



HAL
open science

Use of new types of assistive mobility device in public transportation: assessment of the potential risks

Thomas Robert, Céline Grange-Faivre, Claude Marin-Lamellet

► To cite this version:

Thomas Robert, Céline Grange-Faivre, Claude Marin-Lamellet. Use of new types of assistive mobility device in public transportation: assessment of the potential risks. 14th International Conference on Mobility and Transport for Elderly and Disabled Persons (TRANSED), Jul 2015, LISBONNE, Portugal. 16 p. hal-01857618

HAL Id: hal-01857618

<https://hal.science/hal-01857618>

Submitted on 20 Sep 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

USE OF NEW TYPES OF ASSISTIVE MOBILITY DEVICE IN PUBLIC TRANSPORTATION: ASSESSMENT OF THE POTENTIAL RISKS.

Robert Thomas¹, Grange-Faivre Céline² and Marin-Lamellet Claude³

¹Université de Lyon, LBMC, UMR_T 9406, IFSTTAR – Université Lyon 1, Bron, France

²ErgOptim – Transpolis LIER, Bron, France

³IFSTTAR, LESCOT, Bron, France

thomas.robert@ifsttar.fr

celine.gange-faivre@ergoptim.fr

claudemarinelamellet@ifsttar.fr

Abstract

New types of assistive mobility devices (AMD) appeared these last years. They may be relatively different from the classical wheelchairs (geometry, mass distribution, manoeuvrability). Thus, it is not clear yet if the requirements on the public transport (PT) vehicles' design initially established for wheelchairs are still suited for these new devices, i.e. if AMD users could access the vehicle and travel without risks of degradations for the PT vehicle and without compromising their safety and the one of other users. To answer this question we proposed an analytical framework to analyse the potential risks of using PT vehicles with AMDs, including a simple model to predict potential tipping. We demonstrated this methodology for two types of PT vehicles (urban buses and tramway) and different AMD's. From this very first analysis it results that access to the designated wheelchair user area (constraints on the AMD manoeuvrability) and strategy to prevent tipping over of AMDs in the wheelchair user area should be carefully considered

Keywords: assistive mobility devices, public transport, accessibility, risk

1 Introduction

Public transport (PT) is getting more and more accessible. In particular, constraints have been imposed on the vehicles' design in order to guaranty their access and a safe journey to wheelchair users (WU) (e.g. European Commission, 2001). However, new types of assistive mobility devices (AMD), who may also access the PT vehicles, appeared recently. In particular, there is a growing usage of larger and heavier AMD, such as three or four wheels scooters (Löfqvist et al, 2012) and devices previously reserved to a young healthy population are getting adapted and used by other disabled population, e.g. three wheel bicycles or self-balancing personal transporters (Metz, 2014; Shaheen et al., 2005; Sawatzky et al., 2007). The potential conflicts and difficulties that may arise from the usage of these new types of AMD in an urban environment have been identified and emphasised (Institut National de Santé Publique du Québec, 2011). More recently, a similar analysis was performed on the use these new types of AMDs in paratransit vehicles (TCRP, 2014). However, there is still a lack of knowledge about the possibility and consequences of using standard PT vehicles with these AMDs.

These new types of AMD may be relatively different from the classical wheelchairs, with very different geometry, mass, mass distribution or manoeuvrability. As such, it is not clear yet if the requirements on the PT vehicles' design initially established for wheelchairs are still suited for these new devices, i.e. if AMD users could access the vehicle and travel without compromising their safety and the one of other users and without risks of degradations for the PT vehicle. The underlying question is to know if the use of PT vehicles should be allowed or recommended to these new AMD users. The main difficulty to answer this question remains the variety of possible scenario to examine. Potential discrepancies between PT vehicle's specifications and new AMDs may occur in different situations (use of a ramp to get in/out of the vehicle, emergency breaking during the journey ...). Moreover, these new AMDs present an extremely wide variety of shapes, weights or number of wheels, which prevents the use of any standards. Therefore, this study aims at proposing a simple methodology to analyse the potential risks of using PT vehicles with AMDs. It consists of an analytical framework, including a simple potential tipping predictive model, which links AMD's characteristics that are relatively simple to estimate to requirements on the PT vehicles' design. We also demonstrate this methodology for two types of PT vehicles (urban buses and tramway) and different AMD's.

2 Methodology to analyze the potential risks of using PT vehicles with AMDs

2.1 Principle

The proposed methodology consists in designing an analytical framework based on analysis grids. These grids are specific to a type of PT (e.g. urban buses, tramways, light rail vehicles...), as each of them has its own constraints and specifications. Each line of a grid corresponds to a potential risk that may arise while using the PT vehicle with an AMD. The design or legal constraints for the PT vehicle that are relevant for this risk are then identified. Eventually we characterise if this constraint may be violated by the AMD through variables that are relatively simple to estimate. As a result, a grid for a given type of PT is a succession of criteria on AMD characteristics. Therefore, once these grids are built, analysing the risk of using a PT for a given AMD ends up in estimating simple AMD's characteristics and verifying that they fulfil the criteria listed in the grid.

2.2 Criteria

The first step consists in identifying the potential risks that may arise while using the PT vehicle with an AMD. In order to restrain our investigation within a reasonable range, we considered only AMD that are stable at rest (e.g. 2 wheels bicycles are excluded) and we consider only the situation where AMD users travel on their AMD and do not carry it as a luggage (e.g. folding bicycles).

Given these limitations, we propose to focus on the following situations:

- Ingress/Egress
 - Are the AMD dimensions compatible with the use of devices facilitating the ingress (ramps, bridging plate...)?
 - Is there a risk of sliding or tipping over due to a too big vertical gap or a too steep ramp?
- Access to the WU reserved area
 - Is the AMD's manoeuvrability good enough to access the designated area?
 - Are the AMD's dimensions compatible with those of the designated area?
- AMD's behaviour on board
 - Can the AMD be kept stationary (presence of a parking brake)?
 - Is there a risk of sliding or tipping over due to the PT vehicle's dynamics (e.g. emergency breaking)?

2.3 Pertinent PT Vehicles' characteristics

The potential risks previously listed are related to constraints on the vehicle's design and dynamics. In this study we decided to build the analysis grids for two types of vehicles: urban buses, as they are the most frequent PT vehicle, and tramways, for their really high accessibility.

2.3.1 Urban buses

Constraints on the urban buses' design were found in the EC directive 2001/85/CE (EC, 2001), which notably defines the specific provisions for carrying WU. We selected the limit values proposed by this directive for the minimal dimensions of the access ramp, its maximal slope or the maximal allowable load on it. They related to the possibility to use the ramp, the risk of sliding/tipping over or the risk to damage the ramp mechanism. We also retained the minimal dimensions of the designated WU area. However, we did not find any quantified specifications relative to the access to this designated area (e.g. minimal distance between obstacles, maximal turning circle necessary...).

Regarding the vehicle's dynamics, we chose to refer to acceleration/deceleration that may be encountered relatively classically in normal operations. The selected value was extracted from experimental measurements (DeGraaf and Van Weperen, 1997; Palacio et al., 2009; Toussaint, 2010). In particular we can remark that transvers accelerations (sharp turn) may be as high as longitudinal acceleration (acceleration/breaking). Overall, selected constraints for the urban buses are summed up in the Table I bellow.

Table I: Selected constraints for urban buses

	Constraints	Value
ramp	Minimal dimensions	800*1200 mm
	Maximal load	300 kg
	Maximal slope	12 %
WU area	Minimal dimensions	750*1300 mm
Vehicle's dynamics	Maximal acceleration	5 m.s ²

2.3.2 Tramways

Constraints on tramway’s design were taken from the French decree relative to the accessibility of urban guided public transport to disabled users (France, 2009). We selected the maximal load allowed on the bridging plate (risk of deterioration), the maximal size of the vertical gap (risk of tipping over during the egress) and the minimal size of the WU designated area. Here again, we did not find any quantified specifications relative to the possibility and ease of access to this area.

Regarding the vehicle’s dynamics, the EN-13452 norm (EN, 2003) on light rail vehicle’s breaking specifies minimal breaking performances (the minimal deceleration that the vehicle has to be able to perform) as well as maximal breaking performances that should not be overcome in order to limit the passengers’ risk of fall. We selected this last value to verify the risk of sliding or tipping over during the journey. Selected constraints for the tramways are summed up in the Table II below.

Table II: Selected constraints for tramways

	Constraints	Value
Ingress/egress	Max. load on bridging plate	200 kg
	Max vertical gap	50 mm
WU area	Minimal dimensions	800*1300 mm
Vehicle’s dynamics	Maximal Acceleration	5 m.s ²

2.4 Characteristics of the AMD to consider

The next step consists in identifying the relevant AMD’s characteristics associated to the risks and constraints.

2.4.1 AMD’s characteristics to analyse

A first analysis is summed up in the Table III. It relies on the following hypotheses:

- While accessing urban buses, the AMD should be able to be fully on the ramp, i.e. distances between wheels/ground contact points should be smaller than the ramp dimensions and AMD’s weight should be smaller than the maximal load allowed on the ramp. Moreover, the AMD should not tip over or slide, i.e. the slope inducing a tipping over or a sliding should be higher than the maximal slope of the ramp.
- For tramway ingress/egress, we make the hypothesis that only the wheel of an axletree lies on the bridging plate. Thus maximal AMD’s mass per axletree should not exceed the maximal load allowed on the bridging plate. Moreover, the vertical gap that induces a tipping over of the AMD should be larger than the maximal vertical gap allowed.
- Regarding the WU designated area, the AMD should be smaller than the area dimensions. Moreover, the AMD manoeuvrability should be good enough, i.e. the turning circle small enough, to allow the access to the area. We can note that, while other criteria are binary, this one is continuous and doesn’t have a threshold value.

- Finally, in order to allow a safe travel, the AMD has to be equipped with a parking brake to be kept stationary in the PT vehicle. Moreover, acceleration thresholds that induce a sliding or a tipping over of the AMD should be smaller than the ones of the PT vehicle.

Table III: the AMD’s characteristics to analyse and the corresponding PT vehicle’s constraints. Characteristics in blue are to be compared to quantified constraints (binary criterion) while those in green are to be analysed in a continuous way (no quantified constraint).

	AMD Characteristics	Identified Constraints	
		Urban Bus	Tramway
Ingress/Egress	Distances between contact points	< ramp dimensions	
	Weight	< max load on ramp	
	Weight per axletree		< bridging plate max load
	Tipping over angle threshold	> ramp max. slope	
	Tipping over vertical gap threshold		> max vertical gap
	Sliding slope threshold	> ramp max. slope	
WU area	Dimensions	< WU area dimensions	< WU area dimensions
	Turning circle	Difficulty to access the WU area	
On board behaviour	Parking brake	Yes	
	Tipping over acceleration threshold	> max vehicle acceleration	
	Sliding acceleration threshold	> max vehicle acceleration	

2.4.2 Modelling the risk of tipping over

Among the AMD characteristics listed in Table III, some are easily identifiable, such as the existence of a parking brake or the AMD’s geometrical characteristics. However, tipping over or sliding thresholds are not easily accessible. Therefore we propose a simple model to assess these characteristics from simple AMD variables.

In this simplified approach, the AMD and its occupant are modelled as a single rigid body whose mass M is concentrated at the point G (see Figure 1). The problem is reduced in the plane perpendicular to the tipping over axe, i.e. the axe that goes through the two wheel/ground contact points around which the AMD tips over (point A in the Figure 1). Note that three-wheeler and four-wheeler AMDs have three and four tipping axes respectively (see for example Figure 2.B), and that each could be investigated separately. Contact between AMD’s wheels and the ground is represented using a Coulomb dry friction model. We consider two kinds of perturbations: an inclination angle α and an acceleration γ of the PT vehicle. We also consider that the AMD is not stabilised through a specific active device such as gyroscopes embedded in Segways type of personal transporters. From this we can deduce the tipping over and sliding thresholds as reported in Table IV.

Table IV: Sliding and tipping over threshold estimated from the simple 2D modelling

	Inclination angle only	Acceleration only
Sliding threshold	$\mu_s < \tan(\alpha_{lim})$	$\mu_s < \frac{\gamma_{max}}{g}$
Tipping over threshold	$\frac{l}{H} < \tan(\alpha_{lim})$	$\frac{l}{H} < \frac{\gamma_{max}}{g}$

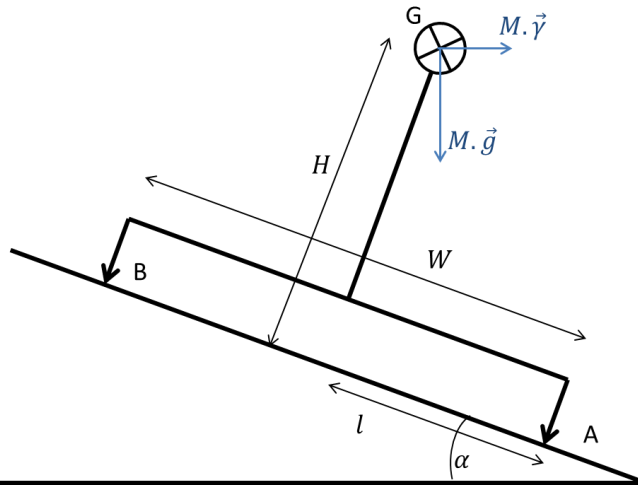


Figure 1 – 2D model of the AMD and its user.

One can observe that the only AMD characteristics that relate to the sliding thresholds is the static friction coefficient μ_s , which is characteristic of the materials and surface conditions (e.g. dry or wet) at the interface between the AMD's wheels / PT vehicle's floor. This information does not depend solely on the AMD but also on the PT vehicle's floor, it does not discriminate between the different types of AMD devices of interest in this study and it is relatively difficult to measure. Moreover preliminary assessment using classical values for μ_s showed that the sliding thresholds were systematically above the tipping-over thresholds. We therefore chose to not include the sliding in the remaining of this study.

The mass repartition between axletrees can also be estimated from this model. In particular, we are interested in this variable for the case of an AMD passing over the bridging plate to enter a tramway. In this situation we can neglect the acceleration between the AMD and the vehicle and consider that inclination angles remain small. Given these hypotheses, the mass at point A is given by $M_A = M \cdot \frac{W-l}{W}$.

2.4.3 List of characteristics variables

The list of variables characterising the use of PT by an AMD can be summed up in the Table V. The main variables are illustrated in Figure 2.

Table V: Variables characterising the use of PT by an AMD

Variable	Symbol
Wheelbase	W
Track	T
Max length	X
Max width	Y
Turning circle radius	R
Mass	M
Altitude of the Centre of Mass relative to the tipping axis	H
Smallest distance between projection of the CoM on the ground and a tipping axis forward/backward or sideways	$l_{fb} \text{ et } l_s$
Existence of a parking brake	F

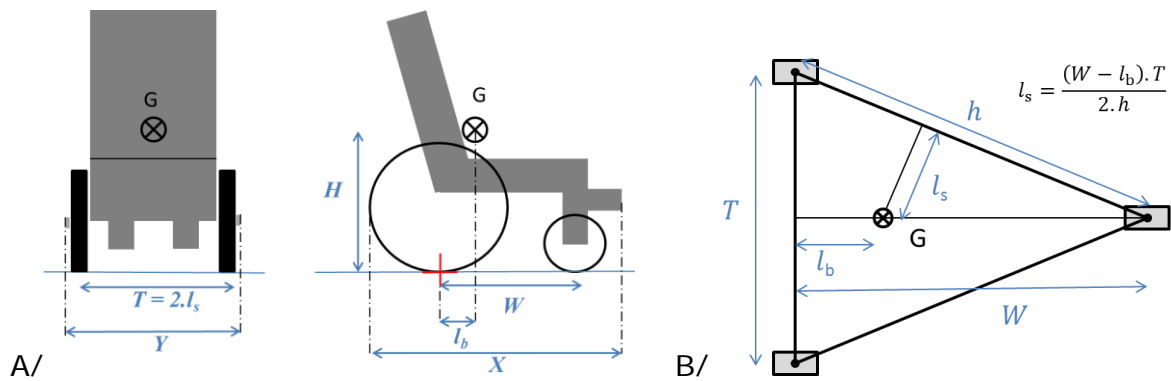


Figure 2 – Illustration of the characteristic variables for two types of AMD: A/ frontal and side view of a four wheeler; B/ top view of a three wheeler.

2.5 Analysis grids

The above analyses can be summed up in analysis grids. Grids for the urban buses and tramways are displayed in Tables VI and VII below.

Table VI: Analysis grid for the urban buses

URBAN BUS	AMD characteristics		Constraints
Ingress/Egress	Distances between contact points	W	< 1200 mm
		T	< 800 mm
	Mass	M	< 300 kg
	Tipping over angle thresholds	$l_{f/b}/H$	> 12 %
		l_s/H	> 12 %
WU area	Dimensions	X	< 1300 mm
		Y	< 750 mm
	Turning circle radius	R	minimum
On board behaviour	Parking brake	F	Yes
	Tipping over acceleration thresholds	$l_{f/b} \cdot g/H$	> 5 m.s ⁻²
		$l_s \cdot g/H$	> 5 m.s ⁻²

Table VII: Analysis grid for the tramways

TRAMWAYS	AMD characteristics		Constraints
Ingress/Egress	Weight per axletree	$M \cdot (W - l_{f/b})/W$	$T < 200$ kg
	Tipping over vertical gap threshold	$l_s \cdot T/W$	> 12 %g
WU area	Dimensions	X	< 1300 mm
		Y	< 800 mm
	Turning circle radius	R	minimum
On board behaviour	Parking brake	F	Yes
	Tipping over acceleration threshold	$l_{f/b} \cdot g/H$	> 5 m.s ⁻²
		$l_s \cdot g/H$	> 5 m.s ⁻²

3 Analysis of different AMDs

There are two main objectives in this section: 1/ to demonstrate the use of the proposed methodology; 2/ to gather a first knowledge about the possibility to use some of the new types of AMDs in the PT vehicles.

3.1 Types of devices analysed

We tried to cover a reasonable range of devices that may be used by persons with reduced mobility in France. Nevertheless we could not analyse all types of devices. In particular, Segways types of personal transporter were excluded as they still appear as relatively rare and as data about their stability (tipping over thresholds) could not be estimated with our model. For each type of AMD, we selected two different devices. The choice of the devices was mainly driven by: 1/ the availability of information on the characteristic variables to analyse (see Table V); 2/ the wish to cover a large spectrum of devices. It results that AMD's analysed may not be the most representatives.

Six AMDs were analysed:

- Two electrical wheelchairs, one (referred to as WC1) relatively similar to the classical manual wheelchair, more design for an inside use, and another (WC2) more polyvalent and heavier ;
- Two electrical scooters: a medium sized 3-wheeler (S1) and a 4-wheeler specifically designed for overweight users (S2);
- Two recumbent tricycles: a "delta", with two rear wheels (T1) and a "tadpole", with two front wheels (T2).

As it is not the aim of this study to assess specific AMDs, we chose not to give the exact reference of these AMDs, nor their specific adjustments or options.

Two types of loadings were considered: an average 75th percentile male user (75 kg) and an overweight user whose mass is the maximal one allowed for the considered AMD. For recumbent tricycles, only the average user was considered. Characteristic variables were either measured either obtained from the manufacturer (from a direct contact or from commercial datasheets).

3.2 Results

Results are presented in tables that merge the analysis grid for urban buses and tramways. In these tables, AMD characteristics are coloured based on their proximity to the acceptable limit: Green = below the limit; Orange = less than 10% to the limit; Red = conflict between the AMD characteristic and the PT vehicle constraint.

An example of results is given in Table VIII for the medium sized 3-wheeler electrical scooter (S1) with a 140 kg user. The weight per axletree is close to the limit, i.e. there is a non negligible risk that this AMD with this kind of user **damage tramways' bridging plate** by applying a too high load on it while entering or exiting the vehicle. There is also a risk that this scooter tips over sideways due to the bus or tramway deceleration. This risk is reinforced by the fact the WU area may be difficult to reach due to the scooter's large turning circle.

Tables for the different AMDs and loading cases are placed in Appendix.

Table VIII: Example of results table for a medium-sized three wheels electrical scooter loaded with a 140 kg user.

		Urban buses		Tramways		
		AMD	Ref Value	AMD	Ref Value	
Ingress/Egress	Distances between contact points	Wheelbase (mm)	980	< 1200		
		Track (mm)	640	< 800		
	Mass (kg)	201	< 300			
	Weight per axletree (kg)			192	< 200	
	Tipping over angle thresholds (%)	Backward	59	> 12		
		Sideway	51	> 12		
Tipping over vertical gap threshold (mm)				579	> 50	
WU area	AMD's dimension	Max Length (mm)	1220	< 1300	1220	< 1300
		Max Width (mm)	625	< 750	625	< 800
	Turning circle radius (mm)		1310		1310	
On board behaviour	Parking brake (Y/N)		0		0	
	Tipping over acceleration threshold (m/s ²)	Backward	5.8	> 5	5.8	> 5
		Sideway	5.0	> 5	5.0	> 5

3.3 Analysis

These results provide some insight into the usability of different types of AMD within the PT. As an example recumbent tricycles do not seem to be adapted to the use in PT, mainly due to their very low manoeuvrability. Similarly we identified a potential conflict between the mass of heavier AMDs driven by an overweight user and the design requirements of the ramp or bridging plate. Likely more problematic is the potential difficulty to reach the WU area with some AMDs because of their low manoeuvrability and their dimensions that may exceed those of the WU area. This point may be critical as the tipping over acceleration threshold of most of the AMDs analysed is relatively close, or even below, the acceleration levels classically encountered in normal buses/tramways operations (not to talk about degraded situations such as very harsh breaking in buses or light collisions). As such there is potentially a high risk of tipping over of AMDs located outside of the reserved areas. Tipping over of such heavy devices may have dramatic consequences not only for the user but also potentially for other vehicle's occupants. This risk must thus be carefully considered. Also interesting is the fact that some AMDs, in particular the three-wheel electrical scooters, present lower tipping over acceleration threshold sideways than backward. This is opposed to what can be observed on classical electrical wheelchairs, who present very low backward acceleration thresholds. As such, classical protection measures, consisting in placing the AMD with its back opposed to the main direction of perturbation may have to be reconsidered.

4 Conclusion

In this study we proposed a methodological framework to analyse the possibility to safely use different AMDs in PT vehicles. This method necessitates only the assessment of relatively simple AMD characteristics such as geometrical information, mass and location of the centre of mass. In particular, we used a simple model to estimate the perturbation threshold (acceleration or inclination) that initiates a potential tipping for the AMD and its occupant. This model should nonetheless be experimentally assessed, notably the hypothesis that the user does not move relatively to the AMD (they are modelled as a single rigid body). One should also remember that we did not consider the risk of sliding, although it may happen in some critical degraded situations (e.g. wet vehicle's floor). Using this methodology we could perform a first analysis for various AMDs and two types of PT vehicles. However further developments are still necessary to study some interesting types of AMD, such as AMD with active stabilisation systems (Segways like personal transporters).

The first analysis performed allowed highlighting potential conflicts between AMD's characteristics and PT vehicles' properties. In particular, access to the designated WU area (constraints on the AMD manoeuvrability) and strategy to prevent tipping over of AMDs in the WU area should be carefully considered.

References

EN (2003). EN 13452-1 - Railway applications - Braking - Mass transit brake systems - Part 1: Performance requirements.

European Commission (2001). Directive 2001/85/EC of the European Parliament and of the Council of 20 November 2001 relating to special provisions for vehicles used for the carriage of passengers comprising more than eight seats in addition to the driver's seat, and amending Directives 70/156/EEC and 97/27/EC

France (2009). Arrêté du 13 juillet 2009 relatif à la mise en accessibilité des véhicules de transport public guidé urbain aux personnes handicapées et à mobilité réduite.

de Graaf, B. and van Weperen, W. (1997). The retention of balance: an exploratory study into the limits of acceleration the human body can withstand without losing equilibrium. *Human Factors* 39 (1), 111–118.

Institut National de Santé Publique du Québec (2011). Avis de santé publique sur la circulation des aides à la mobilité motorisées sur le réseau routier.

Löfqvist, C., Pettersson, C., Iwarsson, S., Brandt, A. (2012). Mobility and mobility-related participation outcomes of powered wheelchair and scooter interventions after 4-months and 1-year use. *Disability and Rehabilitation: Assistive Technology* 7 (3), 211–218

Metz (2004). Disabled Embrace Segway. The New York Times, October 2014. Available online at http://www.nytimes.com/2004/10/14/technology/circuits/14segw.html?_r=0 (last accessed on March 16, 2015)

Palacio, A., Tamburro, G., O'Neill, D., Simms, C. K. (2009). Non-collision injuries in urban buses – strategies for prevention. *Accident Analysis and Prevention* 41 (1), 1–9.

Sawatzky, B., Denison, I., Langrish, S., Richardson, S., Hiller, K., Slobogean, B. (2007). The segway personal transporter as an alternative mobility device for people with disabilities: A pilot study. *Archives of physical medicine and rehabilitation* 88 (11), 1423–1428.

Shaheen, S. A., Rodier, C. J., Eaken, A. M. (2005). Improving california's bay area rapid transit district connectivity and access with segway human transporter and other low-speed mobility devices. *Transportation Research Record: Journal of the Transportation Research Board* 1927 (1), 189–194.

TCRP (2014). Use of mobility devices on paratransit vehicles and buses. TRCP Report 171, Transportation Research Board, Washington, D.C.

Appendix – Result tables for different AMDs and different loading conditions

Classical electrical wheelchair (WC1) + 75th percentile user

			Urban buses		Tramways	
			AMD	Ref Value	AMD	Ref Value
Ingress/Egress	Distances between contact points	Wheelbase (mm)	570	< 1200		
		Track (mm)	580	< 800		
	Mass (kg)	122	< 300			
	Weight per axletree (kg)			94	< 200	
	Tipping over angle thresholds (%)	Backward	30	> 12		
		Sideway	66	> 12		
	Tipping over vertical gap threshold (mm)				168	> 50
WU area	AMD's dimension	Max Length (mm)	1070	< 1300	1070	< 1300
		Max Width (mm)	775	< 750	775	< 800
	Turning circle radius (mm)		930		930	
On board behaviour	Parking brake (Y/N)		Y		Y	
	Tipping over acceleration threshold (m/s ²)	Backward	2.9	> 5	2.9	> 5
		Sideway	6.5	> 5	6.5	> 5

Classical electrical wheelchair (WC1) + 130 kg user

			Urban buses		Tramways	
			AMD	Ref Value	AMD	Ref Value
Ingress/Egress	Distances between contact points	Wheelbase (mm)	570	< 1200		
		Track (mm)	580	< 800		
	Mass (kg)	122	< 300			
	Weight per axletree (kg)			137	< 200	
	Tipping over angle thresholds (%)	Backward	26	> 12		
		Sideway	58	> 12		
	Tipping over vertical gap threshold (mm)				148	> 50
WU area	AMD's dimension	Max Length (mm)	1070	< 1300	1070	< 1300
		Max Width (mm)	775	< 750	775	< 800
	Turning circle radius (mm)		930		930	
On board behaviour	Parking brake (Y/N)		Y		Y	
	Tipping over acceleration threshold (m/s ²)	Backward	2.6	> 5	2.6	> 5
		Sideway	5.7	> 5	5.7	> 5

Heavier electrical wheelchair (WC2) + 75th percentile user

			Urban buses		Tramways	
			AMD	Ref Value	AMD	Ref Value
Ingress/Egress	Distances between contact points	Wheelbase (mm)	500	< 1200		
		Track (mm)	600	< 800		
	Mass (kg)	235	< 300			
	Weight per axletree (kg)			197	< 200	
	Tipping over angle thresholds (%)	Backward	21	> 12		
		Sideway	79	> 12		
	Tipping over vertical gap threshold (mm)			105	> 50	
WU area	AMD's dimension	Max Length (mm)	1065	< 1300	1065	< 1300
		Max Width (mm)	625	< 750	625	< 800
	Turning circle radius (mm)		945		945	
On board behaviour	Parking brake (Y/N)		0		0	
	Tipping over acceleration threshold (m/s ²)	Backward	2.1	> 5	2.1	> 5
		Sideway	7.7	> 5	7.7	> 5

Heavier electrical wheelchair (WC2) + 130 kg user

			Urban buses		Tramways	
			AMD	Ref Value	AMD	Ref Value
Ingress/Egress	Distances between contact points	Wheelbase (mm)	500	< 1200		
		Track (mm)	600	< 800		
	Mass (kg)	290	< 300			
	Weight per axletree (kg)			252	< 200	
	Tipping over angle thresholds (%)	Backward	15	> 12		
		Sideway	71	> 12		
	Tipping over vertical gap threshold (mm)			77	> 50	
WU area	AMD's dimension	Max Length (mm)	1065	< 1300	1065	< 1300
		Max Width (mm)	625	< 750	625	< 800
	Turning circle radius (mm)		945		945	
On board behaviour	Parking brake (Y/N)		0		0	
	Tipping over acceleration threshold (m/s ²)	Backward	1.5	> 5	1.5	> 5
		Sideway	6.9	> 5	6.9	> 5

Three wheel medium sized scooter (S1) + 75th percentile user

			Urban buses		Tramways	
			AMD	Ref Value	AMD	Ref Value
Ingress/Egress	Distances between contact points	Wheelbase (mm)	980	< 1200		
		Track (mm)	640	< 800		
	Mass (kg)	201	< 300			
	Weight per axletree (kg)			145	< 200	
	Tipping over angle thresholds (%)	Backward	72	> 12		
		Sideway	58	> 12		
Tipping over vertical gap threshold (mm)				710	> 50	
WU area	AMD's dimension	Max Length (mm)	1220	< 1300	1220	< 1300
		Max Width (mm)	625	< 750	625	< 800
	Turning circle radius (mm)		1310		1310	
On board behaviour	Parking brake (Y/N)		0		0	
	Tipping over acceleration threshold (m/s ²)	Backward	7.1	> 5	7.1	> 5
		Sideway	5.7	> 5	5.7	> 5

Three wheel medium sized scooter (S1) + 136 kg user

			Urban buses		Tramways	
			AMD	Ref Value	AMD	Ref Value
Ingress/Egress	Distances between contact points	Wheelbase (mm)	980	< 1200		
		Track (mm)	640	< 800		
	Mass (kg)	201	< 300			
	Weight per axletree (kg)			192	< 200	
	Tipping over angle thresholds (%)	Backward	59	> 12		
		Sideway	51	> 12		
Tipping over vertical gap threshold (mm)				579	> 50	
WU area	AMD's dimension	Max Length (mm)	1220	< 1300	1220	< 1300
		Max Width (mm)	625	< 750	625	< 800
	Turning circle radius (mm)		1310		1310	
On board behaviour	Parking brake (Y/N)		0		0	
	Tipping over acceleration threshold (m/s ²)	Backward	5.8	> 5	5.8	> 5
		Sideway	5.0	> 5	5.0	> 5

Four wheel heavy scooter (S2) + 75th percentile user

		Urban buses		Tramways		
		AMD	Ref Value	AMD	Ref Value	
Ingress/Egress	Distances between contact points	Wheelbase (mm)	1021	< 1200		
		Track (mm)	650	< 800		
	Mass (kg)	223	< 300			
	Weight per axletree (kg)			164	< 200	
	Tipping over angle thresholds (%)	Backward	64	> 12		
		Sideway	77	> 12		
Tipping over vertical gap threshold (mm)				656	> 50	
WU area	AMD's dimension	Max Length (mm)	1475	< 1300	1475	< 1300
		Max Width (mm)	660	< 750	660	< 800
	Turning circle radius (mm)		1810		1810	
On board behaviour	Parking brake (Y/N)		0		0	
	Tipping over acceleration threshold (m/s ²)	Backward	6.3	> 5	6.3	> 5
		Sideway	7.6	> 5	7.6	> 5

Four wheel heavy scooter (S2) + 230 kg user

		Urban buses		Tramways		
		AMD	Ref Value	AMD	Ref Value	
Ingress/Egress	Distances between contact points	Wheelbase (mm)	1021	< 1200		
		Track (mm)	650	< 800		
	Mass (kg)	378	< 300			
	Weight per axletree (kg)			282	< 200	
	Tipping over angle thresholds (%)	Backward	50	> 12		
		Sideway	63	> 12		
Tipping over vertical gap threshold (mm)				511	> 50	
WU area	AMD's dimension	Max Length (mm)	1475	< 1300	1475	< 1300
		Max Width (mm)	660	< 750	660	< 800
	Turning circle radius (mm)		1810		1810	
On board behaviour	Parking brake (Y/N)		0		0	
	Tipping over acceleration threshold (m/s ²)	Backward	4.9	> 5	4.9	> 5
		Sideway	6.1	> 5	6.1	> 5

Recumbent tricycles type with two rear wheel (T1) + 75th percentile user

		Urban buses		Tramways		
		AMD	Ref Value	AMD	Ref Value	
Ingress/Egress	Distances between contact points	Wheelbase (mm)	1540	< 1200		
		Track (mm)	800	< 800		
	Mass (kg)	91.3	< 300			
	Weight per axletree (kg)			76	< 200	
	Tipping over angle thresholds (%)	Backward	47	> 12		
		Sideway	58	> 12		
Tipping over vertical gap threshold (mm)				728	> 50	
WU area	AMD's dimension	Max Length (mm)	2050	< 1300	2050 < 1300	
		Max Width (mm)	860	< 750	860 < 800	
	Turning circle radius (mm)		1850		1850	
On board behaviour	Parking brake (Y/N)		0		0	
	Tipping over acceleration threshold (m/s ²)	Backward	4.6	> 5	4.6 > 5	
		Sideway	5.7	> 5	5.7 > 5	

Recumbent tricycles type with two front wheel (T2) + 75th percentile user

		Urban buses		Tramways		
		AMD	Ref Value	AMD	Ref Value	
Ingress/Egress	Distances between contact points	Wheelbase (mm)	1140	< 1200		
		Track (mm)	710	< 800		
	Mass (kg)	90	< 300			
	Weight per axletree (kg)			67	< 200	
	Tipping over angle thresholds (%)	Backward	94	> 12		
		Sideway	82	> 12		
Tipping over vertical gap threshold (mm)				1066	> 50	
WU area	AMD's dimension	Max Length (mm)	2080	< 1300	2080 < 1300	
		Max Width (mm)	787	< 750	787 < 800	
	Turning circle radius (mm)		2790		2790	
On board behaviour	Parking brake (Y/N)		0		0	
	Tipping over acceleration threshold (m/s ²)	Backward	9.2	> 5	9.2 > 5	
		Sideway	8.0	> 5	8.0 > 5	