Perfectly and imperfectly driven wheelchairs: correctional factors and spatial margins

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This preliminary material has been prepared as part of on-going research by Hunarch Consulting into the spatial correlates of wheelchair and scooter use in buildings and facilities.

It is possible to accurately model stationary occupied wheelchairs and, from the inherent geometry of wheelchair travel and manoeuvring, develop a model of travel and manoeuvring. The model can be used to determine the minimum required travel and manoeuvre space for wheelchairs. However, such determination presumes perfect wheelchair driving control.

To be of value in real settings, a correctional factor for imperfect control needs to be incorporated in the manoeuvring model.

But why are correctional factors for imperfect control required, how should they be measured?

Wheelchair travel

Wheelchair travel can be analysed as a function of:

- Speed
- Control
- Space

Additionally for purposes of this discussion, apart from achievement of destination, goals of wheelchair travel can be summarised in terms of:

- Personal safety and comfort
- Property damage avoidance (wheelchairs and facilities)

Hence, the slower the travel, generally the greater will be the driving control, the less the need for space and, therefore, the less the likelihood of injury or damage. Conversely, the greater the speed and the less the control, the greater the space will need to be, and the greater the risk of injury or damage. On the other hand, the greater the space, the more fluid the wheelchair manoeuvring can be and the greater therefore the safety and comfort and the less the risk of property damage.

It is possible to drive a manual or electric wheelchair or scooter with elbows, arms or knuckles just touching walls, i.e. closely matching the model of perfectly driven vehicles. However this requires either skilled driving or slower speeds, or both, and smooth walls. So, why is additional space, or margins, required if all that is required to negotiate small spaces is a reduction of speed?

It is highly unlikely that even an extremely skilled wheelchair driver can maintain a perfect course. If walls were textured and abrasive it would take negligible straying from the travel course to incur abrasions to fingers, knuckles or elbows. Furthermore, there comes a point at which, even if reduced speed were all that were required to achieve sufficient control, the speed may be so slow as to be frustrating to the driver and, in socio-economic terms, inefficient. After all, ambulant people are not expected to sidle or dawdle through doorways and along passageways.

Whilst only a very small margin might be required for skilled drivers who can exercise considerable control over their wheelchair, greater margins are required by drivers who are unable to exercise much control. Limited control may be due to vision or cognitive impairment, resulting in diminished spatial judgment, or to impaired functioning of arms used for driving (e.g. due to lack of hand and arm strength, or involuntary movements of hands and arms).

Some drivers experience involuntary movement of their limbs, head and torso. If there is insufficient margin, it is possible that a driver's foot, hand or even head, as it moves suddenly to one side, could sustain injury. This could be avoided by the use of body restraints, however this can cause, for instance, pressure ulcers, and may for a variety of reasons be an unreasonable and an unwelcome imposition for some driver (on the other hand, some drivers require body constraints, i.e. body supports, for wheelchair use). The purpose of the comments here is not to debate the merit, need or morality of constraints, but to describe the potential range that need to be considered in relation to margins.

Driving skill and disability

There appears to be no simple or useful correlation of disability type (e.g. multiple sclerosis, spinal chord injury, cerebral palsy, spina bifida) with driving skill. Nor does there appear to be a simple correlation of wheelchair type with driving skill[i].

There are, of course, approximate correlations between some types of disability and types of wheelchair, and with various capabilities, however these correlations do not simply equate with driving skill, i.e. with degree of driving control.

Skill Factors

Driving skill can be analysed as a function of:

- Handedness
- Manual Dexterity
- Arm extensibility, retractability and control
- Neck flexibility and control
- Torso flexibility and control
- Visual field and acuity
- Cognitive capacity

Handedness refers not just to ambi-dexterousness, but also to the ability to use, or to favour (intentionally or unintentionally), one or either side of the body.

Manual dexterity denotes the ability to operate in a controlled way the driving controls of an electric wheelchair or scooter, or to effectively grip the hand rims of a manual wheelchair.

[i] This was found by Hunarch Consulting in its research for the Australian government. It has also been similarly reported by Steinfeld et al.

Arm extensibility, retractability and control are most applicable to manual wheelchair propulsion and scooter steering. They also enable a person to reach with one arm across themselves to their other side.

Neck flexibility and control is the ability to swivel and tilt the head in any direction for more efficient navigation, and is also instrumental in reach, and manual wheelchair propulsion.

Torso flexibility and control is the ability to twist and tilt the upper body in any direction for efficient navigation, and for propulsion of manual wheelchairs and, to a lesser extent, steering of scooters.

Visual field and acuity: many wheelchair drivers have significantly impaired vision, and some are blind. Some drivers, for example those with little or no torso or neck flexibility, rely almost solely upon peripheral vision and movement of the eyes for navigation. Visual field and acuity will therefore influence spatial judgments and hence accuracy of wheelchair navigation and targeting of doors and door handles.

Cognitive capacity: impaired cognitive capacity impedes wheelchair navigation. Cognitive and visual capacities act in concert in the formation of spatial judgments in navigation.

The foregoing skill factors determine the ability of drivers to maintain an intended or optimum travel path and manoeuvre, as well as the required positioning and manoeuvring of wheelchairs for reach to handles and controls and the like, and the negotiation of doorways. Some drivers without hand, arm, torso or neck functionality use “sip and puff” driving devices and may be quite skilled in wheelchair driving. However, the geometry of their travel can still, appropriately, be analysed in terms of absent limb and torso functionality, and not their sip-and-puff skills.

The role of visual and cognitive capacities in navigational judgments is illustrated by performance of a right-angled turn from a narrow pathway, through a narrow opening in one of the pathway boundaries. Typically, for a single-rotation manoeuvre, the driver needs to initially swing the wheelchair away from the boundary so that there is room to perform the subsequent rotational movement for alignment with the opening. The judgment about when to perform the rotations will determine the efficiency of the opening negotiation. Similarly, if a reversing manoeuvre is employed, judgment is required about where to commence it in the space available, or in the intended space.

The classification of the factors presented here is necessary not only for the understanding of the geometry of wheelchair travel, but also for sampling of participants in trials, i.e. to facilitate achieving representativeness of the sample. Only by ensuring that there is a representative participation of drivers with these skill factors can there be confidence that the sample is representative in terms most relevant to the geometry of wheelchair travel and manoeuvring.

Unfortunately, no databases appear to exist, in terms of the above skill factors with which to compare collected data (for example for purposes of sample weighting). Establishment of such databases is therefore an important task for research into spatial correlates of wheelchair driving. With regard to visual and cognitive capacities, however, this may be impossible. Unless a driver has already been reliably “graded” for visual and cognitive capacity, and that information is made available to the researcher, it is highly unlikely that a researcher will be able to provide such grading. The other skill factors are obviously much easier to grade.

Determining correctional factors and spatial margins

Correctional factors and margins are determined by comparing actual manoeuvring spaces or paths with spaces and paths determined from models. The difference between the two is the margin for that driven wheelchair or scooter. For a representative correctional factor or spatial margin, the factors and margins for many occupied wheelchairs are ascertained and a common factor or margin calculated for all of them (expressed as a mean or percentile value).

Correctional factors vs. spatial margins

Spatial margins

The calculation of spatial margins entails the calculation of additional "architectural" space required for imperfect wheelchair and scooter manoeuvring.

It appears that the only work to date that has used a modelling technique and the calculation of spatial margins is that by Bails[1] in Australia[ii]. He calculated additional space required in relation to different parts of wheelchairs during various manoeuvres, expressing them in terms of additional lengths and widths of spaces.

Correctional factors

Correctional factors denote the amount by which modelled travel paths need to be adjusted to reflect imperfect driving. The differentiation from spatial margins is made because the correctional factors are related to the movement of vehicles, not to the spaces within which it occurs.

The corrections are based on variations in:

- Linear travel
- Stopping distance, and
- Rotational radii

Once the model has been corrected, it can then be used to determine the size of spaces required for imperfect driving.

Determining correctional factors

Linear travel

Variation of linear travel is simply determined by measuring the extent of straying from the straight line. Whereas the uncorrected model would have nil variation, the corrected model would incorporate the measured variation.

Stopping distance

Variations in stopping distance are determined by measuring the under-run, or over-run of a wheelchair or scooter relative to the targeted stop-point.

As for linear travel, for stopping distance the uncorrected model would have nil variation, whereas the corrected model would incorporate the measured variation

[ii] This work, completed in 1983, is the basis of the dimensional requirements within the Australian Standard, AS1428: 'Design for access and mobility'.

A stopping factor needs to be added to the length of vehicles for calculation of minimum lengths of spaces for travel cessation (e.g. vestibules and lifts).

Rotational radii

Establishing a correctional factor for rotational radii is more difficult in practice than for linear travel, and stopping.

A perfectly executed rotational manoeuvre is one that has the intended radius, and that has this radius throughout the rotational manoeuvre, i.e. that is a perfect circle or arc. Variation in radius of travel is easy to measure and is simply the difference between the actual radius and the ideal radius. However, many drivers are unable to maintain a perfect rotation, instead making a number of rotational adjustments during the manoeuvre. The result will either be elliptical or spiralled path. In this case the correctional factor would need to be based on the difference between the ideal radius and a synthesis of the constituent radii, for example the average of the radii, a percentile value of them, or the greatest radius.

Furthermore, many drivers will be even less skilled, and will perform numerous small reversing procedures in order to maintain an approximately circular path. In trials to determine correctional factors, such reversing adjustments might be avoidable after a small amount of practice. However, many drivers will still have insufficient skill to maintain an approximately circular path without small reversing adjustments. The procedure in this case would therefore need to treat the extremities of the reversing points as if they were on an arc.

Testing the accuracy of correctional factors

The accuracy and reliability of calculated correctional factors can be tested by driving trials in actual or simulated architectural settings. Using only the estimated least overall width and length of a space for a particular manoeuvre, derived for the corrected model, a driver is asked to perform that manoeuvre. If the actual width and length match the estimated, then the correctional factor is accurate. The procedure should be repeated for several different types of manoeuvres. The same procedure is followed for additional drivers.

Practice effects

Previous studies have attempted to offset practice effects by minimising the number of trials, and by allowing a lapse of time between them.

The need for offsetting practice effects is dependent upon whether determination of driving skills, and margins for imperfect driving, should be related to familiar or unfamiliar environments. In familiar environments, practice effects do not have the same significance. It is a policy judgement as to whether familiar or unfamiliar environments are the most appropriate criterion for this sort of research. However, unfamiliar environments present the greatest challenge, and reference to them is probably the most appropriate, in which case, offsetting practice effects should be considered.

References

1. Bails J H, 'Determining the Minimum Requirements'. In seminar proceedings: Building Design for Access, 1989, Standards Australia, Melbourne
2. Steinfeld E, Schroeder S, Bishop M. Accessible Buildings for People with Walking and Reaching Limitations. State University of New York at Buffalo. For U.S Dept of Housing and urban Development, Office of Policy Development and Research, 1979