International Best Practice Guidelines

BPG1
Transportation of People Seated in Wheelchairs

1st Revision 2019

Use of this document
As a code of practice, this Best Practice Guideline (BPG) takes the form of guidance and recommendations. It should not be quoted as if it were a specification, and particular care should be taken to ensure that claims of compliance are not misleading.

Contractual and legal considerations
This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Document Version Table

Version	Date	Co-ordinator	Rationale
1.0	February 2013	J. Tiernan	First Issue
2.0	July 2019	B. Appleyard	1st Revision
2.1	August 2019	O. Ellis	'Travel Safe' leaflet relocation

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Section 5 – Wheelchair Tie-downs and Occupant Restraint Systems

Section 6 – Road Vehicle Categories and Wheelchair Access

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1 Introduction

1.1 Foreword

The PMG Best Practice Guidelines for Transportation of People Seated in Wheelchairs (BPG1) provides healthcare professionals who prescribe wheelchairs and seating systems for individuals with mobility impairments with guidance on the prescription and selection of equipment likely to be used in transport. The document first published in June 2013 underwent a five year review in early 2018 when comments were invited from PMG members and collected via the PMG website.

A revision review panel was created which included some members of the original drafting team. The 2018 review panel included professionals from Kings College Hospital NHS Foundation Trust Rehabilitation Engineering Division, UK; The Queen Elizabeth Foundation Mobility Centre, UK; Enable Ireland SeatTech, Ireland; University of Michigan Transportation Research Institute, USA; and The Rehabilitation Technology Unit, Royal Perth Hospital, Western Australia.

The revision of the Best Practice Guidelines for Wheelchair Seated Passenger Transport document was co-ordinated and edited by Mobility Support Services Ltd., as commissioned by The Posture and Mobility Group.

As with the previous version, the document has been divided into sections for ease of navigation, and includes a new section on Risk Management. Each section begins with a summary so that readers may quickly refresh their knowledge as required.

The success of the original document has been observed and noted. The extent of its success culminated with the UK Medicines and Healthcare Products Regulatory Agency's (MHRA) withdrawal of their guidelines document DB2001(2003) and subsequent referral of readers to the PMG BPG1 content. This in itself indicates that the readership of the BPG1 document has gone well beyond PMG membership and has reached the eyes of a broad range of stakeholders engaged.

Comments gathered by the review process indicated a need for clarification on a number of subjects, a greater depth of understanding on other subjects, and the addition of transport related topics not addressed in the first edition.

Suggestions were made for a simple means of navigation around the document where inter-relating topics within the various sections can be easily found. This has been addressed by the division and sub-division of headings within each section and the addition of internal links to relevant subject headings within sections.

Many comments have been addressed by expansion of text on various subjects throughout the guidelines. In some instances, revisions that have been made to industry standards have addressed technical issues raised, such as the addition of *ISO 7176-19:2008+A1:2015* [11] Informative Annex G for rear impact assessment of wheelchairs and the inclusion of children of mass 12-22kg within the next revision of *ISO 7176-19* expected in late 2019.

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Requests for information on additional subjects such as use of tilt and recline in transport, the value and function of postural support devices including head supports, and the function of effective occupant restraint have also been addressed.

Significant development of guidelines related to roles and responsibilities in this field has indicated that the subject merits a section of its own, therefore a new *Section 2 Roles and Responsibilities* has been created.

The original *Section 4 Vehicle Categories* has been renamed *Section 6 Road Vehicle Categories and Wheelchair Access*. In order to adequately address comments received, the section has been re-formatted with significant expansion on wheelchair accessible road vehicle types and their operating environments. In addition to resolving technical comments, the re-structured section examines vehicle operations and accessibility with a view to allowing transport planning, in both short and longer terms, to occur.

A notable development has come as a result of a significant number of comments regarding risk management resulting in the drafting of a new chapter, named *Section 7 Risk Management.* The new section identifies two distinct arenas for the subject: the prescription of medical devices, and risk management in a transport environment.

The new section on transport risk management also suggests a probable list of an individual's transport requirements to be summarised by equipment prescribers and clinicians for presentation and risk assessment discussion with transport professionals. Based on the content of the summary, clinicians and transport professionals can together identify low risk transport solutions for further implementation.

An example of transport risk management in action, as conducted by the Royal Perth Hospital, Western Australia, provides a working demonstration of the process.

1.2 Overview

Generally, the choice of a wheelchair for a person is based on their clinical need and their requirements for comfort, postural support, tissue integrity, function, and general mobility. Use of a wheelchair as a seat in a motor vehicle is an important additional consideration to be addressed by wheelchair manufacturers and equipment prescribers when taking into account a wheelchair occupant's many differing social and medical needs.

Safe transport is a key element in a wheelchair occupant's ability to improve quality of life through participation in education, work, and leisure as well as to access medical facilities. Equipment prescribers should consider transport needs at an early stage in the wheelchair and/or seating assessment process, and should make use of the transport safety information regarding crashworthiness available from respective wheelchair and seating manufacturers, as this may influence the choice of wheelchair and/or seating to be prescribed.

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Generally, it is safest for a wheelchair occupant to make an internal or external transfer out of their wheelchair to a fixed vehicle seat and use the vehicle seatbelt system, or a restraint system for children which complies with vehicle legislation. It is therefore strongly recommended that wheelchair occupants transfer into a vehicle seat where possible and practical. This is especially true in the case of mobility scooters, which are generally not intended to be transported occupied. Where an occupant transfers out of their wheeled mobility device, the device should be safely secured in the vehicle as an item of luggage, although it is acknowledged that this in itself can present a challenge.

Historically, transport best practice has recommended that child occupants of a mass less than 22kg should be transferred to a Child Restraint System (CRS) approved for use in motor vehicles. [2,3,4,5,6]

However, it has been observed that there are significant occasions where it is necessary to provide wheelchair seated transport for a child of mass less than 22kg who, because of extreme discomfort or difficulty, could not transfer to a CRS device. This may be due to a complex form of disability and the mobility device plays an important or fundamental role in maintaining position and/or providing postural support. On occasions, a child may have dependency on medical devices attached to their buggy or wheelchair, or their physical proportions do not align with non-disabled peers. At times, risks associated with the manual handling [7] of a child from a mass or a safeguarding respect can also discourage the transfer of a child to a CRS device.

It is in recognition of these considerations that amendments to the scope of the crash standard *ISO 7176-19* have been made.[11] The expected 2019/20 issue of the standard will include devices intended for use in transport for occupants of a mass range of 12 to 22kg, with a design requirement for the device to be supplied with a 5-point occupant harness type restraint system integrated into its structure, supplied and fitted by the original equipment manufacturer (OEM), in a similar manner to a compliant CRS.

While it is the objective of each stakeholder to seek levels of safety for wheelchair seated passengers comparable to those for vehicle seated passengers, there are bound to be variances in the risk of injury posed to the two groups. Wheelchair occupants will frequently have reduced musculoskeletal strength due to injury or disability, and contractures or physical deformities may lead to reduced injury tolerance. Such characteristics may also create difficulties with the accommodation and application of occupant restraint systems. Careful selection by prescribers of the wheelchair and seating systems that are capable of allowing best possible routing of an occupant restraint system will play an important role in reducing risks to acceptable levels during transport.

At times, the relevant recommendations and available equipment for safe transport may contradict the individual's seating and positioning needs. In such cases, risk assessment (incorporating a risk/benefit analysis and evaluation) will play an important part in the decision making process, as well as careful documentation thereof.

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International Standard *ISO 14971:2012* [8] specifies a process to identify the hazards associated with the use of medical devices to help estimate and evaluate the associated risks, to control these risks, and to monitor the effectiveness of the controls. An additional section (Section 7) has been added to BPG1 where further details of the operation of a risk management process are provided.

Decisions taken at the time of issue to a person of a piece of equipment should be periodically reviewed to take account of the person's changing presentation, changing needs, or alterations to their equipment configuration. Changes with time to the condition of equipment also need to be considered, and a system put in place to manage maintenance, including replacement of worn parts, such as straps.

The purpose of this document is to gather and describe relevant standards and regulations, as well as to describe commonly accepted solutions to maximise safety and minimise risk levels pertaining to passengers transported in wheelchairs as vehicle seats during road vehicle transport.

National and international standards and codes of practice, as well as professional experience, change over time, and the intent is that this document shall be updated from time to time. This document is therefore not available in hard copy but is being placed on a publicly available website (www.pmguk.co.uk) where individuals can download the document in its latest version. Readers who download and locally store the document must be reminded that they are using an uncontrolled version of BPG1 and that they should be aware that an updated version may exist.

Readers are able to place their comments and make suggestions for improvement on the PMG website. Ultimately these will be considered for inclusion in the next version of these International Best Practice Guidelines for Transportation of People Seated in Wheelchairs.

1.3 References

[1] ISO 7176-19:2008+A1:2015 *Wheelchairs—Wheeled mobility devices for use as seats in motor vehicles.*

[2] Economic Commission for Europe ECE - R44 *Uniform Provisions Concerning the Approval of Restraining Devices for Child Occupants of Power-driven Vehicles*.

[3] Economic Commission for Europe ECE - R129 *Uniform Provisions Concerning the Approval of Enhanced Child Restraint Systems used Onboard of Motor Vehicles*.

[4] Code of Federal Regulations, Title 49, Transportation, Part 571.213; *Child restraint systems*. Washington, DC 2003 National Archives and Records Service, Office of the Federal Register.

[5] Canadian Standards Association, CMVSS 213 *Child restraint systems*, Ottawa, Canada.

[6] AS/NZS 1754:2010 *Child restraint systems for use in motor vehicles.*

[7] UK Manual Handling Operations Regulations 1992, as amended 2002.

[8] ISO 14971:2012 *Medical devices -- Application of risk management to medical devices.*

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1.4 Abbreviated Terms

The following abbreviated terms will be used throughout this document:

ATD – Anthropomorphic Test Device

ANSI – American National Standards Institute

CRS – Child Restraint System

EN – European Standard generated by the European Committee for Standardisation

IFU – Information for Users

ISO – International for Standards Organisation

MPV – Multi-Purpose Vehicle

OEM – Original Equipment Manufacturer

OM – Owner's Manual

PHV – Private Hire Vehicle

PSD – Postural Support Device

IPSD – Integrated Postural Support Device

PSV – Public Service Vehicle

RESNA – Rehabilitation Engineering and Assistive Technology Society of North America

RF-WPS – Rearward Facing – Wheelchair Passenger Station

WAV – Wheelchair Accessible Vehicle

WTORS – Wheelchair Tie-down and Occupant Restraint System

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1.5 General Summary

- Transport considerations should be factored into the initial phase of the wheelchair and seating assessment and prescription process.

- Manufacturers of wheelchairs and seating systems should make information relating to the safe transportation of their products readily available and easy to understand, in both printed and electronic format.

- With the desire to provide the safest possible transport environment for wheelchair-seated passengers, and other vehicle occupants, all stakeholders must engage in a multi-disciplinary approach to ensuring transport safety, involving the wheelchair occupant with their families, carers, equipment prescribers, and transport providers.

1.6 Wheelchair Securement and Passenger Restraint

- When properly installed and used, a wheelchair tie-down and occupant restraint system (WTORS) allows a wheelchair to be secured to a vehicle floor and the wheelchair seated passenger to be restrained by an effective seatbelt system.

- A crashworthy wheelchair, or wheelchair base and seating system, used in conjunction with a proven WTORS, is fundamental to the provision of safe transport for people who remain seated in their wheelchairs in a motor vehicle, and for other vehicle occupants.

- Exceptions to the requirement for use of WTORS exist on certain high-mass, low-speed urban public transport vehicles that allow standing passengers where the likelihood of a crash situation and the severity thereof are low. Large urban transit buses, for example, in which passengers may travel while standing, offer a safer transport environment because their large mass and low travel speeds, which greatly reduce the frequency and severity of crash events. In these situations, use of a rear-facing wheelchair passenger station may be appropriate.

- Manual and powered wheelchairs offer a large variety of seated postures through their tilt, recline, and other mechanisms. Guidelines should be given by manufacturers with respect to use of these mechanisms during transport, however, manufacturer recommendations may not wholly align with an individual's seating and positioning needs. In such instances, a risk management process should be undertaken to ensure risks are acceptable. See Section 7 Risk Management.

- Wheelchair manufacturers should highlight in their pre-sale literature any special requirements relating to the use of their wheelchair with WTORS. The configuration of the specific representative wheelchair which underwent the crashworthiness test should be provided so that informed decisions can be made with respect to wheelchair selection and configuration.

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1.7 Seating

The combination of a crashworthy seating system, that accommodates the correct fit of the occupant restraints, and a crashworthy wheelchair base frame, serve to indicate to the prescriber that the risks of equipment failure when exposed to crash conditions during transport have been reduced as far as reasonably possible.

- To minimise injury risk for wheelchair occupants, prescribers shall seek to ensure that the means of attachment of the seating system to the wheelchair (the wheelchair to seating interface) is suitable for use in transport. It is imperative that the manufacturer's instructions for use and fitting instructions for seating systems are carefully adhered to.

1.8 Risk Management

- Due to the individual nature of disability, prescribers may at times be faced with the need to request modification to a wheelchair or off-the-shelf seating system (Class 1 medical devices) in order to maximise medical benefits, and to address the postural and functional needs of a wheelchair occupant. In such cases access to transport should not be denied. Rather, necessary modifications should be undertaken and documented in line with relevant medical device legislation, and a risk management process should be followed before decisions are made about suitability of the system to be used as an occupied seat in a vehicle. There may be cases where in-spite of all efforts to enable transport, risks of occupant injury may be deemed unacceptable.

- Stakeholders, which includes prescribing practitioners, wheelchair and seating manufacturers and suppliers, transport professionals, wheelchair occupants, their families and care providers, should have a working comprehension of a documented risk assessment process (incorporating a risk/benefit analysis and evaluation) and understand the relevant risk/benefit analysis and evaluation undertaken for each case.

- Prescriber awareness of the type of transport environment and the facilities available to assist vehicle entry and egress is highly beneficial in the risk management process.

- Informed risk/benefit analysis can only be undertaken on the basis of sound evidence. There should be an aim to create an open climate around the safety issues such that incidents and injuries must be reported back to the transport companies, with formalised reporting procedures that facilitate the collation of facts without seeking to assign blame to individuals.

- The reader's attention is drawn the content of Section 7 Risk Management.

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2 Roles and Responsibilities

2.1 General

According to the Convention on Road Traffic, the driver of a vehicle holds the ultimate responsibility for the safe carriage of passengers, and for taking necessary precautions to avoid any risk of accident or injury [1]. That said, persons associated with the transportation of a person with a disability have a "duty of care" i.e. *a requirement to take reasonable care of a person to avoid acts or omissions which he or she could reasonably foresee are likely to injure that person".* This duty of care is shared over a number of people engaged in the supply and use of equipment. The responsibilities of these people are listed below [2, 3].

2.2 Wheelchair Occupant or His/her Advocate

- Understands principles of, and advocates for, his/her own safe transport
- Liaises with stakeholders / clinicians to understand the rationale for the use of the prescribed equipment and, where possible, oversees the correct and safe use on an on-going basis
- Liaises with stakeholders to undertake risk assessments as appropriate
- Offers feedback on difficulties or problems with the postural support seating, wheelchair occupant restraint, and/or wheelchair restraint

2.3 Clinician

- Works within his/her area of expertise
- Keeps abreast of current and new information relating to transport safety
- Understands and applies applicable transport safety guidelines
- Informs stakeholders of their responsibilities
- Provides up-to-date information to stakeholders
- Provides relevant documentation and training to those involved in the transportation of the wheelchair occupant, bearing in mind physical and cognitive abilities
- Verifies that the wheelchair occupant and support team understand the function of WTORS [4]
- Liaises with stakeholders to undertake risk assessments as appropriate
- Feeds back problems and difficulties with transportation to his/her supervisor

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- Works with other specialists in the design and development of custom-made equipment, bearing in mind factors relating to transportation safety, and takes a key role in relevant risk management.

2.4 Technical Support

- Has access to, understands, and applies appropriate guidelines, standards and design rules as they relate to transport safety
- Works with other specialists in the design and development of custom-made equipment to meet the client's and caregiver's needs
- Optimises safety requirements in the design and development of custom equipment
- Reviews new developments and designs, both custom-made and commercially available, in the light of the appropriate standards and design rules, and informs clinicians of the suitability of products and risks involved
- Liaises with stakeholders to undertake risk assessments as appropriate.

2.5 Family/Care Provider

- Maintains equipment as recommended in the manufacturers' Instructions For Use and Owner Manuals (IFU/OM) [5] [6].
- Understands their role in sharing responsibility for the wheelchair occupant's best interests
- Uses the prescribed equipment correctly and safely, and understands the necessity for its use on an on-going basis
- Liaises with stakeholders to undertake risk assessments as appropriate
- Offers feedback on difficulties or problems with the postural support seating, wheelchair, occupant restraint, and wheelchair securement systems.

2.6 Wheelchair Manufacturer

- Provides clear information on the safe transportation of their wheelchair – both in the pre-sales literature and in the IFU/OM [5] [6].
- Clearly discloses which of their wheelchairs comply with which relevant international standards
- Ensures tie-down points on wheelchairs are clearly marked and easily accessed
- Provides information in an appropriate and timely manner, and rectification where possible in the event of a product recall.

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2.7 Seating Manufacturer

- Provides clear information about the safe transportation and limitation of use of their seating system(s), both in pre-sales literature and IFU/OM [5] [6]
- Clearly discloses which of their seating systems comply with which relevant international standards
- Provides information to prescribers regarding compatible wheelchair bases for use with their seating system interface devices

2.8 Equipment Supplier/Retailer

- Works within his/her area of expertise
- Keeps abreast of current and new information relating to transportation safety
- Understands and applies applicable transport safety guidelines
- Provides up-to-date information to stakeholders
- Provides relevant documentation and training to those involved in the transportation of the wheelchair occupant
- Provides clear information on the safe transportation of their product – both in the pre-sales literature and in the IFU/OM [5] [6]
- Ensures tie-down points on wheelchairs are clearly marked and easily accessed
- Clearly discloses which of their products comply with which relevant international standards
- Engages with stakeholders in the undertaking of risk assessments as appropriate
- Provides information in an appropriate and timely manner, and rectification where possible in the event of a product recall

2.9 Vehicle Conversion Company

- Ensures that wheelchairs and their occupants can be adequately accommodated within adapted vehicles
- Ensures WTORS and their anchorages are crashworthy and suited to the wheelchair and occupant mass to be transported
- Ensures that the occupant restraint can be used in a manner that provides effective occupant restraint in accordance with the manufacturer's instructions

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- Provides adjustable elements of wheelchair occupant restraint systems to enable correct routing, ensuring close and appropriate contact with load bearing parts of a disabled passenger's skeletal structure

- Ensures that wheelchair tie-downs are installed in the adapted vehicle in such a manner that they can be easily attached to the wheelchair in accordance with ISO 10542-1 [4]

- Provides relevant written documentation regarding the use of boarding aids, wheelchair tie-downs, and occupant restraint systems fitted to the vehicle

- Provides 'hands-on' demonstration/training to all involved in the transportation of the wheelchair occupant, bearing in mind the physical and cognitive abilities of the vehicle users

- Provides details of equipment inspection and maintenance requirements

2.10 Transport Provider

- Provides vehicles that are of suitable dimensions and are suitably equipped to transport individuals using a variety of wheelchairs, and equipped for safe access/egress of same

- Provides relevant training to all staff involved in the transportation of individuals with mobility impairments with particular respect to disability awareness and equality in the provision of services

- Provides staff training in the use of ramps, winches, and passenger lifts as vehicle boarding aids in line with employer responsibilities [3]

- Provides staff training in the use of wheelchair tie-downs and occupant restraint systems in line with employer responsibilities [3]

- Provides suitably competent personnel to co-ordinate and participate in the transport risk management process

- Develops and implements systems of monitoring and reporting on transport safety issues

- Tests, maintains, and replaces as necessary components of the vehicle integral to the correct functioning of the WTORS

2.11 Contract Transport Personnel

- Undertakes relevant training on the safe transportation of those with mobility impairments which includes disability awareness and equality

- Undertakes training in the use of ramps, winches, and passenger lifts as vehicle boarding aids in line with employee responsibilities [3]

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- Undertakes training in the use of wheelchair tie-downs and occupant restraint systems in line with employee responsibilities [3]
- Undertakes training on transport risk management and appreciates and participates in the transport risk management process
- Understands their role in providing feedback to appropriate transport management on difficulties or problems with postural support seating, wheelchair occupant restraint, and wheelchair securement
- Keeps WTORS tracking free of debris to maximise lifespan of equipment
- Regularly checks the restraint systems for wear and/or damage in accordance with the WTORS manufacturer service guide and Instructions For Use, and liaises with the transport management for their repair or replacement

2.12 References:

[1] UNECE (1968) *Convention on Road Traffic,* Vienna.

[2] Disability Services Commission, Australia (1998) *Reducing the Risk.*

[3] UK Provision and Use of Work Equipment Regulation 1998 (PUWER)

[4] International Standards Organisation, ISO10542:2012 Assistive Products for Persons with Disability — Wheelchair Tie-downs and Occupant Restraint Systems. Geneva, Switzerland.

[5] EN 12183:2014 Manual wheelchairs. Requirements and test methods.

[6] EN 12184:2014 Electrically powered wheelchairs, scooters and their chargers. Requirements and test methods.

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3 Wheelchairs for Use in Transport

3.1 Section Summary:

- 'Crash testing' of representative wheelchairs is only one aspect of occupant safety. Prescribing practitioners, transport professionals, wheelchair and seating manufacturers and suppliers, wheelchair occupants, their families and caregivers, all need to consider the whole content of this document when determining the suitability for transport of a given wheelchair and seating configuration.
- The benchmark approach to wheelchair design assessment allows a certain amount of set-up flexibility to achieve a 'reasonable' level of safety for the occupant when in transport.
- Not all conditions of product usage can be directly represented in a crash test, and it is therefore not practicable to test all possible product permutations.
- Information relating to the safe transportation of wheelchairs should be provided by wheelchair manufacturers/suppliers in their pre-sales literature and IFU/OM.
- Any wheelchair models intended to be occupied in vehicles must have passed a dynamic crash test, and information related to each model's crashworthiness must be provided by manufacturers/suppliers in their pre-sales literature and IFU/OM.
- Wheelchair tie-down securement points should be clearly labelled using the karabiner symbol.
- IFU/OM should include instructions on how to transport the wheelchair when unoccupied.
- For small children with physical impairment of mass under 22kg, for whom transfer to a Child Restraint System (CRS) is not possible or is highly undesirable, prescribers of mobility devices such as a buggy or stroller should contact manufacturers for information regarding product usage when occupied in transport, with respect to compliance to the latest version of ISO 7176-19.

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- When seating requirements for tilt and/or recline exceed manufacturer recommendations, prescribers should establish and apply minimum angles of tilt and/or recline required by the wheelchair seated passenger whilst in transport.

- For wheelchair users in transport, a crashworthy wheelchair integrated lap belt with shoulder belt attachment will provide greater control of lap belt position than a standard vehicle anchored lap and diagonal belt.

- The integrity of a wheelchair seat back and head support is proven by satisfaction of the rear impact crash simulation given in ISO 7176-19 Annex G. Prescribers should contact device suppliers for further information of compliance.

- Where concerns exist with respect to the use in transport of a given equipment configuration, a thorough interdisciplinary risk assessment needs to be carried out.

- Where un-validated add-on components or third party items are required, prescribers and technicians should design and test the integrity, attachment, and position of the items to ensure their security and minimise risk of damage to the wheelchair occupant and others in foreseeable crash circumstances, as part of a risk management process.

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3.2 Suitability for Transport

The suitability of a wheelchair for use when occupied as a seat in a vehicle should be clearly indicated in a statement by the wheelchair manufacturer's pre-sale literature and IFU/OM [1]. It is the responsibility of the wheelchair manufacturer to state the intended use of its product, to specify any limitations in usage, and to provide warnings of conditions of usage that may lead to increased risk of injury to an occupant.

Information supplied by the manufacturer [2, 3] should include:

- A description of the intended use and intended environment for use
- A description of the intended occupant of the wheelchair (as a minimum this will include occupant mass plus any specific requirements for functional capability, visual ability, and cognisance, to operate the wheelchair safely in its intended environment)
- Instructions as to how to transport the wheelchair when unoccupied
- That the wheelchair is - or is not - suitable for use as a seat in a vehicle
- If it is suitable for use as a seat in a vehicle, the method of attaching wheelchair tie-downs and occupant restraint systems (WTORS)
- Recommendation of suitable wheelchair tie-downs and occupant restraint systems
- Any actions to be undertaken with respect to add-on components during transport (e.g. tray or head support)
- Effects of additional mass attached to, or carried by, the wheelchair, on wheelchair stability

Manufacturers of transportable mobility devices are expected to provide information relating to seating orientation (e.g. forward or rearward) and any recommended limits on the settings of adjustable elements of the wheelchair when used in transport (e.g. tilt or recline angles).

Images of mechanical settings and wheelchair tie-down attachment points at front and rear should be clearly illustrated in the IFU/OM. Tie-down attachment points should be clearly marked on the wheelchair frame by a karabiner symbol (figure 1).
The means of illustrating the tie-down attachment point on the wheelchair frame needs to be durable, bearing in mind that it may be subject to abrasion during the fitting and removal of tie-downs.

Where tie-down attachment brackets are fitted to a wheelchair to facilitate the attachment of wheelchair tie-downs, it is recommended that they are coloured in a manner that makes them easily identifiable.

Figure 1. Karabiner Symbol

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The presence of a karabiner symbol does not mean that a wheelchair is approved for use with docking-type securement systems. (For further reading on docking-type systems go to Section 5.7.3. Wheelchair Docking Systems).

3.3 Testing for Transport Safety

To determine if a wheelchair is suitable for use as a vehicle seat in transport, the manufacturer will subject the wheelchair to a dynamic crash simulation following the test methods given in relevant voluntary standards, such as *ISO 7176-19:2008+A1:2015* or *ANSI/RESNA WC-4 Section 19* [4, 5].

The test methods involve a dynamic crash test that exposes a forward-facing wheelchair and surrogate occupant to a simulated, severe frontal crash event [4]. The frontal impact test in both ISO and ANSI/RESNA standards require the test wheelchair to be subjected to the specified dynamic test when secured with a four-point tie-down, selected because it is the most common means of wheelchair securement system for transportable wheelchairs. This design requirement written into both standards works towards achieving a common global means of wheelchair securement. If a wheelchair manufacturer wishes to use another type of securement system such as a docking device, then the wheelchair should be re-tested accordingly.

The frontal crash severity chosen is common with that used by the automotive industry for the evaluation of child restraint systems, car seat anchorage validation, and luggage retention devices, and is generally accepted as being representative of a typical small passenger vehicle such as a private car or multi-purpose vehicle-type (MPV) in a moderate-to-severe frontal collision. Whilst it is accepted that different types or categories of vehicle possess differing crash aggressivity, a wheelchair manufacturer has no control over where their product will be used, therefore the dynamic crash severity employed represents the potentially most aggressive situation. (For further reading go to Section 6, 6.3 Vehicle Categories.)

In conducting the test, the wheelchair to be assessed is secured to a sled test rig with the four-point tie-down system according to the instructions provided by the manufacturer. Two webbing straps are attached to the front of the wheelchair, and two webbing straps with tensioning mechanisms are attached to the rear, at the designated tie-down attachment points.
(For further reading go to Section 5, 5.7.1 Four Point Strap Type Tie-downs)

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A surrogate occupant, or Anthropomorphic Test Device (ATD) representing the appropriate occupant mass is seated in the wheelchair in a 'normally upright seated position' and fitted with a three-point lap and diagonal restraint system of design and function similar to a seatbelt system used for automotive drivers or passengers.
(For further reading go to Section 5, 5.3 Objectives of Occupant Restraint)

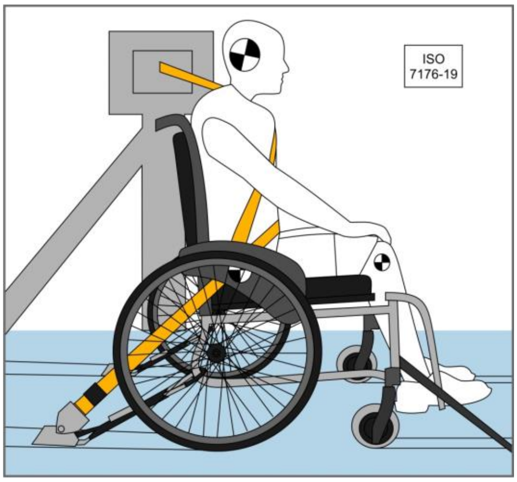

Figure 2. Dynamic Sled Test Set-Up

The secured wheelchair and the restrained occupant are then exposed to the dynamic crash simulation. Measurements are made of ATD and wheelchair movement during the crash event and, when combined with post-test observations, are compared with written pass/fail criteria to determine the outcome of the test.

Measurements taken during the frontal crash simulation include a means to determine whether an occupant is subjected to injurious loads by the wheelchair pushing the occupant into the restraint system.

Measurements made during the test include:

- Sled deceleration profile
- ATD head forward and rearward excursion
- ATD knee forward excursion
- Wheelchair excursion

Post-test observations require that no structural failure of the occupant seat support occurs, and that if sharp edges have been created that they are not contactable by the seated passenger. A certain amount of vertical collapse of the wheelchair is allowed and may in fact provide a means of energy absorption thereby reducing injury potential. Some parts may detach during a test, but their allowable mass is limited to a very low level.

The frontal impact test method serves as a benchmark for product performance, whereby not all conditions of product usage are directly represented. This is frequently the case, as there are countless possible wheelchair set-up conditions and configurations to suit the wide range of individuals' requirements, and the cost of testing would be prohibitive.
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Wheelchair manufacturers should provide detailed information on the configuration in which the wheelchair may be used whilst in transport, and, as far as possible, these configuration details should to be adhered to.

Whilst the frontal impact test methods of the two standards are very similar there is a notable difference where the *ANSI/RESNA WC-4 Section 19* Standard has a design requirement for wheelchairs to be tested with a crashworthy wheelchair anchored lap belt, to which can be attached a vehicle anchored shoulder belt. The ISO standard allows wheelchair manufacturers the option of either vehicle or wheelchair anchored lap belt locations.
(For further reading go to Section 5 WTORS Para 5.4 Wheelchair Integrated Lap Belts.)

A second notable difference between the two standards is that the now current version of *ISO 7176-19:2008+A1:2015* includes *Informative Annex G: Wheelchair design, performance, and labelling recommendations for improved protection of occupants seated facing forward in wheelchairs during rear impacts*. In this informative annex it is recognised that, when people travel in motor vehicles in forward-facing wheelchairs and are involved in a rear-impact collision, the wheelchair back support and head support provide the primary occupant restraint. Annex G is currently optional for wheelchair manufacturers; it provides a test method with performance criteria which include minimum and maximum back support deformation limits, maximum head to torso angle changes observed throughout the rear impact crash test to ensure effective ‘ride down’ of forces and at the same time reduce the risk of occupant ejection. The satisfaction of the given criteria provide prescribers with additional confidence of seat back and head support strength.
(For further reading go to Section 5 Para 5.3 Objectives of Occupant Restraint.)

At the time of writing (2019) there are few wheelchairs or seating system combinations that have been rear impact tested according to Annex G; prescribers should contact relevant manufacturers for further information.

3.3.1 Wheelchairs, Buggies and Strollers for Occupants 12-22kg.

Hitherto, transport best practice has recommended that wheelchair occupants of a mass less than 22 kg, the accepted mass of an average 6 year old, should be transferred to a Child Restraint System (CRS) approved for use in motor vehicles. [1,2,3,4,5]

However, it is now evident that it is often necessary to provide wheelchair seated transport for a child of mass less than 22 kg who, because of extreme discomfort or difficulty, cannot transfer to a CRS device. This may be due to the mobility device playing an important or fundamental role in maintaining position and/or providing postural support for a child with complex disability. Some children are dependent upon medical devices attached to their buggy or wheelchair. Some children’s physical proportions do not align with a non-disabled peer, and therefore with a standard CRS. Manual handling risks [6] associated with child mass or a safeguarding respect can also discourage the transfer of a child to a CRS device.

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It is in recognition of these considerations that amendments to the scope of the crash standard ISO 7176-19 have been made. [4] The 2019 issue of the standard will cover devices intended for use in transport for occupants of a mass range of 12 to 22kg, with a design requirement for the device to be supplied with a 5-point occupant harness type restraint system integrated into its structure, supplied and fitted by the OEM, in a similar manner as a compliant Child Restraint System.
(For further reading go to Section 5 Para 5.3.5 Restraint of Passengers 12 to 22kg.)

Prescribers of mobility devices such as a buggy or stroller for small children with physical impairment of mass under 22kg, for whom transfer to a CRS is not possible or highly undesirable, should contact manufacturers for information regarding product usage when occupied in transport.

3.3.2 Wheelchair Base and Seating System Combinations

When assessing for a wheeled mobility device for patients with more complex seating requirements, a practitioner may wish to employ the seating characteristics of a particular type of seating system offered by a specialised manufacturer. Generic types or designs of seating systems are capable of providing a particular style or method of postural support or interactive posture management. This requirement may lead practitioners to select a particular special seating system to be fitted to a preferred wheelchair base. The wheelchair base may itself be chosen for its own characteristics and the two elements of seating system and wheelchair base will combine to provide the desired mobility device solution.

In order to enable such a solution to be used as a seat in a vehicle, a test protocol is required to independently evaluate that the seating system and its means of attachment to the host wheelchair base are suitable for use in transport.

With this in mind, the *ISO 16840-4 Seating systems for use in transport* [7] and *ANSI/RESNA WC-4 Section 20* [6] standards provide a dynamic test method for seating systems that can be conducted in isolation of a host wheelchair. These standards involve the attachment of a seating system unit to a surrogate wheelchair base, which represents a typical manual wheelchair, using the same attachment hardware or interface device intended to be used with a host *ISO 7176-19* [4] compliant wheelchair. The satisfaction of specific pass/fail criteria provides an assurance that the seating product and its means of interface or attachment to a host wheelchair base is suitable for use as a seat in a vehicle.

In such a case, it is imperative that the seating system fitting instructions provided by the unit manufacturer are closely followed.

A considerable number of special seating system manufacturers have developed their own wheelchair base for use with their seating systems and tested their combinations using the *ISO 7176-19* [4] or *ANSI/RESNA WC-4 Section 19* [5] standards as a wheelchair unit. Some specialised seating manufacturers have also entered into agreements with wheelchair manufacturers and conducted collaborative tests following the wheelchair test standards.

In order to execute best practice, practitioners should carefully examine the methods and results of product assessment employed by manufacturers to ensure that an acceptable level of transport readiness is in place.
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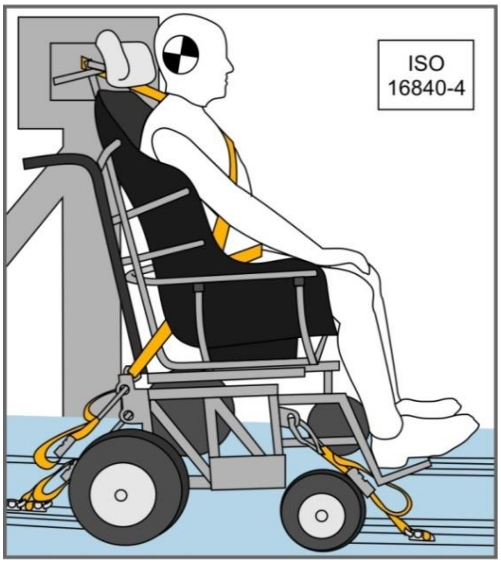

Figure 3. ISO 16840-4 test set-up with surrogate wheelchair base

3.3.3 Wheelchair Test Set-up - Tilt and Recline

Tilt and/or recline functions of wheelchair occupant seat surfaces can be valuable features for the achievement of optimal comfort, posture, pressure management, or other clinical objectives. Tilt is a feature frequently associated with wheelchair and seating systems combinations, where occupant position is maintained against the effects of gravity.

When testing for transport safety, manufacturers of wheelchairs will generally set tilt and recline to create an upright seated position of the ATD surrogate occupant. Test set-up procedures given in *ISO 7176-19* [4] and *ANSI/RESNA WC-4 Section 19* [5] urge a manufacturer to state seat rail and back support angles when in transport, and suggest a seat rail angle of less than 30° to horizontal and a back support angle of less than 30° to vertical for wheelchairs with a tilt or recline facility. If the support surface angles are greater than these values, the description of the body's position moves from "seated" posture and into supine position (lying).
(For further reading go to Section 4 Seating, Para 4.10 Tilt and Recline in Transport.)

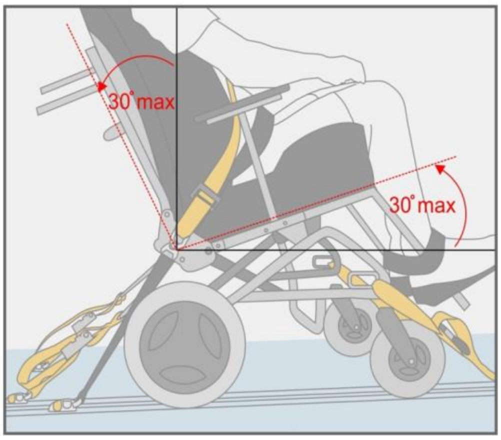

Figure 4. Full tilt

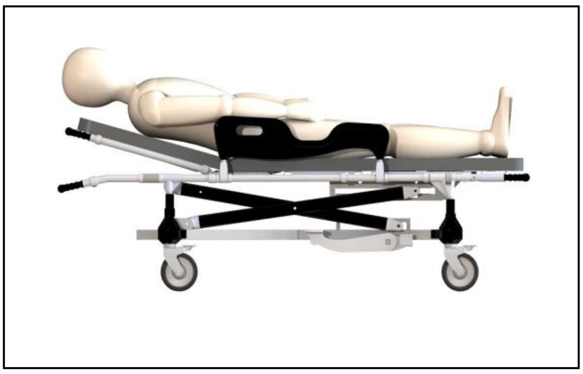

Figure 5. Supine Position

When adjustable, seat rail angles of 6° to 8° and back support angles of 10° to 12° are typical of a crash pre-test set-up. These settings are more likely to produce a satisfactory function of the occupant restraint system and limit forces applied to the

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wheelchair structure during the dynamic test. The set-up conditions that produce a satisfactory test outcome will naturally find their way into manufacturer Information for Use and Owner Manuals.

However, upright seat positions when in transport may contradict user positioning requirements for occupant comfort or bodily function as identified by a seating specialist. The greater the departure from manufacturer recommended tilt and/or recline angles, the greater the probability of hardware failure or of ineffective occupant restraint system function.
(For further reading go to Section 5.3 Objectives of Occupant Restraint.)

When seating requirements exceed manufacturer recommended settings when in transport, prescribers should establish and apply the minimum angles of tilt and/or recline clinically required by the wheelchair seated passenger whilst in transport. (For further reading go to Section 4 Seating Para 4.10 Tilt and Recline in Transport.)

Due to the individual nature of wheelchair configurations and seating system combinations, it is not possible to test all possible product permutations. The benchmark approach to wheelchair validation allows a certain amount of flexibility to achieve a ‘reasonable’ level of safety for the occupant when in transport.

Crash testing of representative wheelchairs is only one aspect of occupant safety. Prescribing practitioners, transport professionals, wheelchair occupants, their families, and caregivers need to consider numerous matters such as vehicle type, vehicle access and egress, WTORS type, use of accessories, etc. when determining acceptability for transport of a given wheelchair and seating configuration.

Where concerns exist with respect to the use in transport of a given equipment configuration, a thorough interdisciplinary risk assessment needs to be carried out and recorded, to highlight, consider, and address the risks associated with transport of the wheelchair occupant.
(For further reading go to Section 7, Risk Management Para 7.5 Transport Risk Management.)

3.3.4 Add-on Components and Third Party Equipment

Add-on components are defined as hardware attached to the wheelchair frame subsequent to sale by the wheelchair manufacturer, in a manner that requires the use of tools for attachment and removal, in order to enhance the design and/or performance of the wheelchair. They include integrated postural support devices such as anterior knee supports (knee blocks), medial knee supports (pommels and abductors), lateral thoracic supports, and trays.

Third party equipment consists of items attached to the wheelchair in order to support the welfare of the occupant, such as medical support devices (ventilators, suction devices, oxygen supply devices), or propulsion assist power-packs. Third party equipment might also include Electronic Assistive Technology including Augmentative and Alternative Communication (AAC) systems.

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Prescribers of mobility devices, where it is necessary to fit add-on components or third party devices in order to satisfy user requirements, should consult with wheelchair and/or seating system and device suppliers to ascertain the extent of previous testing or experience relating to crashworthiness.

The necessity for devices that provide a 'life-support' function to remain attached to the wheelchair while in transport must be assessed, recognising that their frequent removal and refitting by unskilled personnel would increase the risk of malfunction.

When it is necessary to attach high-mass devices, they should be mounted on the wheelchair as low as possible to maintain stability and be attached in a manner that is crashworthy. Particular consideration should be made for the securement of high-density objects such as battery packs and gas cylinders. It should be remembered that risks surrounding the carriage of oxygen in a pressure vessel also include flammability in an oxygen rich atmosphere, especially in the presence of oil.

With some exceptions, full dynamic testing for transport safety of wheelchairs and seating systems fitted with such add-on components is unlikely to have occurred. However, manufacturers, or those assuming the responsibilities of a manufacturer, will often conduct 'in-house' sub-system tests that can indicate that a basic level of item security has been achieved. These tests act as risk assessments of the attachment of individual components, and the outcomes should be recorded in product technical files. In case of inspection by a competent authority or an adverse incident, this information would support a decision made regarding crashworthiness.

In the absence of such information, prescribers and their engineering support team should evaluate, prescribe, and provide device attachments that are assessed as being crashworthy, and this should be recorded as part of their risk management process. (For further reading go to Section 7 Risk Management.)

3.4 References:

[1] Council Directive 93/42/EEC of 14 June 1993 concerning medical devices, OJ L 169, 12.7.1993, p.1.
[2] EN 12183:2014 Manual wheelchairs. Requirements and test methods.
[3] EN 12184:2014 Electrically powered wheelchairs, scooters and their chargers. Requirements and test methods.
[4] International Standards Organisation ISO 7176-19:2008+A1:2015: Wheeled mobility devices for use as seats in motor vehicles. Geneva, Switzerland.
[5] ANSI/RESNA WC-4:2012 Section 19: Wheelchairs Used as Seats in Motor Vehicles.
[6] ANSI/RESNA WC-4:2012 Section 20: Seating systems used as Seats in Motor Vehicles.
[7] International Standards Organisation ISO 16840-4:2009 Wheelchair seating - Part 4: *Seating systems for use in motor vehicles.* Geneva, Switzerland

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4 Seating Systems

4.1 Section Summary

- Where a seating system is an integral part of a wheelchair, the wheelchair and seating combination should have been tested and should comply with a relevant crashworthiness performance standard.
- If a separate seating system is fitted to the wheelchair, the wheelchair base frame should comply with ISO 7176-19 and the seating system and attachment mechanism should comply with ISO 16840-4.
- Prescribers and technicians involved with the positioning of thoracic or pelvic lateral postural support surfaces and/or the design of planar or custom-made contoured seating such as carved foam or moulded seat inserts should consider the means by which a crashworthy lap belt may be located on load bearing parts of the occupant's skeletal structure.
- A back support should ideally be set at shoulder height, but definitely be no lower than the spine of the highest scapula.
- An un-proven head support may offer some occupant protection, primarily in low speed rear vehicle impact.
- When seating requirements for tilt and/or recline exceed manufacturer recommendations, prescribers should establish and apply minimum angles of tilt and/or recline required by the wheelchair seated passenger whilst in transport.
- Wheelchair cushions to be used in transport should be of minimal weight and secured to the wheelchair using hook and loop fastenings or straps.
- Where more complex disabilities are presented it will become necessary to accept that a wheelchair occupant may be exposed to a higher risk of injury whilst in transport.
- Unless specifically required, it is recommended that third party accessories such as trays and other ancillary items should be removed from a wheelchair during transit, and secured/stowed separately.

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- The potential for a postural support device to induce injurious loads to non-load bearing parts of an occupant's body during transport should be evaluated under a risk management process and be documented accordingly.

- Risk management processes should be used by equipment prescribers to record and support decisions made and actions taken.

4.2 Seating System Requirements

The primary objective of wheelchair seating is to meet the wheelchair occupant's medical and positioning needs. Minimising injury risk to the occupant in the event of a motor vehicle crash or an adverse event, such as abrupt braking or an accident avoidance manoeuvre, is also an important factor to be considered.

Since the loads through the seating system during a severe impact can be considerable, the seating system is required to have sufficient structural integrity to support and contain the occupant so that the crash restraint systems can remain in position, correctly applied on the passenger's body throughout an event, and prevent occupant ejection and harmful contact with any internal parts of the vehicle, other occupants, or objects.
(For further reading go to Section 5, WTORS, Para 5.2 Passenger Crash Protection.)

Where a seating system is an integral part of a wheelchair supplied by a wheelchair manufacturer, the wheelchair and seating combination should comply with a relevant crashworthiness performance standard such as *ISO 7176-19* [1] or *ANSI/RESNA WC-4 Section 19* [2].

If a third party seating system is fitted to the wheelchair, the wheelchair base or frame should comply with *ISO 7176-19* [1], while the seating system and attachment mechanism should comply with *ISO 16840-4* [3], to ensure a minimum recognised safety standard for the occupant. In this case, seating systems that comply with the standard will be labelled with a statement that it complies with *ISO 16840-4:2009* [3].
(For further reading go to Section 3 Wheelchairs, Para 3.3.2 Wheelchair Base and Seating System Combinations.)

Regardless of whether the seating system is already part of the wheelchair or has been tested separately, there are certain requirements of seating systems that must be satisfied in order to maximise safety.

4.3 Attachment of the Seating System to the Wheelchair Base

If a seating system has been designed specifically for a wheelchair base, it must be fitted to the wheelchair base using the attachment hardware provided.

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When a seating system is intended to be used with a range of wheelchair bases it is essential to use the attachment hardware for the compliant seating system as supplied and instructed by the seating manufacturer.

Generally, there should not be a need for prescribers or technicians to drill or weld the wheelchair frame to attach seating hardware. However, in the preparation of custom modifications for more complex situations, prescribers and technicians may need to consider such actions to create the required seating solution.

In such circumstances, prescribers and technicians should consult with wheelchair and seating system suppliers to explore appropriate mechanical techniques to achieve the desired set-up before work commences. Under such circumstances, a thorough risk assessment should document agreed actions to modify the wheelchair or seating unit structure with particular attention to the requirement for regular inspection and monitoring of the device when in service.
(For further reading go to Section 4 Seating, Para 4.7 Custom Modifications.)

4.4 Back Support

A back support should ideally be set at shoulder height, as a minimum it should be at the level of the spine on the highest scapula.

The back support should be capable of providing the attachment of a head support and other integrated postural support devices to suit a user's postural needs.

A back support may be capable of angle adjustment independent of the seat to provide a back recline function.

The back support should be attached or linked to the seat rails by a means that allows easy routing of the lap section of a crashworthy restraint system low on the pelvis of the occupant preferably without the need to thread the lap belt through the wheelchair / seating structure, such as through the arm supports.

Back support mounting and adjustment mechanisms must not present sharp edges that could be capable of cutting seat belt webbing when under tension. This is a common means of restraint system failure in dynamic crash testing.

4.5 Seat Cushions

A wheelchair seat cushion or insert is frequently prescribed for clinical benefits such as aiding occupant posture, pressure distribution or relief, prevention of skin breakdown, and comfort and also to minimise mechanical shock.

4.5.1 Seat Cushion Attachment

From a seating function perspective, the stability of a cushion is a fundamental requirement. Therefore, the means of attachment of the cushion to the wheelchair support surface needs to be capable of repeated fitting and removal without impairment or deterioration. Cushions may need to be frequently removed for cleaning and maintenance, and an individual user may have a number of cushions for short or long term use.
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From a transport perspective, a cushion that is poorly attached to a wheelchair seat surface may slide forward and provide the means by which the occupant can slide down and under a crash restraint system (e.g. lap and diagonal belts). This would be typical in a lengthy, low g vehicle braking incident that would not be severe enough to trigger the locking mechanism of an inertia sensing occupant restraint system retractor.

One of the most common methods of cushion attachment to the wheelchair seat surface is by means of a ‘hook and loop’ system. The hook and loop (Velcro® style) interface is typically strong in shear but less so in tension.

To ensure effective cushion attachment the following design considerations should be followed:

- The shear characteristics of the hook and loop product must be sufficient for the purpose.
- The contact area between the hook and loop surfaces must be sufficient to achieve effective attachment of the cushion.
- The shear strength of adhesive used to attach hook and loop tape to the mating surfaces must have sufficient strength.
- Sewing of hook or loop tape to a cushion underside is preferable practice.
- Adhesive used to attach hook and loop tape must not be affected by intended cleaning practice and/or chemicals.

Additional operational practices regarding the use of hook and loop tapes which should be observed:

- The ‘polarity’ of hook and loop surfaces must be opposite, i.e. not hook to hook or loop to loop.
- The orientation of hook and loop tapes must be the same, i.e. longitudinal or transverse, and the tapes must be aligned to enable full surface engagement.
- The surfaces of either hook or loop faces must not be affected by fabric pilling or contamination.

Note: A UK (BSI) standard on the subject of seat cushion attachment is currently in development.

4.5.2 Seat Cushion Mass and Use of Webbing Attachment Straps

Cushions with higher mass will exert higher inertia forces to cushion attachment in a crash event and are therefore more likely to become detached. It is therefore wise for prescribers to be mindful to use low mass cushions where possible. When it is necessary to use high mass cushions in order to satisfy seating requirements, webbing type cushion securement straps may be needed to ensure effective cushion securement.

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4.6 Postural Support Devices

General postural support is a fundamental function of a wheelchair, or wheelchair and seating system. A basic wheelchair is comprised of key postural support elements such as the seat base, back support, arm supports, and calf and foot supports. These are parts which may be considered as base equipment and will be tested as an assembly for suitability to act as a seat in a motor vehicle by the crash test process.

As seating complexity increases, additional postural support devices will be required according to the nature and complexity of an individual's presentation. Additional postural support devices may be relatively straightforward, in the form of passive, webbing based arrangements, such as an 'H- Harness' to control the position of the upper torso, or a tethered pelvic support belt to maintain the pelvis in the correct position or orientation. Such devices are termed 'Secondary Postural Supports'.

More interactive devices may function as part of a rehabilitation process or posture management programme with the objectives of improving function and / or inhibiting development of postural deformities. Such devices are termed Integrated Postural Support Devices (IPSD) and include pelvic and thoracic lateral supports attached to the seating system and typically fitted with the use of tools in modular seating systems, or such supports may be features of a moulded or foam carved seat.

Also included in the IPSD category are quick-attach/detach devices such as a tray, knee blocks (anterior knee supports), or pommel/abductor (medial knee support) -- devices that need to be easily and quickly removed in order for the occupant to get in or out of their mobility device. Regardless, such quick attach/detach devices generally require interface hardware to be fitted to the wheelchair or seating system and therefore would be considered as of the integrated type.

From a user comfort and welfare perspective, if an individual requires postural support devices when sitting in normal, non-transport conditions, then the individual will require the same support in a vehicle.

From a transport safety perspective, postural support devices can be seen as helpful by maintaining an upright occupant position which enables crash restraint systems to function correctly. Conversely, they can be seen as a source of harm as a result of the application of forces to non-load bearing parts of a wheelchair seated passenger's anatomy.
(For further reading go to Section 5 WTORS, Para 5.6 Posture Belts in Transport.)

4.6.1 Integrated Postural Support Devices

Integrated postural support devices (IPSDs), such as lateral trunk supports or medial knee supports, are generally attached to seating systems such that they maintain a continuous supportive surface. Such a surface will generally be appropriately padded for user comfort.

For a forward facing occupant in a frontal crash or heavy braking incident, lateral supports are unlikely to impart injurious loads to an occupant. However, for devices which prevent forward movement of an individual within their seating system, such as knee blocks or trays, this may not be the case.
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It is therefore best practice for seating specialists to determine a desired maximum strength/retention capability for postural support devices capable of resisting forward motion of a user during a severe crash event. *ISO 16840-3 Postural Support Devices* [4] provides manufacturers of PSDs methods by which the structural mounting strength can be determined and presented to prescribers or developers of seating for selection on a 'test and disclose' basis. Careful selection of integrated PSD (IPSD) mounting methods according to their maximum and minimum strength should therefore be applied, especially for devices that control forward movement. As a general guideline, an integrated PSD mounting strength capable of sustaining a 1.0g static loading may be considered sufficient. A 1.0g static load is described as the load created by supporting the mass of an occupant against the force of gravity.

(For further reading go to Section 4 Seating, Para 4.9 Head Restraints and Head Supports.)

4.6.2 Integrated Postural Support Devices and Crash Belt Routing

Thoracic or pelvic lateral support surfaces may be attached to a modular style of seating system and are likely to be secured in place by clamp type mechanisms. However, in other types of seating system such as carved-foam or moulded seat inserts, lateral support surfaces are likely to be a continuous part of the support surface structure which may impede the correct location of effective occupant restraint routing.

Prescribers and technicians involved with the positioning of thoracic or pelvic lateral postural support surfaces and/or the design of planar or custom-made contoured seating such as carved foam or moulded seat inserts should consider the means by which a crashworthy lap belt may be located on load bearing parts of the occupant's skeletal structure.

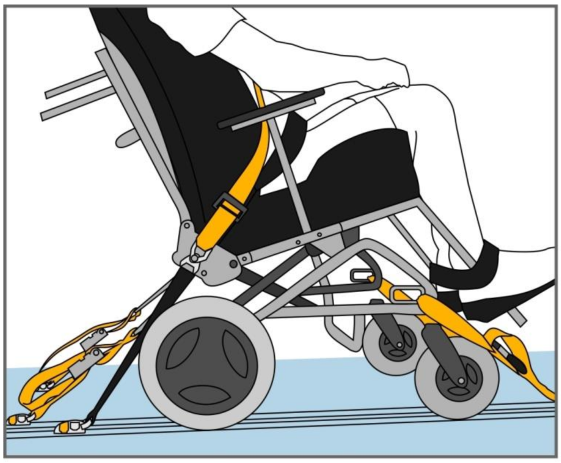

Figure 6. Preferred lap belt routing

The seating engineer/manufacturer should include clear routing for the occupant restraint within the structure of the seating to ensure that the occupant restraint has good contact across the occupant's pelvis (skeletal structure). Where the occupant restraint path does not have good contact across the occupant's pelvis, there will be a high probability of the occupant submarining with abdominal intrusion.

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A test method that assesses seating system design and the ease of fitting and routing of crashworthy occupant restraints so as to contact load bearing parts of the occupant's skeletal structure, especially the occupant lap belt section, is provided in *ISO 16840-4:2009 Annex D*. [3]

The use of a wheelchair-integrated, correctly located crashworthy lap belt can provide a vastly improved restraint solution for complex seating needs [1].
(For further reading go to Section 5 WTORS para 5.4 Wheelchair Integrated Lap Belts.)

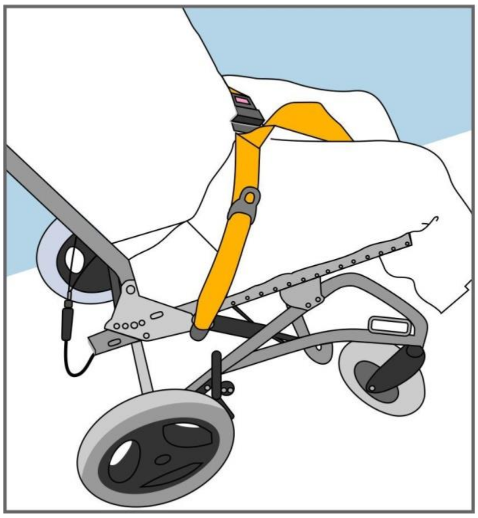

Figure 7. Wheelchair Integrated Lap Belt

4.6.3 Postural Support Devices (Secondary)

Secondary postural support devices capable of sustaining a 1.0g loading will often serve the purpose of supporting the occupant during severe vehicle 'accident avoidance' manoeuvres. Postural supports can also help the passenger maintain a seated posture and allow crashworthy occupant restraints to fit the passenger properly and load the strongest parts of the body during a crash.

The determination of the use of postural support devices of both types whilst in transport will vary according to individual conditions and circumstances. The determination of 'best practice' should be made on an individual basis by the application of a risk management process.

When considering the removal of a postural support device during transport, the risk management process should consider the skills available at the point of transport for the removal and refitting of devices and the possibility and outcome of re-fitting errors, equipment damage, or equipment loss.

Assessors may apply a number of risk control measures that are capable of creating a positive 'risk-benefit' evaluation for the use of postural support devices whilst in transport.
(For further reading go to Section7 Risk Management, Para 7.5 Transport Risk Management.)

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4.7 Custom Modifications

An off-the-shelf crash test compliant seating system may not be practical or meet all the needs of a client, and custom modification or custom manufacture of a seating system may be necessary. Such alterations to a seating system should only be made by clinically and technically competent individuals, with the manufacturer's consent, or by specialist workshop units that are equipped for, and experienced in, the custom modification and manufacture of seating systems, and relevant medical device regulatory requirements must be met.
(For further reading go to Section 4 Seating, Para 4.3 Attachment of Seating System to a Wheelchair Base.)

Since such modifications may affect the crashworthiness of the wheelchair they may affect the original chain of responsibility and place additional responsibility on the modifier. Consequently, a full risk management process should be carried out and recorded before any modified seating equipment is issued to a client with the intention of being used in transport, and the modifications should be documented in line with applicable medical device regulations.
(For further reading go to Section 7 Risk Management, Para 7.4 Risk Management for Medical Devices.)

As previously mentioned, in instances where more complex disabilities are presented, it will become necessary to accept that a wheelchair occupant may be exposed to a higher risk of injury whilst in transport. In such cases, the employment of a full risk management process should be used by equipment prescribers to record and support the decisions and actions taken to address a wheelchair occupant's needs, bearing in mind the manufacturer's responsibilities as outlined in *ISO 16840-4:2009* [3].

In undertaking risk management, all options should be considered in an effort to provide transportation that is as safe as possible for all occupants of the vehicle. This may involve modification to a vehicle to secure oxygen cylinders, or an increase in the size of the vehicle, or a reduction in the number of passengers being transported in the vehicle.

4.8 Add-on Components and Third Party Equipment

When and where possible, it is recommended that trays and other ancillary items and equipment should be removed from a wheelchair during transit, and stowed and secured separately. To prevent confusion, items that should be removed should be labelled as such by the manufacturer.

Exceptions to this recommendation may exist. For example, if a tray is required to provide postural support (benefit) and the potential for injury is increased while travelling without the tray (risk), the benefit outweighs the risk, and therefore it may be preferable to include the tray for transport. In such a situation, risk of injury may be reduced by the adding padding to the tray or using a non-rigid postural support.

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When it is necessary to carry life-support equipment attached to some component of the wheelchair/seating system, it is critical that every effort is taken to protect both the wheelchair occupant and other vehicle occupants against the risks associated with transporting such equipment

4.9 Head Restraints and Head Supports

A head restraint is a device fitted to an automotive seat and is primarily intended to prevent neck hyper-extension in low speed rear impact situations. The function of an effective head restraint relies on it being mounted to a seatback with known minimum strength. Automotive safety standards or regulation have implemented design and performance requirements to address seatback and head restraint strength to ensure functional capability.

In European Vehicle Type Approval regulations, the presence of a head restraint is a legal requirement on the two outboard seats in the first row of seats in an M1 passenger or N1 goods vehicle.
(For further reading go to Section 6 Vehicles, Para 6.3 Vehicle Categories.)

A head support is a postural support device intended to help maintain a person's head in a desired position, or prevent the head from moving into undesired or harmful positions. Provision of a head support will be based upon assessment of a wheelchair occupant's clinical need rather than as a regulatory requirement. The need for head support may be increased in transport as muscle weakness or spasticity may result in the passenger being unable to handle the forces of cornering or changes in speed, forces created by normal vehicle motion. The design of the head support used must be based on the occupant's clinical requirements, which may be at odds with the design requirements of an automotive head restraint.

Concerns from the wheelchair seated passenger transport sector that generate questions about the capability of a head support to act as a head restraint relate to rear impact crash scenarios.

Crash related standards for wheelchair and seating system hardware have so far focused on the most common crash scenario which is the frontal impact. Rear impact events account for few fatalities, but this crash mode results in a large proportion of automotive related trauma in the general population and low severity rear impact accounts for more long term injury than any other crash mode.

In response to the need to address rear impact conditions for wheelchair seated passengers, amendments within the current version of *ISO 7176-19:2008+A1:2015* [1] includes an Informative Annex G Wheelchair design, performance and labelling requirements for improved occupant protection of occupants seated forward facing in wheelchairs during rear impacts. This 'optional to manufacturers' rear impact test method and pass/fail criteria includes minimum and maximum back support deformation limits and maximum head to torso angle changes observed throughout the rear impact crash event to ensure effective 'ride down' of forces and at the same time reduce the risk of occupant ejection.
(For further reading go to Section 5 Para 5.3 Objectives of Occupant Restraint.)
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In the satisfaction of the Annex G pass/fail criteria, a wheelchair or wheelbase and seating system with head support attached to a seatback would be identified as crashworthy thus providing prescribers with a greater level of confidence.

Prescribers concerned about rear impact protection should seek information from their equipment suppliers regarding their intent to supply hardware that complies with *ISO 7176-19:2008 Annex G* [1] for Rear Impact

Hitherto, head supports have been shown to reduce the potential for neck injury in rear impact scenarios, i.e. offer a partial function as a head restraint [5]. A head support and its attachment mechanism that has demonstrated integrity when subjected to the static loading and impact tests given in *ISO 16840-3:2014* [4] should be considered as suitable head support.

(For further reading go to Section 4 Seating, Para 4.6.1 Integrated Postural Support Devices.)

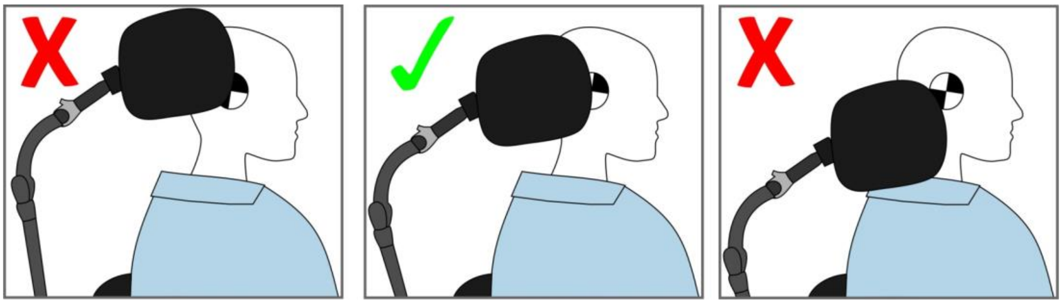

Figure 8. Preferred position of head support for transport

In cases where wheelchairs will be used regularly in transport, a head support capable of offering a degree of head restraint should be considered necessary. Care must be taken to ensure that the head support does not present any sharp edges, shafts, or adjustment screws that could cause injury to a passenger seated behind the wheelchair occupant. In instances where such a hazard does exist it is advised that the wheelchair seated passengers sit at the rear of the vehicle or have additional free space between them and any passenger travelling behind them.

Where a head support is prescribed with the intention of also providing a degree of head restraint, the top of the head support should be no lower than the most prominent point on the back of the head (above the top of the person's ears). It should be positioned as close as possible to the back of the head, be well padded, firmly attached to the seating system, and be able to withstand a substantial horizontal load to the front contact surface of the head support. [4]

Under such situations a comprehensive risk assessment must be undertaken and recorded by competent individuals.
(For further reading go to Section 7 Risk Management.)

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4.9.1 Vehicle Mounted Back and Head Restraints

Vehicle-mounted back and head restraints are commercially available, some with combined occupant restraints and wheelchair tie-downs integrated into their structure. Where viable, the option of vehicle mounted systems should be considered.

The fact that a typical wheelchair back support is likely to deform somewhat during rear impact loading is possibly a positive factor in most rear impacts, since the forces on the neck are reduced when there is some deformation of the seatback. In this regard, it is important not to install a vehicle-anchored head support system without including additional vehicle-anchored support for the wheelchair back support, since a strong rear head restraint without strong back support could result in injurious loading to the neck in a rear impact.

The primary challenge in providing effective rear head and back support using a vehicle-mounted system is achieving close positioning of the support surfaces to the back support of the wheelchair and head of the occupant. This is not easily accomplished when a wheelchair space in a vehicle is used by a wide range of wheelchair occupants, with different types and sizes of wheelchairs.

In response to the need to establish design and performance criteria for vehicle anchored head and back restraints, the *ISO 10542-1:2012* revision will include an Informative Annex M, Design recommendations and rear-impact test method with associated performance criteria for vehicle-mounted head-and-back restraints.
(For further reading go to Section 5 WTORS, Para 5.9.3 Informative Annex M Head and Back Restraints.)

4.10 Tilt and Recline in Transport

For initial background information, readers are referred to the text within Section 3 Wheelchairs, Para 3.3.3 Wheelchair Test Set-Up – Tilt and Recline.

In a seating context, recline refers to the change of a back support angle from upright towards a supine position without moving the seat, resulting in a change of hip angle.

Tilt refers to the change of the seating orientation in a sagittal plane whilst maintaining the seat to back support (and therefore hip) angle. [6].

Tilt and/or recline functions of wheelchair occupant seat surfaces are valuable features for the achievement of occupant comfort, postural correction, pressure distribution, and bodily function. Tilt is a feature frequently associated with wheelchair and seating systems, where occupant position is maintained against the effects of gravity.

Test set-up procedures given in *ISO 7176-19* [1] and *ANSI/RESNA WC-4 Section 19* [2] urge manufacturers to state recommended seat rail and back support angles when in transport.

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Both standards suggest a seat rail angle of less than 30° to horizontal and a back support angle of less than 30° to vertical for wheelchairs with a tilt or recline facility because support surfaces of angles greater than these values may result in occupant ejection during a crash event. Additionally, it should be recognised that at greater angles the occupant position moves out of the definition of seated posture and into a semi-supine position.

As previously mentioned in Section 2 Wheelchairs, seat rail angles of 6° to 8° and back support angles of 10° to 12° are typical of a crash pre-test set-up, settings that are likely to produce a satisfactory function of the occupant restraint system and limit forces applied to the wheelchair structure during the dynamic test. It is unsurprising, therefore, that many, but not all, manufacturers of wheelchairs with a tilt and recline function recommend an upright position during transport.

Upright seat positions when in transport may contradict user positioning requirements as identified by a seating specialist. The greater the departure from manufacturer recommended tilt and/or recline angles the greater the probability of hardware failure or ineffective occupant restraint system function.
(For further reading go to Section 5 WTORS, Para 5.3, Objectives of Occupant Restraint.)

Prescribers of wheelchairs with a tilt and recline function should contact manufacturers for clarification of recommended settings for tilt and recline angles during transport. When seating requirements, including those whilst in transport, exceed recommended angles prescribers should establish and apply the minimum angles of tilt and/or recline clinically required by the wheelchair seated passenger for application whilst in transport.
(For further reading go to Section 3 Wheelchairs, Para 3.3.3 Wheelchair Test Set-Up - Tilt and Recline.)

Where concerns exist with respect to the use in transport of a given equipment configuration, a thorough interdisciplinary risk assessment needs to be carried out and recorded, to highlight, consider, and address the risks associated with transport of the wheelchair occupant. Prescribing practitioners, transport professionals, wheelchair occupants, their families, and caregivers, need to consider numerous matters such as vehicle type, vehicle access and egress, WTORS type, use of accessories, etc. when determining acceptability for transport of a given wheelchair and seating configuration.
(For further Reading go to Section 7 Risk Management, Para 7.5 Transport Risk Management.)

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4.11 References

[1] International Standards Organisation ISO 7176-19:2008+A1:2015 Wheeled mobility devices for use as seats in motor vehicles. Geneva, Switzerland.

[2] ANSI/RESNA WC-4:2012 Section 19: Wheelchairs Used as Seats in Motor Vehicles.

[3] International Standards Organisation ISO 16840-4:2009 Wheelchair seating - Part 4: Seating systems for use in motor vehicles. Geneva, Switzerland.

[4] International Standards Organisation ISO 16840-3:2014 Determination of Static, Impact and Repetitive Load Strengths for Postural Support Devices. Geneva, Switzerland

[5] Simms C, Madden B, Fitzpatrick D, Tiernan J, (2009) Rear Impact Neck Protection Devices for Adult Wheelchair Users, Journal of Rehabilitation Research and Development, 46(4) pp 499-514

[6] International Standards Organisation ISO 7176-26 Wheelchairs - Part 26: Vocabulary. Geneva, Switzerland.

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5 Wheelchair Tie-downs and Occupant Restraint Systems (WTORS)

5.1 Section Summary

- Vehicle occupant restraints are the primary means of providing effective occupant protection in a frontal crash event.
- The most common type of wheelchair tie-down uses a four-point strap system to secure the wheelchair to the vehicle floor.
- Not all types of wheelchair tie-down systems are suitable for all wheelchairs – consult the wheelchair manufacturer's IFU/OM.
- The pelvic or lap portion of a crashworthy wheelchair occupant restraint system generally anchors to structural regions of the vehicle, or to the wheelchair tie-down straps.
- Some crash-tested wheelchair designs feature an integrated crashworthy lap belt that anchors to the wheelchair and has connector hardware to attach to a vehicle mounted shoulder belt.
- Wheelchair integrated lap belts can provide a major risk control measure in a transport risk management process, by reducing probabilities of incorrect lap belt routing or placement on a wheelchair seated passenger's body when in transport.
- Wheelchair and seating system prescribers should seek clarification from wheelchair or wheelbase and seating system manufacturers or suppliers regarding the use and availability of a wheelchair integrated lap belt for a specific mobility device.
- The upper anchor point of the shoulder belt should be attached to a point above and behind occupant shoulder level.
- Anchoring the upper end of the shoulder belt to the floor has been shown to significantly increase harmful compressive loading on the occupant's torso and spine in the event of a crash and is strongly discouraged. Occupant restraint systems with floor anchored shoulder belts do not comply with industry standards.

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- Wheelchair and seating prescribers, as well as transport providers and their operatives, must be made aware of the increased risk of ineffective occupant restraint that can be created in significant tilt conditions, with particular attention to the importance of close and continuous contact with occupant restraint webbing and the importance of correct anchorage locations.

- Prescribers of wheelchairs, and wheelchair seated passenger transport providers, should seek clarification from WTORS suppliers regarding the maximum user mass for their occupant restraint systems.

- Equipment prescribers and wheelchair seated passenger transport providers engaged with the transport of bariatric users should seek recommendations for the effective restraint of bariatric wheelchair seated passengers. They should take into account the potential for occupant restraint system failure in case of a vehicle crash and record any actions taken to control risks to the passenger and other people travelling in the same vehicle as part of their transport risk management process.

- Docking-type wheelchair tie-down is another type of wheelchair securement system in commercial use, but is wheelchair specific.

- Prescribers of wheelchairs should seek clarification from wheelchair manufacturers regarding the use of a docking type securement system for use in a vehicle. Docking systems to be used with specific wheelchairs must follow the wheelchair manufacturer and docking system manufacturer's installation instructions.

- Transport providers must be familiar with WTORS manufacturer IFU/OM regarding equipment maintenance and inspection regimes.

- In passenger transport vehicle environments that allow standing passengers, wheelchair stations, such as rear-facing wheelchair spaces, may be appropriate.

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5.2 Passenger Crash Protection

While the vehicle seat is an important part of the occupant protection system, vehicle occupant restraints (i.e. seatbelts) are the primary means of providing effective occupant protection in a frontal impact event and have an overall effectiveness of between 40% and 50% in reducing crash-related fatalities [1]. To work well together, seats must allow the proper fit of the seatbelt systems and they must support the occupant throughout the crash so that the seatbelts remain properly positioned. [2, 3, 4]

For those wheelchair occupants who cannot transfer to a vehicle seat or child safety seat without compromising their medical or positioning needs, safe transport requires the use of after-market equipment to:

- Secure the occupied wheelchair firmly to the floor, facing forward in the vehicle
- Provide effective, crashworthy occupant restraint for the person in the wheelchair

Commercial products that accomplish both goals are called Wheelchair Tie-Down and Occupant Restraint System, or WTORS. Testing WTORS involves undertaking a dynamic crash test for a forward facing wheelchair seated passenger, similar to the tests for crashworthiness of child restraint systems, standard vehicle seats, and standard occupant restraint systems. [5, 6, 7, 8, 9, 10, 11, 12]

There are also several national WTORS standards. [13, 14, 15] These standards are similar to *ISO 10542-1* in spirit and requirements. WTORS systems that comply with these similar standards may also comply with *ISO 10542-1* for forward facing wheelchair seated passengers.

In larger passenger vehicles with accepted lower crash aggressivity, other forms of occupant restraint system such as a two point lap belt may be considered appropriate to address the requirements for occupant restraint.
(For further reading go to Section 6 Vehicles, Para 6.5 M2 Vehicle Category Review.)

Large passenger vehicles, such as buses, that allow standing passengers offer a generally safer transport environment because of their large mass and low travel speeds which greatly reduce the frequency and severity of crash events. In these vehicles, the provision of safety for wheelchair seated passengers is based on achieving safety levels comparable to those for standing passengers, using a rear facing wheelchair position with head and back support, and with additional hand rails to maintain stability and to focus on keeping the wheelchair and occupant in position during normal travel such as sudden stops and turns.
(For further reading go to Section 6 Vehicles, Para 6.6.2 M3 Vehicle Category Low Floor Bus.)

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5.3 Objectives of Occupant Restraint

The objective of a crashworthy occupant restraint for a forward facing vehicle occupant in a frontal impact is to decelerate the user in a controlled manner throughout a crash event. The controlled manner is often referred to as ‘ride down’ of forces created by a crash event. This is achieved by allowing some occupant movement during a road traffic accident whilst preventing occupant contact with the vehicle interior, which could lead to injury. Effective occupant restraint will also prevent ejection of the passenger from their seated position in the vehicle.

In order to function correctly, the location and positioning of both lap and diagonal sections that form the occupant restraint must be such that forces created are applied to load bearing parts of the occupant’s anatomy.

The forces generated during a severe frontal impact can be high and, in some vehicle types with harsh crash characteristics, sufficient to result in severe chest injuries, such as broken ribs or ruptured aorta, or severe neck injuries, or traumatic head injury.
(For further reading go to Section 3 Wheelchairs, Para 3.3.3 Wheelchair Test Set-Up – Tilt and Recline.)

5.3.1 Means of Occupant Restraint

Most commonly, an occupant restraint comprises a three-point lap and diagonal belt across the pelvis and torso. An *ISO 10542-1* [5] compliant wheelchair occupant restraint system is based on the three-point system and is considered suitable for use in all vehicles, including small vehicles which have more aggressive crash characteristics.

The system anchors at three separate points in order to provide a lap section and diagonal shoulder belt for the wheelchair seated passenger. The pelvic or lap portion of a crashworthy vehicle mounted wheelchair occupant restraint system anchors to structural regions of the vehicle, or to the wheelchair tie-down straps [5]. The upper anchor point of the shoulder belt is attached to the structural points on the sidewall of the vehicle with the lower end of the shoulder belt connecting to the pelvic belt near the hip.

5.3.2 Occupant Restraint Path or Routing

The occupant restraint path is the route that the occupant restraint webbing takes over the seated passenger’s body and seat and then secures to specific anchorages within the vehicle structure. In order for the human body to effectively ‘ride-down’ the forces created by a webbing-based occupant restraint system, those forces must be applied to strong skeletal parts of the human anatomy. In the case of the lap belt section, webbing must contact low on the pelvis (below the ASIS - anterior superior iliac spines), and the shoulder belt section (or upper torso restraint) should pass diagonally over the torso from hip, across the sternum and across the collarbone.

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In an automotive environment, Vehicle Type Approval regimes ensure that occupant restraint path and routing is controlled with relatively fixed seat belt anchorage locations that position a three point occupant restraint system on strong skeletal parts of the upright seated vehicle occupant's anatomy. With the vast array of wheelchairs, wheelbases, and seating systems plus the varied postures of wheelchair seated passengers, positioning of occupant restraint systems is more difficult to standardise and requires thoughtful fitting by transport personnel with a level of understanding of the characteristics of good belt fit.

In the wheelchair seated passenger transport sector, instead of the strict controls of design and performance that are applied in the automotive sector, manufacturers of wheelchair tie-downs and occupant restraint systems are required by the *ISO 10542-1* standard to provide user instructions, both written and pictorial, for the use of tie-downs and the correct application and positioning of their occupant restraint systems.

The basic principles of wheelchair seated passenger restraint are as follows:

- In order to remain in contact with load bearing parts of the anatomy during a crash event, the lap section should lie low over the hips, touch the top of the thighs, and be angled between 45° and 75° (figure 9) to the horizontal when viewed from the side. Failure to create this steep angle of application is likely to allow 'submarining', resulting in pressure on the abdomen from the lap belt, and possibly leading to fatal injuries due to damage of internal organs.

- The shoulder belt should cross the collarbone (the clavicle) and the centre of the chest over the sternum, and connect to the lap belt near the opposite hip. It should have a straight run from the point of contact with the occupant to the upper anchorage point, which should be at or above the level of the shoulder (see figures 9 and 10). The occupant restraint webbing should be at least 25mm away from any sharp edges along the full length of its path.

Figure 9. Poor fit of a lap/shoulder belt

Figure 10. Good fit of a lap/shoulder belt

(Illustration courtesy of University of Michigan, used with permission)

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5.3.3 Occupant Restraint Routing and Wheelchair Design

The standards for wheelchairs and seating systems provide manufacturers of wheeled mobility devices for use in transport a rating system which describes how to achieve a satisfactory occupant restraint path. Annexes within the standards *ISO 7176-19:2008+A1:2015*, [11] *ISO 16840-4:2009* [12] and *ANSI/RESNA WC-4 Section 19* [14] and 20 [15] provide a test method by which the routing of a vehicle anchored occupant restraint system can be assessed and expressed. The rating system addresses:

a) The ease of positioning a vehicle anchored lap and shoulder belt restraint system on the wheelchair occupant.
b) The fit and contact of a vehicle anchored lap and shoulder belt restraint system to the wheelchair occupant.
c) The potential for contact of the belt restraint system with sharp edges of the wheelchair or seating system.

Numerical values are awarded for the achievement of the following criteria:

- Ease of routing the restraint over the occupant and the wheelchair.
- Pelvic belt contact: the lap belt should fit low over the hips, touch the top of the thighs, and make contact with the sides of the pelvis.
- Pelvic belt angle: the lap belt should be angled between 45° and 75° to the horizontal when viewed from the side [16].

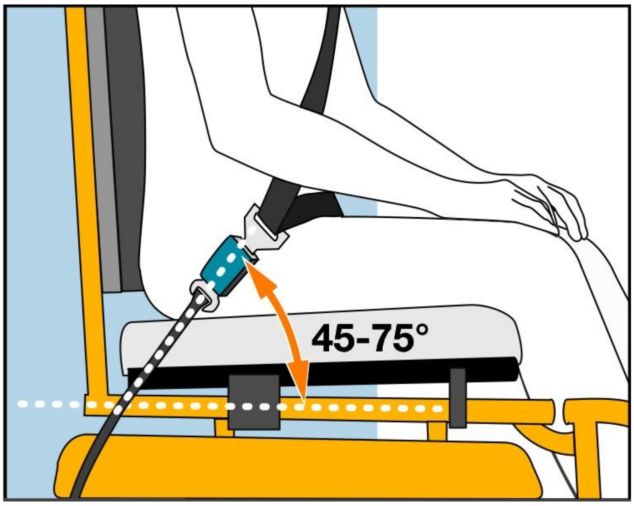

Figure 11. Preferred lap belt angle
(Illustration courtesy of University of Michigan, used with permission)

- Shoulder belt contact: the belt should make good contact with chest and shoulder and cross the middle of the shoulder.
- Belt path to anchor points: should be straight to anchor point and minimise contact with the wheelchair.

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- Some wheelchair hardware, such as arm supports, can interfere with good lap belt fit of vehicle anchored restraints by holding the belt away from the occupant resulting in submarining.

- Belt does not come within 25mm of sharp edges that can cause tearing of webbing.

Using the assessment methods in the standards, the design of a wheelchair or seating system can be numerically assessed, modified, and reassessed until an excellent score and therefore improved safety can be achieved.

Further reading on the application and beneficial outcomes of the assessment method can be found in the following documents, available from https://www.pmguk.co.uk/resources/best-practice-guidelines-bpgs/associated-papers

- 'A study of the occupant restraint path in a bespoke seating system', by V. Curling.
- 'The number and location of attachment points for occupant restraints in crashworthy custom contoured seating' (2012) by Paul Harrington

5.3.4 Floor Anchored Shoulder Belts

In order to prevent spinal compression of the occupant, the effective anchorage for the upper torso restraint must be positioned above and behind the shoulder of the occupant. (See figure 12 and figure 13)

Anchoring the upper end of the shoulder belt to the floor has been shown to significantly increase harmful downward loading on the occupant's torso and spine in the event of a crash and results in very poor upper body restraint [17]. An occupant restraint system with a direct to the floor anchorage for the upper end of the shoulder belt does not comply with *ISO 10542-1*, and is not compatible with wheelchair manufacturers' instructions for use. Such a configuration is strongly discouraged**.**

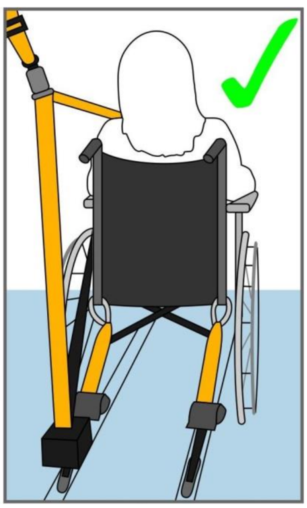

Figure 12. Compliant 3 point restraint

Figure 13. Non-compliant restraint

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5.3.5 Restraint of Passengers of Mass 12 to 22kg

Historically, transport best practice has recommended that child occupants of a mass less than 22kg should be transferred to a Child Restraint System (CRS) approved for use in motor vehicles. [1,2,3,4,5]

However, it has been observed that there are significant occasions where it is necessary to provide wheelchair seated transport for a child of mass less than 22kg who, because of extreme discomfort or difficulty, could not transfer to a CRS device. This may be due to a complex form of disability and the mobility device plays an important or fundamental role in maintaining position and/or postural support. On occasions, a child may have dependency on medical devices attached to their buggy or wheelchair, or their physical proportions do not align with a non-disabled peer. At times, risks associated with the manual handling [7] of a child from a mass or a safeguarding respect can also discourage the transfer of a child to a CRS device.

It is in recognition of these considerations that amendments to the scope of the crash standard *ISO 7176-19* have occurred. [11] The 2019 issue of the standard covers devices intended for use in transport for occupants of a mass range of 12 to 22kg, with a design requirement for the device to be supplied with a 5-point occupant harness type restraint system integrated into its structure, supplied and fitted by the OEM, in a manner similar to a compliant Child Restraint System (CRS).

It must be noted that three point occupant restraint systems intended for use by adult passengers, such as those in compliance with the WTORS standard *ISO 10542-1* [5] or *ANSI/RESNA WC-4 Section 18* [17] would not provide adequate crash protection for a small child passenger.
(For further reading go to Section 3 Wheelchairs, Para 3.3.1 Wheelchairs, Buggies and Strollers for Occupants 12-22kg.)

Prescribers of mobility devices such as a buggy or stroller for small children with physical impairments, for whom transfer to a Child Restraint System is not possible or is highly undesirable, should contact manufacturers for information regarding product usage when occupied in transport.

5.3.6 Restraint of Bariatric Passengers

Bariatric wheelchair seated passengers provide challenges to transport provision not only with respect to the increased load on occupant restraint systems and their anchorages, but also boarding aids such as ramps and passenger lift platforms. The width of their wheelchairs presents a challenge in terms of access to, and the space dedicated to, passenger locations within a vehicle.

Test methods for mobility devices (wheelchairs and seating systems) apply a risk management approach whereby testing with an ATD (Anthropomorphic Test Device) of a specific mass will indicate suitability for use within a mass or weight range. For example, successful dynamic testing with a mid-sized adult male ATD (50th percentile) of mass 76kg will indicate that a mobility device is suitable for use by an actual user of mass between 75 and 136kg. With a product intended for use by users of mass greater than 136kg, a mobility device manufacturer will

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dynamically test with the large adult male ATD (95th percentile), of 102kg. Successful testing with the large adult male ATD enables manufacturers to recommend the product for use by users heavier than 136kg, with no upper limit on user mass.

Performance standards for wheelchair tie-downs and occupant restraint systems [5] [17] require dynamic testing using an average size male ATD of mass 76kg. There is currently no requirement for manufacturers of WTORS to validate their product with a heavier ATD for use by occupants of mass greater than 136kg.

Prescribers of wheelchairs, and wheelchair seated passenger transport providers, should seek clarification from WTORS suppliers of the maximum user mass for their occupant restraint systems, and any recommendation for the effective restraint of bariatric wheelchair seated passengers.

Equipment prescribers and wheelchair seated passenger transport providers engaged with the transport of bariatric users should consider the potential for occupant restraint system failure in case of a vehicle crash and record any actions taken to control risks to the passenger and other people travelling in the same vehicle as part of their transport risk management process.

5.4 Wheelchair Integrated Lap Belts

Some crash-tested wheelchair designs feature an integrated crashworthy lap belt that anchors to the wheelchair, and has connector hardware to attach to a vehicle mounted shoulder belt. Optimum routing of the integrated lap belt between the structure of the wheelchair, buggy, or integrated postural support (such as lateral pelvic support) and the user's pelvis greatly improves pelvic restraint fit. This scenario reduces the need for a third party to invade the personal space of the wheelchair occupant to fit a vehicle anchored lap belt. (For further reading go to Section 4 Seating, Para 4.6.2 ISPDs and Crash Lap Belt Contact.)

The advantage of the optimum positioning achieved with an integrated lap belt and the subsequent reduced risk of occupant submarining is particularly valuable for tilt wheelchairs, as the anchorages of the lap belt remain constant relative to the occupant throughout the range of tilt angles.
(For further reading go to Section 3 Wheelchairs, Para 3.3 Testing for Transport Safety.)

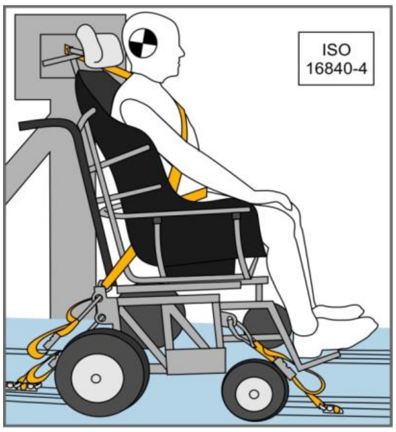

Figure 14. Integrated lap belt

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Wheelchair integrated lap belts can provide a major risk control measure in a transport risk management process, by reducing probabilities of incorrect lap belt routing or placement on a wheelchair seated passenger's body when in transport.

Due to the safety advantages of a wheelchair integrated crashworthy lap belt, the *ANSI/RESNA WC-4 Section 19* [14]contains a design requirement for all wheelchairs to provide anchorages for and be dynamically tested with a wheelchair integrated lap belt. Within the *ISO 7176-19: 2008+A1:2015* [11] standard for transportable wheelchairs, manufacturers have an option to provide anchorages and may dynamically test with either wheelchair integrated or vehicle anchored lap belt restraints.

However, a wheelchair anchored pelvic belt will increase loads applied to wheelchair tie-downs which may become an issue when heavier wheelchairs are used in transport. In these cases, it may be desirable to use more than two rear tie-down straps or a four-point tie-down system with an appropriate load-bearing capacity. (For further reading go to Section 5 WTORS, Para 5.7.2 Securing Heavy Wheelchairs.)

Wheelchair and seating system prescribers should seek clarification from wheelchair or wheelbase and seating system manufacturers or suppliers regarding the use and availability of a wheelchair integrated lap belt for a specific mobility device.

5.5 Occupant Restraint with Tilt and Recline

Effective occupant restraint relies on a snug fit of the lap and diagonal sections of a webbing based restraint system with the passenger's body**.** Avoiding a loose belt condition is critical to preventing the build-up of energy before contact is made with the restraint system. This is a fundamental requirement in achieving the desired 'ride-down' of forces created by crash acceleration, therefore reducing forces to tolerable levels for the human body to endure.

Large tilt angles are likely to result in a gap between the shoulder belt section of a restraint system and the passenger's upper torso, especially when the upper torso restraint anchorage and wheelchair tie-down locations are longitudinally limited within the vehicle passenger environment.

Wheelchair and seating prescribers, as well as transport providers and their operatives, must be made aware of the increased risk of ineffective occupant restraint that can be created in significant tilt conditions, with particular attention to the importance of close and continuous contact with occupant restraint webbing and the effect that anchorage locations play in the achievement of correct function of restraints.
(For further reading go to Section 3 Wheelchairs, Para 3.3.3 Wheelchair Test Set-Up Tilt and Recline.)

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5.6 Posture Belts in Transport

Postural support belts and harnesses used to position a person in the wheelchair are intended for postural positioning, and it should be assumed that they are **not** strong enough to withstand the forces of a crash. As posture positioning supports, they are often not positioned in such a way as to apply the necessary forces to the strong parts of the skeletal system and thus restrain the occupant safely. They should not be relied upon for occupant restraint during travel, but can be used in conjunction with a crashworthy lap/shoulder belt system.

Secondary postural support devices capable of sustaining a 1.0g loading will often serve the purpose of supporting the occupant during pre-crash vehicle 'accident avoidance' manoeuvres. Postural supports can also help the passenger maintain a seated posture that allows crashworthy occupant restraints to fit the passenger properly and apply load the strongest parts of the body during a crash.
(For further reading go to Section 4 Seating Para 4.6. Postural Support Devices.)

5.7 Wheelchair Securement

Wheelchair securement is an essential requirement for wheelchair seated passenger transport for two very basic reasons: firstly, to allow a wheelchair to provide a stable seat support surface for the passenger being restrained by an occupant restraint system and, secondly, to effectively prevent the wheelchair, as an item of mass designed to be mobile, from impacting other passengers travelling in the same vehicle.

Wheelchair securement may be provided by a number of different types of tie-down devices, each with particular characteristics that make them appropriate for different operating environments and conditions.

Details for the design and performance requirements of wheelchair securement hardware (tie-downs) and their associated occupant restraint systems are provided in recognised and well established standards, such as *ISO 10542-1:2012* [5] and *ANSI/RESNA WC-4 Section 18* [17]. It is by the process of standardisation that compatibility between transportable wheelchairs and wheelchair tie-downs and occupant restraint systems is maximised.

5.7.1 Four-point Strap Tie-downs

The most common type of wheelchair tie-down uses a four-point strap system to secure the wheelchair to the vehicle floor. These wheelchair tie-downs are very effective and can be used to secure many types and styles of wheelchairs, but usually require someone other than the wheelchair user to attach and tighten the straps. For these systems to work properly, all four straps must be used as recommended by the manufacturer.

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The use of four-point strap tie-downs is much easier if the wheelchair occupant is using a crash-tested wheelchair that complies with *ISO 7176-19* [6] *or ANSI/RESNA WC-4 Section 19* [14] (see Section 3), since these standards require wheelchair frames to include four designated points for attaching the four tie-down straps. (For further reading go to Section 3 Wheelchairs, Para 3.3 Testing for Transport Safety.)

Tie-downs must always be attached to designated tie-down attachment points on a transportable wheelchair, as marked by the device manufacturer. Tie-downs should never be attached to removable elements like arm supports, foot supports, lower leg support assemblies, or to the wheels.

When using a typical four-point wheelchair tie-down (see figure 15), it is best to position the wheelchair so that the floor anchor points for the rear tie-down straps are directly behind the securement points on the wheelchair. A side-view angle of 30° to 45° relative to the horizontal is desirable. If possible, attach the front wheelchair tie-down straps to floor anchor points that are wider than the wheelchair to avoid interference with wheelchair foot supports and also increase lateral stability during vehicle movement.

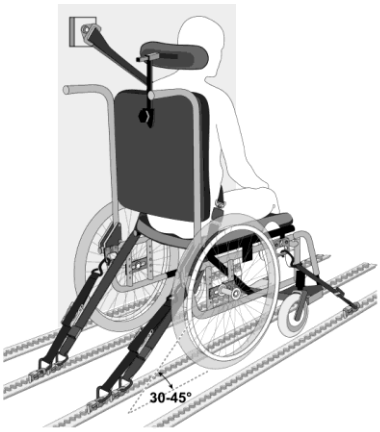

Figure 15. A 4-point strap type wheelchair tie-down system
(Illustration courtesy of University of Michigan, used with permission)

Figure 16. A 4-point strap type wheelchair tie-down system

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5.7.2 Securing Heavy Wheelchairs

Concerns regarding the securement of heavy wheelchairs are generally associated with powered devices. A heavy manual wheelchair with tilt and recline facilities, combined with a seating system, may reach 45kg. A powered wheelchair, with heavy duty batteries, powered tilt and recline, and seat elevator can reach 200 kg, unoccupied.

WTORS standards require systems to be tested in a 20g/48kmh vehicle crash environment where tie-downs will secure an 85kg surrogate wheelchair and an ATD of 76kg, representing a 50^{th} percentile human occupant. The selection of an 85kg mass wheelchair is made on the basis of ensuring ease of equipment use and sufficient load bearing capacity, rather than to represent the mass of an average powered wheelchair.

However, when wheelchair mass becomes significantly greater than the 85kg test mass, additional risk control measures need to be applied to ensure effective securement of a wheelchair, particularly in a harsh crash environment, such as of M1 Vehicle Category.
(For further reading go to Section 6 Vehicles, Para 6.4.3. M1 Category Vehicle – Wheelchair Mass Carrying Capacity.)

Many tie-down manufacturers have responded to the increasing mass of powered wheelchairs and have developed tie-downs with a greater load bearing capacity. In such cases, WTORS manufacturers will generally indicate the rated capacity of the tie-downs on equipment labelling.

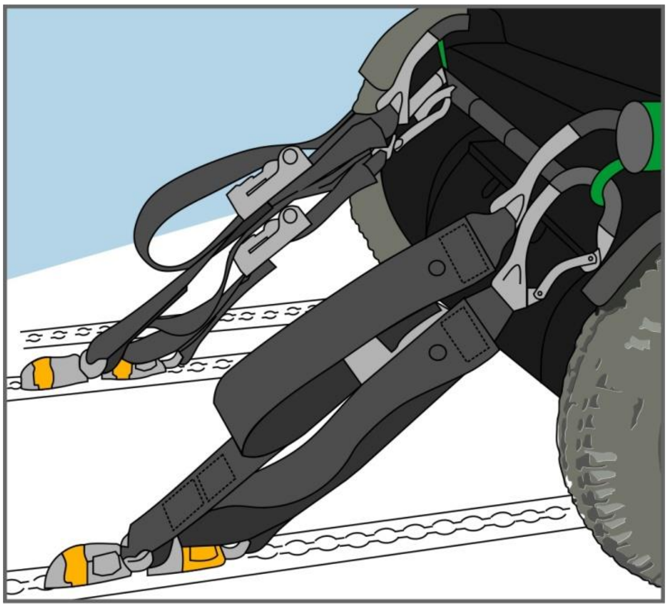

Figure 17. Doubled rear tie-downs

NOTE: Rear tie-downs are rated as a pair rather than individually.

Transport providers should consult with their tie-down manufacturer regarding the rated capacity of their tie-down system.
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The requirements for the wheelchair tie-down system should also be specified in the wheelchair manufacturer's pre-sales literature as well as in the IFU/OM.

A simple, common, and effective solution for the securement of a heavy powered wheelchair is to fit a second pair of tie-downs at the rear. This approach gives transport providers a simple solution, reduces the number of tie-down types carried, and may simplify training issues. This action will also serve to spread the load of securement over a larger floor area, thus reducing floor load intensity.

The presence of a wheelchair integrated lap belt will create additional loading of rear tie-downs during a crash event. As an approximation of the additional loading created by an integrated lap belt, transport providers may add 66% of the user mass to the wheelchair mass.
(For further reading go to Section 5, Para 5.4 Wheelchair Integrated Lap Belts.)

5.7.3 Wheelchair Docking Systems

Another type of wheelchair securement system in commercial use is a docking-type wheelchair tie-down (see figure 18 and 19), whereby components on the wheelchair engage with a docking station mounted to the vehicle floor when the wheelchair is moved into position in the vehicle. The use of a docking type wheelchair securement system is more frequently seen with rigid manual or powered wheelchairs that do not have a folding function. Firmly attached docking hardware will generally prevent such a folding action.

The main advantage of a docking-type wheelchair tie-down is that it is quick and easy to use, does not require manual effort, and allows the wheelchair occupant to secure and release his or her wheelchair independently. A frequently observed disadvantage of a docking system is the reduction of wheelchair ground clearance due to engagement hardware fitted to the underside of the wheelchair.

As previously mentioned in Section 3 Wheelchairs, Para 3.3 Testing for Transport Safety, according to ISO and ANSI/RESNA standards, wheelchair manufacturers are required to provide and test their product with a four-point tie-down system. Should a manufacturer wish to secure their product with a different type of tie-down system such as a docking system, then they must re-test their product with the chosen type of securement system.

In response to the demand for greater levels of user independence, especially in private transport vehicles, increasing numbers of wheelchair manufacturers are re-testing products with proprietary docking systems. Manufacturers of powered wheelchairs prepare their products for the post-production attachment of particular docking hardware at the manufacturing stage, for the fitting of a particular docking device. It is likely, therefore, that an adapted wheelchair would be capable of securement with either a four-point or docking type securement system.

Such a mutually developed wheelchair docking solution would be more likely to provide the wheelchair stability and securement system required for 'drive from wheelchair' vehicle applications.
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Prescribers of wheelchairs should seek clarification from wheelchair manufacturers regarding the use of a docking type securement system for use in a vehicle. Docking systems to be used with specific wheelchairs must comply with the wheelchair manufacturer and docking system manufacturer's installation instructions.

In circumstances where it is proposed to fit a docking system without approval from a wheelchair manufacturer, personnel involved should be reminded of their responsibilities as a manufacturer. In such cases, a detailed risk management process should be undertaken and recorded by both the equipment installer and vehicle converter to ensure that the probability and consequences of tie-down failure do not present unacceptable risks to the wheelchair user or other people travelling in a vehicle.
(For further reading go to Section 7 Risk Management, Para 7.5 Transport Risk Management.)

Because of the need for a specific hardware match, docking-type securement is not currently practical in public transport vehicles where a single wheelchair station may need to accommodate many types of wheelchairs. Universal docking system geometry has been specified in *ISO 10542* [10] in the hope that it will lead to standardised systems in a wide range of public transport vehicles that will allow people to dock their wheelchairs independently.

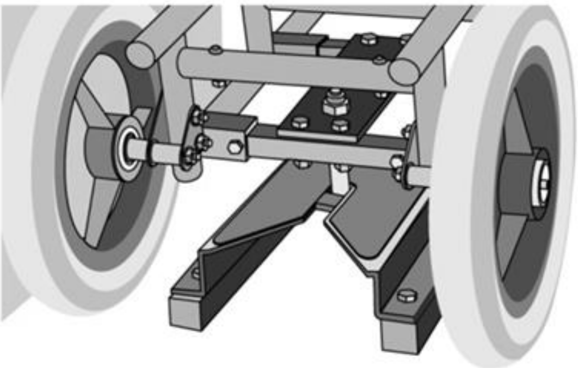

Figure 18. A docking type wheelchair tie-down system
(Illustration courtesy of University of Michigan, used with permission)

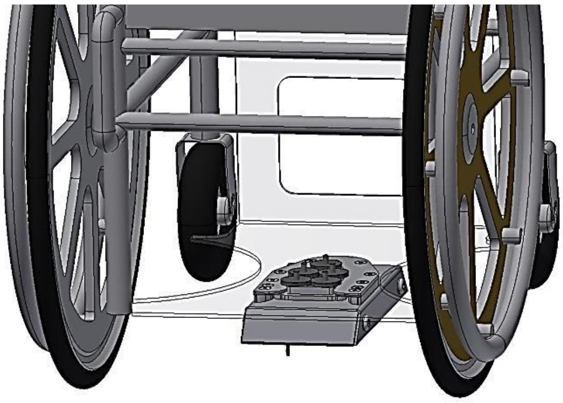

Figure 19. A docking type wheelchair tie-down system
(Illustration courtesy of Dahl Engineering)

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5.8 Maintenance of Securement Devices

The transportation provider is responsible for the safe transport of passengers. It is the ultimate responsibility of the driver to maintain WTORS in a clean and fully functioning state, and to replace WTORS that have become worn or damaged. Webbing should be regularly inspected in accordance with manufacturers' instructions.

Transport providers must be familiar with WTORS manufacturer IFU/OM regarding equipment maintenance and inspection regimes.

Upon arrival at a destination, WTORS should be removed and stowed to avoid theft, vandalism, soiling, or damage caused by wheelchairs rolling over them during access and egress. Loose items of equipment can also become dangerous missiles in the event of a crash.

Where floor tracking is used as the means of anchorage of the WTORS to the vehicle floor, rails should be kept clean of debris.

In the event of a crash of such severity that the vehicle must be towed away, WTORS equipment should be quarantined for deep inspection and considered for replacement.

5.9 ISO 10542-1 Developments

Progress on the ongoing revision of the *ISO 10542-1:2012* [11] standard for wheelchair tie-downs and occupant restraint systems is expected to deliver a new version of the standard in 2019. The key changes to the standard are the addition of three informative annexes intended to stimulate industry to respond to the desire to achieve continued improvements in occupant protection for wheelchair seated passengers.

5.9.1 Informative Annex K Tie-downs for Rear Impact

Intended to shadow the introduction of Informative Annex G Wheelchairs in rear impact within *ISO 7176-19:2008+A1:2015* [6], the WTORS standard *ISO 10542-1* [11] has the addition of a similar rear impact test for wheelchair tie-downs. In order to enable wheelchairs that offer rear impact protection to function as intended, it is necessary to ensure that wheelchair front tie-downs are capable of securing a wheelchair in an effective manner.

The test method contained within Informative Annex K limits rearward excursion of an occupied surrogate wheelchair of mass 85kg in a moderate to severe rear impact. The limit for wheelchair excursion is set at 200mm, with the aim of maintaining a wheelchair and occupant within the recommended 'free space' behind the wheelchair seated passenger.

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5.9.2 Informative Annex L Tie-downs for use with Wheelchairs with Integrated Lap Belts

In acknowledgement of the potential high probability of tie-down failure when securing a powered wheelchair fitted with an integrated lap belt, Informative Annex L provides manufacturers of wheelchair tie-downs with a test method to ensure that risk of equipment failure in a severe frontal impact is reduced to an acceptable level.

5.9.3 Informative Annex M Vehicle Anchored Head and Back Restraints

It has long been recognised that wheelchair design in terms of seatback strength and head restraint mounting for crash protection purposes presents a challenge to wheelchair manufacturers.

With this in mind, Informative Annex M has been prepared with design and performance criteria for supplementary head and back restraints for wheelchair seated passengers.

The Informative Annex M provides a full range of design considerations to maximise the effective interaction of a wheelchair seated passenger with supplementary head and back protection, closely aligned with the content and intentions of existing wheelchair and tie-down standards.
(For further reading go to Section 4 Seating, Para 4.9.1 Vehicle Mounted Head Restraints.)

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5.10 References

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6 Road Vehicle Categories and Wheelchair Access

6.1 Section Summary:

- Knowledge of the types of vehicle environment intended to be used by wheelchair seated passengers can assist equipment prescribers and parents/care providers with preparations for transport. It is within M1 category vehicles where more aggressive vehicle crash characteristics exist.

- As far as possible, safety provisions for wheelchair seated passengers are similar to those for ambulant passengers throughout the vehicle categories.

- Customer choice is the basis for selection of a private WAV and the market is supplied by a number of vehicle converters, each with their own technical approach to passenger accommodation. Private purchasers of WAVs should be urged to make a full review of the requirements before committing to the purchase of a vehicle.

- Clinicians, equipment suppliers, and wheelchair users and their care providers who are using high mass powered wheelchairs and intend to travel in M1 category vehicles should be made aware of the probable requirement for additional measures to effectively secure the wheelchair.

- Forward facing occupancy is the preferred seating orientation for wheelchair seated passengers, with proper use of a WTORS.

- When a wheelchair seated passenger is positioned rearward facing in a taxi, the wheelchair should be positioned against the partition between driver and passenger compartment, with the wheelchair head/back support placed in close proximity, ideally no more than 50mm, to the bulkhead, not including the push handles. WTORS should then be used to secure the wheelchair and restrain the occupant.

- A sideways facing seated passenger is not permitted in an M1 category vehicle of any description. This includes wheelchair seated passengers in taxis where sideways facing is particularly hazardous due to wheelchair instability and passenger lateral impact with wheelchair and vehicle structure.

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- A taxi with wheelchair and passenger rear entry will control seating orientation to forward facing only.
- If there is a choice of wheelchair orientation, forward facing with proper use of a WTORS is the safest option for M1 vehicles.

  M2 vehicles will often have a flexible floor layout where wheelchair seated passenger transport is more easily achieved. WTORS devices can be fitted to vehicle floor tracking and vehicle side wall anchorages. Wheelchair seated passengers in M2 type vehicles will generally be forward facing.

- A wheelchair seated passenger travelling in an urban bus that allows standing passengers may travel in a purpose-made rearward facing wheelchair passenger space (RF-WPS), where the occupant backs up to a padded barrier that stops the wheelchair from rolling forward and may offer additional head and back support and hand holds.
- Wheelchair users, their parents/carers and transport providers must be made aware of the limitations of stability when using a ramp as a vehicle boarding aid.
- Operator competency in the use of boarding aids, particularly passenger lift platforms, is a vital part of providing safe wheelchair seated passenger transport. Lift platform operators should take part in user training programs, both practical and theoretical, and follow the operating instructions supplied by the boarding aid manufacturer in their IFU/OM. Lift platform suppliers are required by law to provide full training in the use of their products as part of their duty of care responsibilities.
- When a particular wheelchair and passenger presentation or behaviour is not covered by lift manufacturer training or instructions, a detailed risk management process must be undertaken by a transport provider with close collaboration with other stakeholders such as the user, their parent/care provider, and equipment supplier. Risk control measures that reduce probability of harm to as low as possible must be defined and recorded and made available to all transport personnel involved in the transport provision.

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6.2 General

This document has focused on the use of wheeled mobility devices and seating systems in transport. Understanding different types of road transport vehicles, and each type's safety requirements and potential sources of harm will assist all parties involved in wheelchair provision and usage in transport. Additionally, understanding the road travel environment assists all parties in planning for immediate and future transport requirements and thus avoid surprises or disappointments.

Passenger transport vehicles come in various shapes and sizes according to intended operating purposes and are grouped according to their mass, the number of passengers a vehicle is to accommodate, and the type of service to be provided, be it private or public.

In order to ensure that the various types of road passenger vehicles are suitable for general use, technical design and performance requirements need to be established for various vehicle types. General technical design and performance requirements for all road vehicles are controlled by a process of Vehicle Type Approval, and Approval Authorities exist within all the major manufacturing nations and international collaboration on technical requirements and their implementation allows vehicles to enter different markets globally.

6.3 Vehicle Categories

Within the EU, vehicles are separated into 'categories' of vehicle types. For example, passenger vehicles with at least four wheels are denoted by a letter of M, whereas goods vehicles are denoted by the letter N, and trailers by the letter O.

The vehicle category M is further divided into M1, M2 and M3, each separated by the number of passengers carried with consideration for vehicle mass.

Table 1: Directive 2007/46/EC [1], Annex II, Definition of Vehicle Category

Category	Description
M1	Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat
M2	Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass not exceeding 5 tonnes
M3	Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 tonnes

(For further reading go to Section 3 Wheelchairs, Para 3.3 Testing for Transport Safety.)

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6.3.1 Technical Requirements

The process of vehicle approvals covers a vast number of vehicle topics, including lights, direction indicators, driver field of vision, glass characteristics, and engine exhaust emissions. Passenger safety related topics cover a range of subjects such as vehicle seats, seat belt design and function, seat belt anchorage strength, interior projections, and more.

One very important and relevant factor relating to passenger safety is the reducing crash aggressivity of passenger vehicles as they become larger and heavier. Vehicle aggressivity is a vehicle characteristic which changes mainly due to increasing mass, design construction, and typical travelling speeds. Aggressivity is also influenced by operating conditions, which includes private or public passenger access.

The crash severity of any individual incident will be influenced by the aggressivity of the vehicle and the amount of force imparted to the vehicle occupants during a crash event. The forces are primarily dependant on the rate at which the vehicle and its occupants change speed during the crash event (deceleration).
(For further reading go to Section 5, para 5.3 Objectives of Occupant Restraint.)

Table 2: Definition of Vehicle Categories and their Crash Aggressivity

Category	Description	Crash Aggressivity
M1 Car/MPV/Taxi	Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat	20g/48kmh
M2 Minibus/Ambulance	Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass not exceeding 5 tonnes	10g/30kmh
M3 Inter-city Coach	Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 tonnes	6.6g/30kmh
M3 Low-Floor Bus	Vehicles designed and constructed for the carriage of sitting and standing passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 tonnes	1g

Knowledge of the types of vehicle environment intended to be used by wheelchair seated passengers can assist equipment prescribers and parents/care providers with preparations for transport. It is within M1 category vehicles where more aggressive vehicle crash characteristics exist.

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6.3.2 Provisions for Wheelchair Seated Passengers

As far as possible, safety provisions for wheelchair seated passengers are similar to those for ambulant passengers throughout the vehicle categories. Greater extent of choice is naturally available with vehicles for private use, whereas in vehicles intended to provide wheelchair seated passenger transport in general public service, measures need to be adopted that will allow them to accept a broad range of wheelchairs and user size and mass.

6.4 M1 Category Review - Private Vehicle (Car and MPV)

M1 category passenger vehicles will be a car or multi-purpose vehicle (MPV), often modified by a vehicle converter to carry a wheelchair seated passenger. Generally, private M1 category, wheelchair accessible vehicles (WAVs) will be chosen for family usage and to suit the needs of a family member with mobility impairment. Private vehicles will be used on all types of roads, be they urban, rural, motorway, or highway, and may be driven by anyone with a basic driving licence, be they newly qualified or experienced.

Customer choice is the basis for selection of a private WAV and the market is supplied by a number of vehicle converters, each with their own technical approach to passenger accommodation. Private purchasers of WAVs should be urged to make a full consideration of their requirements, especially with respect to the function and fit of the wheelchair seated passenger occupant restraint system, before committing to the purchase of a vehicle.

Regarding accommodation of wheelchair users, standard vehicles may be used by passengers who have sufficient mobility to make an ‘external transfer’ from their wheelchair to a vehicle seat, and their wheelchair carried as luggage. Alternatively, an ‘internal transfer’ may occur where the wheelchair seated passenger enters the vehicle seated in a wheelchair and then transfers to a vehicle seat. This is often the choice for individuals who are able to drive with the assistance of adapted vehicle controls.

When a transfer from wheelchair to vehicle seat has occurred, the unoccupied wheelchair must be secured so that it is not likely to become a projectile within the passenger environment during an accident

Wheelchair users for whom transfer is not possible will require additional vehicle adaptation that will ensure that the wheelchair seated passenger can embark and disembark from the vehicle and, once in place, their wheelchair can be effectively secured, and an occupant restraint system can be made available to restrain the passenger.

In private vehicles, wheelchair seated passenger orientation is generally forward facing. Vehicle entry may be made from the vehicle side or from the rear. Generally, vehicles with rear entry are able to offer larger door apertures by virtue of floor lowering mechanisms following modification by a vehicle converter.

More extensive vehicle conversions with adapted controls can allow vehicles to be used for ‘drive from wheelchair’, mainly within the domain of private ownership.

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6.4.1 M1 Category Review – Licensed TAXI Vehicle (Car/MPV)

M1 category vehicles used to provide a taxi service may include a car or multi-purpose vehicle (MPV), or a vehicle designed specifically for taxi operations, such as the London cab. Taxis are sometimes referred to as 'Small Public Service Vehicles'. (For further reading go to external link https://tfl.gov.uk/info-for/taxis-and-private-hire/passengers-and-accessibility.)

Taxis are able to 'ply for hire' and pick up passengers from the roadside by hailing, and their conditions of usage are regulated by regional licensing requirements. Vehicle conditions will be required as part of the licensing process such as the display of an external 'Taxi For Hire' sign, have the passengers' fare on display by a taximeter, and may need to have a security partition between driver and passenger compartments, and be wheelchair accessible.

Taxi service vehicles will be used on all types of roads, be they urban, rural, motorway, or highway. Most taxi drivers are self-employed and run their own vehicle. Taxi drivers will be generally over 21 years of age, and will be trained and licensed to collect a vast range of passengers and provide them with the shortest and cheapest route to their destinations. Taxi drivers are required to help passengers with luggage and to assist passengers with mobility impairments.

Part of the 'conditions of fitness' for a vehicle to operate as a licensed taxi will often include being able to carry a wheelchair-seated passenger. Drivers are required to assist with boarding and alighting from the vehicle, securement of the wheelchair, and fitting of an occupant restraint system.

Most taxis will prefer side loading of a wheelchair-seated passenger to enable taxi users to board from a pedestrian walkway, whereas rear entry taxis will require loading from the road, which requires additional space and may require negotiating kerb drops.

Seating orientation for a wheelchair seated passenger once inside the taxi may be either forward or rearward facing. When forward facing the wheelchair must be secured using four-point tie-downs with the occupant restrained using a three-point occupant restraint system, in compliance with WTORS standards.

In cases where a wheelchair seated passenger is positioned rearward facing, the wheelchair will be positioned against the partition between driver and passenger compartment, with the back support of the wheelchair placed in close proximity (not more than 50mm) to the bulkhead. WTORS should then be used to secure the wheelchair and restrain the occupant.

A sideways facing seated passenger is **NOT** permitted in an M1 category vehicle of any description. This includes wheelchair seated passengers in taxis where sideways facing is particularly hazardous firstly due to wheelchair instability and, secondly, the inability to apply and use the occupant restraint system, with the potential for lateral impact between the passenger and the wheelchair and vehicle structure.

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Note: Wheelchair tie-down and occupant restraint systems (WTORS) design and performance requirements are generally based on forward facing configuration.

The driver has responsibility for the safety of their passengers including effective wheelchair securement and occupant restraint.

A taxi with wheelchair and passenger rear entry will generally control seating orientation to forward facing only.

6.4.2 M1 Category Review – Private Hire Vehicles

Private Hire Vehicles are known in the UK as minicabs or 'ride share vehicles' and are not allowed to 'ply for hire' to pick up passengers from the street. They cannot display a Taxi light on the roof of the vehicle. Instead, private hire vehicles must be pre-booked online, or by telephone, or by attending a minicab office.

Private hire vehicles, very often saloon or estate cars, will be used on all types of roads, be they urban, rural, motorway, or highway. Most taxi drivers are self-employed and run their own vehicle. Private Hire Vehicle drivers will be generally over 21 years of age, and will be licensed to operate by a regional authority. There will be fewer controls over vehicle design and facilities, and the vehicles are not required to be able to accommodate a passenger seated in a wheelchair. Some of these vehicles can only accommodate a wheelchair-seated passenger who can transfer to a vehicle seat.

6.4.3 M1 Category Vehicles - Wheelchair Mass Carrying Capacity

For preliminary reading on this subject, the reader is directed to Section 5 WTORS, Para 5.7.2 Securing Heavy Wheelchairs.

Within Europe, Vehicle Type Approval regimes, enforced by government agencies, ensure that vehicles placed on the market are 'fit for purpose'. The most commonly applied design and performance requirements for Wheelchair Accessible Vehicles (WAVs) are given in EU Regulation. [2]

The performance requirement for a WAV type vehicle includes the validation of wheelchair tie-down and occupant restraint system hardware, and their vehicle anchorages, by well-established test methods that are based on a 20g/48kmh M1 vehicle crash characteristic, when securing an 85kg surrogate test wheelchair and an average male occupant in the form of a 77kg ATD surrogate human.

The test methods serve as a benchmark test that does not directly reflect all 'real world' operating conditions. The benchmark test approach serves the purpose of reducing the risk of hardware failure and consequential human injury to a limited extent.

When the actual mass of a mobility device becomes significantly greater than the 85kg benchmark test surrogate wheelchair, the probability of either WTORS or vehicle anchorage failure can reach unacceptable levels.

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With acknowledgement of the existence of powered wheelchairs of mass significantly greater than 85kg, UK wheelchair accessible vehicle converters and WTORS manufacturers have, as a duty of care, established a test method involving a surrogate wheelchair capable of mass augmentation up to 200kg. [3]

It should be noted that some M1 Category vehicles may have limited rear axle carrying capacity which could prevent the carriage of a heavy powered wheelchair and occupant. Taxi and Private Hire operators should be aware of the load bearing capacity of their vehicle. Details of limitations of rear axle capacity will be included in Vehicle Registration documentation.

Solutions to the effective securement of high mass powered wheelchairs may be the supply of specific high capacity wheelchair rear tie-downs to be used as a pair, or by the use of multiple pairs of standard rear tie-downs attached to multiple floor anchorage locations (paired). Full details will be provided in the vehicle IFU/OM.

Note: Wheelchair tie-down load bearing capacity is expressed for a pair of tie-downs, not as individual units.

Clinicians, equipment suppliers, wheelchair users and their care providers, transport procurement personnel, and transport providers must be aware of wheelchair manufacturer user instructions regarding how to achieve effective securement when in transport.

Clinicians, equipment suppliers, and wheelchair users and their care providers, who are using high mass powered wheelchairs and intend to travel in M1 category vehicles should be made aware of the probable requirement for additional measures to secure their wheelchair.

6.5 M2 Category Review - Wheelchair Accessible Minibus

More often built on a commercial vehicle platform, an M2 category passenger vehicle will carry more than 8 seated passengers, not including the driver, and be of a gross vehicle mass less than 5 tonnes. Very often, the maximum number of passengers that an M2 vehicle will carry will be 16 adults. The passenger carrying capacity may be reduced if the vehicle has the additional mass of a passenger lift platform fitted as a boarding aid.

An M2 vehicle, often called a 'minibus', may be operated as a light public service vehicle, as a school minibus for sports or field trips, or by a club for community function. Such vehicles will frequently be used in urban and rural and less frequently in motorway or highway road environments. M2 vehicle operating speeds will generally be less than that of M1 vehicles.

M2 vehicles will often have a flexible floor layout, where seats can be removed or repositioned as required, and the vehicle seats with their built in seat belt systems are locked into tracking laid into the vehicle floor.

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Wheelchair seated passenger transport is more easily achieved in vehicles with a flexible floor layout, where WTORS devices can be fitted to vehicle floor tracking and vehicle side wall anchorages. Wheelchair-seated passengers in M2 type vehicles will generally be forward facing.

6.6 M3 Category Review - Bus/Coach

Passenger vehicles of a gross vehicle mass greater than 5 tonnes fall into the commercially operated bus or coach categories. A bus will generally be operated in urban and rural road environments, whereas a coach will be capable of travel at higher speeds on motorways and highways providing an inter-city service. Drivers will be highly trained and will hold public service vehicle licenses.

6.6.1 M3 Category Wheelchair Accessible Coach Provisions

Coaches, often in the US termed an 'over-the-road coach', generally have a single, high floor passenger deck, and regulated public service vehicles are required to provide for at least one wheelchair seated passenger, seated forward facing, in the passenger deck. Wheelchair securement and occupant restraint will be provided by either a vehicle specific or by an imported, compliant WTORS system.

Wheelchair tie-downs and occupant restraint systems that include a form of seat back and head support are sometimes provided, although wheelchair compatibility with such hardware may present difficulties. Wheelchair and passenger access will generally be provided by a passenger lift platform.

6.6.2 M3 Category Low Floor Accessible Bus Provisions

M3 category includes low floor passenger vehicles that operate on a scheduled or time-tabled basis, very often allowing standing passengers, where hand holds and grab rails are provided to enable standees to maintain stability during vehicle motion. Drivers will be highly trained and will hold public service vehicle licenses.

Low floor vehicles will generally be used in urban or city conditions, travelling in traffic with relatively low road speeds with frequent stops and starts. In such operating conditions, low floor busses are said to present a maximum 1g travel environment to their passengers.

Wheelchair accommodation within such vehicles is provided by a rearward facing passenger station, with a padded back and head support and additional hand holds for a wheelchair seated passenger to maintain their stability. A fold-down horizontal handrail is frequently mounted on the inboard side of the passenger station, to prevent wheelchair and passenger movement into the gangway or aisle during vehicle manoeuvres. Within *ISO 10865-1* [4], a rearward facing wheelchair passenger station is abbreviated to 'RF-WPS'.

The primary advantage provided by a rearward facing passenger station is the independence of the wheelchair-seated passenger who may achieve rapid boarding without the need for their wheelchair to be secured by a bus driver or an attendant.
Within Europe, the design layout and spatial requirements for both rearward and forward facing wheelchair seated passenger station is provided by *UNECE Reg. 107.02 Annex 8.* [5]

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Within ISO Standards, the design layout and spatial requirements for a rearward facing wheelchair seated passenger station is provided in *ISO 10865-1* [49] and forward facing wheelchair seated passenger station in *ISO 10865-2*. [6]

6.7 Vehicle Boarding Aids

Gaining access into a vehicle from ground level will often require a significant change of height, normally accomplished by a non-disabled person by simply taking a number of steps to reach the passenger level within the vehicle. The change of height may be 350mm for a taxi or more than 2000mm in the case of an inter-city coach.

In order to make the required change in height, wheelchair users will require some form of vehicle boarding aid, either a ramp or a passenger lift platform. The potential for the combined mass of wheelchair and occupant to fall without control creates a significant hazard, and incident review confirms that use of boarding aids, such as ramps and passenger lift platforms, accounts for the highest numbers of occupant injury and fatality throughout the entire transport process.

Operator competency in the use of boarding aids, particularly lift platforms, is a vital part of providing safe wheelchair seated passenger transport. Whilst there may be general practices involved with the operation of boarding aids, specific and detailed operational practices may need to be flexible to accommodate different wheelchair and user presentations that arise.

Under these circumstances, transport operators must follow the operating instructions supplied by the boarding aid manufacturer in their Instructions for Use and/or Operating Manual. Manufacturers are duty bound to supply such information regarding safe operations as part of their responsibilities under the *Provision and Use of Workplace Equipment Regulations* [7] and CE Mark Approval [8].

The implementation of the risk control measures identified and recorded during a risk management process must be applied by all parties involved in the transport operation.

6.7.1 Ramps

Different types of ramp devices may be used to gain vehicle access for wheelchair users and will be selected according to the height change required and frequency of usage.

Ramp types include:

- Portable ramps, usually two channel sections, where one end hooks onto the vehicle entrance or doorway and the other sits on ground or pavement level.
- Portable sliding ramps, again usually two channels that can slide out to increase their length and therefore decrease ramp slope angle.
- Portable folding ramps that fold either along their length or across their length to reduce storage size.

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Note: Portable ramps must be safely stowed when not in use to prevent becoming a source of harm during a crash event.

- Vehicle mounted ‘under-floor’ ramps, where a single flat surface can slide out and hinge to provide a ramp surface, either manually operated or under power, often used in a side entry M1 taxi or a side entry M3 public service vehicle.
- Vehicle mounted, hinged single surface ramps, often fitted at the rear of a rear entry M1 category private or taxi vehicle. These can be a two part folding ramp surface to reduce ramp slope.

6.7.2 Ramp Angle

Resulting ramp surface gradient will depend on the height change required and the length of the ramp surface. Vehicle ‘kneeling’ or ‘squatting’ systems often found with public service vehicles can reduce vehicle height and thus significantly reduce ramp angles and lengths.
Typical values for recommended ramp angles are in the order of a maximum of 7° (1 in 8) for unassisted manual wheelchair users and 14° (1 in 4) for assisted manual wheelchair users. (Source Oxley 2007).

6.7.3 Ramp Width and Edge Guard

In a private vehicle application, the ramp width will be selected in order to accommodate a particular user.

In public service vehicles carrying a broad range of wheelchairs and users, a minimum ramp surface width of 800mm is required.

The side edges of the ramp surface should have a vertical guard of at least 25mm.

6.7.4 Ramp Load Bearing Capacity

In a private vehicle application, the ramp load bearing capacity may be selected according to the maximum mass of the particular wheelchair and user combination.

In public service vehicles carrying a broad range of wheelchairs and users, a minimum load bearing capacity of 300kg is required. Ramp products are commonly available with a load bearing capacity of 500kg.

Note that the combined mass of the wheelchair and occupant including luggage may often exceed 300kg.

6.7.5 Ramp Surface Slip Resistance

Wheelchair access ramp surfaces should be treated with slip resistant materials to reduce the risk of a wheelchair or an assistant sliding, especially in wet conditions. Coatings generally include a granular aggregate material mixed with a two part hardening paint. A grip value, when measured in accordance with the procedure given in BS EN 13036-1, should be ≥35 for all ramp surfaces. [9]

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6.7.6 Ramp and Winch Combinations

Difficulty in propelling an occupied wheelchair up a ramp surface, and maintaining control of an occupied wheelchair travelling down a ramp has been frequently observed, especially for frailer family members or spouses. The consequences of losing control of a wheelchair and occupant in such circumstances are not to be underestimated.

In such situations, a low powered winch fitted to the vehicle floor at the front end of the wheelchair space can be used to assist the boarding and alighting process. It is imperative that wheelchair front tie-downs are fitted and tensioned to secure the wheelchair during transport.

Note: Some winch systems fitted in M1 Category rear entry vehicles may also function as wheelchair front tie downs.

6.7.7 Wheelchair Stability and Vehicle Access Ramps

Whilst it is accepted that wheelchair users will be faced with hills and slopes within the pedestrian or built environment, vehicle access ramp angles can vary significantly as a result of the variation in vehicle entry and exit locations depending on where and how the vehicle is parked.

Therefore, vehicle drivers should plan their parking orientation on a slope with the aim of minimising ramp angles and reducing risks to wheelchair stability. The ultimate aim is to reduce the effort required to load and unload a wheelchair seated occupant and minimise the risks of tipping.

Prescribers and seating engineers must consider the higher risk of a wheelchair tipping over backwards during vehicle entry and exit. Risks of tipping are greater for users of manual user-propelled wheelchairs, where effective propulsion and manoeuvrability of the wheelchair requires a fine balance with regard to the location of the combined wheelchair and user centre of gravity.

Wheelchair stability will be affected by a number of considerations:

a) User position and change of position such as by tilt and/or recline.
b) Effect on combined centre of gravity change as a result of the addition of fixed items, such as add-on components, such as communication aids, battery powered medical devices, oxygen cylinders, and feeding systems.
c) Effect on the change of centre of gravity by the addition of baggage such as shopping or chattels to the wheelchair, additions that are uncontrolled in terms of mass or location.

Wheelchair users, their parents/carers, and transport providers must be made aware of the limitations of stability when using a ramp as a vehicle boarding aid.

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6.7.8 Passenger Lift Platforms

Passenger lift platforms are generally used to achieve greater vertical height change than that offered by a ramp. These forms of boarding aid are sometimes referred to as hydraulic passenger lift platforms and should not to be confused with a vehicle tail lift which is a product designed and intended for the loading of cargo into an N category goods vehicle.

Lift platforms will be built into a vehicle structure and supplied with power to drive a hydraulic pump used to provide platform lift. Lift controls will generally be located on a pendant with press button controls and audible alarms will be provided whilst the lift is in operation.

Passenger lift platforms are often used in a side access configuration in private wheelchair accessible vehicles, or in M3 inter-city coaches. Passenger lift platforms are often used at the rear of an M2 minibus type wheelchair accessible vehicle operated to provide a commercial or community transport service.

6.7.9 Lift Operation and Passenger Safety

Working at height automatically creates a high risk condition as the consequences of a fall are likely to be serious. Design features such as roll off stops and additional side hand rails act as barriers to prevent a lateral fall.

Transport providers must ensure that these features are fully functional prior to loading a person seated in a wheelchair.

The primary risk control measure available is in the competency and awareness of the lift operator who must be capable of taking actions or practices that are appropriate to the mass and dimensions of a wheelchair seated passenger.

Responsible operation of a lift platform in all circumstances should be achieved by participation in lift platform manufacturer user training programs, both practical and theoretical. Lift platform suppliers are required by law to provide full training in the use of their products as part of their duty of care responsibilities. [7] [8] [10]

This document cannot make recommendations relating to the operation and use of passenger lift platforms that may conflict with manufacturer instructions for use, as required by law. However, a number of operational issues that could give rise to potential sources of harm have been gathered anecdotally, which may be echoed by transport providers, vehicle drivers, and passenger assistants.

The operators of passenger lift platforms should seek clarification from manufacturer training materials and tuition regarding the safe operation of their products with respect to the following:

- Limits on the maximum permitted slope when in use as a boarding aid
- Passenger and wheelchair combinations that may challenge the lift capacity or function of a lift platform

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- Which orientation should the wheelchair take on the platform, forward or rearward?
- Should an attendant ride on the platform during lift operation?
- Should a powered wheelchair be turned off during the loading process?
- Who should operate a powered wheelchair during the loading/unloading process?
- What is the preferred number of staff involved in the loading/unloading process?
- The manufacturer or equipment maintenance contractors' contact details and operation breakdown procedures
- Emergency manual over-ride of hydraulic control systems
- How to operate the lift platform in the event of power failure
- Power isolation of the lift platform when not in use
- Means by which vehicle occupants, ambulant or wheelchair seated, would be prevented from accidental vehicle exit

When in a situation where a particular wheelchair and passenger presentation or behaviour is not covered by lift manufacturer training or instructions, a detailed risk management process must be undertaken by a transport provider with close collaboration with other stakeholders such as the user, their parent/care provider, and equipment supplier if required. Risk control measures that reduce probability of harm to as low as possible must be defined and recorded and made available to all transport personnel who may become involved in the transport provision.

6.7.10 Lift Platform Dimensions

In private vehicle applications, a lift platform size may be selected in order to accommodate a particular wheelchair and occupant, or an unoccupied wheelchair.

In public service vehicles where a broad range of wheelchairs and users will be carried, a minimum platform surface width of 800mm and a length of 1200mm is required. Additionally, a roll-off stop will be required.

6.7.11 Passenger Lift Capacity

In private vehicle applications, a lift platform lifting capacity may be selected in order to accommodate a particular wheelchair and occupant, or an unoccupied wheelchair.

In public service vehicles where a broad range of wheelchairs and users will be carried, a lifting capacity of 300kg is the minimum requirement.

Note that the combined mass of the wheelchair and occupant including add-ons, equipment, and/or luggage may often exceed 300kg.

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6.7.12 Passenger Lift Maintenance

As a safety critical device, the manufacturer is duty bound to provide maintenance schedules and inspection procedures. Passenger lifts are required by European Law to undergo a full safety inspection every 6 months. [10]

Transport provider vehicle maintenance personnel must acknowledge lift manufacturer inspection schedules and keep records of specific requirements.

6.8 Vehicle Doorway Dimensions

The principle dimensions required are door width and door height. Internal ride height once inside the vehicle is also a major factor that influences passenger comfort and field of vision.

Within M1 category wheelchair accessible vehicles intended for private use, models with door dimensions may be selected to suit user needs. However, in M1 taxis used as small public service vehicles intended to carry a broad range of wheelchair users, door dimensions of 800mm wide and 1400mm from vehicle floor to the top of the door aperture are preferred.

A minimum value of 750mm wide and 1250mm high is deemed acceptable, although a wheelchair user will need to duck down in order to clear the top of the doorway. A ride height of 1350mm is also deemed acceptable. Tables 1 and 2 provide dimensions for vehicle access.

6.9 Seat Location and Passenger Clear Space

A longitudinally central location in which a person is seated as close to the vehicle chassis as possible, i.e. as low in the vehicle as possible, is considered to be the most comfortable position in which to be transported in a vehicle. The field of vision and visibility of the wheelchair occupant, for communication or attendance, are also important considerations when choosing the wheelchair position within a vehicle.

When selecting the wheelchair position and WTORS mounting points, priority should be given to a location within the vehicle where a ceiling or side-wall mounted upper torso restraint anchorage allows the occupant restraint system shoulder belt to pass over the centre of the occupant's shoulder, and anchor to a point on the vehicle higher than shoulder level.

It is a requirement of EU Type Approval that all passengers travelling within a vehicle must have free access to a door or an emergency exit in the case of emergency. This has particular relevance for vehicle layouts where maintaining free gangways for evacuation in the case of an accident or emergency is required.

A forward and rearward clear zone, based on details given in ISO 10542, should be provided in order to reduce the potential for injurious head impact with the vehicle interior or other passengers or objects in a crash (see figure 20).

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The forward and rearward clear zones ensure that obstacle free space is provided to allow the movement of an occupant during 'ride-down' of crash forces. (For further reading go to Section 5 WTORS, Para 5.3 Objectives of Occupant Restraint.)

It is also recommended that a clearance space of 75mm exists between the top of the occupant's head and the vehicle roof lining.

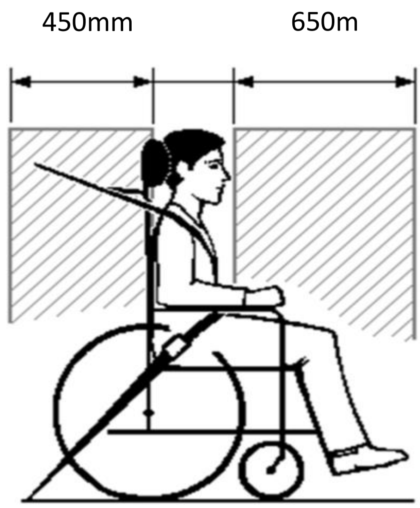

Figure 20. Clear space requirements.

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6.10 Vehicle Size Specifications

Table 3: Ideal Dimensions for a wheelchair accessible M1 Vehicle (Oxley, 2007)

Item	Dimension
Doorway	
- height	≥ 1595mm (≥1500mm)**
- width	≥ 850mm
Entrance step	≤ 100mm
Boarding aid	
- width	≥ 800mm
- ramp gradient	≤ 7° (less than 1-in-8, unassisted)** ≤ 14° (less than 1-in-4, assisted)
Wheelchair space*	
- width	≥ 1300mm (≥800mm**)
- length	≥ 1340mm (≥1300mm**)
Roof height	≥ 1625mm (≥1410mm**)

* side-entry taxi
**Australian Disability Standards for Accessible Public Transport 2002

Table 4: Dimensions for a wheelchair accessible low floor bus (2001/85/EC, UNECE Reg 107.02 and ECMT (2006)

Item	Dimension
Door	
- height	1800mm*
- width	1200mm**
Entrance step	≤ 250mm
Boarding Aids	
- kneeling system	
Or	
- powered lift	
- length	≥ 1200mm
- width	≥ 800mm
- capacity	≥ 300kg
Or	
- ramp (powered/manual)	
- width	≥ 800mm
- gradient	≥ 12%
- capacity	≥ 300kg
Gangway	
- min.	750mm
- preferably	> 800mm
Wheelchair space*	
- width	≥ 750mm
- length	≥ 1300mm
Wheelchair back rest	
- lower end	350mm
- upper end	1400mm
- width	300mm
Horizontal rail, wall-mounted	
- height	850-1000mm

* Class I
** Double door

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6.11 References

[1] Directive 2007/46/EC *Establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles*

[2] EU Regulation No. 214/2014 Annex XI Special Purpose Vehicles , Appendix 3 Wheelchair Accessible Vehicles.

[3] BSI PAS 2012:2012 Annex C

[4] International Standards Organization ISO10865-1 *Assistive products for persons with disability -- Wheelchair containment and occupant retention systems for rearward-facing wheelchair-seated passengers -- Part 1: Systems for accessible transport vehicles designed for use by both sitting and standing passengers*

[5] UNECE 107 *Uniform provisions concerning the approval of category M2 or M3 vehicles with regard to their general construction*

[6] International Standards Organization ISO10865-2 *Assistive products for persons with disability -- Wheelchair containment and occupant retention systems for forward-facing wheelchair-seated passengers -- Part 2: Systems for accessible transport vehicles designed for use by both sitting and standing passengers*

[7] UK HSE Provision and Use of Work Equipment Regulations, 1998 rev1 03/13

[8] 2001/95/EC General Product Safety Directive (GPSD)

[9] EN 13036-1:2010 Road and Airfield Surface Characteristics

[10] UK HSE Lifting Operations and Lifting Equipment Regulations (1998) as amended

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7 Risk Management

7.1 Section Summary

- Risk management is the name given to the process of identifying and evaluating potential sources of harm and taking actions to prevent or minimise harm occurring, resulting in the production of a device or an activity that has an acceptable level of safety.
- By following and recording a recognised process, the task of risk management serves to show that risk has been considered and will diminish the risk of a finding of negligence. A failure to risk manage will provide increased scope for successful allegations of negligence to be made.
- Any modifications made to wheelchair and seating equipment must be documented in line with relevant medical device legislation and a risk management process followed, such as that found within EN ISO 14971:2012. [1]
- Where a particular presentation significantly differs from the least complicated 'upright seated passenger', transport service providers enter into the realm of transport risk management. The greater the clinical complexity – the greater departure from the least complicated scenario - the deeper the transport risk management process becomes.
- Transport services for wheelchair seated passengers will require the identification of sources of harm, the potential consequences of harm and residual risk evaluation, followed by the identification and application of available risk control measures.
- Transport commissioners may as a condition of a service agreement, require transport providers to engage in a risk management process when required.
- A system for presenting essential information for wheelchair securement, occupant restraint and other needs of the wheelchair user to the transport operative in a clear manner will not only reduce risks associated with travel, but enable greater confidence for the passenger, their carers and families in the achievement safest possible transport

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7.2 General

Risk Management is the name given to a process of identifying sources of harm and taking actions to prevent harm occurring thus making a device or an activity as safe as possible. In everyday life this process is a typically sub-conscious activity.

The design or modification of a wheelchair and seating system to suit individual requirements will require specific clinically based skills and expertise. For medical practitioners there is a clear need for the satisfaction of clinical requirements to be met as the highest priority.

Additional design criteria must be recognised and met when wheelchairs and seating systems are to be used in transport The effect that clinically oriented designs and/or modifications to wheelchairs and seating systems may have in the provision of transport services requires an additional appreciation of sources of harm for vehicle passengers. If when building equipment that meets clinical user needs we can identify design features that reduce risks in transport - then a primary objective will have been achieved.
(For further reading go to Section 1.8 Risk Management.)

7.2.1 Risk Management and Supportive Decision Making

Formalising the process of risk management helps people engaged in a design task to deal with multiple sources of harm, their evaluation and their reduction. Recording the process demonstrates to a third party that an individual, or a team of practitioners, has followed a systematic approach to maximise effectiveness of a product or safety of an activity.

By following and recording a recognised process of risk management, an individual or a team will be much better able to defend their actions should any professional criticism or allegation of negligence be levelled against them.

7.3 General Steps in Risk assessment

A risk assessment generally follows a process. With reference to figure 21:

Identify qualitative and quantitative characteristics

These are all those characteristics that could affect the safety of the system. It involves understanding the forces involved and the issues related to transportation of people with disabilities.

Identifying the hazards

This is where 'Murphy's law' takes effect – 'whatever can go wrong will go wrong'. This is the most difficult part of the risk analysis. It involves identifying all of the hazards, or potential sources of harm that may result from the system proposed. The transport checklist in section 7.6 provides a list of questions to identify hazards that typically occur with the transportation of people travelling in

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a wheelchair. The checklist is not an exhaustive list of hazards and you should always ask ‘What could go wrong?’

Accepting or mitigating the risk for each identified hazard

If the risk is unacceptable for an identified hazard, a solution must be sought to either remove the hazard or mitigate the risk. If the risk cannot be reduced to an acceptable level then it may be unacceptable for the person to travel seated in a wheelchair in a vehicle. (‘Exit’).

Identifying the effects a particular hazard mitigation strategy has on other hazards

Occasionally the mitigation of one hazard may create another hazard. In this case the new hazard must be either removed or mitigated and the risk reassessed.

Review the risk analysis

The risk analysis should be reviewed on a regular basis since wheelchair users and their equipment deteriorate and things don’t always remain the same.

7.4 Risk Management for Medical Devices

Due to the individual nature of disability, prescribers may at times be faced with the need to request modification or adaptation of a wheelchair or an ‘off-the-shelf’ seating system (class 1 medical device) in order to maximise medical benefits, and to address the postural and functional needs of a wheelchair occupant.

It is in this situation where equipment manufacturer Instructions for Use and Limitations in Use will have a strong influence on product selection. A practitioner may then be required to extend a product’s function towards the limits of, or beyond those boundaries given by a manufacturer, in order to satisfy needs.

Necessary modifications should be undertaken and documented in line with relevant medical device legislation, and a risk management process such as that found within *EN ISO 14971:2012* [1] should be followed.

The essential parts of any risk management process are:

a) Risk Analysis
b) Risk Evaluation
c) Risk Control
d) Observation of the effectiveness of risk control measures

A schematic flow diagram for the overall process is shown in figure 21.

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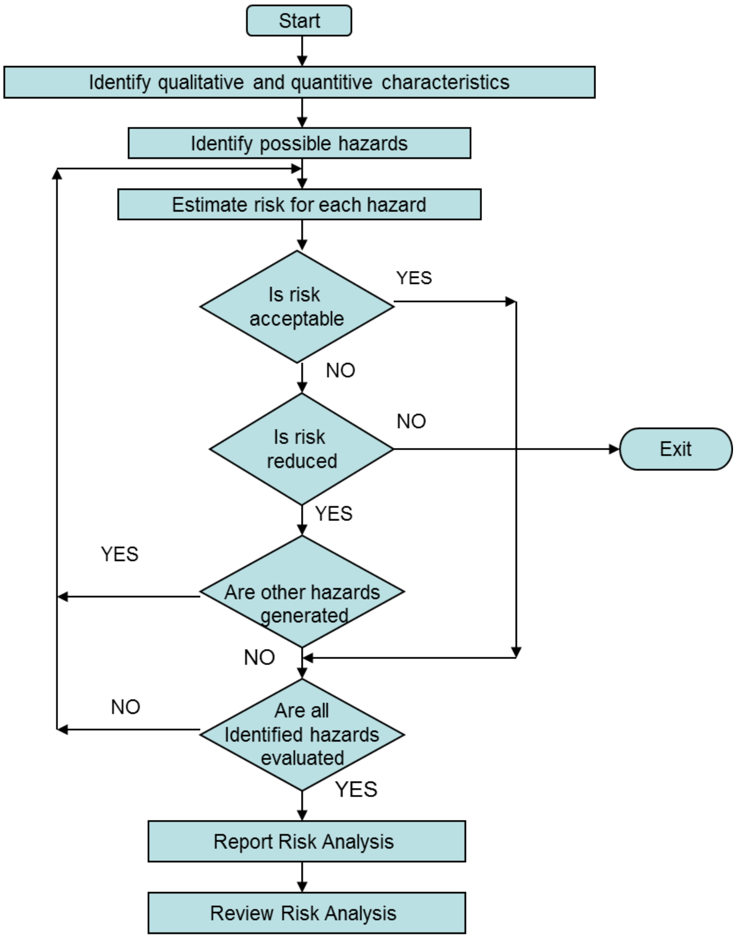

Figure 21. Flow diagram of risk management process (ISO 14971:2012 [1])

7.5 Transport Risk Management

Automotive provisions for occupant safety have led to what is generally accepted as 'safe transport' for drivers and passengers in road vehicles. Provisions developed by panels of US and European crash evaluation experts during the 1960s and 1970s are based on risk control measures that implement engineering design and performance requirements for key elements such as vehicle interior, seats, seatbelts, and seatbelt anchorage locations relative to an occupant.

It is by implementation of automotive regulations that risks to occupants are controlled 'by design'. In order to function as intended, all the occupant has to do is wear the vehicle seatbelt.

With respect to wheelchair seated passenger safety, it is important for prescribers to understand and accept the departures from automotive safety design parameters.
When considering transport services for wheelchair seated passengers, transport risk management will require the identification of additional sources of harm, re-evaluation of potential consequences of harm, and risk evaluation followed by the identification and application of available risk control measures.

The transport standards provided by ISO and ANSI/RESNA establish hardware requirements for a basic level of safety for the least complicated upright seated passenger, where the level of risk strives to be comparable to a non-disabled driver

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or passenger in the same vehicle, restrained by original equipment manufacturer (OEM) restraints and seating.

With more complex cases, where a particular presentation significantly differs from the least complicated 'upright seated passenger', transport service providers enter into a new realm of transport risk management. The greater the clinical complexity – the greater departure from the least complicated scenario - the deeper the transport risk management process becomes. In these types of situations, a mature appreciation of the risk-benefit balance of an assessment will lead to acceptable process outcomes that enable transport to occur.
(For further reading go to Section 3 Wheelchairs, Para 3.3.3 Wheelchair test set-up Tilt and Recline.)

7.6 Where Clinicians/Equipment Suppliers and Transport Providers Meet

It is at this point where the outcome of clinicians' or prescribers' selection of mobility equipment becomes a tangible reality in transport. The next part of the process in delivery of low risk travel for wheelchair users is in the hand-over of key information between the equipment prescriber to the transport provider.

Dedicated transport providers will adopt their practices to accommodate the specific needs of a wheelchair seated passenger based on and according to the details provided by the clinical source. It is often the case that the parent or care provider will be the mouthpiece of the 'clinical source'.

In order to achieve effective collaboration, a summary of key clinically sourced information regarding the needs of an individual wheelchair seated passenger will need to be established and shared with the transport provider. Subsequent risk assessment and risk control measures can then be evaluated and agreed by the two main parties, with the participation and acceptance of the wheelchair seated passenger, their parent or care providers.

7.6.1 Clinician to Transport Provider -- Key Information

The key information that the clinical prescriber should possess and present when entering into a transport risk assessment process should as a minimum cover the following subjects:

- Passenger identification
- Passenger medical summary and requirement for supporting medical devices
- Individual positioning requirements for transport
- Reliance on postural support devices, including head support
- Seating and mobility device settings for transport
- Requirements for wheelchair securement
- Requirements for occupant restraint

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- Requirements for storage of ancillary medical devices. E.g. ventilators
- Requirements for specific instructions in case of medical emergency

7.6.2 Transport Provider Functions

Personnel involved in the provision of wheelchair seated passenger transport will need to,

- Take an active role in the application of identified risk control measures
- Be responsible for passenger safety
- Act in accordance with general health and safety practices
- Secure wheelchairs
- Fit occupant restraint systems
- Work in all weather conditions
- Be quick and efficient about their duties
- Work in harmony with colleagues
- Remain calm in an emergency
- Tolerate frustrating conduct of other road users

With regard for passenger welfare, all staff involved will need to,

- Have compassion for the welfare of passengers
- Have patience when dealing with passenger difficulties
- Be conscious of passenger physical welfare
- Be conscious of passenger mental and emotional welfare
- Be sensitive to passenger needs
- Be aware of potential safeguarding issues

Actions to accommodate straight forward normally upright wheelchair seated passengers, such as those with a temporary mobility impairment, will generally be covered in operator blanket training provided by WTORS equipment suppliers.

For more complex passengers, transport providers will respect and respond to the clinical needs of individual wheelchair seated passengers, acting in union with the clinical prescribers of mobility equipment.

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7.7 Transport Hazard Checklist

The following checklist contains typical hazards relating to the transportation of people with disabilities and requires specific responses to each item.

Note: The 'Yes' or 'No' column should be ticked accordingly to indicate that action to reduce risk is required, not required or not applicable. Marking the box will serve to indicate to a third party that the subject has been considered.

7.7.1 User requirements

Does the user possess:

No.	Check	Yes	No	N/A
1	A reclined, oblique, tilted or poorly controlled seating position that could affect occupant restraint? Detail: Mitigation Strategy:			
2	Poor head control Detail: Mitigation Strategy:			
3	Possible musculoskeletal injury Detail: Mitigation Strategy:			
4	Require an immediate change of position (seizure or epilepsy) Detail: Mitigation Strategy:			
5	Any behavioural problems, such as fear or anxiety. Detail: Mitigation Strategy:			
6	The requirement for additional medical devices such as oxygen or need for a ventilator or feeding system. Detail: Mitigation Strategy:			
7	A medical condition affected by transport. Detail: Mitigation Strategy:			
8	Has the occupant been issued with a formal exemption certificate for the use of an occupant restraint system. Detail: Mitigation Strategy:			

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7.7.2 The Wheelchair

No.	Check	Yes	No	N/A
1	Does the wheelchair manufacturer recommend the wheelchair as suitable for use in transport? Detail: Mitigation Strategy:			
2	Are there any limitations of use of the wheelchair in transport given by the manufacturer? Detail: Mitigation Strategy:			
3	Is there information given by the manufacturer regarding configuration of the wheelchair when used in transport? Detail: Mitigation Strategy:			
4	Does the wheelchair manufacturer identify a specific tie-down system used to secure the wheelchair? Detail: Mitigation Strategy:			
5	Is there a requirement for additional load bearing capacity of the tie-downs? Detail: Mitigation Strategy:			
6	Is the wheelchair being used to host a seating system? Detail: Mitigation Strategy:			
7	Has the wheelchair been fitted with add-on components? Detail: Mitigation Strategy:			
8	Are add-ons approved for use by wheelchair manufacturer? Detail: Mitigation Strategy:			
9	If add-on components are approved for use by the manufacturer, are there additional instructions for use in transport provided? Detail: Mitigation Strategy:			
10	Has the wheelchair been modified in any way? Detail: Mitigation Strategy:			
11	If the wheelchair has been modified or adapted, are there additional instructions for use in transport provided? Detail: Mitigation Strategy:			
12	Is there any wheelchair manufacturer information on the use of a head support whilst in transport? Detail: Mitigation Strategy:			

7.7.3 The Seating System

No.	Check	Yes	No	N/A
1	Does the seating system manufacturer recommend it as suitable for use in transport? Detail: Mitigation Strategy:			
2	Is the seating system compatible for use with the host wheelchair in transport? Detail: Mitigation Strategy:			
3	Has the interface between seating system and host wheelchair been proven as suitable for use in transport? Detail: Mitigation Strategy:			
4	Are there any limitations of use given by the manufacturer of the seating system when in transport? Detail: Mitigation Strategy:			
5	Is there information given by the manufacturer regarding configuration of the seating system when used in transport? Detail: Mitigation Strategy:			
6	Is there a special tie-down system to be used to secure the combined wheelchair and seating system? Detail: Mitigation Strategy:			
7	Can the wheelchair and seating system be secured with standard 4 point tie-downs? Detail: Mitigation Strategy:			
8	Will it be necessary to provide warnings of the overall stability of the wheelchair with seating system and user? Detail: Mitigation Strategy:			
9	Does the seating system have postural support devices attached? Detail: Mitigation Strategy:			
10	Are webbing type postural belts used to maintain the posture of the passenger? Detail: Mitigation Strategy:			
11	Are the postural devices or belts likely to impart injurious loads to the user in the event of a minor crash event? Detail: Mitigation Strategy:			

12	Will the postural devices or belts impart injurious loads to the occupant in the event of a serious crash event? Detail: Mitigation Strategy:			
13	Will any form of postural support device need to be removed whilst in transport? Detail: Mitigation Strategy:			
14	Does the seating system and wheelchair have an integrated crashworthy lap belt attached? Detail: Mitigation Strategy:			
15	Will a standard three-point lap and diagonal restraint system be adequate to restrain the user in transport? Detail: Mitigation Strategy:			
16	Is there a need for additional occupant restraint specification to suit the needs of the user? Detail: Mitigation Strategy:			
17	Is there a need for any additional specific instructions to transport providers regarding the configuration or settings of the wheelchair and seating system when in transport? Detail: Mitigation Strategy:			

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7.7.4 Driver/Passenger Assistant Instructions

No.	Check	Yes	No	N/A
1	Is there a need for driver and assistant instruction regarding the medical needs or behaviour of the passenger? Detail: Mitigation Strategy:			
2	Is there a need for driver and assistant instruction regarding the mechanical settings of the wheelchair and seating system when in transport? Detail: Mitigation Strategy:			
3	Is there a need for driver and assistant instruction regarding the detachment of accessories or add-on components of the wheelchair and seating system? Detail: Mitigation Strategy:			
4	Is there a need for the removal of any accessory or add-on components of the wheelchair and seating system? Detail: Mitigation Strategy:			

7.7.5 Driver/Passenger Training Requirements

No.	Check	Yes	No	N/A
1	Is there a need for driver and assistant training in order to deal with the medical or behavioural needs of the passenger? Detail: Mitigation Strategy:			
2	Is there a need for driver and assistant training in order to remove or adjust any add-on item or accessory of the wheelchair? Detail: Mitigation Strategy:			

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7.7.6 The Vehicle

No.	Check	Yes	No	N/A
1	Is there a limitation to the type of vehicle that may be used for transportation of the wheelchair? Detail: Mitigation Strategy:			
2	Is there a need to position the wheelchair and user in a particular location or position within the vehicle in order to achieve effective occupant restraint? Detail: Mitigation Strategy:			
3	Does the user have a preference of seating location within the vehicle? Detail: Mitigation Strategy:			

7.7.7 Vehicle Entry and Egress

No.	Check	Yes	No	N/A
1	Does the stability of the combined wheelchair, seating system and occupant generate particular concern? Detail: Mitigation Strategy:			
2	Is there a preferred means of vehicle entry or exit? Detail: Mitigation Strategy:			
3	Is the combined mass of wheelchair, seating system and occupant within the load capacity of the lift or ramp? Detail: Mitigation Strategy:			
4	Is the combined mass of wheelchair, seating system and occupant within the load capacity of the lift or ramp? Detail: Mitigation Strategy:			
5	Should the passenger assistant ride on the lift platform with the passenger and wheelchair? Detail: Mitigation Strategy:			
6	If the wheelchair is powered, does the wheelchair have the ability to climb over a roll-off barrier? Detail: Mitigation Strategy:			

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7.7.8 Occupant Restraint

No.	Check	Yes	No	N/A
1	Are there any particular instructions regarding the type of occupant restraint to be used to restrain the passenger? Detail: Mitigation Strategy:			
2	Is there a need to position the wheelchair and user in a particular location or position within the vehicle in order to achieve effective occupant restraint? Detail: Mitigation Strategy:			
3	Does the wheelchair and seating system have a crashworthy integrated lap belt? Detail: Mitigation Strategy:			
4	Can the passenger be restrained using a three-point lap and diagonal restraint system? Detail: Mitigation Strategy:			
5	Is there a requirement to adjust or remove postural support belts? Detail: Mitigation Strategy:			

Note: The hazards listed above are those typically encountered and do not comprise a comprehensive list.

7.8 Risk Control Measures and Information Transfer

For the majority of wheelchair seated passengers who can assume a normally upright seated posture in un-modified production wheelchairs, the blanket training and instruction provided by WTORS manufacturers for the securement of wheelchairs and the fitting of an occupant restraint system, should be sufficient to ensure safe transport in a road vehicle [2])

However, for more complex presentations that may include the requirement for posture management and/or medical devices, a risk management process may be required to establish and inform of best practice in transport.

Transport commissioners may as a condition of a service agreement, require transport providers to engage thoroughly in a risk management process when required.

(For further reading go to Section 2 Roles and Responsibilities, Para 2.10 and 2.11.)

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Engagement in risk control measures may also fall within a transport providers' responsibilities by national regulation, such as in the UK by the *Health and Safety at Work Act 1974 Section 3 (1), (2) and (3) and Section 33 (1) a), b) and c).* [3]

Also by The *Road Traffic Act 1988 (amended 1991)* [4] and the *Road Vehicles (Construction and Use) Regulations (1986)* [5].

The outcomes of the transport risk assessment process, or the risk control measures, should be agreed by all parties, recorded and maintained by the transport provider. It is fundamentally important that agreed practices and actions should be made available to all personnel or staff engaged in the provision of transport, in particular drivers and passenger assistants.

A system for presenting essential information for wheelchair securement, occupant restraint and other needs of the wheelchair user to transport providers in a clear manner with a common method of operation will not only reduce risks associated with travel, but enable greater confidence for the passenger, their carers and families in the achievement of the safest possible transport.

The information established may be presented in a number of ways, depending on circumstances. On occasions, a simple wallet attached to the individual's wheelchair can provide the information required.

For other, more complex situations, a folder with detailed photographs for wheelchair securement, how to achieve effective occupant restraint, the positioning or re-positioning of postural support devices and medical devices may be appropriate. In such cases, the folder would be stored within the vehicle by the driver to be readily available when needed.

An additional important function may also be to notify transport providers of planned review periods where changes in user needs or equipment provision can be installed.

The British Standard *BS 8603;2013 Wheelchair Passport Scheme Code of Practice* [6] gives recommendations for the provision and operation of systems to present essential information required by wheelchair users, their carers, vehicle drivers and their assistants, for the safer transport of wheelchair seated passengers in a road vehicle. (reference required).

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Annex A of the *BS 8603:2013 Code of Practice* provides a sample generic transport risk assessment template (GTRAT) which may be adapted to for general transport provider usage.

Figure 22. Wheelchair attached passport

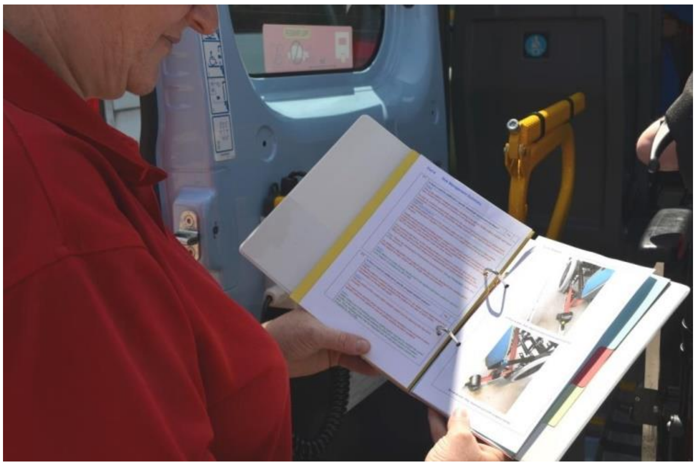

Figure 23. Portable Folder Passport
Photo Courtesy of Lady Zia Werner School, Luton

Figure 24. QR Code Access to Passport

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7.9 References

[1] ISO 14971:2012 Risk Management for Medical Devices
[2] UK HSE Provision and use of work equipment regulations, 1998 rev1 03/13
[3] UK Health and Safety at Work Act 1974 [1] Section 3 (1), (2) and (3) and Section 33 (1) a), b) and c).
[4] UK Road Traffic Act 1988 (as amended)
[5] Road Vehicles (Construction and Use) Regulations (1986) (as amended)
[6] BS 8603:2013 Code of practice for wheelchair passport schemes

Further Resources

Cooper R, Ohnabe H, Hobson DA (2007) *An introduction to rehabilitation engineering*

EC (1995) *COST Action 322 Low floor buses*, Brussels: European Commission.

EC (2005) *COST Action 349 Accessibility of coaches and long distance buses for people with reduced mobility,* Brussels: European Commission.

ECMT (2006) *Improving transport accessibility for all - guide to good practice* (Vol. 81) Paris: ECMT.

RERC (1999) *VI. RERC VI Guidelines for WTORS Transportation Authorities and Installers,* Pittsburgh: The Department of Rehabilitation Science and Technology, University of Pittsburgh, www.rercwts.org

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Appendix A

Risk Assessment Case Study 1 – Add-on O_2 Cylinder and Ventilator

(Case study provided with the approval of the State Rehab Service of Fiona Stanley Hospital, Murdoch, Western Australia).

B is a patient who is an 18 year old female that has a diagnosis of C1 tetraplegia as a result of a motor vehicle accident and lives in supported accommodation.

She is dependent on a ventilator and has a permanent tracheotomy. B therefore may require urgent access by attendant staff in an emergency.

In addition to the ventilator is a suction pump, a stock of suction tubes, an “ambu-bag” (manual ventilator) and an oxygen bottle all mounted on the wheelchair.

The estimated weight of these extra components is approximately 30kg. This extra weight is mounted to the back support frame.

B has low muscle tone and is required to travel in a recline angle of 40° to the vertical.

Positioning restraints include an H-harness and an anterior pelvic support. The patient also has a scoliosis which is supported by both integrated lateral thoracic supports and the add on thigh length hip supports.

The manufacturer/provider of the accessory systems has already undertaken wider risk management in relation to the assembly of the life support equipment to the wheelchair and adaptation of the powered wheelchair.

The wheelchair is a Pride Q6 Edge.

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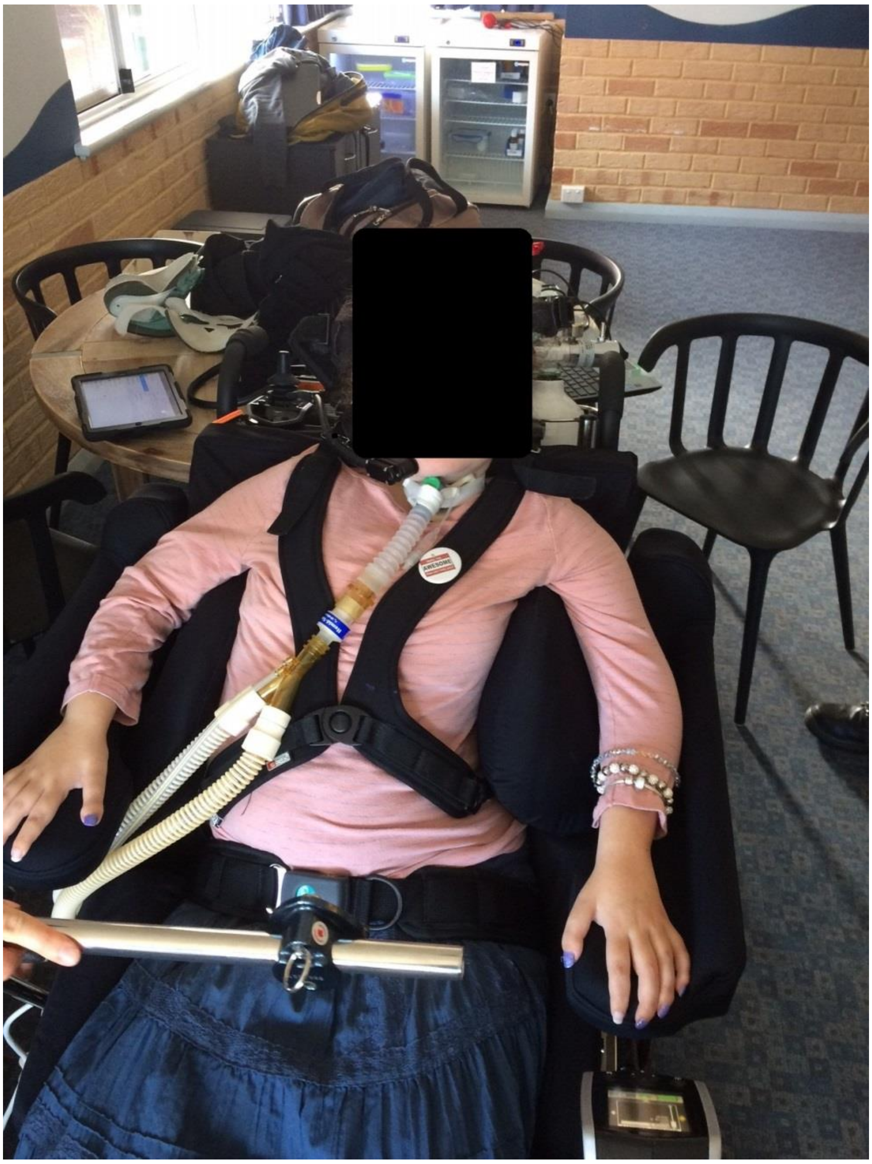

B is wishing to privately purchase a WAV and have suitable restraints fitted.

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Using the transport hazard checklist of section 7.7 .

7.7.1 User requirements, does the user possess,

No.	Check	Yes	No	N/A
1	A reclined, oblique, tilted or poorly controlled seating position that could affect occupant restraint? Detail: Increased recline may result in lack of contact of shoulder restraint if upper anchorage positioning is not considered. Anterior pelvic restraint geometry may allow the pelvic restraint to ride over the ASISs. Mitigation Strategy: Optimise anterior pelvic support anchorages to reduce submarining effect. Appropriate positioning of thoracic restraint anchorages and optimise anterior pelvic attachment angle to minimise loads on the proximal thighs.	X		
2	Poor head control Detail: Poor head control due to low tone in neck. Mitigation Strategy: Retain recline and provide lateral head supports. Soft collar is impractical due to tracheotomy.	X		
3	Possible musculoskeletal injury Detail: Need to determine the stability of the injured cervical vertebrae. Mitigation Strategy: If the spinal fracture remains unstable, fully supportive seating may be required.	X		
4	Require an immediate change of position (seizure or epilepsy) Detail: Ventilator failure or dislodgement of the tracheotomy tube may require immediate further seat recline and access to the side of the wheelchair by attendant staff Mitigation Strategy: Transport the wheelchair to one side of the cabin to allow unhindered access by attendant staff.	X		
5	Any behavioural problems, such as fear or anxiety Detail: Mitigation Strategy: None required		X	
6	The requirement for additional medical devices such as oxygen or need for a ventilator or feeding system Detail:. Hazards include Integrity of the oxygen bottle and ventilator mounting frame. Security of the oxygen bottle in the oxygen bottle mounting frame. Need to shut off the oxygen supply in the event of a fire. Mitigation Strategy: Ensure that the oxygen bottle or ventilator mounting frame will not detach when a load of 20 x the weight of the oxygen bottle + frame is applied in all horizontal directions to the frame. A strap around the neck of the oxygen bottle and through the top rail of the mounting frame to ensure it does not fall out. Ensure unhindered access to the shut off valve of the oxygen bottle.	X		
7	A medical condition affected by transport Detail: Mitigation Strategy: None required		X	

8	Has the occupant been issued with a formal exemption certificate for the use of an occupant restraint system. Detail: Mitigation Strategy: None required		X	

7.7.2 The Wheelchair

No.	Check	Yes	No	N/A
1	Does the wheelchair manufacturer recommend the wheelchair as suitable for use in transport? Detail: Q6 Edge is being used as a host wheelchair for a bespoke seating system. Mitigation Strategy: See later detail.	X		
2	Are there any limitations of use of the wheelchair in transport given by the manufacturer? Detail: Occupant mass <96kg Mitigation Strategy: None required	X		
3	Is there information given by the manufacturer regarding configuration of the wheelchair when used in transport? Detail: Wheelchair must be forward facing in the vehicle. Manufacturer IFU recommends seatback angle no more than 30° to vertical when in transport. Mitigation Strategy: Occupant requires seatback angle greater than 30° in order to maintain head position, supplied as part of the special seating system attached to the wheelchair. Risk considered acceptable following risk-benefit evaluation.	X		
4	Does the wheelchair manufacturer identify a specific tie-down system used to secure the wheelchair? Detail: Requires an ISO 10542-1 compliant wheelchair tie-down system Mitigation Strategy: Identify and use a ISO 10542 compliant wheelchair restraint system. As this is to be a private vehicle a docking system may be considered after consultation with the manufacturer.	X		
5	Is there a requirement for additional load bearing capacity of the tie-downs? Detail: The structural integrity of the seat back may be compromised with the added weight of the ventilator, oxygen bottle and suction pump. Mitigation Strategy: Product search initiated whereby oxygen cylinder can be removed from the back support mounting and effectively secured to the vehicle, when in private transport. The subsequent reduction in mass attached to the seatback considered to reduce risk of seatback failure to acceptable level.	X		
6	Is the wheelchair being used to host a seating system? Detail: Significant postural support required by B can only be provided with a bespoke seating system. Mitigation Strategy: The seating system complies with ISO 16840.4..	X		
7	Has the wheelchair been fitted with add-on components? Detail: Essential add-on medical devices required to support B at all times.	X		

	Mitigation Strategy: Check that sharp edges are padded and components are not easily detached. (See point 5)			
8	Are add-on components approved for use by wheelchair manufacturer? Detail: Mitigation Strategy: None Required	X		
9	If add-on components are approved for use by the manufacturer, are there additional instructions for use in transport provided? Detail: Awaiting further details regarding removal of oxygen cylinder for vehicle mounted stowage. Mitigation Strategy: Pending		X	
10	Has the wheelchair been modified in any way? Detail: The wheelchair has been fitted with an ISO 16840-4 compliant seating system Mitigation Strategy: Compliant seating system attached to the host wheelchair following seating system manufacturer fitting instructions	X		
11	If the wheelchair has been modified or adapted, are there additional instructions for use in transport provided? Detail: A significant number of additional instructions are required Mitigation Strategy: The wheelchair user, her attendant and transport provider are provided with a list of these requirements as well as photographs of how the wheelchair and its occupant are restrained as well as special requirements during transport.	X		
12	Is there any wheelchair manufacturer information on the use of a head support whilst in transport? Detail: See below Mitigation Strategy: Provide the wheelchair user, her attendant and transport provider with details for the use and adjustment of the head support as part of the information package above.	X		

7.7.3 The Seating System

No.	Check	Yes	No	N/A
1	Does the seating system manufacturer recommend it as suitable for use in transport? Detail: Must be fitted according to manufacturer instructions. Mitigation Strategy:: None required	X		
2	Is the seating system compatible for use with the host wheelchair in transport? Detail: Mitigation Strategy: None Required	X		
3	Has the interface between seating system and host wheelchair been proven as suitable for use in transport Detail: Mitigation Strategy: None Required	X		
4	Are there any limitations of use given by the manufacturer of the seating system when in transport? Detail:		X	

	Mitigation Strategy: None Required			
5	Is there information given by the manufacturer regarding configuration of the seating system when used in transport? Detail: Forward facing seating orientation Mitigation Strategy: Note to transport provider in hand over documentation	X		
6	Is there a special tie-down system to be used to secure the combined wheelchair and seating system? Detail: Mitigation Strategy: None required		X	
7	Can the wheelchair and seating system be secured with standard 4 point tie-downs? Detail: Mitigation Strategy: None required	X		
8	Will it be necessary to provide warnings of the overall stability of the wheelchair with seating system and user? Detail: Mitigation Strategy: None required		X	
9	Does the seating system have postural support devices attached? Detail: Hip guides are attached that fold down level with the seat pan. Mitigation Strategy: The hip guides fitted run for the length of the thigh so that the occupant's body is not likely to come into contact with edge of the positioning device during her excursion in an accident.	X		
10	Are webbing type postural belts used to maintain the posture of the passenger? Detail: Postural belts may assist with restraining the occupant during violent vehicle manoeuvres. Throat contact with the cross brace of the H-harness should be considered during excursion from the seat during an accident. Mitigation Strategy: Mount the cross brace as low as possible without reducing the function of the postural belt.	X		
11	Are the postural devices or belts likely to impart injurious loads to the user in the event of a minor crash event? Detail: Mitigation Strategy: None required		X	
12	Will the postural devices or belts impart injurious loads to the occupant in the event of a serious crash event? If this is a concern, anchorages can be designed to fail at low loads. Detail: Mitigation Strategy: Attach postural belt anchorages to the wheelchair frame with #10-32 or M5 screws.		X	
13	Will any form of postural support device need to be removed whilst in transport? Detail: Mitigation Strategy: None required		X	
14	Does the seating system and wheelchair have an integrated crashworthy lap belt attached? Detail: Mitigation Strategy: It is considered that a 3 point harness will provide suitable support if recline is not increases further than it currently is.		X	

15	Will a standard three-point lap and diagonal restraint system be adequate to restrain the user in transport? Detail: Mitigation Strategy: None required	X		
16	Is there a need for any additional specific instructions to transport providers regarding the configuration or settings of the wheelchair and seating system when in transport? Detail: Mitigation Strategy: Instructions required on emergency procedures for ventilator failure, fire (oxygen shut off) and maintaining ventilation.	X		

7.7.4 Driver/Passenger Assistant Instructions

No.	Check	Yes	No	N/A
1	Is there a need for driver and assistant instruction regarding the medical needs or behaviour of the passenger? Detail: Mitigation Strategy: Instructions required on emergency procedures for ventilator failure, fire (oxygen shut off) and maintaining ventilation.	X		
2	Is there a need for driver and assistant instruction regarding the mechanical settings of the wheelchair and seating system when in transport? Detail: Mitigation Strategy: The following should be provided in print form attached to the wheelchair: • How to adjust seat positions • How to remove foot/leg supports • Ventilator failure emergency procedures • Oxygen shut off • Wheelchair free running dis-engagement	X		
3	Is there a need for driver and assistant instruction regarding the detachment of accessories or add-on components of the wheelchair and seating system? Detail: Mitigation Strategy: None Required		X	
4	Is there a need for the removal of any accessory or add-on components of the wheelchair and seating system? Detail: Mitigation Strategy: None Required		X	

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7.7.5 Driver/Passenger Training Requirements

No.	Check	Yes	No	N/A
1	Is there a need for driver and assistant training in order to deal with the medical or behavioural needs of the passenger? Detail: Mitigation Strategy: Basic first aid related to ventilator dependent patients provided attached to the wheelchair and practical training	X		
2	Is there a need for driver and assistant training in order to remove or adjust any add-on item or accessory of the wheelchair? Detail: Mitigation Strategy: None Required		X	

7.7.6 The Vehicle

No.	Check	Yes	No	N/A
1	Is there a preferred vehicle type or category required for the transport of the wheelchair seated passenger? Detail: Mitigation Strategy: Even though the intent is to travel in her private vehicle it may be necessary on occasions to travel in a public vehicle.		X	
2	Is there a need to position the wheelchair and user in a particular location or position within the vehicle in order to achieve effective occupant restraint? Detail: Potential injured vertebral instability Mitigation Strategy: It is advised to avoid locating the wheelchair over the back axle of the vehicle in order to minimise road induced shock. Position the wheelchair to one side in the cabin to allow access for attendant staff.	X		
3	Does the user have a preference of seating location within the vehicle? Detail: Mitigation Strategy: It is more comfortable for B if they have a good view of the surroundings rather than a direct view of the road.	X		

7.7.7 Vehicle Entry and Egress

No.	Check	Yes	No	N/A
1	Does the stability of the combined wheelchair, seating system and occupant generate particular concern? Detail: Mitigation Strategy: None required		X	
2	Is there a preferred means of vehicle entry or exit? Detail: Mitigation Strategy: Rear entry due to the interior cabin size limits manoeuvrability.	X		
3	Is the combined mass of wheelchair, seating system and occupant	X		

	within the load capacity of the lift or ramp? Detail: Mitigation Strategy: None required			
4	Should the passenger assistant ride on the lift platform with the passenger and wheelchair? Detail: Mitigation Strategy: Access to the wheelchair and user can be achieved by standing next to the lift platform.		X	
5	If the wheelchair is powered, does the wheelchair have the ability to climb over a roll-off barrier? Detail: Mitigation Strategy: The wheelchair power should be turned off during raising or lowering on the lift platform	X		

7.7.8 Occupant Restraint

No.	Check	Yes	No	N/A
1	Are there any particular instructions regarding the type of occupant restraint to be used to restrain the passenger? Detail: An ISO 10542-1 compliant wheelchair tie-down and occupant restraint system using a 3-point lap and diagonal will be considered satisfactory. Mitigation Strategy: Considering the posture of B, with a 40° seatback angle and relatively open hip presentation, correct placement of the lap and diagonal will be essential. The lap belt must be positioned as low as possible on the hips and run at a steep angle of application to reduce risk of abdominal intrusion during a violent vehicle manoeuvres.	X		
2	Is there a need to position the wheelchair and user in a particular location or position within the vehicle in order to achieve effective occupant restraint? Detail: Shoulder belt restraint anchorage needs to be positioned low and behind the wheelchair to achieve close contact with B's shoulder. Mitigation Strategy: In order achieve a close fit of the shoulder belt on the upper torso the wheelchair should be positioned relatively forward in relation to the shoulder belt anchorage.	X		
3	Does the wheelchair and seating system have a crashworthy integrated lap belt? Detail: Not available on this particular model of the Pride Q6 Edge Mitigation Strategy:		X	
4	Can the passenger be restrained using a three-point lap and diagonal restraint system? Detail: Yes, see text above Mitigation Strategy:	X		
5	Is there a requirement to adjust or remove postural support belts? Detail: Need to adjust posture belts to ensure correct function whilst in transport Mitigation Strategy: The H-Harness will help to maintain an as upright as possible position whilst in transport. H-Harness to be placed low on torso.	X		

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Appendix B

Risk Assessment Case Study 2 – Add-on Communication Device

(Case study provided by Paul Hewett of the Ace Centre, UK, providing support for people with complex communication difficulties).

N uses a powered wheelchair for mobility with an integrated control system which he uses to access his electronic Augmentative and Alternative Communication (AAC) device and his mobile phone.

He uses a chin joystick, with two switches mounted in his headrest, one laterally, one posteriorly.

The lateral switch is used for mode change to enable him to switch between devices, the function of the other varies depending on the current mode.

His devices are both mounted in front of him so he can easily see the screen, but still allowing a view above and below for driving. The mounting system is removable and can fold.

He frequently attends meetings some distance from home and often travels for journeys longer than one hour.

He's very keen to be able to communicate during the journey.

He's unable to power the chair off independently. He always travels with a personal assistant.

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7.7.1 User requirements: Does the user possess:

No.	Check	Yes	No	N/A
1	A reclined, oblique, tilted or poorly controlled seating position that could affect occupant restraint? Detail: Mitigation Strategy:			X
2	Poor head control Detail: While Neil is able to use his head switches independently, he would be unable to sufficiently control his head position in the event of an emergency stop. During normal travel, he is likely to activate the lateral switch unintentionally during changing the power chair mode. This could switch the chair into drive unintentionally should it remain powered on. If it was powered down, he would be unable to access his AT devices during travel. Mitigation Strategy: The switches could cause an injury in the event of an accident so an alternative headrest will be provided during transport. This will be used in conjunction with paper-based AAC with the personal assistant. Alternative Solution: To retain independent communication during transport an alternative access solution will be provided in addition to a headrest for use in transport. A communication device with a single, padded switch will be used during transport.	X		
3	Possible musculoskeletal injury Detail: Mitigation Strategy: None required		X	
4	Require an immediate change of position (seizure or epilepsy) Detail: Mitigation Strategy: None required		X	
5	Any behavioural problems, such as fear or anxiety Detail: Mitigation Strategy: None required		X	
6	The requirement for additional medical devices such as oxygen or need for a ventilator or feeding system Details: The electronic AAC device is a medical device, the mobile phone is not, neither is the mounting system used to attach them to the wheelchair. All these devices though could create a significant hazard if kept in position to the user and the driver and personal assistant sitting directly in front of him. Mitigation: The AT devices should be removed during transport.	X		

7.7.2 The Wheelchair

No.	Check	Yes	No	N/A
1	Does the wheelchair manufacturer recommend the wheelchair as suitable for use in transport? Detail: Yes, limitations are forward facing and max user mass of 136kg. Mitigation Strategy: None Required.	X		
2	Are there any weight limits of use of the wheelchair in transport given by the manufacturer? Detail: Mass of the occupant, seating devices and AT within 5% of manufacturer's weight limits. Mitigation Strategy: Any equipment changes should be documented and a review of documentation should be carried out if changes are made. This should be communicated to all services involved in equipment provision.	X		
3	Is there information given by the manufacturer regarding configuration of the wheelchair when used in transport? Detail: Mitigation Strategy: None Required			
4	Does the wheelchair manufacturer identify a specific tie-down system used to secure the wheelchair? Detail: Mitigation Strategy: None Required			
5	Is there a requirement for additional load bearing capacity of the tie-downs? Detail: Power chair close to maximum, but within capacity. Mitigation Strategy: None required.		X	
6	Is the wheelchair being used to host a seating system? Detail: Wheelchair manufacturer supplied comfort backrest and seat cushion. Mitigation Strategy: Manufacturer supplied the package (without AT attached) as suitable for use in transport.	X		
7	Has the wheelchair been fitted with add-on components? Detail: The wheelchair has been fitted with a number of devices to facilitate communication and independence. Mitigation Strategy: AT devices should be removed in transport and any remaining components attached to the wheelchair not designed to be regularly removed should be free from sharp edges and not likely to cause an injury during travel or an accident. Alternative Solution: Only essential functions of the AT devices will be required during transport: electronic AAC for communication and the ability to send	X		

	and receive text messages. The mobile phone will be removed and stored within range but elsewhere in the vehicle to enable the messaging functions of the AAC device to be used, accessed using the single switch. A rigid mounting system will be used to position the device outside of the head excursion limits specified in ISO 7176-19, and at a safe distance from other occupants in the vehicle. Any remaining accessible parts of the device or mounting system will be padded. An additional safety strap(s) securing the device and mount will be considered to prevent excessive movement or rebound in the event of an accident.			
8	Are add-on components approved for use by wheelchair manufacturer? Detail: The AT fitted to the chair has not been specifically approved by the manufacturer, nor does a joint compatibility statement exist between the wheelchair manufacturer or the manufacturers of the AT devices. Mitigation Strategy: The devices have been fitted by a competent individual following the fitting instructions of the AT device manufacturer. No permanent modification has been made to the power chair. The AT devices have been supplied as suitable for use with this power chair.		X	
9	If add-on components are approved for use by the manufacturer, are there additional instructions for use in transport provided? Detail: No specific instructions regarding use in transport supplied Mitigation Strategy: AT devices should be removed from wheelchair during transport.		X	
10	Has the wheelchair been modified in any way? Detail: No permanent modification but devices mounting interface mechanisms are clamped onto frame tubing and may only be removed by the use of tools. Mitigation Strategy: None required	X		
11	If the wheelchair has been modified or adapted, are there additional instructions for use in transport provided? Detail: Mitigation Strategy: None required			X
12	Is there any wheelchair manufacturer information on the use of a head support whilst in transport? Detail: Information is included in wheelchair manufacturer User Instruction booklet. Mitigation Strategy: Provide the wheelchair user, his attendant and transport providers with details for the use and adjustment of the head support as part of the information package.	X		

7.7.3 The Seating System

No.	Check	Yes	No	N/A
	Standard wheelchair seat used, No additional seating system supplied			X

7.7.4 Driver/Passenger Assistant Instructions

No.	Check	Yes	No	N/A
1	Is there a need for driver and assistant instruction regarding the medical needs or behaviour of the passenger? Detail: Mitigation Strategy: None required		X	
2	Is there a need for driver and assistant instruction regarding the mechanical settings of the wheelchair and seating system when in transport? Detail: Standard operating instruction as supplied by wc manufacturer User Instructions Mitigation Strategy: Ensure Driver/PAs are in possession of manufacturer User Instructions		X	
3	Is there a need for driver and assistant instructions regarding the detachment of accessories or add-on components of the wheelchair and seating system Detail: AT devices need to be removed during transport. Mitigation Strategy: Instructions need to be provided for safe removal and stowage of AT devices. Alternative Solution: Provide step-by-step video showing the steps required to swap the switch-enabled headrest for that suitable for use in transport, and the additional securing straps required for the AAC device. This can be made available on the AAC device so the user can direct others to the resource when required.	X		
4	Is there a need for the removal of any accessory or add-in component of the wheelchair and seating system? Detail: AT devices need to be removed during transport. Mitigation Strategy: Instructions need to be provided for safe removal and stowage of AT devices. Appropriate bags for devices and mounts should be provided that can be safely tied down or stowed elsewhere in the vehicle. Alternative solution: Headrest suitable for use in transport needs to be in place, as does the alternative access solution.			

7.7.5 Driver/Passenger Training Requirements

No.	Check	Yes	No	N/A
1	Is there a need for driver and assistant training in order to deal with the medical or behavioural needs of the passenger? Detail: Mitigation Strategy: None required		X	
2	Is there a need for driver and assistant training in order to remove or adjust any add-on item or accessory of the wheelchair? Detail: AT devices need to be removed during transport Mitigation Strategy: Driver and assistant would benefit from training on removal, safe stowage during transport, and replacement once the destination has been reached.	X		

7.7.6 The Vehicle

No.	Check	Yes	No	N/A
1	Is there a preferred vehicle type or category required for the transport of the wheelchair seated passenger? Detail: Mitigation Strategy: None Required		X	
2	Is there a need to position the wheelchair and user in a particular location or position within the vehicle in order to achieve effective occupant restraint? Detail: Mitigation Strategy: None Required		X	
3	Does the user have a preference of seating location within the vehicle? Detail: Mitigation Strategy: None Required		X	

7.7.7 Vehicle Entry and Egress

No.	Check	Yes	No	N/A
1	Standard operating procedures to be followed		X	

7.7.8 Occupant Restraint

No.	Check	Yes	No	N/A
1	Is there a need for additional or specific occupant restraint systems? Detail: Mitigation Strategy: None required		X	
2	Is there a need for additional or specific positioning of postural support devices during transport? Detail: Mitigation Strategy: None required		X	

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