Journal of Transport & Health 13 (2019) 128–136

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Risk of non-collision injuries to public transport passengers: Synthesis of evidence from eleven studies

Rune Elvik

Institute of Transport Economics, Gaustadalleen 21, 0349, Oslo, Norway

ARTICLE INFO

Keywords:
Non-collision injury
Public transport
Risk

ABSTRACT

Research problem: This paper reviews and summarises studies of the risk of non-collision injuries to public transport passengers. Non-collision injuries include injuries when boarding or alighting and falls onboard as a result of e.g. sudden braking. It was possible to reconstruct exposure to risk for eleven studies, providing a total of twelve estimates of risk for boarding and alighting and twelve estimates of risk for falls onboard.

Results: The mean risk of falling in a moving vehicle is about 0.3–0.5 per million passenger kilometres. The mean risk of injury associated with boarding or alighting is about 0.8–1.7 per million passengers.

Variability of results: Estimates of risk are uncertain and vary substantially from study-to-study, largely for unknown reasons. Half of the estimates of exposure to risk were rated as very or somewhat uncertain.

1. Introduction

Travel by public transport – bus, train or tram – is very safe and perceived to be so (Elvik and Bjørnskau, 2005). Estimates for Norway for 1998–2002 indicated 0.93 fatalities in road crashes per billion passenger km for bus, versus 3.82 fatalities per billion km for car occupants (driver and passenger). Being a large vehicle, a bus protects its occupants well. Hence, most injuries in collisions where buses are involved are sustained by other road users.

Yet, travel by bus may not be as safe as the low risk of injury to bus passengers in road collisions suggests. Several studies, many of which are reviewed by Kendrick et al. (2015), have found that there are many non-collision injuries to bus passengers. A non-collision injury is any injury not sustained in a road collision, but due to other events. The two most common events are (1) sudden braking/ acceleration or turning, resulting in falls inside the vehicle, particularly among standing passengers, and (2) falls while boarding or alighting the vehicle. The survey by Kendrick et al. (2015) shows that non-collision injuries are numerous; in some of the studies several thousand injuries were recorded.

None of the studies reviewed by Kendrick et al. (2015) give any data on travel exposure. Hence, the risk of injury to passengers of public transport vehicles in non-collision events is unknown. An estimate of this risk is useful if, for example, measures to prevent non-collision injuries or reduce their severity are considered. An estimate of the expected number of non-collision injuries in a public transport system producing a certain number of passenger km per year is then needed to estimate the benefits of the measures under consideration. One of the objectives of the ongoing Horizon 2020 project VIRTUAL is to develop and evaluate the costs and benefits of measures that may reduce the risk of falling onboard public transport vehicles or make falls less serious. This paper, written as part of the VIRTUAL project, is intended to provide a basis for such evaluation by estimating the risk of non-collision injury to bus

E-mail address: re@toi.no.

https://doi.org/10.1016/j.jth.2019.03.017
Received 30 December 2018; Received in revised form 28 March 2019; Accepted 30 March 2019
Available online 08 April 2019

Table 1
Studies of non-collision injury to public transport passengers.

Author(s) and publication year	Country	Number of injured passengers (data source)	Source of injury data	Reconstruction of exposure possible (source of data)	Included in risk study
Brooks et al. (1980)	Great Britain	1755 (Table 2, page 25 in Brooks et al., 1980)	Special survey of hospital treated injuries	Yes, relying on assumptions explained in Table 2	Yes
Nue Møller et al. (1982)	Denmark	183 (Kendrick et al., 2015)	Hospital emergency department	No	No
Albrektsen et al., 1983	Denmark	221 (Kendrick et al., 2015)	Hospital emergency department	No	No
Jovanis et al. (1991)	United States	Approximately 200 (Text)	Bus operator	No	No
Vaa (1993)	Norway	53 (Table 8, page 37)	Hospital emergency departments	Yes (Table 9, page 40)	Yes
Fruin et al. (1994)	United States	5128 (Table 2, page 45)	Bus operator	Yes, see details in Table 2	Yes
Kendall et al. (1994)	Great Britain	15 (Text page 57)	Hospital emergency department	No	No
King (1996)	United States	17223 (Table 3, page 5)	Bus operators	Yes (Table 2, page 5)	Yes
Sagberg and Sætermo (1997)	Norway	264 (tram), 1324 (bus)	Bus and tram operator	Yes (spreadsheet Sporbuss.xls)	Yes
Skjøth-Rasmussen 1999	Denmark	37 (Fig. 1, page 5804)	Hospital emergency department	Yes, by combining paper and public statistics (see Table 2)	Yes
Kirk et al. (2003)	Great Britain	17772 (Estimated from Table 1 and Fig. 2) [a]	Police reports (STATS-19 data)	Yes, using published transport statistics (see Table 2)	Yes
Björnstig et al. (2005)	Sweden	154 (Fig. 1, page 80)	Hospital emergency department	Yes, using published transport statistics (see Table 2)	Yes
Halpern et al. (2005)	Israel	123 (Table 4, page 109)	Hospital emergency department	Yes, by combining paper and public statistics (see Table 2)	Yes
Strathman et al. (2010)	United States	2001 (Table 1, page 139)	Bus operator	Yes (TriMet statistics)	Yes
Fildes et al. (2012)	Australia	2030 (Table 3, page 11)	Hospital emergency departments	No	No
Barnes et al. (2016)	Great Britain	17464 (Estimate) [b]	Police reports (STATS-19 data)	Yes, using published transport statistics (see Table 2)	Yes

[a] Kirk states that an average of 9100 bus passengers were injured per year and that 65.1% of injuries were non-collision events. Based on this, the total number of injured passengers in non-collisions was estimated as $9100 \cdot 0.651 \cdot 3 = 17,772$. These were allocated between alighting, boarding, standing and sitting based on Fig. 4 of the paper.

[b] Barnes et al. state that 62% of injuries were in non-collision events. It was assumed that all injuries when boarding or alighting were non-collision injuries. The number of falls was estimated by subtracting injuries when boarding or alighting (3,358) from the estimated total number of non-collision injuries ($17,464 = 0.62 \cdot 28,168$) ($17,464–3358 = 14,106$).

passengers, stated as the number of injuries per million passenger km (for falls onboard) or per million passengers (for injuries when boarding or alighting).

2. Identification and review of previous studies

The comprehensive review presented by Kendrick et al. (2015) was used as a starting point for identifying relevant studies. ScienceDirect was searched for relevant studies using "non-collision injury" as search term occurring in the title, abstract or keywords of a paper. The search yielded 191 hits, of which less than 10 dealt with non-collision injuries in public transport. Most of these studies dealt with biomechanical models of injury and not with their frequency. A search of TRID gave 31 hits, but no new studies not included in the review by Kendrick et al. (2015). Google scholar gave about 2040 hits, of which the first 100 were screened. Finally, colleagues in the VIRTUAL-project consortium identified two studies. Thus, the following studies not included in Kendrick et al. were identified: Vaa (1993), Sagberg and Sætermo (1997), Skjøth-Rasmussen and Rasmussen (1999), Strathman et al. (2010), Fildes et al. (2012), and Barnes et al. (2016). Table 1 lists the studies that were identified.

The studies were reported between 1980 and 2016 and were made in Australia, Denmark, Great Britain, Israel, Norway, Sweden, and the United States. The number of injuries recorded in each study varied from 15 to more than 17,000. Three sources of injury data were used in the studies: Data provided by transport companies, data recorded by hospital emergency departments and police reports. For each study an assessment was made of whether it is feasible to reconstruct the exposure to risk, i.e. the distance travelled and the number of passengers the injury data refer to. Thus, for example, the injuries recorded by Fruin et al. (1994) occurred between July 1984 and January 1991 to passengers on the Washington D. C. metrobus system. The relevant exposure is the number of passengers and passenger kilometres performed by Washington D. C. metrobuses in this period.

With the exception of the study by Brooks et al. (1980), reconstruction of exposure was judged as impossible for studies published before 1990. British studies are an exception, since statistics going back to about 1970 are available in electronic form on the statistics webpages maintained by the UK Department for Transport. Exposure to the risk of non-collision injury has been reconstructed for eleven of the sixteen studies listed in Table 1.

3. Estimators of risk of non-collision injury

There are two main types of non-collision injury events in public transport passengers:

1. Falls of standing or seated passengers inside the vehicle,
2. Injuries, mainly falls, when boarding or alighting the vehicle.

The most relevant measure of exposure for the first type of event is the number of passenger kilometres. The most relevant measure of exposure for the second type of event is the number of passengers (trips). Thus, two estimators of risk have been defined:

$$\text{Risk of injury due to falls in a moving vehicle} = \frac{\textit{Number of passengers injured in falls inside}}{\textit{Number of passenger kilometres}}$$

$$\text{Risk of injury when alighting/boarding} = \frac{\textit{Number of passengers injured when alighting or boarding}}{\textit{Number of passengers}}$$

Most injuries when alighting or boarding are sustained in falls, but injuries when caught between doors have also been included.

4. Reconstructing exposure to risk of injury

Brooks et al. (1980) mention that their study included operators representing approximately 60% of the vehicles owned by the stage carrier operators of Great Britain. Based on this, it was assumed that the operators represented 60% of nationwide exposure in terms of bus passenger kilometres or number of bus passengers in the year 1976 (to which the injury data presented refer). Exposure was estimated from Tables published in Transport Statistics Great Britain; see Table 2. Due to the age of the study and the somewhat imprecise description of its coverage, the estimate of exposure must be regarded as highly uncertain.

The next study for which exposure was estimated, was Vaa (1993). He presented passenger kilometres in the report and only the number of passengers needed to be estimated. This was done by using official transport statistics for Norway stating the mean trip length (13 km) for trips by bus. These estimates of exposure are very precise.

Fruin et al. (1994) present the injury rate for non-collision injuries (number of injuries per million passengers). By taking the total number of injured passengers (5,128) and dividing by the mean injury rate for the period covered by the data (4.93 injuries per million passengers) one gets the total number of passengers, 1039.5 million. This corresponds to about 157 million passengers per year, which is consistent with WMATA (Washington Metropolitan Area Transport Authority) statistics. Mean trip length, based on WMATA statistics for 2015 and 2016, is 5.06 km. Passengers kilometres are $1039.5 \cdot 5.06 = 5260$ million passenger kilometres. These estimates are rated as very precise.

King (1996) provides data on injuries, number of passengers and passenger miles (converted to kilometres). These data are regarded as reliable and estimates of risk are therefore rated as very precise. Sagberg and Sætermo (1997) also present data on injuries, number of passengers and passenger kilometres for several years for bus and tram in the city of Oslo. Estimates of risk based

Table 2
Studies of non-collision injury to public transport passengers.

Author(s) and publication year	Information about exposure in publication	Estimation of exposure	Estimated exposure	Quality of estimate
Brooks et al. (1980)	Operators providing data represented approximately 60% of the vehicles owned by the stage carrier operators of Great Britain (page 22, top)	It is assumed that operators included in the study represented 60% of total bus exposure in Great Britain in 1976	Number of passengers: 4284.6 million Passenger km: 25000 million (Tables Tbbus0101 and Tbbus0301b in online edition of Transport Statistics Great Britain)	Highly uncertain
Nue Møller et al., 1982	Study was not retrieved	Study too old to link to available statistics	Not estimated	
Albrektsen et al., 1983	Study was not retrieved	Study too old to link to available statistics	Not estimated	
Jovanis et al. (1991)	No information given	No suitable data source was found	Not estimated	
Vaa (1993)	Passenger km stated in Table 9 of report	Used directly; mean travel distance per passenger taken from official statistics	Number of passengers: 57 million Passenger km: 741.2 million	Very precise
Fruin et al. (1994)	Injury rate per year is given in Fig. 4	By dividing the number of injured passengers by risk, the number of passengers is obtained	Number of passengers: 1039.5 million Passenger km: 5260 million (Passenger km estimated according to mean trip length as stated by WMATA)	Very precise
Kendall et al. (1994)	No information given	Study refers to Leicester and is too old for relevant data to be found	Not estimated	
King (1996)	Exposure data in Table 2 of report	Used directly (converted from miles to km)	Number of passengers: 4584.6 million Passenger km: 26293.5 million	Very precise
Sagberg and Sætermo (1997)	Exposure data in spreadsheet Sporbuss.xls (in project directory in the project archive at TOI)	Used directly	Tram passengers: 312 million Tram passenger km: 602 million Bus passengers: 403 million Bus passenger km: 1490.7 million	Very precise
Skjøth-Rasmussen and Rasmussen (1999)	For the municipality of Frederiksberg, the number of bus passengers and bus km are stated	Number of passengers scaled by 37/18 assuming same injury risk in the two municipalities covered by the study	Number of passengers: 9.41 million Passenger km: 28.79 million (based on trip lengths in official statistics)	Somewhat uncertain
Kirk et al. (2003)	It is stated that the study covered Great Britain and the years 1999–2001	Tables Tbbus0101 and Tbbus0301b in online edition of Transport Statistics Great Britain were used to estimate exposure	Number of passengers: 13251 million Passenger km: 67400 million	Highly uncertain
Björnstig et al. (2005)	The study is said to include the catchment area of Umeå University Hospital	There were 9.196 million bus trips in Västerbotten county in 2009. It was assumed that 60% were in the catchment area	Number of passengers: 55 million Passenger km: 220 million (Bus passengers in Umeå passed 1 million in 2017 following strong growth; the estimate assumes 550,000 passengers per year in 1994–2003)	Highly uncertain
Halpern et al. (2005)	It is stated that 1900 out of 5000 buses in Israel serve Tel Aviv and that there are 1.37 million passengers per day in the country as a whole	Number of trips in Tel Aviv estimated by scaling according to ED room visits; trip length from official statistics (land transport, table 14)	Number of passengers: 82.5 million Passenger km: 453.75	Somewhat uncertain
Strathman et al. (2010)	The study covered bus operations in Portland, Oregon, by TriMet	TriMet ridership information stated number of passengers and passenger miles	Number of passengers: 158.6 million Passenger km: 910.8 million	Very precise
Fildes et al. (2012)	No information given	No suitable data source found	Not estimated	
Barnes et al. (2016)	It is stated that the study covered the United Kingdom from 2008 to 2012	Tables Tbbus0101 and Tbbus0301b in online edition of Transport Statistics Great Britain were used to estimate exposure	Number of passengers: 22894 million Passenger kilometres: 145800 million	Highly uncertain

on these data are rated as very precise.

Skjøth-Rasmussen and Rasmussen (1999) state the number of bus passengers and bus kilometres in one of the two municipalities included in injury data. 18 of 37 injuries occurred in this municipality. To include both municipalities, the number of passengers and bus kilometres were scaled up by the factor 37/18. Passenger kilometres were estimated by relying on official Danish statistics on the mean trip length by bus. The estimates of exposure and risk thus obtained are rated as somewhat uncertain.

Kirk et al. (2003) state that the injury data apply to Great Britain and are for the years 1999–2001. Exposure was estimated by looking up relevant tables in Transport Statistics Great Britain. While the estimate of exposure can be regarded as quite accurate, the source of injury data in this study, which is police reports, is likely to be affected by incomplete reporting. A Norwegian study (Sagberg and Sætermo, 1997) found that police recorded 24 non-collision injuries to tram passengers in Oslo from 1989 to 1995. The tram operator recorded 299 non-collision injuries in the same period. Police thus recorded less than 10% of injuries. In view of this, the estimate of risk of injury in Kirk et al. is rated as highly uncertain.

Björnstig et al. (2005) compiled injury data for a period of ten years (1994–2003). The age of these data makes it difficult to reconstruct exposure. For the county of Västerbotten, in which Umeå is the largest city, there were 9.196 million trips by bus in 2009 (the oldest data that could be retrieved from Swedish transport statistics). Umeå has about 40% of the population of Västerbotten but is likely to have a larger share of bus trips. It is assumed that 60% of bus trips in Västerbotten are in Umeå. This makes for about 5.5 million trips per year, or 55 million in a period of ten years. If each trip is 5 km, passenger kilometres is 220 million. These estimates must be regarded as highly uncertain.

Halpern et al. (2005) state that 1900 buses serve Tel-Aviv, out of 5,000 for Israel as a whole. For the country as a whole, it is stated that there are 1.37 million bus trips per day (500 million per year). The ratio of the number of emergency room visits in Tel Aviv to the number for the whole country was used to estimate the number of bus trips in Tel Aviv during the period of eight months covered by the study (82.5 million). Mean trip length per bus trip (5.5 km) was found in official transport statistics. The estimates of exposure are rated as somewhat uncertain.

Strathman et al. (2010) state that the injury data refer to buses in Portland, Oregon, for the period from September 2006 to February 2009. The bus operator, TriMet, publishes statistics on the number of passengers and passenger kilometres (miles). These statistics were looked up for the period covered by the injury data. Estimates are regarded as very precise.

Barnes et al. (2016) state that injury data were for the years 2008–2012. Tables bus 0101 (number of passengers) and bus 0301b (passenger kilometres) in the online edition of Transport Statistics Great Britain were used to estimate exposure. Published figures in the transport statistics do not refer to calendar years. The years from 2008/09 to 2012/13 were used. Any error arising from a lack of perfect synchrony between injuries and exposure is judged to be minor, as exposure changes very little from year to year. As the estimate of risk is based on police reports, it is rated as highly uncertain as underreporting of injuries in police data is likely.

5. THE distribution of estimates of risk

Estimates of the risk of injury based on the estimates of exposure developed above are presented in Table 3.

It is seen that the estimates of risk vary considerably, which is perhaps not surprising in view of the fact that many estimates of exposure are uncertain, the injury data used in the studies span a period of about 30 years and are from different countries. It is therefore necessary to assess critically whether trying to develop a mean estimate of risk based on the individual studies makes sense. In general, estimating a mean from a distribution makes sense if the distribution is "well-behaved", i.e. is unimodal with data points scattering symmetrically around the mean. Within meta-analysis, a graphical tool, the funnel plot (Duval and Tweedie, 2000a; 2000b; Duval, 2005) has been developed to help evaluate if it makes sense to estimate a summary mean. There are many ways of showing a funnel plot (Sterne and Egger, 2001). In this paper, funnel plots show estimates of risk on the abscissa and the number of injuries underlying estimates of risk on the ordinate. Fig. 1 shows a funnel plot of estimates of the risk of falls inside the vehicle.

The ordinate has a logarithmic scale to improve readability (otherwise estimates based on few injuries would touch the abscissa). The weighted (by number of injuries) mean estimate of risk is 0.28 per million passenger kilometres. Six estimates of risk are lower than the weighted mean, six are higher. Based on the rating of the quality of exposure data, estimates have been labelled as VP (very precise), SU (somewhat uncertain) or HU (highly uncertain). Outlying estimates of risk were identified by estimating risk based on N – 1 data points and checking whether these estimates were inside the 95% confidence interval of the weighted mean risk based on all N data points. Five outlying estimates of risk were found. Five of the very precise estimates indicate a higher risk than the weighted mean, only one indicates a lower risk. A weighted mean estimate of risk was developed based only on studies with very precise data on exposure. Table 4 shows the summary estimates of risk that have been developed.

Turning to injuries when boarding or alighting a public transport vehicle, Fig. 2 shows a funnel plot of estimates of risk. Estimates are widely scattered, and the weighted mean estimate of risk (1.091) is located to the right of seven estimates and to the left of five, indicating a symmetric distribution. It is notable, however, that half of the estimates based on very precise data on exposure are identified as outlying. Clearly, even estimates based on comparatively good data vary considerably.

The trim-and-fill method (Duval and Tweedie, 2000a, 2000b, Duval, 2005) was applied to the data points in Figs. 1 and 2 to test for the possible presence of publication bias in estimates of risk. This method tests for asymmetry in the distribution of estimates and trims away data points until they are symmetrically distributed around the trimmed mean. More specifically, one might think that studies finding low levels of risk are less likely to be published than studies showing high levels of risk. For the risk of falls inside a vehicle, trim-and-fill deleted two data points, but the trimmed mean, leaving out these data points, differed from the overall mean by only 5%. For injuries when alighting or boarding, one data point was trimmed away. Based on this, it is judged as meaningful to develop mean estimates of risk. Several estimates of mean risk have been developed in order to assess how robust the estimates are

Table 3
Estimates of risk of non-collision injury to public transport passengers.

Study	Falls inside vehicle	Alighting or boarding	Other non-collision events	Total non-collision events	Million passenger kilometres	Million passengers	Falls/other events inside per million passenger km	Alight or board events per million passengers
Brooks et al. (1980)	1205	159	391	1755	25000	4285	0.064	0.037
Vaa (1993)	27	26		53	741	57	0.036	0.456
Fruin et al., (1994) [a]	2032	1896	1200	5128	5620	1040	0.614	1.824
King (1996)	10337	6886		17223	26294	4585	0.393	1.502
Sagberg et al., 1997 [b]	220	357		577	602	312	0.365	1.144
Sagberg et al., 1997 [b]	994	330		1324	1491	403	0.667	0.819
Skjøth-Rasmussen 1999	21	10	6	37	29	9	0.729	1.063
Kirk et al., (2003) [c]	13635	4137		17772	67400	13251	0.202	0.312
Björnstig et al. (2005)	48	106		154	220	55	0.218	1.927
Halpern et al., (2005) [d]	72	41		123	454	83	0.159	0.497
Strathman et al. (2010)	1288	713		2001	910	159	1.414	4.495
Barnes et al. (2016)	14106	3358		17464	145800	25894	0.097	0.130

[a] Fruin et al. state that 5507 injuries were recorded, but the categories given in Table 2 of the paper sum to 5128.
[b] The first row from Sagberg refers to trams, the second to buses.
[c] These are the estimated total number of injuries, based on Table 1 and Figs. 2 and 4 of the paper.
[d] Halpern et al. state that 120 injuries were recorded, but the categories listed in Table 4 of the paper sum to 123.

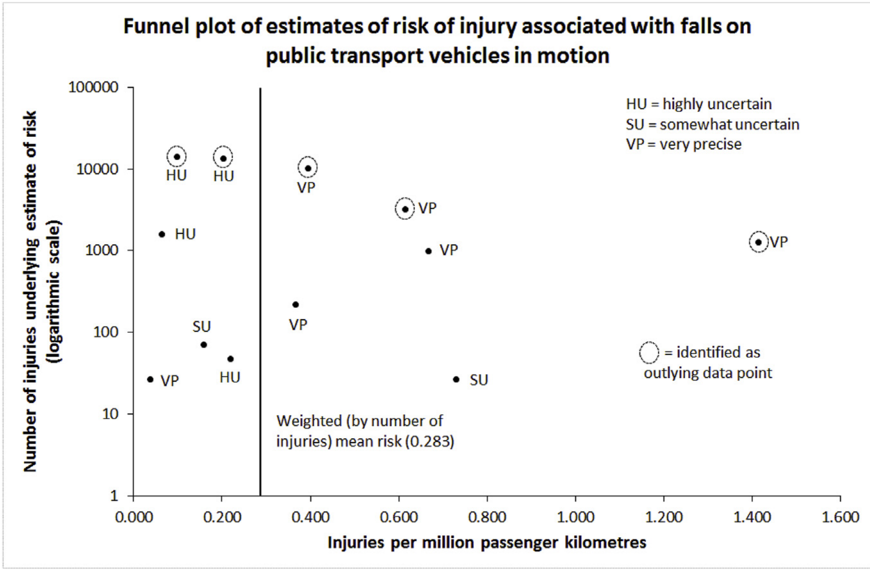

Fig. 1. Funnel plot of risk of injury associated with falls in public transport vehicles in motion.

Table 4
Summary estimates of risk of non-collision injury to public transport passengers.

Estimator of risk	Falls inside vehicle (injuries per million passenger kilometres) (standard error)	Alighting or boarding (injuries per million passengers) (standard error)
Simple (unweighted) mean (N = 12)	0.413 (0.114)	1.184 (0.352)
Mean weighted by number of injuries	0.283 (0.005)	1.091 (0.007)
Range of weighted estimates based on N-1 (omitting one study at a time)	0.250–0.366	0.837–1.324
Mean weighted by number of injuries for studies with very precise estimates of exposure	0.529 (0.008)	1.734 (0.010)

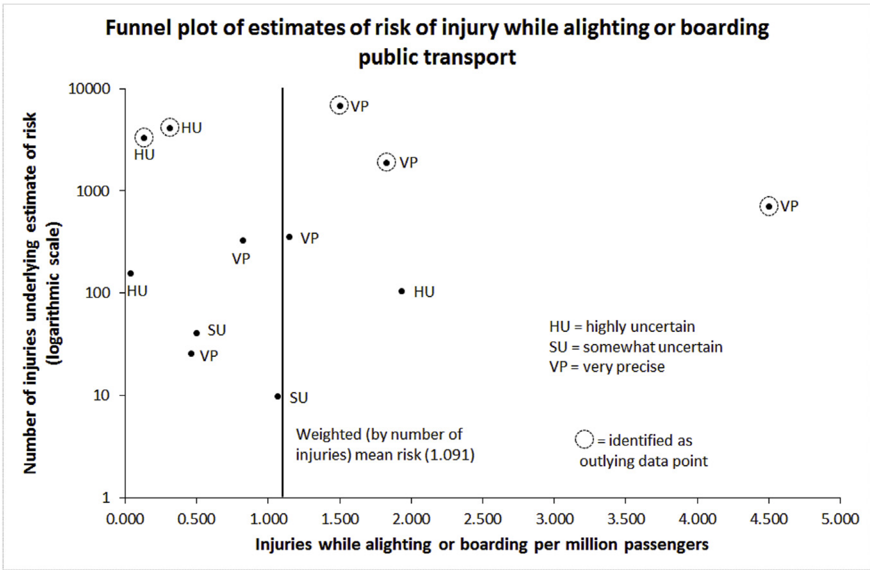

Fig. 2. Funnel plot of risk of injury associated with alighting or boarding public transport vehicles.

with respect to how they have been developed.

6. Best estimates of risk

Table 4 shows the mean estimates of risk that have been developed. Four estimates have been developed:

1. A simple mean of all estimates of risk (N = 12),
2. A weighted mean of all estimates of risk, using the number of injuries as weight (45,582 injuries in total for falls inside; 18,019 injuries in total for alighting or boarding),
3. A set of weighted means, each based on N – 1 (i.e. 11) estimates of risk,
4. A weighted mean based on estimates of risk for which exposure data were rated as very precise (N = 6).

Estimates are found to vary. Simple and weighted mean estimates of risk based on all studies are quite close. When one study is omitted at a time and risk estimated based on the remaining N – 1 studies, rather wide ranges of estimates of risk emerge. Weighted mean estimates based on studies with precise data on exposure indicate higher risk than those based on all studies.

A typical level for the risk of falls inside a moving vehicle is about 0.3–0.5 per million passenger kilometres. If a public transport vehicle produces 1 million passenger kilometres per year (e.g. a bus driving 50,000 km per year with an average of 20 passengers on board), it will on average experience 0.3–0.5 falls onboard leading to injury.

The typical level of risk of injury when boarding or alighting is about 0.8–1.7 injuries per million passengers. If each passenger on average makes a trip of 5 km, 1 million passenger kilometres will correspond to 200,000 passengers. The expected number of injury events per vehicle per year will be 0.2–0.3 (note that the risk involved in boarding or alighting is stated per passenger, not per case of boarding or alighting).

7. Discussion

Passengers in public transport are at risk of injury even if there is no traffic crash. Sudden braking or swerving can make standing passengers fall. In falling they may strike fixed objects in the vehicle, like seat backs, bars for holding, or doors or windows. Entering and exiting buses or trams also involves risk. Usually stairs need to be mounted or descended; in winter they can be wet or slippery. Several studies have been made to determine the number of non-collision injuries to public transport passengers. A total of sixteen studies were identified in this paper. However, very few of these studies provided any data on exposure to the risk of non-collision injury.

In this paper, estimates of exposure were developed for eleven of the sixteen studies identified, providing a total of twelve estimates of the risk of falling inside a vehicle in motion or getting injured (mostly in falls) while boarding or alighting a public transport vehicle. One study provided estimates of risk both for buses and trams. All other studies refer to buses. Six estimates of exposure were rated as very precise, two as somewhat uncertain and four as highly uncertain. For two of the highly uncertain estimates, uncertainty was mainly associated with a high probability that the number of injuries was underreported.

Given the limited number of studies, all estimates of risk must be treated as highly preliminary and uncertain. One may nevertheless use the estimates to give preliminary estimates of the number of non-collision injury events per public transport vehicle per year. Assuming that the vehicle carries 200,000 passengers per year and produces 1 million passenger kilometres, the expected number of events is in the range of 0.5–0.8. There is, no doubt, systematic variation in the expected number of non-collision injury events per vehicle per year. Urban buses, making frequent stops, are likely to have a higher number of events than, say, a long-distance train with no standing passengers. The data available for this paper are too uncertain to estimate variation in the number of non-collision events.

Biomechanical research has modelled some non-collision injury events and the risk of injury associated with them, see e.g. Palacio et al. (2009), Schubert et al. (2017) and Karekla and Tyler (2018). A main focus in all these studies is to find both the critical g-force triggering a fall and the probability that the fall will cause injury. Once these parameters are known, options can be developed for influencing them and thereby reduce both the likelihood of a fall and its severity. To assess the benefits of various measures that reduce the probability of a fall and/or its severity, it is important to know the expected frequency of occurrence of falls, as well as their severity.

The distribution of non-collision injuries by severity is highly uncertain. Thus, one study (Nue Møller et al., 1982) stated that 15% of injuries were AIS 3 or 4 (AIS = Abbreviated Injury Scale, where 0 is no injury and 6 fatal injury; AIS 3 and 4 are serious injuries), another study (Albrektsen and Thomsen, 1983) stated that 14% of injury victims were admitted to hospital and a third study (Kirk et al., 2003) stated that the share of killed or seriously injured passengers in non-collision events was 8.1% when boarding, 11.5% when alighting, 7.2% when standing and 4.1% when sitting. Neither the level of detail nor the scales used for injury severity were the same in these studies. One study used AIS, another admission to hospital and a third the injury severity categories in official accident statistics to indicate injury severity. One study specified four types of events, the other two apparently treated all non-collision events as a single group. This lack of consistency generates uncertainty with respect to the distribution of injuries by severity. Still, between them, the studies at least indicate a plausible range for the share of injuries that are severe (with 4% the lowest and 15% the highest of the percentages quoted above).

8. Conclusions

The main conclusions of the study reported in this paper can be summarised as follows:

1. The mean risk of falls onboard a public transport vehicle is around 0.3–0.5 per million passenger kilometres. There is a wide scatter around the mean, with a range from 0.04 to 1.4 injuries per million passenger kilometres.
2. The mean risk of injury when boarding or alighting a public transport vehicle is about 0.8–1.7 per million passengers. Individual estimates of risk range from 0.04 to 4.5 per million passengers.
3. There is too little data to quantify variation between different types of public transport in the risk of non-collision passenger injury.

Acknowledgement

This study was part of the VIRTUAL-project, funded by the European Commission, grant number 768960.

References

Albrektsen, S.B., Thomsen, J.L., 1983. A casualty ward analysis of bus passenger accidents. Med. Sci. Law 23, 102–105.
Barnes, J., Morris, A., Welsh, R., Summerskill, S., Marshall, R., Kendrick, D., Logan, P., Drummond, A., Conroy, S., Fildes, B., Bell, J., 2016. Injuries to older users of buses in the UK. Publ. Transport 8, 25–38.
Björnstig, U., Albertsson, P., Björnstig, J., Bylund, P.-O., Falkmer, T., Petzäll, J., 2005. Injury events among bus and coach occupants – non-crash injuries as important as crash injuries. IATSS Res. 29, 79–87.
Brooks, B.M., Edwards, H.M., Fraser, C.R., Levis, J.A., Johnson, M.A., 1980. Passenger Problems on Moving Buses. TRRL Supplementary Report 520. Transport and Road Research Laboratory, Crowthorne, Berkshire.
Duval, S., 2005. The trim and fill method. In: Rothstein, H., Sutton, A.J., Borenstein, M. (Eds.), Publication Bias in Meta-Analysis: Prevention, Assessment and Adjustments. John Wiley and Sons, Chichester, pp. 127–144.
Duval, S., Tweedie, R., 2000A. Trim and fill: a simple funnel plot based method of testing and adjusting for publication bias in meta-analysis. J. Am. Stat. Assoc. 95, 89–98.
Duval, S., Tweedie, R., 2000B. A non-parametric trim and fill method of assessing publication bias in meta-analysis. Biometrics 56, 455–463.
Elvik, R., Bjørnskau, T., 2005. How accurately does the public perceive differences in transport risks? An exploratory analysis of scales representing perceived risk. Accid. Anal. Prev. 37, 1005–1011.
Fildes, B., Morris, A., Barnes, J., 2012. Analysis of Injuries to Young and Old Victorian Public Transport Users: 2006 to 2010. Report 319. Monash University Accident Research Centre, Melbourne.
Fruin, J., Huang, H.F., Zegeer, C.V., Smith, N.E., 1994. Recommendations for reducing noncollision bus passenger injuries. Transport. Res. Rec. 1433, 41–48.
Halpern, P., Siebzehner, M.I., Aladgem, D., Sorkine, P., Bechar, R., 2005. Non-collision injuries in public buses: a national survey of a neglected problem. Emerg. Med. 22, 108–110.
Jovanis, P.P., Schofer, J.L., Prevedouros, P., Tsunokawa, K., 1991. Analysis of bus transit accidents: empirical, methodological, and policy issues. Transport. Res. Rec. 1322, 17–28.
Karekla, X., Tyler, N., 2018. Reducing non-collision injuries aboard buses: passenger balance whilst walking on the lower deck. Saf. Sci. 105, 128–133.
Kendall, I.G., Hassan, T., Bodiwala, G.G., 1994. A review of injuries sustained by bus passengers. J. Accid. Emerg. Med. 11, 57.
Kendrick, D., Drummond, A., Logan, P., Barnes, J., Worthington, E., 2015. Systematic review of the epidemiology of non-collision injuries occurring to older people during use of public buses in high income countries. J. Transp. Health 2, 394–405.
King, R.D., 1996. Synthesis of Transit Practice 18. Bus Occupant Safety. Transit Cooperative Research Program. Transportation Research Board, Washington D. C.
Kirk, A., Grant, R., Bird, R., 2003. Passenger Casualties in Non-collision Incidents on Buses and Coaches in Great Britain. Loughborough University Institutional Repository.
Nue Møller, B., Grymer, F., Christensen, S.T., 1982. Bus accidents. J. Traffic Med. 10, 59–62.
Palacio, A., Tamburro, G., O'Neill, D., Simms, C.K., 2009. Non-collision injuries in urban buses – strategies for prevention. Accid. Anal. Prev. 41, 1–9.
Sagberg, F., Sætermo, I.A., 1997. Trafikksikkerhet for Sporvogn I Oslo. Rapport 367. Transportøkonomisk institutt, Oslo.
Schubert, P., Liebherr, M., Kersten, S., Haas, C.T., 2017. Biomechanical demand analysis of older passengers in a standing position during bus transport. J. Transp. Health 4, 226–236.
Skjøth-Rasmussen, J., Rasmussen, S.W., 1999. Tilskadekomst blant buspassagerer i en region i København. Ugeskrift for Læger 161, 5803–5806.
Sterne, J.A., Egger, M., 2001. Funnel plots for detecting bias in meta-analysis: guidelines on choice of axis. J. Clin. Epidemiol. 54, 1046–1055.
Strathman, J.G., Wachana, P., Callas, S., 2010. Analysis of bus collision and non-collision incidents using transit ITS and other archived operations data. J. Saf. Res. 41, 137–144.
Vaa, T., 1993. Personskader Og Risiko Ved Bussreiser. Reviderte Beregninger. Rapport 160. Transportøkonomisk institutt, Oslo.