Testing Wheelchair Driving Skills: the Slalom

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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 one of several essays that, collectively, serve to document research completed or underway by Hunarch, assist in Hunarch's exploration of issues in this research, and identify required future work.

This study seeks to:

- Measure driving skill in terms of maintaining intended travel paths (space traversed)
- Determine correctional factors to be applied to modeled (perfect) travel to simulate imperfect travel
- Determine the accuracy of correctional factors, and
- Evaluate a slalom course as a suitable tool for testing driving skills.

Advantage of modeling

To date, space for wheelchair travel in buildings and facilities has been calculated by use of actual or replicated architectural spaces, and expressed in architectural spatial terms also[1,2,3,4,5].

However, it is possible to develop an accurate graphical model of wheelchair and scooter travel that is independent of architectural constructs. The model can then be used to determine the size of spaces for the travel.

The model is derived from the dimensional characteristics of (stationary) occupied wheelchairs, but assumes perfect driving. A correctional factor therefore needs to be applied to allow for modeling of typical, imperfect driving.

A travel model with correctional factor would simplify the task of determining the least size of spaces required for wheelchairs and scooters in buildings and facilities because it would not require the use of actual or replicated architectural settings, nor the time-consuming need to test for numerous combinations of space variables. This is illustrated by turning manoeuvres into and through a wall opening.

For openings negotiation, there is an inverse proportional relationship between the width of the opening and the width of the approach and exit pathways at each side of the opening. Hence, the wider the opening, the narrower the pathways need be, and the wider the pathways the narrower the opening need be. If actual replicated settings were used to determine the range of combinations of these various pathway and opening widths, for the same driver, numerous successful trials would be necessary. With the modeling method, only one successful trial is necessary, enabling a correcting factor to be calculated, and a corrected model then used to estimate the relative dimensions of alternative pathway/opening width combinations. Where a large number of drivers need to be measured, the time and cost saving would be great.

Use of an obstacle course has previously been reported by Webster et al [6,7,8] and of a slalom course by Kirby et al[9]. Kirby used the slalom as part of a more extensive wheelchair skills test (WST). However, the slalom part of the WST did not measure the space traversed or the speed taken for slalom negotiation. The obstacle course used by Webster et al is described by Kirby as a 'series of left and right turns'. However, no details are at hand as to the actual form of the obstacles. The Webster studies used the obstacles to record the number of 'swipes' and 'strikes'. It appears that speed and space traversed were not recorded.

Purpose of slalom course

The function of the slalom in this study is to test driving skills in relation to:

- Single rotational movements
- Multi-rotational manoeuvres and manoeuvring strategies
- Linear travel, and
- Stopping

Criteria for slalom courses

If representative sampling is required, widespread testing is necessary. Consequently, test settings need to be inexpensive, maximally compact, very portable, easily and quickly set up and dismantled, and operable by few people (preferably by only one person), and safe to wheelchair drivers (and testers).

Compactness is required because there is typically little space that is readily or inexpensively available in typically available venues. Inexpensiveness facilitates fabricating several slalom courses so that simultaneous testing by different people in different locations can occur. Portability facilitates sole operation by testers, and sole operation increases the feasibility of more broadly based simultaneous testing.

Most importantly, the slalom course needs to entail all of the key rotational manoeuvres required for most-compact travel and rotational manoeuvres in buildings and facilities.

The slalom course for this study has been developed to meet these criteria.

Description of slalom course

The principal components of the slalom are the cylindrical bollards[i]. They are complemented with spacer bollards, a stopping "gate", and a doorway.

<u>Shape</u>

The primary bollards used in this study are cylindrical[i]. Bollards that are square in cross-section were contemplated because of their closer resemblance to typical architectural features. However, this is not critical because negotiating circular and square bollards involve the same travel and rotational manoeuvres. Furthermore, square bollards, if they were laterally displaced by wheelchair impact, would take longer to realign than circular bollards.

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[i] The bollards used by Kirby were also circular, comprised of hollow plastic tubes containing sand to give them sufficient weight to withstand displacement. However they were not self-righting nor resilient.

Secondary bollards that are rectangular in cross-section are used as spacer panels between the cylindrical bollards.

Stability

To facilitate testing by one person, bollards need to be resistant to displacement and toppling. This can be achieved by temporarily fixing the bollards to the travel surface, or by making them very heavy. There was concern that this could increase the risk of injury, hence self-righting bollards have been adopted. There are two ways of achieving this: suspended bollards (as in white water rafting slaloms), or having weighted bases with incorporating a self-righting mechanism.

A disadvantage of suspended bollards is that they require a framework and are therefore not as efficient to fabricate and install.

The bollards and panels adopted for this study have weighted bases in which is located a wire coil spring. The upper part of the bollard is mounted over the spring. The disadvantage of this system is that the weight of the bases may be insufficient to resist displacement when the bases themselves sustain impact. However, this can be minimised by taping the bases to the travel surface. A strongly adhering tape is available for this purpose that enables application to a variety of surfaces including carpets.

The experience so far is that the displaceability of the bollards is actually an advantage for some rotational trials (e.g. mid-axle rotations). It has also been found that if the position of a displaced bollard is recorded, it does not necessarily invalidate the trial.

Safety

The bollards in this study are of hollow polystyrene sections. Because they are light, resilient, and self-righting, the chance of injury is greatly reduced.

Damage

The polystyrene is easily damaged, however because it so inexpensive and so easy to work with, this is not regarded as a problem. Nevertheless, the lower portions of the bollards are protected with a thin metal sheath for protection from feet and foot supports.

Feedback

To facilitate navigation and task dedication by drivers, bollards are fitted with audible and visible signals that are activated whenever they are bumped. The device for this is battery operated and incorporates a tilt-sensitive switch that activates the signal light and buzzer whenever the bollards are bumped.

The other function of the signals is to alert the measurer to “hits” during the slalom trials, and to facilitate the operation of the slalom course by one person.

Testing single and multi-rotational movements

The single rotational movements tested are the rotations that have been identified as key rotations in most-compact rotational turns, i.e. rotation about the mid-axle and either wheel.

Components and procedure

Numerous possible slalom configurations are possible for various types of driving tests.

Single bollards (single rotation)

Drivers adopt a start position, approximately two metres away from a bollard. They are then asked to travel straight towards one side of it and then to complete either a 90°, 180° or 360° single rotational turn around it, keeping as close as possible to it at all times. The trials are conducted for clockwise and anti-clockwise rotations.

The bollard position is marked beforehand (and also during the trial if they are displaced). The wheel track of the drive wheel closest to the bollard is also recorded.

Two bollards configuration (figure-eight course)

Drivers adopt a start position, approximately two metres away from a pair of bollards, so that they are facing the space between the two bollards. Drivers are then asked to perform a figure-of-eight circuit of the two bollards, exiting on the opposite side to, and in the same direction as their starting position. The task is to keep as close to each bollard as possible without bumping it.

The bollard positions are marked beforehand and the wheel track of the drive wheel closest to each bollard is recorded.

The figure eight circuit not only tests for handedness in the one trial, but also tests for alternation between the two.

Four bollards configuration

Four bollards are placed in the corners of a rectangular layout. Drivers are asked to perform a rotation about the mid-axle, both clockwise and anti-clockwise, followed by an anti-clockwise rotation about the left wheel and a clock-wise rotation about the right wheel, as compactly as possible and without bumping the bollards. The wheel track of one of the drive wheels is recorded after each rotational movement (for rotations about either drive wheel, it is the track of the drive wheel about which rotation occurs that is recorded).

Four bollards, two panels configuration

This arrangement tests for 90° turn sequences that are identical to the modeled most-compact negotiation of openings. It consists of a row of four cylindrical bollards, with the space between the outer pairs having a spacer panel, and the space between the inner two bollards being left open for wheelchair travel.

Like the two bollard slalom, this one is also run as a figure of eight circuit.

Wheelchair drivers will be asked to position themselves as close as possible to, and alongside a bollard at the start of the course. They will then be asked to:

- Move forward and then perform a 90° left-hand turn into the opening and, once through
- Perform a 90° right-hand turn and adopt a travel path as soon, and as close as possible to the line of bollards
- Perform a right-hand 180° turn around the last bollard, as close as possible to it at all times.
- Move forward and then perform a 90° right-hand turn into the opening and, once through
- Perform a 90° left-hand turn and adopt a travel path as soon and as close as possible to the line of bollards
- Perform a left-hand 180° turn around the last bollard and as close as possible to it at all times to approximately resume their starting position.

<u>Re-runs</u>

If a bollard is toppled, the participant will be asked to recommence the course, However, if they are only displaced or vibrated, the participant will be asked to complete the course, ready for another trial. Trials will be repeated until no bollards are toppled, displaced or vibrated or, at least, until very few bollards are vibrated.

The number of attempts at a successful completion of the course will be recorded. The time to complete the course successfully will also be recorded.

Testing stopping distance

Stopping skill is tested by a gateway.

The gate is comprised of two bollards supporting a rod between them, from which is suspended weighted straps or a bottom-weighted sheet. The straps or sheet form a plane at which the driver is required to stop. The resiliency of the suspended material is intended to reduce the chance of the bollards being toppled or causing injury.

Wheelchair drivers will be asked to travel up to the gate and then to stop, as close as possible to it. Measurements will be made of the under and over-runs of the gateway.

The gate could be used in conjunction with other bollard configurations, or otherwise used for separate trials. Separate trials would be preferable otherwise the slalom course may become confusing.

Testing linear travel

To test for linear travel, drivers would be simply asked to move forward, and backward along a straight line. Variations, or straying from the travel path would then be recorded, as would the time of completion of the course.

The linear travel could be incorporated in one of the slalom trials, however, it is probably best to have it as a separate trial.

The linear travel would be tested using two bollards: the driver would commence travel from alongside one bollard, move to and then around the other one, and then return to the opposite side of the starting bollard. The length of the overall course would therefore be 20 metres [i].

Recording travel paths

There are a number of methods for recording actual travel paths, including laser range-finders[ii], infrared[iii], sonar and electromagnetic tracking devices[iv], video photography[2], trailing pens as used by Bails[1] [v], brushes as used by Ringaert et al[2], piezo cable mats[vi] as developed by Paradiso et al[10], dusted travel surfaces or wheels, and corrugated paper sheets. The latter method has been used by Hunarch Consulting in its Australian research.

<u>Corrugated paper</u>

Rotational travel

The corrugated paper sheets are the simplest and least expensive method. However they are cumbersome to use because the sheets have to be replaced after each slalom trial; temporarily stored; and then prepared for removal upon completion of the trials, and also because the rolls of corrugated paper, whilst light, are bulky to handle. Nevertheless, in tests so far by Hunarch Consulting, it has been found that these problems can be minimised by recording only one drive wheel track and hence reducing the amount of paper used.

Further tests with different grades of backing paper and pitch of corrugations are being carried out. Stiffer backing paper will minimise the "scrunching" of the corrugated paper during some manoeuvres. Finer corrugations might increase the rollability of the travel surface, and facilitate identification of the wheel tracks.

Linear travel

Hunarch Consulting has been investigating various techniques for recording variations in linear travel, but so far has been unable to identify one that is sufficiently inexpensive and accurate.

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[i] This is identical to one of the tests in the Wheelchair Skills Test conducted by Kirby et al (op cit). However, their course length was 25 metres each way. It is probable that variations in maintenance of travel path would be manifest in approximately half this distance, if not less.
[ii] E.g. Sick LMS laser scanner:
http://www.sickoptic.com/kommerce_server/kommerce_productdata.asp?Web_class=164&type=2
Surphaser http://www.ageo.co.uk/laser_scanning/index.htm
[iii] E.g. Codamotion. http://www.codamotion.com/
[iv] E.g. Polhemus Isotrack II. http://www.polhemus.com/isotrkds.htm
[v] The trailing pens were used on a scale model of wheelchairs, not on actual wheelchairs
[vi] http://www.msiusa.com/piezo/piezo_coax_cable.htm

Two options currently being considered by Hunarch Consulting are sonar tracking and the use of corrugated paper sheets (described above). Given that the length of the travel should probably be at least ten metres, the corrugated paper technique could be unwieldy. However, it would be easily used in multiple locations and would therefore facilitate broad-scale sampling.

The sonar tracking technique, inclusive of software and algorithm development, whilst not very expensive for one testing site, would be expensive for multiple sites.

Comparison data

Data upon which to establish a model of each participating occupied wheelchair or scooter, and to which to apply the correctional factor, is obtained by tracing key points of the occupied vehicles, either before or after completion of the course.

The key points are the inner and outer faces of the drive wheels at their contact with the travel surface; and all other outer-most points on either side, and at the front and back of the occupied vehicle.

Other performance measures

Completion time

Three performance factors are inherent in successfully negotiating a slalom course: speed, control, and space traversed. However, skill will be measured in terms of traversed space and test completion time. Whilst it is the traversed space that is the primary performance measure, speed may also be an important qualitative measure.

Self-assessments

At the end of each of the various trials, participants will be asked to provide a simple rating of the ease of completion of the course.

Validating correctional factors

The reliability of correctional factors can be validated in two ways.

One way would be to establish a correctional factor after the single-rotational movements using the two and four bollard slalom courses. The driver would then be asked to negotiate the four bollards, two panels course. If the radii of the actual wheel tracks were the same as the modelled radii, the reliability of the correctional factor would be supported.

The other way would be to have a driver negotiate the four bollards, two panels course, with the opening set at one distance, and then to have the driver repeat the course with the opening set at another distance. If the radii of the actual wheel tracks were the same as the modelled radii, the reliability of the correctional factor would be supported.

The same procedure would be repeated for the same driver on successive occasions, and for the same overall procedure repeated for additional drivers.

Consistency of results would support the validity of the correctional factors.

Boundaries

A slalom course by itself has no boundaries. Whilst the feedback provided by the bollards may be sufficient for task focusing by participants and recording by measurers, additional feedback may be beneficial. Actual or virtual boundaries would serve this purpose.

Boundaries can be easily added at key locations, either in the form of additional bollards; panels; or a virtual boundary. Examples of the latter are lines drawn or tapes fixed to the travel surface; or photoelectronic ”curtains”.

Additional suspended or free-standing panels can be easily incorporated into the slalom course. The panels can be of the same fabrication as the bollards. The disadvantage of bounding panels is that it increases the testing task for the slalom measurer because the panels will have to be realigned and re-positioned. This can be minimised, however, by a special panel suspension unit.

A suspension unit fabricated for this study is comprised of a base sheet that has tracks on its upper surface. A wheeled frame sits in the tracks, so that it can be easily adjusted for position, and has at its top a suspension track from which hang four panels. The panels can have tilt-sensitive signals for feedback. Whilst portable and dismantlable, the unit is nevertheless cumbersome to handle.

A simpler, but slightly more expensive alternative to actual bounding panels is a virtual, infrared light curtain. Like panels, this also has to be repositioned, however, because it cannot be toppled, repositioning will be less frequent.

Infrared light curtains, at their simplest, are comprised of a single infrared beam between a transmitter at one end and a receiver at the other. When the beam between the two is interrupted, a switch is activated that operates some device such as the sound and light signal in this study. More advanced versions[i] have multiple beams, and units at each end that are combined transmitters and receivers. The limitation of these units is that parts of an occupied wheelchair could penetrate above, below or between the beams and therefore not be detected. A superior version[ii] of the curtain has inclined beams that form an infrared mesh. The chance of undetected penetration is therefore very small.

A significant advantage of infrared light curtains is that penetration of them does not require the occupied wheelchair to stop. Instead the driver can complete the penetrating motion ready for a re-trial. This might cause less frustration to drivers than, for solid boundaries, having to reverse or engage in more intricate manoeuvres in order to clear the boundary, hence saving overall testing time as well.

<u>Bounded slaloms as further validation</u>

Bounded slalom arrangements are closer to replicated architectural settings than unbounded slaloms, and therefore provide additional levels of testing of accuracy of correctional factors.

An additional purpose is where space parameters are required, such as the overall length and width of manoeuvring spaces.

[i] http://www.sickoptic.com/kommerce_server/sick_catalog.asp?class=428
[ii] http://www.sigratech.com.au/index.html

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