Measurement Accuracy

The accuracy of the measurements taken in an 'anthropometric' survey such as this is critical to the validity of the results.

The minimum accuracy of both of the scales used for weighing the devices and their occupants was $\pm$ 0.5kg.

All photographers and photo analysts involved in the data collection and transcription (extraction of the dimensions) phases of the study were required to undertake a period of training to ensure measurer error and accuracy were at an acceptable level. Photographers were asked to take a sample of photographs three times (replications) and the accuracy of their results was compared using a two-way ANOVA technique.

The comparisons were made on four test dimensions; height, length, width and wheelbase. The errors found are given in Table 6 below.

	Average Mean Percentage Error	Error Compared with a Single Measurement by Hand
Height	0.1%	0.3%
Length	0.1%	0.5%
Width	0.3%	0.6%
Wheelbase	0.3%	0.3%
Overall	**0.2%**	**0.4%**

Table 6: Error rates identified in validating photogrammetry accuracy

These error rates were well within the criteria of 1% which is stated within BS EN ISO 15535:2003 ‘General requirements for establishing an anthropometric database’.

Results from the ANOVA tests indicated that for the dimensions height, length and width there were no significant differences registered for either photographers or replications. For the wheelbase dimension, while there was no significant difference between replications, a significant difference between photographers (alpha = 0.03) was registered. On inspecting the raw data a maximum range of 5mm was observed for five photographers each completing three replications. On a target figure of 400mm, this was also considered to be an acceptable level of accuracy.

It was thought useful to compare the errors recorded in the photographic tests with those incurred using repeated hand measurement. The results obtained for seven researchers measuring the four trial dimensions are recorded in Table 7 below. The improvement in accuracy of measurement using the photogrammetry technique is clear.

	Average Mean Percentage Error
Height	1.4%
Length	4.7%
Width	1.0%
Wheelbase	3.9%
Overall	**2.8%**

Table 7: Error rates identified in hand measurement of devices

4.0 SIZES DATA

For the purposes of this survey, nine dimensions were extracted from the photographs taken of each of the 1356 occupants and their devices:

1. Height of device and occupant
2. Length of device and occupant
3. Width of device
4. Weight of device and occupant
5. Wheelbase of device
6. Height of armrest or device controls
7. Distance between device handles
8. Angle of the front wheel to the front of the device (wheelchairs only)
9. Angle of the rear wheel to the rear of the device (wheelchairs only)

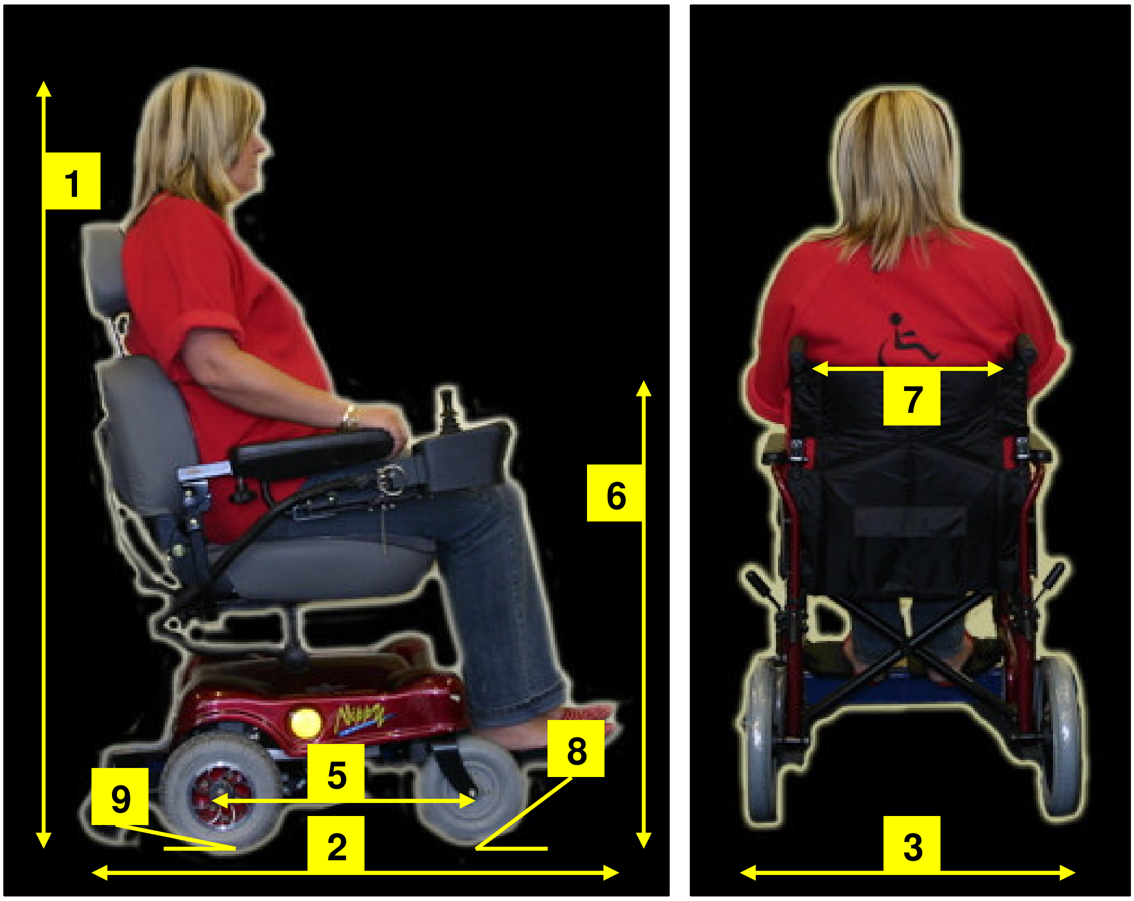


Figure 6: Guide to the measurements of this survey

The results for each of these dimensions are presented for both adult and child devices in the remainder of this section.

4.1 Summary of Adult Device Sizes

	n	Mean	Min	Max	5%ile	50%ile	95%ile
Height of device & occupant (mm)	921	1287	932	1550	1141	1291	1428
Length of device & occupant (mm)	927	1113	633	1604	893	1116	1339
Width of device (mm)	923	612	393	992	531	612	692
Weight of device & occupant (kg)	964	130.7	36.8	338.6	67.5	118.4	230.2
Wheelbase of device (mm)	925	549	338	1192	394	483	869
Height of armrest or controls (mm)	754	779	378	1220	671	747	973
Distance between handles (mm)	526	356	181	650	287	357	423
Front wheel/device angle (degrees)	714	26	6	65	12	25	47
Rear wheel/device angle (degrees)	225	13	1	45	5	13	25

Table 8: Summary of adult device sizes

4.2 Summary of Child Device Sizes

	n	Mean	Min	Max	5%ile	50%ile	95%ile
Height of device & occupant (mm)	211	1125	915	1374	972	1123	1267
Length of device & occupant (mm)	211	978	685	1412	768	981	1210
Width of device (mm)	211	546	397	689	459	541	642
Weight of device & occupant (kg)	220	66.5	23.0	217.6	31.7	53.9	139.6
Wheelbase of device (mm)	211	463	300	917	366	452	561
Height of armrest or controls (mm)	186	705	472	1052	604	694	846
Distance between handles (mm)	166	292	153	448	180	289	401
Front wheel/device angle (degrees)	185	39	3	77	21	37	63
Rear wheel/device angle (degrees)	87	14	3	46	7	13	26

Table 9: Summary of child device sizes

HEIGHT OF DEVICE & OCCUPANT

Definition of Measurement

Height from the floor to the top of the occupant's head (or the top of the device if any part of it is higher).

ADULT DEVICES

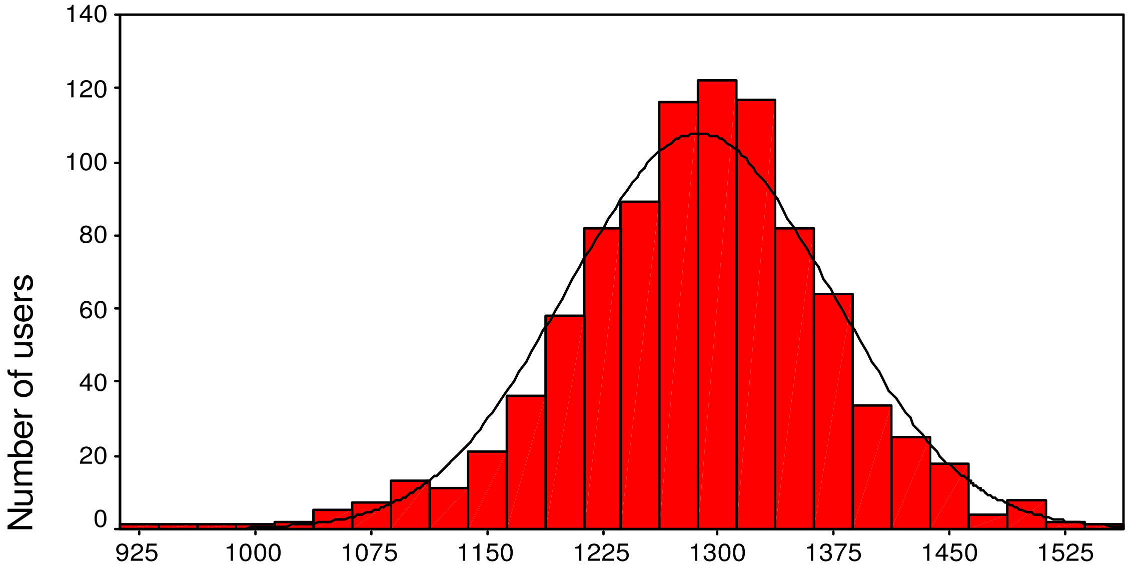


Figure 7: Distribution of heights of adult *device & occupant* (Dimensions in mm)

Device Type	Survey Year	Mean	Min	Max	5%ile	50%ile	95%ile
Self-Propelled	1999	1241	956	1407	1111	1244	1352
	2005	1271	932	1475	1138	1279	1376
Attendant-Propelled	1999	1190	956	1374	1078	1192	1324
	2005	1210	953	1436	1096	1218	1300
Electric Wheelchair	1999	1269	1005	1451	1133	1276	1374
	2005	1292	1006	1492	1152	1302	1408
Electric Scooter	1999	1340	1071	1502	1202	1345	1438
	2005	1349	974	1550	1230	1342	1490
All Chairs	1999	1255	956	1502	1110	1259	1382
	2005	1287	932	1550	1141	1291	1428

Table 10: Comparison of heights of adult *device & occupant* - 1999 and 2005 surveys (Dimensions in mm)

Trends

Table 10 shows a large overall increase in the average height of adult *device & occupant* of 32mm over the six-year period between surveys. The 95th percentile figure has increased by 46mm over the period.

- Data for the Self-Propelled Wheelchair show very significant rises in height from the 1999 survey - for both the average (30mm) and 95th percentile (24mm).
- The Attendant-Propelled Wheelchair has a significantly higher average height (20mm) but the 95th percentile is somewhat reduced by 24mm from the 1999 survey.
- Data for the Electric Wheelchair register very significant increases in height for both the average (23mm) and 95th percentile (34mm).
- Comparisons with the 1999 survey data for Electric Scooters show only a marginal increase in average height (9mm) but show a very significant increase in the 95th percentile (52mm).

CHILD DEVICES

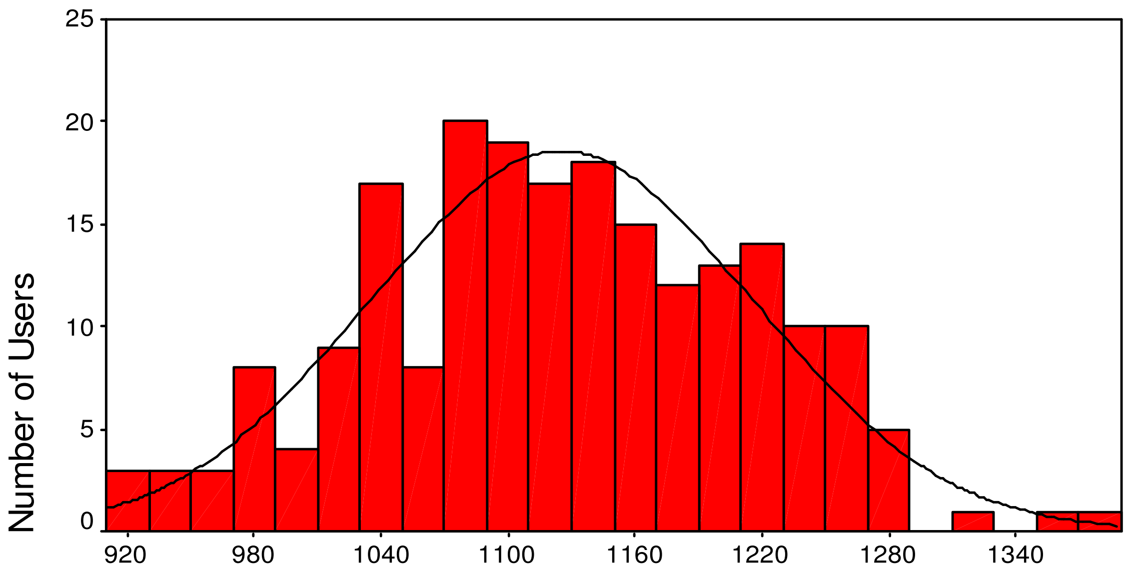


Figure 8: Distribution of heights of child *device & occupant* (Dimensions in mm)

Sizes

	Mean	Min	Max	5%ile	50%ile	95%ile
All Child Devices	1125	915	1374	972	1123	1267

Table 11: Heights of child *device & occupant* (Dimensions in mm)

LENGTH OF DEVICE & OCCUPANT

Definition of Measurement

Length of the device from the furthest points at both ends including the occupant's head and feet, but not including items overhanging at the back of the wheelchair.

ADULT DEVICES

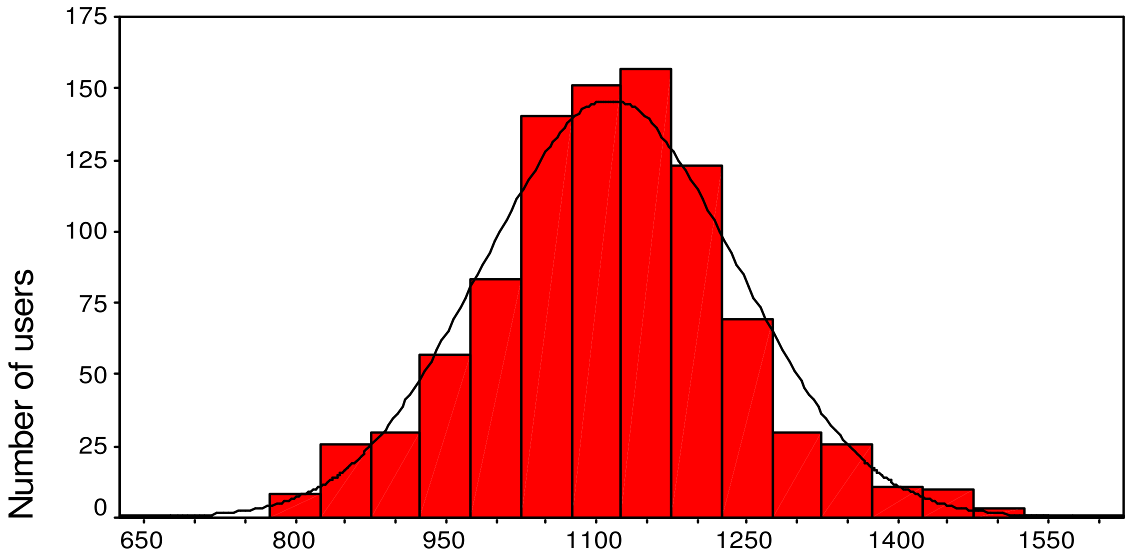


Figure 9: Distribution of lengths of adult *device & occupant* (Dimensions in mm)

Device Type	Survey Year	Mean	Min	Max	5%ile	50%ile	95%ile
Self-Propelled	1999	1059	707	1357	870	1069	1223
	2005	1068	776	1534	864	1075	1254
Attendant-Propelled	1999	1080	742	1318	928	1086	1197
	2005	1123	951	1375	1003	1116	1344
Electric Wheelchair	1999	1107	758	1549	949	1092	1328
	2005	1142	633	1604	955	1138	1339
Electric Scooter	1999	1187	971	1500	1000	1191	1402
	2005	1168	828	1503	956	1166	1416
All Chairs	1999	1084	707	1549	894	1086	1273
	2005	1113	633	1604	893	1116	1339

Table 12: Comparison of lengths of adult *device & occupant* - 1999 and 2005 surveys (Dimensions in mm)

Trends

Table 12 shows a large overall increase in the average length of adult *device & occupant* of 29mm over the six year period between surveys. The 95th percentile figure has increased considerably by 66mm over the period.

- Data for the Self-Propelled Wheelchair show an empirical increase in average length (9mm) but a more significant increase of 31mm at the 95th percentile.
- Results for the Attendant-Propelled Wheelchair suggest very significant increases in both average length (43mm) and the 95th percentile (147mm).
- Survey data for the Electric Wheelchair demonstrate a very significant increase in average length (35mm) but a non-significant rise in the 95th percentile of 11mm.
- The average length of the Electric Scooter has fallen significantly by 19mm whereas the 95th percentile value has risen slightly by a statistically non-significant 14mm.

CHILD DEVICES

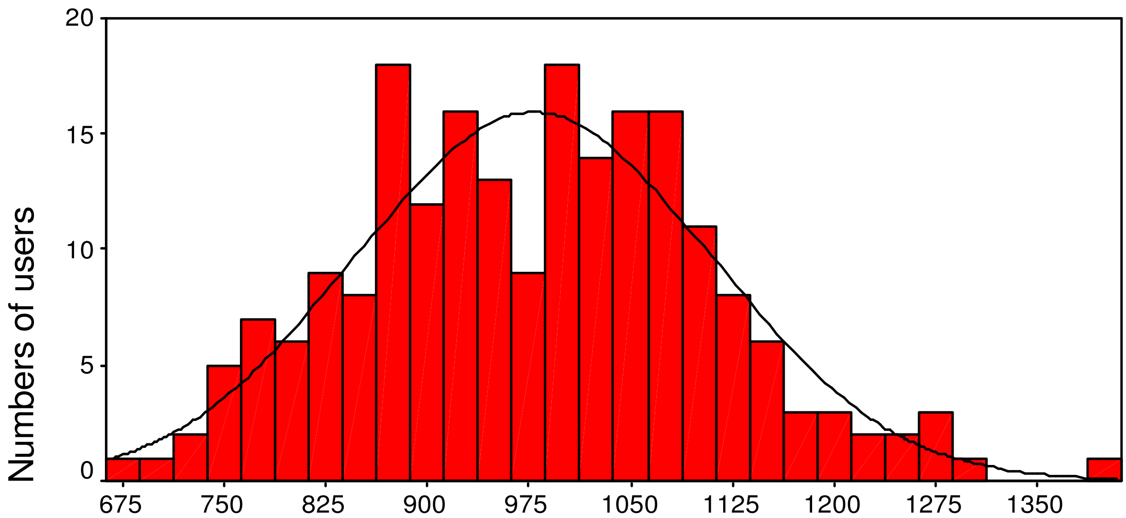


Figure 10: Distributions of length of child *device & occupant* (Dimensions in mm)

Sizes

	Mean	Min	Max	5%ile	50%ile	95%ile
All Child Devices	978	685	1412	768	981	1210

Table 13: Lengths of child *device & occupant* (Dimensions in mm)

WIDTH OF DEVICE

Definition of Measurement

Width of the device from the two most external points.

ADULT DEVICES

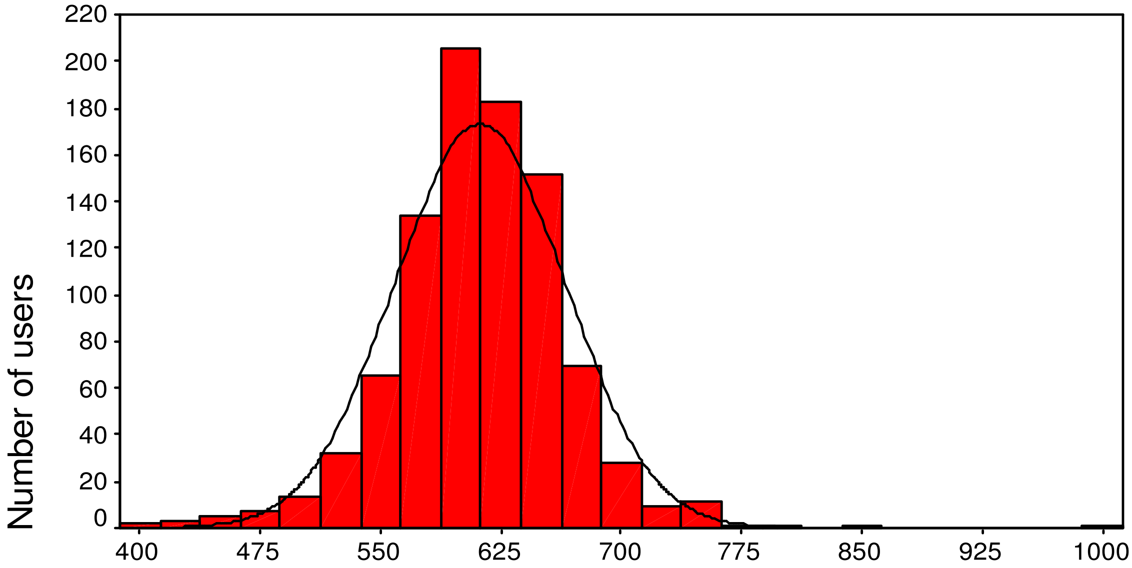


Figure 11: Distribution of widths of adult *device* (Dimensions in mm)

Device Type	Survey Year	Mean	Min	Max	5%ile	50%ile	95%ile
Self-Propelled	1999	630	512	741	560	627	697
	2005	635	393	992	572	634	707
Attendant-Propelled	1999	596	520	674	528	598	658
	2005	595	505	719	538	595	662
Electric Wheelchair	1999	635	521	755	552	636	706
	2005	605	399	745	536	606	670
Electric Scooter	1999	607	501	695	529	608	685
	2005	579	426	840	478	586	669
All Chairs	1999	627	501	755	558	625	695
	2005	612	393	992	531	612	692

Table 14: Comparison of widths of adult *device* - 1999 and 2005 surveys (Dimensions in mm)

Trends

Table 14 shows 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.

- The Self-Propelled Wheelchair data show an empirical rise in both average (5mm) and 95th percentile (10mm) values – but neither of these rises is significant in a statistical sense.
- Similarly, there are no significant changes in both the average (1mm decrease) and 95th percentile (4mm increase) width dimensions for the Attendant-Propelled Wheelchair.
- The Electric Wheelchair data reveal highly statistically significant decreases in width between the two survey periods both for average value (30mm) and the more extreme 95th percentile (36mm).
- The results for Electric Scooters demonstrate a very statistically significant decrease in average width (28mm), but only a marginal decrease of 16mm for the 95th percentile.

CHILD DEVICES

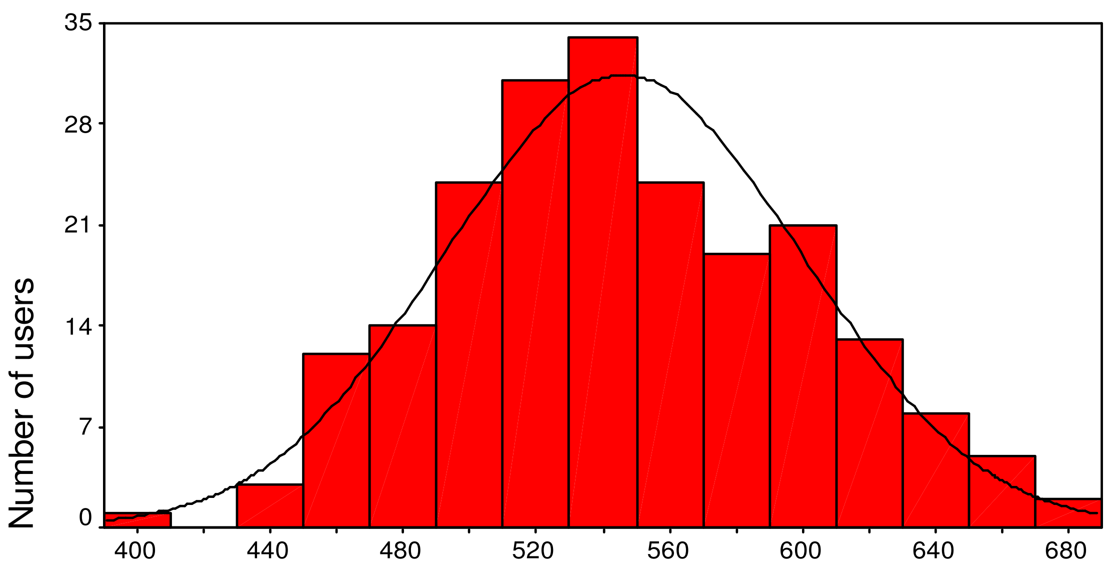


Figure 12: Distribution of widths of child *device* (Dimensions in mm)

Sizes

	Mean	Min	Max	5%ile	50%ile	95%ile
All Child Devices	546	397	689	459	541	642

Table 15: Widths of child *device* (Dimensions in mm)

WEIGHT OF DEVICE & OCCUPANT

Definition of Measurement

Total weight of the device, occupant and carried items.

ADULT DEVICES

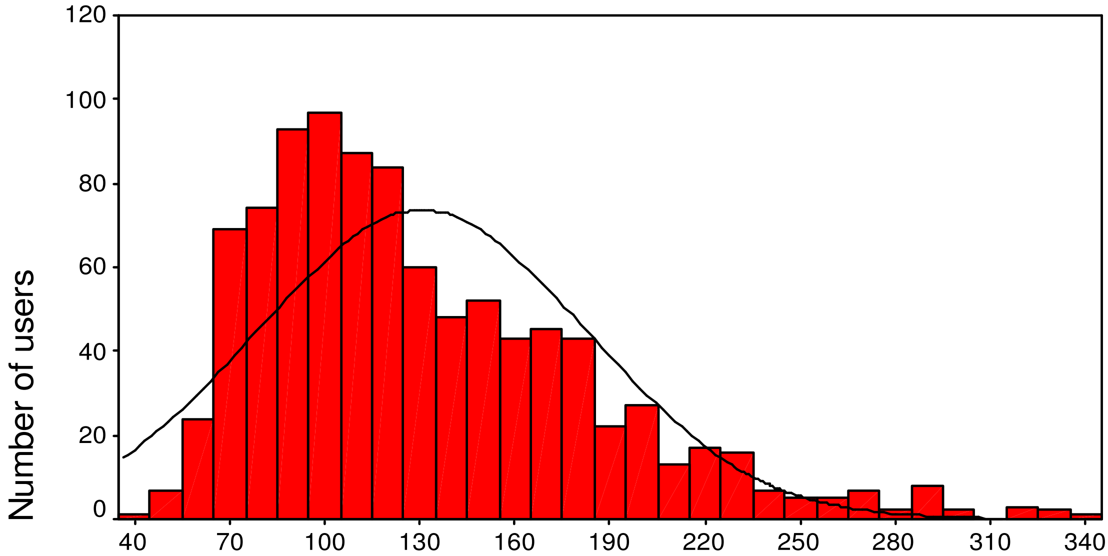


Figure 13: Distribution of weights of adult *device & occupant* (Dimensions in kg)

Device Type	Survey Year	Mean	Min	Max	5%ile	50%ile	95%ile
Self-Propelled	1999	96.0	46.6	184.4	67.2	93.0	131.4
	2005	99.7	50.0	197.2	65.6	97.0	145.2
Attendant-Propelled	1999	89.0	58.0	181.0	68.0	83.0	127.0
	2005	91.9	36.8	185.6	58.2	88.4	136.7
Electric Wheelchair	1999	168.0	94.0	384.0	116.0	158.8	258.0
	2005	180.1	90.6	326.2	114.8	171.6	273.4
Electric Scooter	1999	166.0	79.0	314.0	109.0	159.2	222.0
	2005	162.5	86.6	338.6	108.0	149.8	258.4
All Chairs	1999	120.5	47.0	384.0	70.0	108.0	206.0
	2005	130.7	36.8	338.6	67.0	118.4	230.2

Table 16: Comparison of weights of adult *device & occupant* - 1999 and 2005 surveys (Dimensions in kg)

Trends

Table 16 shows an overall increase in the average weight of *device and occupant* of 10.2kg over the six-year period between surveys. The 95th percentile figure has increased considerably by 24.2kg over the period.

- The Self-Propelled Wheelchair has significantly increased both its average (3.7kg) and 95th percentile (13.8kg).
- The Attendant-Propelled Wheelchair shows an increase in average weight of just 2.9kg and 9.7kg at the 95th percentile .
- The Electric Wheelchair has significantly increased both its average (12.1kg) and 95th percentile (15.4kg) weights.
- The Electric Scooter shows a small decrease in average weight of 3.5kg but a large increase of 36.4kg at the 95th percentile

CHILD DEVICES

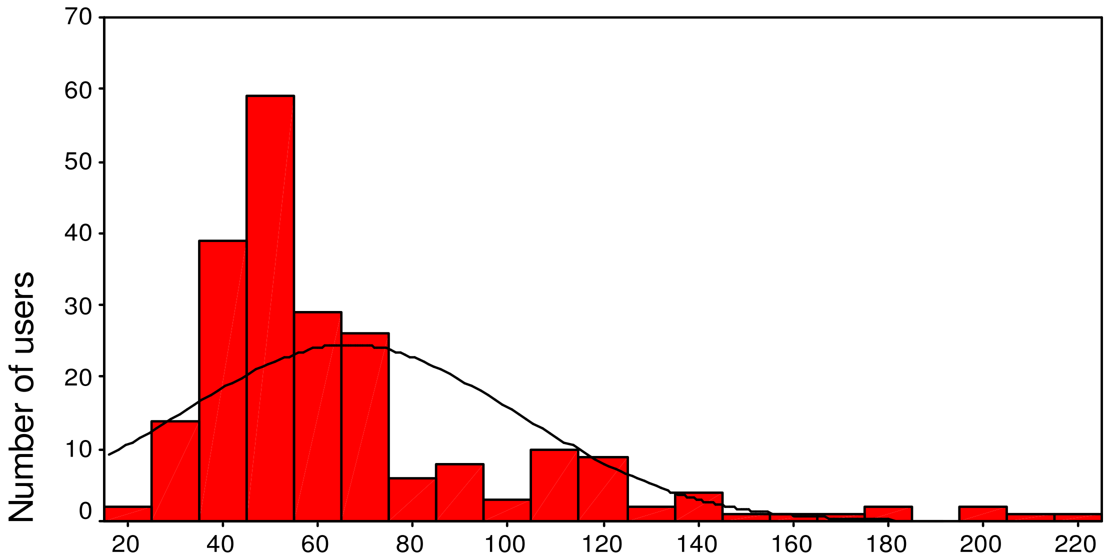


Figure 14: Distribution of weights of child *device & occupant* (Dimensions in kg)

Weights

	Mean	Min	Max	5%ile	50%ile	95%ile
All Child Devices	66.5	23.0	217.6	31.7	53.9	139.6

Table 17: Weights of child *device & occupant* (Dimensions in kg)

WHEELBASE OF DEVICE

Definition of Measurement

Distance between the front and rear axles (rear wheel centre to front wheel centre).

ADULT DEVICES

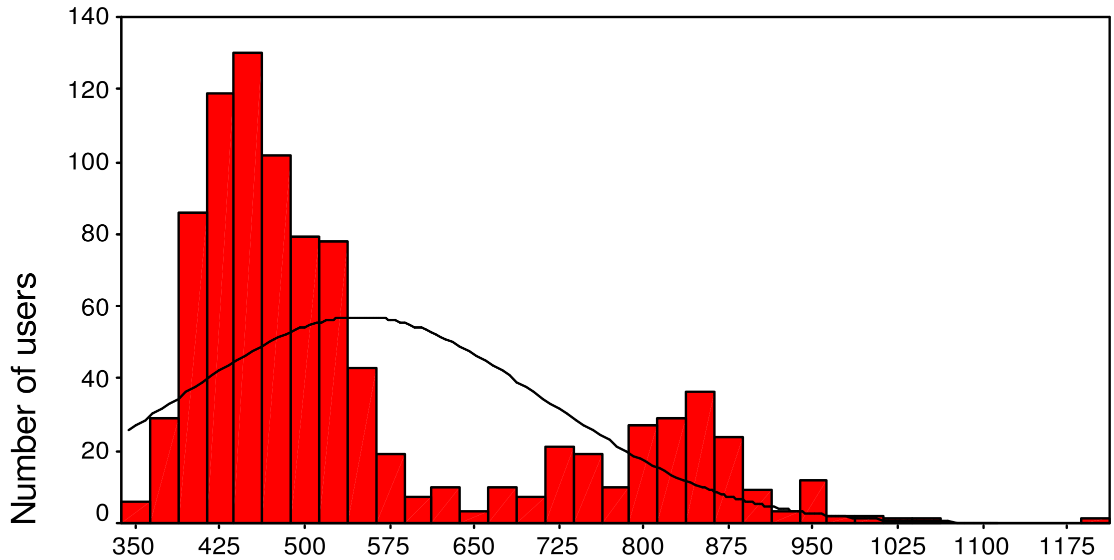


Figure 15: Distribution of wheelbase of adult *devices*
(Dimensions in mm)

Device Type	Mean	Min	Max	5%ile	50%ile	95%ile
Self-Propelled	439	338	563	379	437	506
Attendant-Propelled	459	378	582	401	453	532
Electric Wheelchair	562	392	1192	426	524	846
Electric Scooter	809	446	1053	665	829	947
All Chairs	549	338	1192	394	483	869

Table 18: Wheelbase dimensions of adult *devices*
(Dimensions in mm)

Trends

The previous 1999 survey did not report dimensions for wheelbase, so no comment can be made regarding trends.

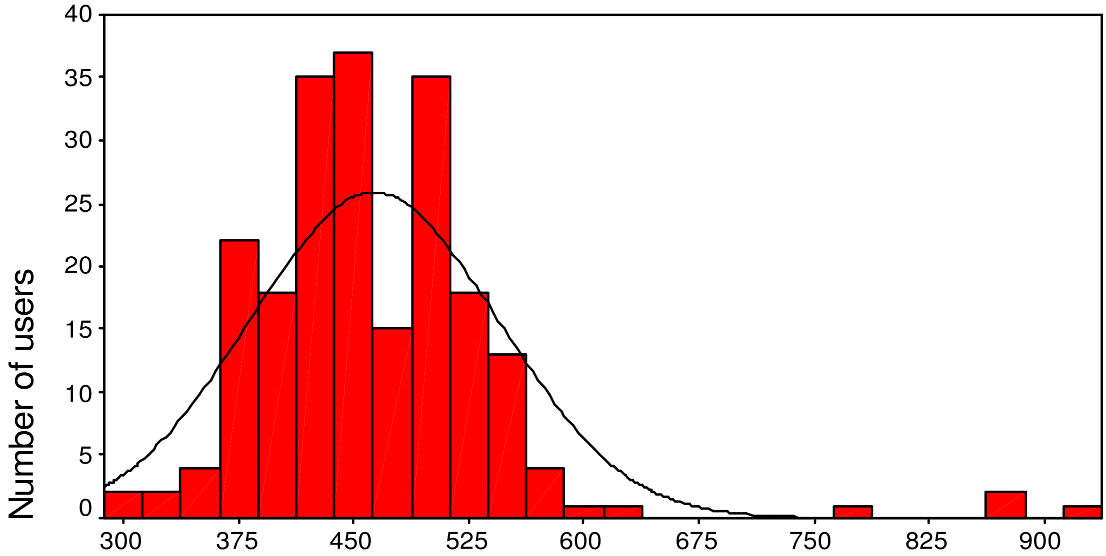


Figure 16: Distribution of wheelbase of child *devices*
(Dimensions in mm)

Sizes

	Mean	Min	Max	5%ile	50%ile	95%ile
All Child Devices	463	300	917	366	452	561

Table 19: Wheelbase dimensions of child *devices* (Dimensions in mm)

HEIGHT OF ARMREST OR DEVICE CONTROLS

Definition of Measurement

Height of the highest point on the armrest, tray or device control (e.g. joystick) if higher.

ADULT DEVICES

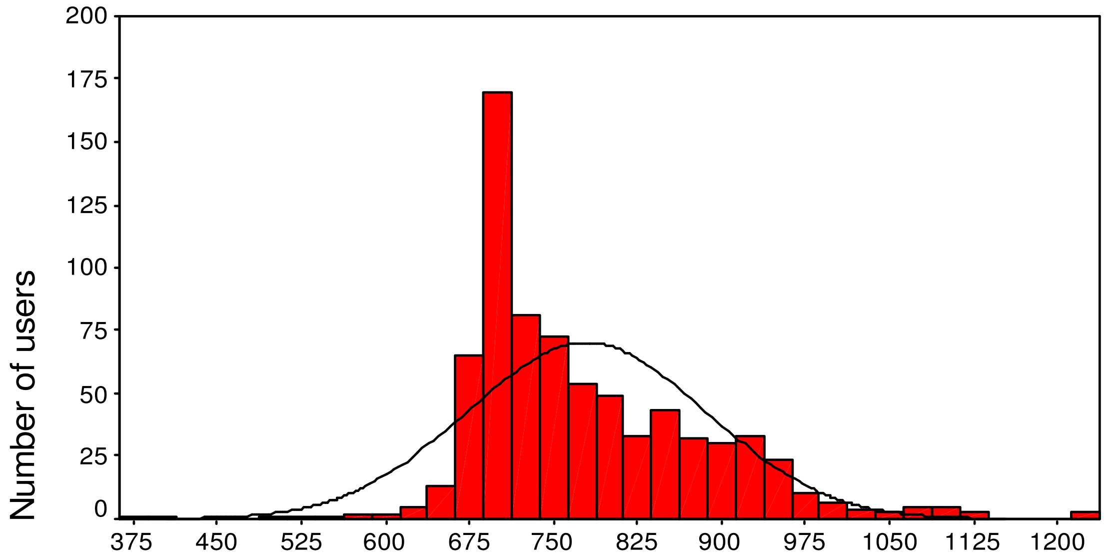


Figure 17: Distribution of armrest height, tray or device controls of adult *devices* (Dimensions in mm)

Device Type	Mean	Min	Max	5%ile	50%ile	95%ile
Self-Propelled	697	378	959	645	696	757
Attendant-Propelled	716	578	1220	660	698	795
Electric Wheelchair	786	519	1107	696	776	924
Electric Scooter	907	587	1219	790	900	1084
All Chairs	779	378	1220	671	747	973

Table 20: Heights of armrest, tray or device controls of adult *devices* (Dimensions in mm)

Trends

The previous 1999 survey did not report dimensions for armrest or device controls height, so no comment can be made regarding trends.

CHILD DEVICES

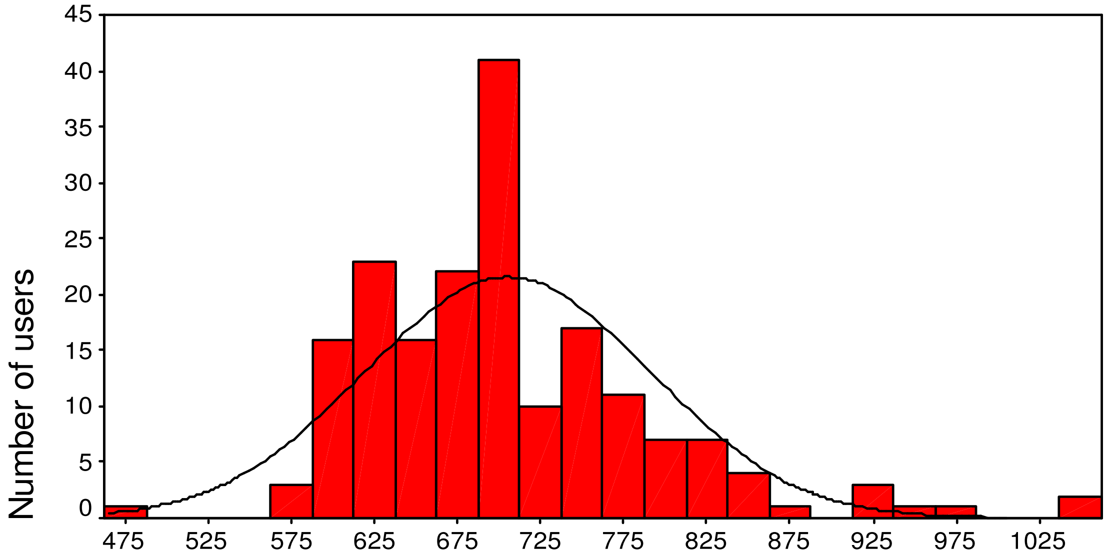


Figure 18: Distribution of armrest height or device controls of child *devices*
(Dimensions in mm)

Sizes

	Mean	Min	Max	5%ile	50%ile	95%ile
All Child Devices	705	472	1052	604	694	846

Table 21: Heights of armrest or device controls of child *devices*
(Dimensions in mm)

DISTANCE BETWEEN HANDLES OF DEVICE

Definition of Measurement

Clearance between the handles at the rear of the device.

ADULT DEVICES

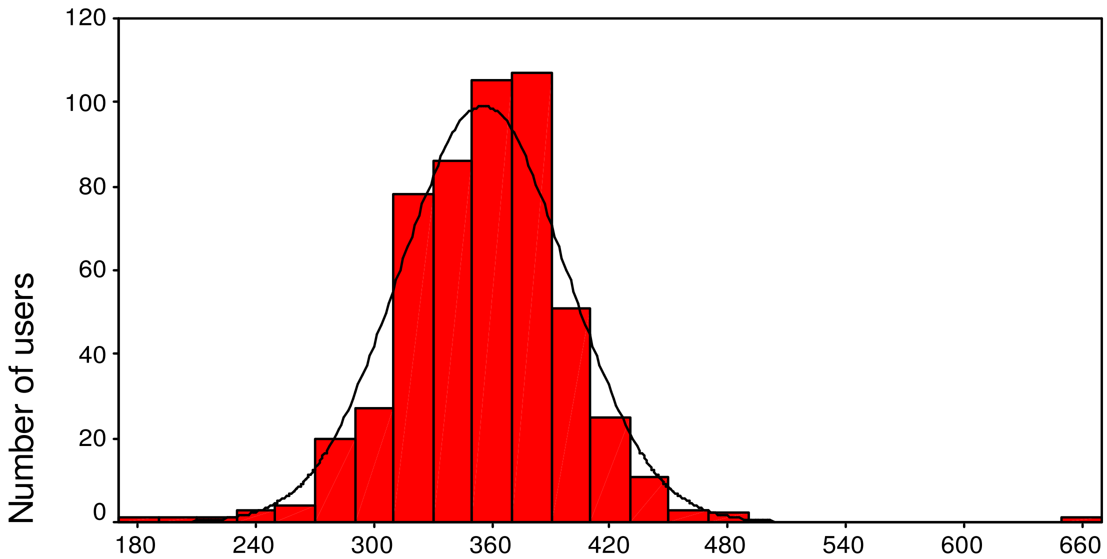


Figure 19: Distribution of distances between handles of adult *devices*
(Dimensions in mm)

Device Type	Mean	Min	Max	5%ile	50%ile	95%ile
Self-Propelled	348	229	650	286	349	416
Attendant-Propelled	369	275	479	312	371	427
Electric Wheelchair	367	240	479	290	372	427
Electric Scooter	311	181	399	181	342	399
All Chairs	356	181	650	287	357	423

Table 22: Distances between handles of adult *devices*
(Dimensions in mm)

Trends

The previous 1999 survey did not report dimensions for the distance between handles, so no comment can be made regarding trends.

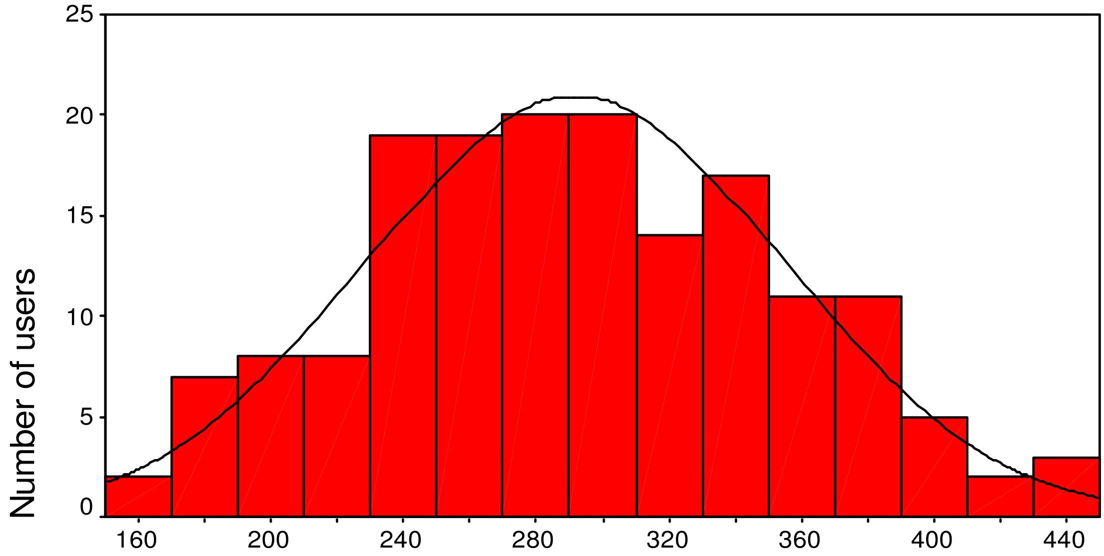


Figure 20: Distribution of distances between handles of child *devices*
(Dimensions in mm)

Sizes

	Mean	Min	Max	5%ile	50%ile	95%ile
All Child Devices	292	153	448	180	289	401

Table 23: Distances between handles of child *devices*
(Dimensions in mm)

ANGLE OF FRONT WHEEL TO FRONT OF DEVICE

Definition of Measurement

The minimum angle made between the point at which the front wheel touches the floor and the lowest point of the device in front of the wheel (typically the footrest). This measurement only applies to wheelchairs and, alongside ‘angle of rear wheel to rear of device’, is useful in determining their capabilities to traverse ramps and gradients.

ADULT DEVICES

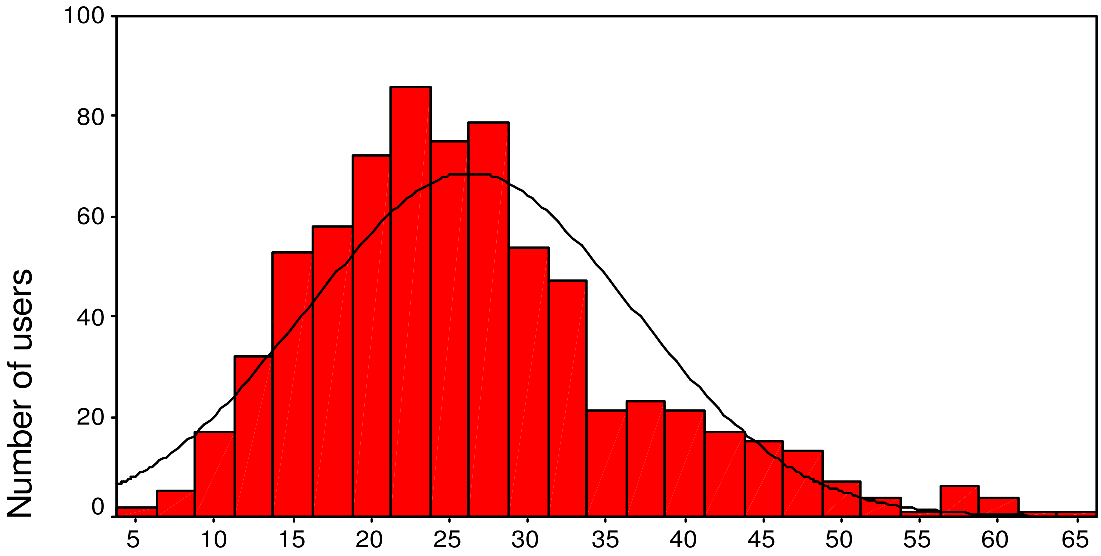


Figure 21: Distribution of minimum angles made between the front wheel and the front of the device of adult *devices* (Dimensions in degrees)

Device Type	Mean	Min	Max	5%ile	50%ile	95%ile
Self-Propelled	26	6	65	12	24	48
Attendant-Propelled	27	9	57	13	26	43
Electric Wheelchair	27	6	59	13	25	46
All Wheelchairs	26	6	65	12	25	47

Table 24: Minimum angles made between the front wheel and the front of the device of adult *devices* (Dimensions in degrees)

Trends

The previous 1999 survey did not report angles made between the front wheel and the front of the device, so no comment can be made regarding trends.

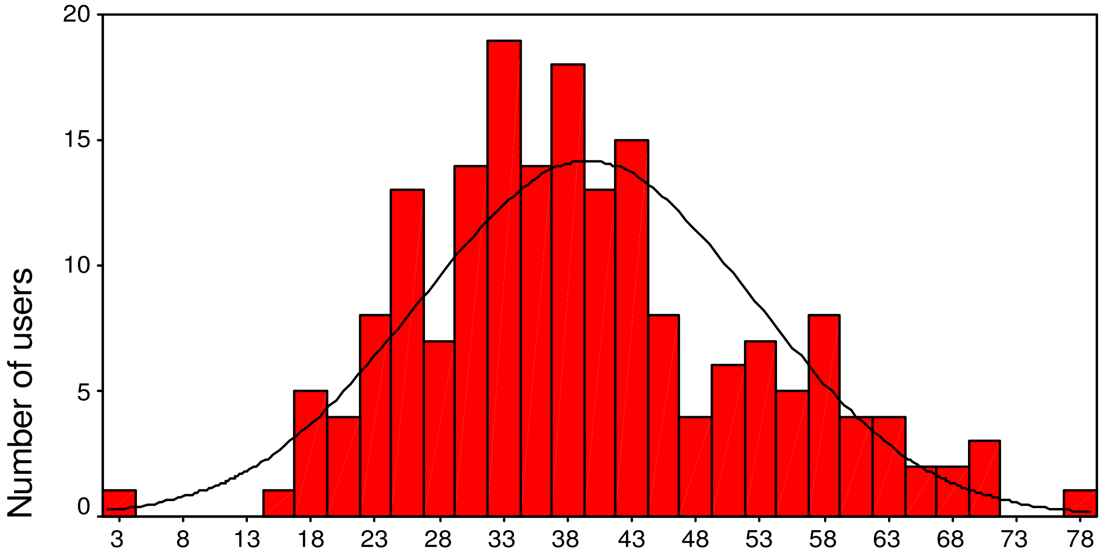


Figure 22: Distribution of minimum angles made between the front wheel and the front of the device of child *devices* (Dimensions in degrees)

Sizes

	Mean	Min	Max	5%ile	50%ile	95%ile
All Child Devices	39	3	77	21	37	63

Table 25: Minimum angles made between the front wheel and the front of the device of child *devices* (Dimensions in degrees)

ANGLE OF REAR WHEEL TO REAR OF DEVICE

Definition of Measurement

The minimum angle made between the point at which the rear wheel touches the floor and the lowest point of the device behind the rear wheel (e.g. anti-tip wheels). This measurement only applies to wheelchairs and, alongside 'angle of rear wheel to rear of device', is useful in determining their capabilities to traverse ramps and gradients.

ADULT DEVICES

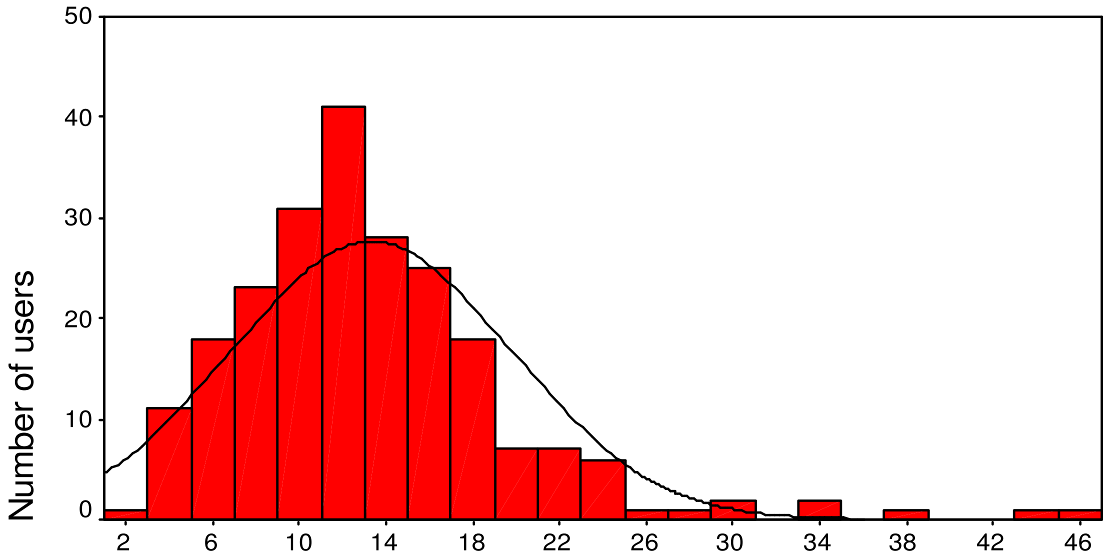


Figure 23: Distribution of minimum angles made between the rear wheel and the rear of the device of adult *devices* (Dimensions in degrees)

Device Type	Mean	Min	Max	5%ile	50%ile	95%ile
Self-Propelled	14	3	45	5	13	31
Attendant-Propelled	12	3	25	-[6]	10	-
Electric Wheelchair	13	1	34	5	12	22
All Wheelchairs	13	1	45	5	13	25

Table 26: Minimum angles made between the rear wheel and the rear of the device of adult *devices* (Dimensions in degrees)

[6] Insufficient measurements could be made to reliably generate 5th and 95th percentile values

.

Trends

The previous 1999 survey did not report angles made between the rear wheel and the rear of the device, so no comment can be made regarding trends.

CHILD DEVICES

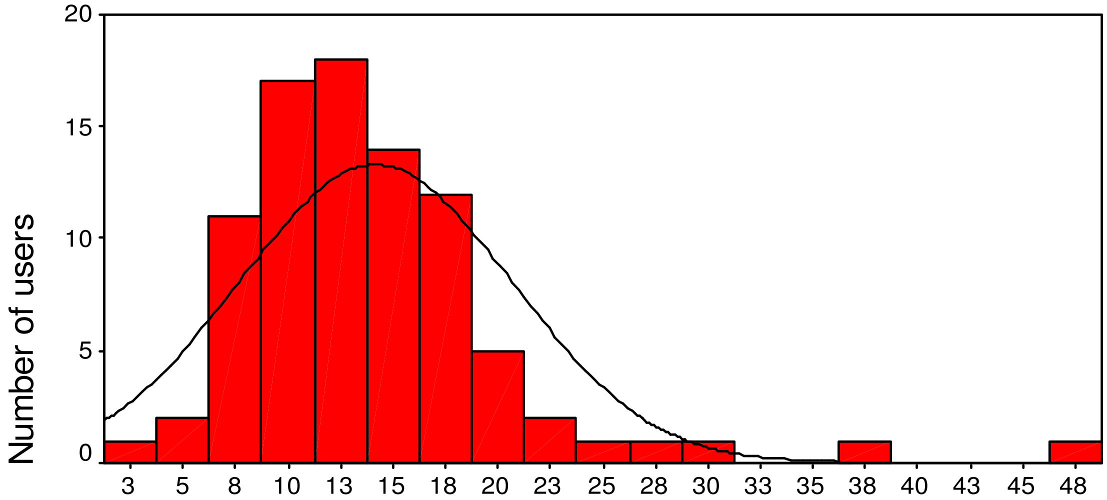


Figure 24: Distribution of minimum angles made between the rear wheel and the rear of the device of child *devices* (Dimensions in degrees)

Sizes

	Mean	Min	Max	5%ile	50%ile	95%ile
All Child Devices	14	3	46	7	13	26

Table 27: Minimum angles made between the rear wheel and the rear of the device of child *devices* (Dimensions in degrees)

5.0 DEVICE FEATURES

In addition to their measurement, the survey sought to describe a number of design features of the devices and consider the nature of their use. This section discusses the findings, and unless otherwise stated, the figures relate to the total sample size.

5.1 Manual Brakes

Each manually operated wheelchair was checked for the presence of manual brakes.

Device Type	n	Wheelchairs with Manual Brakes	%
Self-Propelled	568	545	96%
Attendant-Propelled	182	171	94%
Overall Totals	**750**	**716**	**95%**

Table 28: Manually operated wheelchairs with manual brakes

The 1999 survey reported manual brakes present on 92% of manual wheelchairs, so this latest survey records an increase of 3%, (and closer to the 1991 survey figure of 96%).

5.2 Postural Supports and Mobility Aids

Each device was inspected for the use of leg and head supports and whether walking aids were carried on the device.

Device Type	Leg Support Used	Head Support Used	Walking Aids Carried
Self-Propelled	3%	5%	11%
Attendant-Propelled	4%	41%	8%
Electric Wheelchair	4%	35%	12%
Electric Scooter	0%	10%	36%
Overall Use	**3%**	**19%**	**15%**

Table 29: Percentage of supports used and aids carried for each device type

Leg supports were being used on 3% of the devices – just a single percentage point up on results from the 1999 study but the same as for the earlier 1991 survey.

The most striking difference when compared with the previous study was the increase in head supports. In this latest survey, the overall figure of 19% is a very significant increase on the 3% figure recorded in 1999.

Electric Wheelchairs (35%) and Attendant-Propelled chairs (41%) recorded high figures. This may, in part, be due to the increased number of children in this latest survey - children's devices register an incidence of 44% for headrest users.

The overall figure for the carrying of walking aids (15%) is exactly the same as that recorded in the 1999 survey. It was noted that the majority of people using Attendant-Propelled Wheelchairs tended to carry their walking aids at the front of the device; those using Electric Wheelchairs tended to use the back. Electric Scooter users favoured the front and Self-Propelled Wheelchair users tended not to discriminate and used the front, back and side locations to transport their walking aids.

5.3 Luggage

67% of the devices sampled carried luggage - slightly more than the 62% recorded in the 1999 study (although the authors of the previous study suggest that their figure may have been a slight underestimate). Given that the figure reported in the 1991 survey was 55%, there does seem to be an increase in the proportion of chairs carrying luggage. Table 30 shows where the luggage was carried on the devices.

	Back	Back & Side	Front	Front & Back	Side	Totals
Self-Propelled Wheelchair	79%	1%	10%	9%	1%	100%
Attendant-Propelled Wheelchair	79%	2%	9%	10%	1%	100%
Electric Wheelchair	79%	6%	4%	8%	4%	100%
Electric Scooter	13%	0%	62%	25%	0%	100%
Overall Totals	**64%**	**2%**	**20%**	**12%**	**2%**	**100%**

Table 30: Positions on devices of luggage carried (n=911)

The rear of the device is by far the most popular place for stowing luggage. Front and side locations seem much less popular, except for Electric Scooters where the front basket offers the most convenient stowage.

5.4 Handrails

Overall, 74% of users reported that they could use handrails – intended to minimise the risk of falls on buses - with the highest proportion coming from the users of Electric Scooters (89%). 68% of Electric Wheelchair users reported that they could use handrails. Perhaps surprisingly, only 78% of Self-Propelled Wheelchair users said the same. Occupants of Attendant-Propelled Wheelchairs registered the lowest percentage of handrail users at 53%, As far as handrail location preferences are concerned, those situated on the right seem most popular but nearly a third of respondents expressed equal preferences. Table 31 shows that the preference patterns do not seem dissimilar for the different devices. This is confirmed by the application of the chi-square test (Chi(6) = 9.278, Significance = 0.000).

	Equal Preference	Left	Right	Totals
Self-Propelled Wheelchair	34%	23%	43%	100%
Attendant-Propelled Wheelchair	29%	34%	37%	100%
Electric Wheelchair	29%	30%	41%	100%
Electric Scooter	32%	22%	46%	100%
Overall Totals	**32%**	**26%**	**43%**	**100%**

Table 31: Preferred positions of handrails (n=898)

As far as the orientation of the handrail is concerned, Table 32 suggests that the horizontal position is most popular. Again, one third of users express equal preferences. Similarly, there appears to be no association between preference for handrail orientation and the type of device used (Chi(6) = 13.805, Significance = 0.000).

	Equal Preference	Horizontal	Vertical	Totals
Self-Propelled Wheelchair	32%	48%	19%	100%
Attendant-Propelled Wheelchair	35%	37%	29%	100%
Electric Wheelchair	40%	37%	23%	100%
Electric Scooter	27%	42%	30%	100%
Overall Totals	**33%**	**43%**	**24%**	**100%**

Table 32: Preferred orientation of handrails (n=845)

5.5 Bus Backrest Compliance

Each set of photographs of each wheelchair was inspected to assess whether or not they would be likely to fit against the designated backrest fitted in regulated buses and often in trams. Tables 33 and 34 present the results for each adult and child wheelchair type.

	Fits	Would Fit but for 'Luggage'	Does Not Fit	Totals
Self-Propelled Wheelchair	42%	49%	9%	100%
Attendant-Propelled Wheelchair	38%	60%	2%	100%
Electric Wheelchair	15%	41%	43%	100%
Overall Totals	**32%**	**50%**	**18%**	**100%**

Table 33: Bus backrest compliance of adult wheelchairs (n=737)

	Fits	Would Fit but for 'Luggage'	Does Not Fit	Totals
Self-Propelled Wheelchair	8%	19%	73%	100%
Attendant-Propelled Wheelchair	6%	44%	50%	100%
Electric Wheelchair	11%	18%	71%	100%
Overall Totals	**8%**	**25%**	**67%**	**100%**

Table 34: Bus backrest compliance of child wheelchairs (n=208)

Reasons why the wheelchair would not fit included the handles being too close together, a continuous bar handle preventing the backrest from locating against the body of the wheelchair, narrow wheels, the battery or other items obstructing the backrest.

6.0 DYNAMIC STABILITY

This project also took the opportunity to consider some fundamental aspects of device stability in relation to using public transport. The purpose of the research was not to identify a range of compliant and non-compliant devices or ramp angles, but to review the performance of different devices and different angles. Although extending beyond the requirements of current legislation, the research took the opportunity to include Electric Scooters.

The method of testing was generally in accordance with the standard for the determination of the dynamic stability testing of electric wheelchairs, specifically 'ISO 7176-2:2001 Dynamic Stability Test paragraphs 8.2, 8.3, 8.4 and 9.2'. This standard requires devices to be tested as they move from horizontal surface to ramp and as they traverse the ramp. For this research, the following seven specific manoeuvres were considered:

To test FORWARD dynamic stability:

1. Braking when travelling forwards
2. Travelling forwards from horizontal surface to upward slope
3. Travelling forwards from upward slope to horizontal surface
4. Travelling forwards from horizontal surface to downwards slope
5. Travelling forwards from downwards slope to horizontal surface

To test REARWARD dynamic stability:

6. Stopping after travelling forwards
7. Braking when travelling backwards

For all tests, two occupant weights were used; 111kg and 83kg, to represent close to the maximum test weight of the standard and the 75th percentile.

Subject to risk assessment measures, the occupant was required to drive each device at full-speed for each test and bring the device to a stop by (1) releasing the forward control, (2) switching off the power and (3) putting the device into reverse. The device was then allowed to respond without the occupant intentionally taking evasive or protective action. If a device appeared likely to perform dangerously at full-speed, half-speed was applied as an alternative.

Each device was tested for each manoeuvre, three times using ramp angles ranging between 0^o and 16^o, stopping at the point when the device was considered to have 'failed' or testing became excessively dangerous.

It is inappropriate in the context of this research to describe each device in detail, but all the devices used in the testing were in a good state of repair, and supplied by reputable dealers as representative of their most popular sellers.

Eighteen devices were tested;

- 4 smaller style Electric Wheelchairs (devices a-d)
- 4 larger style Electric Wheelchairs (devices e-h)
- 2 smaller style 3-wheel Electric Scooters (devices i-j)
- 2 larger style 3-wheel Electric Scooters (devices k-l)
- 3 smaller style 4-wheel Electric Scooters (devices m-o)
- 3 larger style 4-wheel Electric Scooters (devices p-r)

Researchers observed the performance of each of these devices and rated them according to the criteria described in Table 35 below.

Observed Dynamic Response		**Score**
No Tip	At least one of the lifting wheels (e.g. front wheels) remained on the test plane.	**3**
Transient Tip	All lifting wheels lost contact, then dropped back onto the test plane The wheelchair anti-tip device(s) did not contact the test plane.	**2b**
	All lifting wheels lost contact then dropped back onto the test plane. The wheelchair anti-tip device(s) contacted the test plane.	**2a**
Stuck on Anti-Tip Device[a]	All lifting wheels lifted off, the wheelchair anti-tip device(s) contacted the test plane and the wheelchair remained stuck on the anti-tip devices.	**1**
Full Tip	The wheelchair tipped completely over (90º or more from its original orientation) – in practice the wheelchair was caught by research personnel for test purposes.	**0**

Table 35: Dynamic stability rating criteria

Figure 25: Six photographs of the dynamic stability testing

The worst rating for each of the three braking techniques was recorded for each of the seven manoeuvres. For this research, the emphasis was on identifying the ramp angle at which an occupant might feel vulnerable due to dynamic instability. Typically this was a score of 2b or 1 (whichever occurred first), although in considering particularly sensitive users a score of 2a was used when the transient tip appeared to be especially unnerving.

Tables 36 overleaf shows at which ramp angle each device type became vulnerable and at which manoeuvre(s) this was first identified. Some devices were unable to negotiate the ramp angles at certain occupant weights, so these do not have a 'failure' point. Three scooters (two larger 3-wheel and one larger 4-wheel) passed all tests at all occupant weights and ramp angles and, therefore, also do not have a 'failure' point.

	ELECTRIC WHEELCHAIRS						
	Manoeuvre number						
	1	2	3	4	5	6	7
3°	device a					device a device f	
4°				device c	device c		
5°							
6°			device a			device e	device g device g
7°							
8°			device c		device c		
9°							
10°			device f	device f			device e device h
11°							
12°	device b						
13°	device b		device b				
14°							
15°							
16°		device d device d					

	3-WHEEL ELECTRIC SCOOTERS						
	1	2	3	4	5	6	7
8°	device j						
9°							
10°							device j

	4-WHEEL ELECTRIC SCOOTERS						
	1	2	3	4	5	6	7
10°	device n						device m
11°							
12°							device n
13°							
14°	device p						
15°							
16°	device p						

Table 36: Dynamic stability results showing angles of ‘failure’
(red = heavier [111kg] occupant, blue = lighter [83kg] occupant)

The cumulative frequency chart in Figure 26 below simplifies the results to show how many of each device type ‘failed’ the dynamic stability tests (irrespective of occupant weight) at each ramp angle.

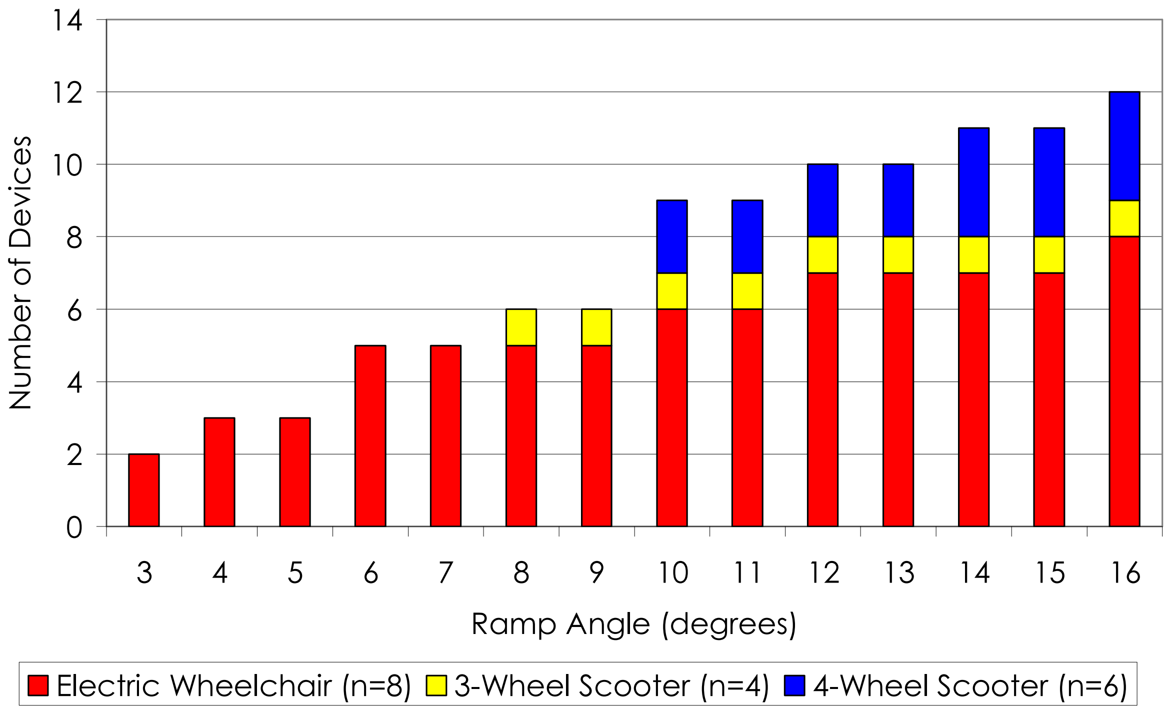


Figure 26: Cumulative frequency of device ‘failures’ at different ramp angles

From the tests performed as part of this research:

- Two of the four smaller Electric Wheelchairs appear to offer greater dynamic stability than all but one (p) of the other 12 devices. Unfortunately the two other smaller Electric Wheelchairs failed at shallow ramp angles of 3^{o} and 4^{o} when driven by the 75th percentile weight occupant.
- At both occupant weights, the larger Electric Wheelchairs appear to offer generally less dynamic stability than the smaller versions
- Only one Electric Wheelchair remained stable above 12^{o}.

7.0 LITERATURE REVIEW

As people with disabilities increasingly integrate themselves into mainstream life, and with the impact in the UK of the Disability Discrimination Act (1995 and 2005)), designers are, with increasing necessity, giving greater consideration to the needs of disabled people.

There have been several studies in which structural and functional anthropometric data for the wheelchair user have been generated. However, few have concentrated on the wheelchair and the variety of measurements attributed to the vast range of wheelchairs on the market.

One study, by Goldsmith (1984) concentrated on DHSS issued Model 8 wheelchairs but did not account for the recent increase in the use of personal mobility vehicles.

Work by Jarosz (1996) in Poland focused on the determination of the workspace requirements of wheelchair users by measuring eighteen different anthropometric characteristics of 170 wheelchair users (101 men and 69 women) sitting in their wheelchairs. The aim of this study was to complement work by Pheasant (1986) into anthropometric characteristics of the non-disabled people as data could be used to design “workstations and home interiors for this group of users”. However, this study made assumptions about the mean dimensions of the wheelchair according to previous work by Skaradzinska (1989) and did not set about measuring the actual mobility devices. Jarosz concluded that many wheelchair users perform daily and professional activities exclusively in their wheelchair, therefore the wheelchair user should be treated as an integral unit with the chair - “the human-chair system”.

More recently, work by Paquet and Feathers (2004) delivered an “Anthropometric Study of Manual and Powered Wheelchair Users”, the objective of which was to generate anthropometric data on adult wheelchair users as part of a larger project that involved developing a database of the structural characteristics and functional abilities of wheelchair users. Paquet and Feathers argue that anthropometric studies of the elderly and disabled have involved smaller sample sizes than studies on the non-disabled population and fewer measurements.

Studies involving disabled subjects have tended to focus on specific disability groups and this, coupled with the lack of standardised dimensional definitions and measurement methods, has made combining information from previous studies very difficult (Bradtmiller and Annis, 1997), with the authors mentioning that “the general lack of anthropometric information about individuals who are wheelchair mobile limits the ability of designers to create environments and products that can be used effectively and safely by this diverse set of users”. Jarosz (1996) concluded that the physical characteristics of individuals have also been shown to be quite different across disability populations.

Paquet and Feathers went on to record a range of information about the wheelchairs occupied during their study such as device type (manual or powered), make, model, age and presence of armrests and footrests, drive wheels, controller and seat support surfaces. The 111 participants, representing a wide range of disabilities were measured, with 36 body and wheelchair landmarks and seven reference planes being used in the calculation of 31 structural anthropometric dimensions. The wheelchair characteristics reported that one-third of all wheelchairs sampled had a headrest, trunk lateral support, thigh lateral support or other positioning support. 81% of the postural supports were found on the powered wheelchairs. Half of the armrests on the manual wheelchairs were height adjustable. The swing-away footrest was the most common type of footrest on the manual chairs. In their study, over half of the participants carried some form of luggage on their wheelchair with 69% carrying the luggage on the back of their chair. 67% of the powered wheelchairs carried luggage making it the most likely wheelchair to do so.

Das and Kozey (1999) offer similar research looking at structural anthropometric measurements for wheelchair mobile adults. They deduce that, “Present workstation design principles based on seated able-bodied anthropometric measurements would not be suitable for this population”. The objective of their research was to generate relevant data towards the design of a universally accessible industrial workstation; following on from work they did five years prior to this study (Das and Kozey 1994). They conclude “In the determination of work surface height for wheelchair mobile adults, besides structural anthropometric measurements, other design criteria should be considered. They include wheelchair armrest type, controls and their dimensions. Consequently, for the workstation design for such a population, the wheelchair design characteristics or dimensions play an important role.”

More recently, Goldsmith (2000) has considered more variants of mobility devices and has attempted to incorporate into the measures certain peripheral, but commonly used, items. For example he comments that the height of the centre of the seat is typically at about 470mm above floor level, however, most wheelchair users place a cushion on the seat, making a seat height of about 490mm. He describes the “standard” wheelchair with a height above floor level at the top face of the handles of 920mm and top face of the armrests at 750mm; length of 1070mm; a footrest width (when “closed”) of 490mm; total width of the wheelchair is 635mm.

Goldsmith (2000) describes an “attendant–pushed” wheelchair as having the following characteristics; fixed armrests, fixed footrests, pneumatic rear wheels with a diameter of 310mm and solid front castor wheels with a diameter of 205mm. This wheelchair, Goldsmith says, has a total width of 635mm and a total length of 790mm. He goes on to state that a “small powered wheelchair” may have a total length of 890mm and a total width of 630mm. A “large powered wheelchair” may have the dimensions of 1170mm (total length) by 680mm (total width) according to Goldsmith. He adds that a “typical powered wheelchair” manufactured in 2000 was designed to carry a weight of 115kg, with heavy duty wheelchairs being able to carry a weight of 165kg.

According to Goldsmith, the increase in use of personal mobility vehicles (powered scooters) available to the wheelchair user has increased as a function of the number of Shopmobility schemes operating in towns and cities across the country. He cites two kinds of personal mobility vehicles and provides dimensions. The 3-wheel scooter, he says, has a total width of 650mm and a total length of 1250mm, while a 4-wheel scooter has a total width of 645mm and a total length of 1390mm. However, he also claims that the largest personal mobility vehicles can have lengths in the order of 1650mm.

In the 1991 survey on information on the basic dimensions of people in their wheelchairs performed by the Transport Research Laboratory nearly half of the sample used old style rear wheel drive manual chairs, such as the NHS Model 8L (48%), and 17% were new style manual chairs (Stait et al, 2001). The 1999 survey showed a reverse in this trend, with 19% using the old style chairs and 40% using the new style chairs. The new style chairs were characterised “as wheelchairs manually driven by the user from the rear wheels, made of modern lightweight construction and often identified by a negative camber on the rear wheels and an adjustable wheelbase”. Electric wheelchairs were the second most popular in use behind the new style chairs.

8.0 ANALYSIS OF SURVEY END-USER NEEDS

While expanding on the previous work, this survey has intentionally sought to be consistent with the two previous surveys in its general approach and presentation. However, the authors took the opportunity to conduct a usability needs analysis to determine how any future surveys might be shaped.

To explore the key issues, the usability study surveyed a number of end-users of the data such as policy makers, architects and wheelchair providers as well as wheelchair users from relevant groups such as local authority day centres, and independent living centres.

In all, 43 stakeholders were questioned, (21 wheelchair users and 22 data users) either in face-to-face or telephone interviews. The requirements from each group were often complementary and overlapping, with differences in requirements mainly arising from one group (designers, architects etc.) more often requiring generalised data based on entire populations while wheelchair users often requiring specific data on specific models of mobility aids to support purchase decision making. Interesting differences arose also in the data users' desires to either have easily accessible data which could be referenced quickly or to receive the rationale behind a recommendation explained so that it could be correctly interpreted in a given setting.

Data users are divided broadly into four main groups:

1. Those who use the data to enable them to choose wheelchairs or make adaptations to meet the needs of individuals, for example wheelchair services managers and occupational therapists who use the data to accommodate individuals and enable them to achieve their personal aims.
2. Those who are responsible for the safety and provision of wheelchairs to the end-users, for example the MHRA and the NHS wheelchair service.
3. Those who use the data for the design or evaluation of facilities, transport systems and policy, for example those responsible for access audits, airport design and operational issues, public spaces, health and safety, integrated transport systems and policy, train and station planning and design, ergonomists and human factors consultants providing advice.
4. Those who offer advice to both disabled people and those trying to meet their needs and who campaign for change, for example information centres such as 'Independent Living' and those aimed at specific groups of disabled people such as spinal injuries or for specific activities such as air travel.

All end-users require data that tells them whether or not a wheelchair is usable in a particular environment to carry out a particular task, with or without a carer. This ranges from the very basic need to ensure that a wheelchair user can get into their own home or can be secured within a vehicle, to much more strategic problems of transport planning for London by 2025 or planning to provide ensuite facilities in NHS hospitals.

Those trying to identify the right wheelchair for an individual (or themselves) need to know the characteristics of the person to which each model is suited. When considering carers, who have to be taken into account as well as the wheelchair user themselves, wheelchair weight and how easy it is to get into the boot of a car may be vital information. This needs to be total weight and not that of the basic chassis with all of the wheels and other additional parts removed, as this is not a practical proposition for many elderly carers. Ability to get the full range of data on the myriad sizes, shapes and styles of wheelchairs in use is also seen as being difficult, but essential.

For data users with responsibility for public facilities, there are a number of issues for which they need to use the data. These include the obvious ones such as accessible toilets, and corridor and circulation space, but also more obscure ones such as how to security-screen people in wheelchairs prior to flights, the interaction of wheelchair weight and platform camber and safe manual handling of wheelchair users and their wheelchairs. Wheelchair sizes data would serve, therefore, to support the information contained in such as BS 8300:2001 Design of buildings and their approaches to meet the needs of disabled people.

Many data users rely on manufacturers' data. Others use published regulations, guidelines and codes of practice. Several people rely still on quite old data while some users have access to very extensive libraries and databases and make use of many different published and electronic sources.

Whilst some users had found manufacturers' data to be good and reliable others did not trust it and in more than one case it had been shown to be totally inaccurate in terms of turning radii, a critical parameter for many data users. Stability and use on a slope is also a major area of concern with little useful information concerning dynamic stability and maximum useable gradients being available. Many ramps are, inevitably, very steep as they have had to be retrofitted into the existing building fabric and the effects of these gradients on safety needs to be established.

At least some of the guidelines used were felt to be inadequate, as they tend to give average figures rather than any indication of ranges or extremes, which can be a problem. There is a further problem of inconsistent advice between different sources and confusions over metric and imperial units.

For some data users, information such as the occupant's reach from the chair, especially dynamic reach whilst moving, or the whole 'person-wheelchair' package is required. Other data users in the transport field need to know about the effects of sudden vehicle stops and starts.

Some users spoke of the need to have the rationale behind a recommendation explained so that it could be correctly interpreted in a given setting. Conversely some data users did want prescriptive advice as this removes the need for further thought or interpretation.

In data from manufacturers, tables, diagrams and photographs are all used but there is little consistency. In guidelines and code of practice the data are chiefly in a form that complies with the British/ISO Standard which is seen as essential for drawing comparisons but much of the advice is just text, presented under a number of headings with few diagrams. The absence of diagrams in documents aimed at the design professions is considered to be a major shortfall as these are seen as people who relate best to a more graphical presentation.

Some data users expressed that the whole approach to presenting data on designing for those in wheelchairs does not support 'design for all' principles. It is worth noting that some of those who work with disabled people are themselves disabled and so it is important to take their specific needs into consideration. A partially sighted access officer reported major difficulties with information in tabular form and also found diagrams very hard to follow. It is, therefore, vital that any information is available in a variety of forms and is not totally reliant on a visual presentation.

Despite this specific need, diagrams are generally seen as being an advantage although they do need to make it very clear what dimension is being referenced. For example seat width can mean the canvas width, the frame width or the useable width between the armrests.

Some felt that the ISO/BSI methods for measuring the wheelchairs should be adhered to for comparison, but stability, especially on slopes, needs to be carefully reviewed to better reflect reality. As the stability of a wheelchair is affected quite profoundly by the addition of various accessories, these need to be taken into account. Consistency across all of the various guidelines from buildings to transport was also seen as an advantage by many.

Users who have to plan for many different and diverse wheelchairs are interested in ranges, but those who need data on a specific model of wheelchair for a specific use or user are not interested in this sort of aggregation as it does not meet their need. Where data on several wheelchairs are presented, data users want to be able to make quick and reliable comparisons across the ranges, and so consistency of presentation is essential.

For several data users, the weight of electric wheelchairs was felt to be important for stowage and carriage as well as for the way in which weight has an interaction with slopes and cambers especially on station platforms. They also need the weight of individual heavy components such as the motor and battery of an electric wheelchair.

One person suggested that it would be useful to know the numbers of wheelchairs within a given size range which could be given some sort of basic size/weight classification. This would then allow transport and facilities operators to know how many wheelchair users may have been excluded if a class of wheelchair is not accommodated. Public transport operators can then know what to expect and make it clear to users which class of wheelchair they can accommodate and which they cannot. This same system could also be used to inform wheelchair users so that they can make an informed choice when they choose a wheelchair. The classification could be extended to restraint systems that are suitable for a given class of wheelchair.

Most data users want to know about trends in wheelchair, and especially scooter, design as scooters and large wheelchairs which exceed the dimensions of the regulatory Reference Wheelchair may be prevented from accessing transport infrastructure and vehicles.

Data users make the point that many of the systems on which they work take 3 to 5 years from drawing board to full use and they find it hard to build in the flexibility needed to accommodate the changes that can happen to wheelchairs in this time frame. This is also the case for many standards that are subjected to 5-yearly reviews and therefore need to be valid for at least this length of time. Other data users are trying to look forward 10 to 15 years and anticipate what will change, particularly in relation to scooter size, weight and design. For the train operators some only have 3 year franchises so are only looking to the immediate future whereas others are carrying out 25-year feasibility studies where proposals for train designs are being considered. Additional data about future trends could feed into these projections and improve future engineering decisions.

The overall impression is that the users of the wheelchairs and scooters data are well attuned to the needs, problems and issues that face the users of wheelchairs. Both groups highlighted the same priority areas. Most particularly the following points should be noted:

- It is important to consider the use of wheelchairs in a holistic way that looks at the chair, the user and the environment in which the chair is to be used. This is consistent with the social model of disability.
- There are many sources of information on wheelchairs and their requirements, but they are not all consistent in the advice they give and in some instances the reliability, accuracy and quality of the data is questionable. Some data users had serious doubts about some particular aspects such as stability and the effects this has on ramp design.
- Some Regulations were felt to be too prescriptive in their approach to designing for people in wheelchairs, and insufficient background and rationale were provided. This resulted in rules being applied in a rather mechanistic fashion. However, some data users felt unable or untrained to do more than apply clear rules and for them this was what is needed.
- Recommendations need to be set out in a simple and easy to understand format. In all cases the implications of infringing space requirements does need to be fully spelled out in terms of the numbers or types of wheelchair users who may be excluded.

- As there is already an accepted way of measuring and recording data on wheelchairs presented in the ISO/BSI standard, those who are familiar with this method wish any new data to be presented in a way that is consistent with this. There has to be an agreed definition of any measurements as these are potentially open to different interpretations.
- Where the current methods of measurement and/or presenting data are considered inadequate, such as in the measurement of turning radii and stability on slopes, improved methods of measurement and data presentation need to be considered.
- Several data users spoke of the need for more dynamic data on wheelchair occupants such as forward reach, especially from scooters, or dynamic reach whilst moving. These should be considered.
- Although visually based methods of presenting data are desirable for the majority of data users, it needs to be borne in mind that at least some of them may have a visual impairment that makes viewing data of this sort difficult or impossible. For these people, and any others who may find diagrams problematic, an alternative format needs to be available.
- Most data users wanted electronic versions of the data as they saw that this would help when information needed to be incorporated into other documents or formats. However it needed to be compatible with other software packages such as CAD. For practitioners who spend time away from the office and therefore without access to a computer, electronic data is not seen as being so helpful and hard copies still need to be available.
- Ranges of wheelchair sizes are of interest to those who have to plan for many different wheelchair users. Those who are trying to find the optimum wheelchair for a client in a particular environment need more detailed model-based information. In both cases data users want to be able to make quick and reliable comparisons across a range of wheelchairs.
- Weight of the whole wheelchair and, for electric wheelchairs, of the heavy components, is important for both data users and wheelchair users and carers.
- Most data users wanted to know about trends in wheelchair, and especially scooter design, as well as population demographics as they felt it was vital to their planning processes.

9.0 REFERENCES

Bradtmiller B. and Annis J. 1997. Anthropometry for persons with disabilities: needs for the 21st century. Report for the US Architectural and Transportation Barriers Compliance Board.

BS 8300:2001 Design of buildings and their approaches to meet the needs of disabled people

Das B. and Kozey J. 1994. Structural anthropometry for wheelchair mobile adults. Proceedings of the 12th Triennial Congress of the International Ergonomics Association, Toronto, Canada Volume 3.

Das B. and Kozey J. 1999. Structural anthropometric measurements for wheelchair mobile adults. Applied Ergonomics Volume 30 Issue 5.

Goldsmith S. 1984. Designing for the disabled. RIBA Publications.

Goldsmith S. 2000. Universal design. RIBA Publications.

Jarosz E. 1996. Determination of the workspace of wheelchair users. International Journal of Industrial Ergonomics Volume 17.

Paquet V. and Feathers D. 2004. An anthropometric study of manual and powered wheelchair users. International Journal of Industrial Ergonomics Volume 33 Issue 3.

Pheasant S. 1986. Bodyspace: Anthropometry, ergonomics and design. Taylor and Francis.

Skaradzinska M. 1989. Data for design and adjustment of flats for wheelchair users. Works and Materials of Institute of Industrial Design Volume 59.

Stait R E, and Savill T A. 1995. A survey of occupied wheelchairs to determine their overall dimensions and characteristics. TRL Report 150.

Stait, R.E., Stone, J. and Savill, T.A., 2000, A survey of occupied wheelchairs to determine their overall dimensions and weight : 1999 Survey, TRL Report 470.

GLOSSARY OF STATISTICAL TERMS

Alpha Value (Significance Level) is used to indicate the probability of the observed sample data values occurring if a particular stated hypothesis is true. In the 1999 sample, for example, the average weight of the adult self-propelled wheelchair and occupant was 96.0kg. In the 2005 study the corresponding average weight for adult self-propelled chairs was 99.7kg. If it is assumed that really nothing has changed and that the increase of 3.7kg is simply due to sampling variation, the alpha value (in this case equal to 0.002), indicates that this is very unlikely to be the case. Of course, significance levels have to be determined with respect to the particular problem being investigated – but a ‘typical’ rule is to assume that alpha values of less than 0.05 are significant and cast substantial doubt on the hypothesis being posited. In the average weight example described above, it can be concluded that it is highly likely that there has been a very real increase in the weight of wheelchairs and occupants between the years 1999 and 2005.

Analysis of Variance is a multi-variant technique that can be used to compare the means of more than two sets of interrelated data.

Chi-Square Test is a very versatile statistical test with many applications. However, in this report it has been used mainly for ‘measuring’ association between different categorical variables.
For example, to investigate the possibility of some form of association between gender and the type of wheelchair device used, in the case of the 2005 data a value of Chi(3) = 25.161 and corresponding alpha value of 0.000 indicate that there is very strong association between the two categorical variables. The figure in parenthesis is known as the degrees of freedom and is determined by the number of categories of both variables.

t-test has many uses but in this study it has been used principally for testing differences in location parameters (averages). The single sample t-test was used in the example given in the above paragraph about Alpha Value.

z-test /Normal Distribution - the famous bell shaped distribution which is the foundation of much statistical theory. It is the limiting form of the t-distribution when the sample size is very large. It has been used in this study mainly for the comparison of percentages.

ACKNOWLEDGEMENTS

The authors wish to thank the following for their help in providing expertise, equipment and venues throughout this survey; Ashfield School (Leicester), Association of Wheelchair Children, Bullring Shopping Centre, Chameleon (Coalville), Fountaindale School (Nottingham), Health & Safety Laboratory, Hildred Shopping Centre, Horizon Mobility (Cornwall), Kidz up North, Meadowhall Shopping Centre, MHRA, Milton Keynes Shopping Centre, Mobility Roadshow, Mobility Solutions (Burton on Trent), Mobility Warehouse (Loughborough), Monks Cross Shopping Park, Oakes Park School (Sheffield), Photarc Surveys (Harrogate), Portland College (Nottingham), Scalesmart (Leicester), White Rose Shopping Centre.