CHALMERS

Investigation of under-reporting and the consistency of injury severity classifications in Swedish police crash data compared to hospital injury data based on the Swedish Traffic Accident Data Acquisition (STRADA)

Master's thesis in Engineering Mathematics and Computational Science

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Department of Applied Mechanics
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ABSTRACT

Police reported road crash data is used for Sweden's official road traffic statistics and is collected by the Swedish TRaffic Accident Data Acquisition (STRADA), which in turn provides a road crash database combining police and emergency hospital reported information.

The general goal of this thesis was the investigation of police road crash data from STRADA for the purpose of gaining a deeper understanding of how certain parts of the police data might need to be weighted and how consistent police and hospital injury severity classifications are. Specifically it was investigated how different sub-populations of road crashes are represented in police data and to which extent they were under-reported. Furthermore, the consistency of police and hospital injury severity classifications was investigated.

This was achieved by taking advantage of the availability of pre-linked hospital data in STRADA. Data from non-fatal crashes that occurred during the years 2003-2013 were used for the examination of under-reporting of road crashes while those that occurred during the years 2007-2013 were used for the investigation of consistency of injury severity classifications.

A direct comparison of the available police and hospital data was used to establish a lower bound for the under-reporting. Capture-recapture methods were used to estimate the actual prevalent amount of under-reporting. Additionally, the longitudinal behaviour of under-reporting was investigated. The influence of different factors on the consistency of injury severity classifications was tested for statistical significance by chi-squared tests and the calculation of odds ratios.

In total, under-reporting was found to be at least 48%. This lower bound decreased to 35% when single bicycle crashes were excluded. Two groups of months that consistently exhibited distinct rates of under-reporting were identified and crash severity was identified as a large influence on the amount of under-reporting. A dependence of under-reporting on the involved vehicles was found as well.

For the investigation of the consistency of police and hospital reported classifications of injury severity it was found that male gender, age above 60, ambulance or helicopter transport and a rural traffic environment lead to higher odds for different classifications by the police and hospitals compared to their alternatives.

Keywords: Under-reporting of road crashes, injury severity, STRADA, population size estimation, capture-recapture

PREFACE

The Swedish Transport Agency and the former Swedish Road Administration worked in collaboration with police forces and a great number of hospitals to create the road crash database STRADA. With it they provide a comprehensive data source to policy makers and researchers and thus further traffic safety in the long run.

When a data source is used for research purposes it is important to know what the contained data reflects and what a researcher can expect to find. This thesis focused on two aspects of the data, the under-reporting of road crashes in the police data and the consistency of injury severity classifications between police and hospital data. Knowledge of these facts can be used to increase the accuracy of future research and thus use the available data even more efficiently.

I want to thank my supervisors Jordanka Kovaceva and Helen Fagerlind for their support and the large amount of time they both dedicated to answer my questions and to provide me with the necessary skills to finish this thesis. I also want to thank András Bálint and Helen Fagerlind for the initial organization of this thesis. Furthermore, I want to thank my examinator Robert Thomson for making all formal matters effortless. For valuable discussions and new ideas during the course of this thesis I am grateful to András Bálint, Carol Flannagan, Stefan Candefjord, Olle Nerman and Nils Lübbe. Further thanks go to the Swedish Transport Agency for providing the necessary data and to Thomas Fredlund for answering a plethora of questions about this data.

Finally I want to thank my friends and family for constant support; my deepest respect to those who patiently listened to all my ideas and worries and those who put me back on track. You know who you are and you are fantastic!

Göteborg, 2016-06-28
Felix Held

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1 Introduction

1.1 Problem definition

Police reported road crash data is used for Sweden's official road traffic statistics and is collected by the Swedish TRaffic Accident Data Acquisition (STRADA), which in turn provides a road crash database, typically called STRADA as well, combining police and emergency hospital reported information. The analysis of the quality of police road crash data in STRADA can be attempted from a multitude of different angles. Two of those are the under-reporting of road crashes in the police data and the consistency of injury severity classifications in police and hospital data.

1.1.1 Under-reporting of road crashes

As the word *under-reporting* already implies, it is inherently connected to systems which are concerned with some kind of reporting. More specifically under-reporting quantifies the amount of cases, in this particular situation road crashes, which are missed by such a reporting system. This can be expressed as an estimated number of missing cases or as the percentage of missing cases with respect to an estimated total number of cases. In comparison to sampling methods, which intentionally only record part of the population following some random sampling criterion, under-reporting usually happens unintentionally.

As shown in Hook and Regal (1992) the missed proportion of data can be so large (in the example reported in the cited source 25-40% of missing data are estimated) that it cannot be neglected and inferences solely from the data could lead to biased results. To use the collected data correctly it thus remains to determine how representative of the total population it is. It is therefore necessary to check if systematic errors exist in the data collection, i. e. if certain parts of the population are unintentionally excluded or systematically under-reported. Should this be the case it is important to know about the extent of under-reporting and to identify the affected sub-populations in the data collection process.

As an example, this knowledge can be important when calculating the risk to be involved in a crash of a certain severity. If there were severe under-reporting in crashes of slight severity then the risk to be in a serious or even fatal crash would be overestimated. To acquire correct results it would thus be imperative to weight the data beforehand. Similarly it is important to know about the actual ratios of slight to severe to fatal crashes when extrapolating data from a smaller in-depth database which potentially has detailed information about individual crashes but covers only a small proportion of the total population.

By its definition under-reporting is related to *population size estimation*. This is a topic which has been investigated in many scientific areas. In ecology and biology it might be of interest to estimate the population size of a certain kind of animal in a specific geographic area or the amount of bacteria in a substance that is difficult to observe. In epidemiology it is of interest to estimate the true amount of people suffering from a certain disease if any specific data source only offers information about part of the population. Criminology is another field where interest in under-reporting and population size estimation is shown. There it is of interest to e. g. estimate the true number of bike thefts from the number of reported thefts. Especially in the latter discipline the number of missed cases is also known as *the dark figure* (Biderman & Reiss, 1967; Neubauer & Friedl, 2006).

Under-reporting in police data has been investigated in many countries and areas. For example in Rhône county, France, Amoros, Martin, and Laumon (2006, 2007) have established that under-reporting increases with decreasing injury severity, younger age and female gender. Additionally they found that the probability to be reported depends on other factors like road user type, involvement of a third party, daylight or crash environment. Considering data from the Australian state of Queensland Watson, Watson, and Vallmuur (2015) have shown that under-reporting is more likely to occur for motorcyclists, cyclists, males, young people and rural areas. Another study performed with data from the province of Funen in Denmark by Janstrup, Kaplan, Hels, Lauritsen, and Prato (2016) also found that the involvement of motorcyclists and cyclists lead to increased under-reporting. According to their research under-reporting decreases with an increasing number of motor vehicles involved, helmet and seat belt use, alcohol involvement, higher speed limit and injured females.

The employed methods to determine under-reporting in these studies have either been based on the comparison of total amounts obtained from two sources or on capture-recapture methods. The influence of factors on the under-reporting has typically been investigated by chi-square tests or logistic regression.

In Elvik and Mysen (1999) it was reported that there have been several investigations of this topic conducted in many countries in the late 1960s, the 1970s, 1980s and 1990s. They mention six studies from Sweden which found reporting rates of the police in comparison to hospital data in a range from 10% to 68% with an average of 52%, i. e. under-reporting of approximately 48%. All of these studies pre-date the existence of STRADA.

In Larsson and Björketun (2008) it was reported for the years 2003-2005 that there is about 53% of under-reporting in the police data acquired from STRADA when police reported counts are compared directly to hospital data. They found that there is almost no difference in under-reporting whether or not the crash occurred in an urban or rural traffic environment. However, they report the largest rate of under-reporting for crashes where bicycles and mopeds (class 2, max. 25 km/h) but no motor vehicle were involved (90% in urban and 95% in rural traffic environments). They also report higher rates of under-reporting for crashes with slightly injured crash participants (46% in urban as well as rural traffic environments) than in crashes with severely injured participants (32% in urban and 21% in rural traffic environments).

1.1.2 Consistency of injury severity classifications

While on the crash scene the police records the injury severity of the involved crash participants, following a set of guidelines (see Section 1.3.4), as uninjured, slightly, severely or fatally injured. If crash participants get a medical examination at an emergency hospital that reports to STRADA, all their injuries are assigned scores according to the Abbreviated Injury Scale (AIS) (see Section 1.3.2). For crashes known to the police as well as to an emergency hospital which reports to STRADA it is therefore possible to compare these ratings.

Knowledge about the consistency in classification can be important when evaluating the possible benefits of new traffic safety features. In such an evaluation it might be of interest to which extent severe injuries could be prevented. If police data is used for this task then it is of interest to which extent the police injury classifications and the medical examinations from hospitals coincide.

This has been investigated for STRADA by Larsson and Björketun (2008) for the years 2003-2005 where they concluded that there are discrepancies between the classifications. The largest discrepancy was found for the police injury classification *severe*, since this was matched by the hospital classification (ISS ≥ 9) only in about one third of all cases. There was however no investigation of which factors possibly influence the identified discrepancies.

1.2 Goals

The general goal of this thesis was the investigation of police road crash data from STRADA for the purpose of gaining a deeper understanding of how certain parts of the police data might need to be weighted and how consistent police and hospital injury severity classifications are.

Thus the concrete goals for this thesis were:

1. Investigate how different subpopulations of road crashes are represented in police data and estimate the corresponding under-reporting.
2. Investigate the consistency of police and hospital injury severity classifications.

1.3 Background

1.3.1 The Swedish Traffic Accident Data Acquisition

STRADA was created in response to a a governmental direction to the former Swedish Road Administration[1]. The task was to establish a new national information system which should be able to collect all police reported road crashes and additionally include emergency hospital information about injuries sustained in road crashes. The goal was to reduce the number of unreported crashes and thus to "provide a better basis for traffic safety efforts at the local, regional and national levels" (Forward & Samuelsson, 2007). As of 2010 the Swedish Road Administration ceased to exist and nowadays the Swedish Transport Agency[2] administers the data collection and manages the data storage as well as the evaluation of data quality.

As of 1999 the data collection from hospitals was tested in the Swedish county Skåne and the cities Gothenburg, Stockholm as well as Umeå. By 2003 STRADA replaced the older database system (OLY) for road crash reporting and therefore became the official source of police reported crash data (Vägverket, 2007).

A feature which makes STRADA stand out in comparison to other road crash databases is that the police and hospital reports belonging to the same crash are matched algorithmically based on the civic numbers[3] of the involved people, the crash time and its location. Since it is not always possible to ensure correct matching, a measure of certainty exists, which is expressed in numbers between 0 (no match) and 100 (exact match on all given information).

While police reporting covered all of Sweden as of 2003 this was not the case for emergency hospital reporting. The goal was to connect all emergency hospitals to STRADA, which has been accomplished as of 2016. There is full reporting coverage to be expected in the future[4]. The development of complete reporting coverage by county is visualised in Figure 1.1. In Table 1.1 the dates are given when the last remaining emergency hospital in the respective county started to report to STRADA.

The Swedish police is obligated by law (SFS 1965:561, last update in SFS 2014:1244) to report every road crash which led to at least one *personal injury*[5]. Crashes including at least one fatality should be reported within five days and crashes which led to injuries of other severities should be reported within seven days. The hospitals on the other hand report voluntarily. Additionally it is necessary that a patient consents to the transmission of the hospital report to STRADA (Howard & Linder, 2014).

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[1] *Vägverket*, in Swedish

[2] *Transportstyrelsen*, in Swedish

[3] *personnummer*, in Swedish

[4] https://www.transportstyrelsen.se/sv/vagtrafik/statistik-och-register/STRADA-informationssystem-for-olyckor-skador/Rapportorer-och-anvandare/ (accessed 2016-06-17)

[5] Meaning an injury inflicted on a person

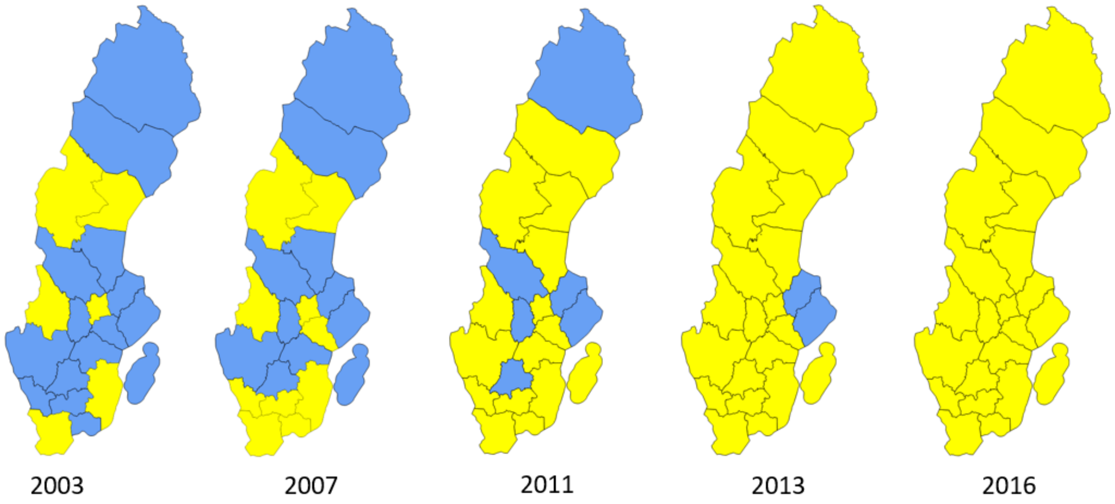

Figure 1.1: *Temporal development of complete emergency hospital coverage by county. Counties marked yellow have achieved complete emergency hospital coverage.*

The type of police reported road crashes which are submitted to STRADA is regulated by law and explained in detail in Section 1.3.3. The reporting criteria for hospitals on the other hand is to report everyone who seeks medical attention because of a road crash or a crash that occurred in the public traffic environment. This does not require that an injury is found.

One difference between police and hospital data is that reports from hospitals are mostly self-reported by the patients while police reports are based on what police officers observed at the crash site (Howard & Linder, 2014).

STRADA is accessable through a web-interface and it is available as a relational database. The version of the database which was used for this thesis is an anonymised version of the relational database. In the following, the tables that were used and their relationships are explained.

Central to the database set-up of STRADA are the two tables for police and hospital reports. These are stored separately with IDs which are unique among all reports, regardless of their originating source. In the following, these tables will be referred to as `police_report` and `hospital_report`. There is one police report per road crash and one hospital report per examined individual. Information that is common to both reports, for example the time and date of a crash, is available in a separate table called `report`.

The results of the matching algorithm are stored in the table `accident` relating each report ID from the tables `police_report` and `hospital_report` to an accident ID. Additionally, the measure of certainty, described above, is available in the variable `Q`.

For every traffic element involved in a crash, such as cyclists, cars, pedestrians, …, a separate entry in the table `traffic_element` is created, which is linked to the table `police_report`. Furthermore, for any person involved in the crash there is an entry in the table `person` that is linked to the respective traffic element in the `traffic_element` table. Thus every recorded person is also linked to exactly one police report. If the matching between crashes was successful then it is possible to link a person recorded in the police report with the available hospital report.

1.3.2 Abbreviated Injury Scale and Injury Severity Score

Two commonly used scales for injury severity rating are the Abbreviated Injury Scale (AIS) (AAAM, 1998, 2008) and, derived from AIS, the Injury Severity Score (ISS) (Baker, O'Neill, Haddon, & Long, 1974).

Table 1.1: Date as of which all emergency hospitals reported to STRADA by Swedish county.

County	Date	County	Date
Skåne	1999-01-01	Västra Götaland	2010-01-01
Västmanland	2000-05-01	Östergötland	2010-06-01
Värmland	2002-02-01	Gotland	2010-09-01
Jämtland	2002-04-01	Västerbotten	2011-01-01
Kalmar	2002-10-01	Jönköping	2011-02-01
Västernorrland	2003-01-01	Stockholm	2011-04-01
Blekinge	2003-09-01	Norrbotten	2011-05-01
Kronoberg	2004-11-01	Örebro	2011-12-01
Hallands	2006-03-01	Dalarna	2012-12-01
Södermanland	2006-09-01	Uppsala	2016-01-01
Gävleborg	2009-02-01		

According to the website of the *Association for the Advancement of Automotive Medicine* (AAAM), which developed the AIS scale, it is "an anatomically based, consensus derived, global severity scoring system that classifies each injury by body region according to its relative importance on a 6-point ordinal scale (1=minor and 6=maximal)"[6]. The scale is widely applied in traffic safety analysis and is also used for injury rating in the hospital reports submitted to STRADA.

The coding which was initially used in STRADA is described in AAAM (1998) and is commonly known as AIS 1990 Update 98 or simply AIS 98. This scale was used during the test phase of STRADA and after its official launch until the end of 2006. As of 2007 injuries are coded in AIS 2005 Update 2008 as described in AAAM (2008).

According to the coding manual for the AIS 2005 Update 2008 there are no fixed "dimensions of severity" which were used to construct the AIS. However they state multiple criteria that at least had an impact on the way the scale was defined. Some of the mentioned dimensions are "threat to life, mortality (...), tissue damage (...), treatment cost, permanent impairment [and] quality of life". They also show that AIS is correlated to mortality in a quadratic fashion. According to the manual the chance of survival is almost 100% for AIS scores 1 and 2 and then decreases quadratically to about 20% in the case of the AIS score 6. Note that this correlation was determined for individuals who sustained one single injury.

The ISS is described by the independent, non-profit organisation Trauma.org as "an anatomical scoring system that provides an overall score for patients with multiple injuries"[7]. The same website describes that the basic idea behind the ISS is to take "the highest AIS score [for] each body region (...) [and to square and add the score of] the three most severely injured body regions (...)". Other mechanisms control for special cases. The possible range of the ISS are integers from 0 to 75. A more detailed description of the method can be found in Baker et al. (1974).

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[6] http://www.aaam.org/about-ais.html (accessed 2016-05-30)

[7] http://www.trauma.org/index.php/main/article/383/ (accessed 2016-06-15)

1.3.3 Definition of a road crash

The Swedish Transport Agency provides guidelines for how the police should report road crashes (Mattsson & Ungerbäck, 2013). The criteria for the police to report a road crash coincide with Sweden's official definition of a road crash, which Transport Analysis[8], the Swedish government agency in charge of transport policy analysis, also state in their yearly reports (compare Transportanalys (2014) for the latest report including explanatory text).

A road crash in Sweden is defined[9]

- to be a crash which has occurred in traffic on a road
- to involve at least one vehicle in motion
- to involve at least one personal injury

According to Förordning om vägtrafikdefinitioner (2001:651) 2§, a road is specified as

1. a road, a street or any other public path or open space which is used for motor vehicle traffic,
2. a path designated for bicycle traffic or
3. a walkway or riding path located close to a road of type 1 or 2.

A vehicle is considered to be a contrivance on wheels, continuous track, skids or similar means which is mainly meant to be driven on the ground and does not run on rails. Vehicles are differentiated into motor vehicles, trailers (further divided into two categories), side-cars, bikes, a vehicle towed by horses and other vehicles. [10]

This definition entails that vehicles on rails are not counted as vehicles. Thus, a crash solely between a tram and a pedestrian is not included in this definition of a road crash (Transportanalys, 2014).

In case of a fatality the police and the Swedish Transport Agency thoroughly investigate the crash. If a person dies on the crash scene or within 30 days of the crash then the person is counted as a crash fatality. In these cases police reports in STRADA are updated in hindsight. Therefore police data coverage of crashes with fatalities is generally considered complete (Howard & Linder, 2014).

1.3.4 Definition of a police reported severe injury

In Mattsson and Ungerbäck (2013) the guidelines for the police when reporting personal injuries are as follows:

> *A person should be reported as dead, severely injured or slightly injured. People considered severely injured sustained broken bones, blunt traumas, disruptions, penetration wounds, a concussion or other internal injuries. Even those who will probably be hospitalised should be considered severely injured.*[11]

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[8] *Trafikanalys*, in Swedish

[9] Translated from Swedish:
"*Vägtrafikolycka - Olycka som inträffat i trafik på väg, vari deltagit minst ett fordon i rörelse och som medfört personskada. Såsom väg räknas enligt 2§ i Förordning om vägtrafikdefinitioner (2001:651):*

1. *Väg, gata, torg och annan led eller plats som allmänt används för trafik med motorfordon*
2. *Led som är anordnad för cykeltrafik*
3. *Gång- eller ridbana invid en väg enligt 1 eller 2.*

" (Transportanalys, 2014)

[10] Translated from Swedish:
"*Fordon - En anordning på hjul, band, medar eller liknande som är inrättad huvudsakligen för färd på marken och inte löper på skenor. Fordon delas in i motordrivna fordon, släpfordon, efterfordon, sidvagnar, cyklar, hästfordon och övriga fordon.*" (Lag om vägtrafikdefinitioner (2001:559) 2§)

[11] Translated from Swedish:
"*Under (...) "Personskada" anges om personen är död, svårt skadad eller lindrigt skadad. Med svårt skadad menas person som vid olyckan erhållit brott, krosskada, sönderslitning, allvarlig skärskada, hjärnskakning eller inre skada. Som svår skada räknas också sådan där den skadade väntas bli inlagd på sjukhus.*" (Mattsson & Ungerbäck, 2013)

During STRADA's existence there has been discussion about the definition of a severe injury. In Forward and Samuelsson (2007) it is criticised that there exists no common definition of a severe injury which is followed equally by the police and hospitals.

1.3.5 Capture-Recapture models

Capture-Recapture models have been developed to estimate the size of a population. An overview of many different ideas and modelling approaches concerning capture-recapture methods is given by Chao (2001), while the textbook Otis, Burnham, White, and Anderson (1978) is an introduction to standard capture-recapture models.

Two known early uses of such methods were the estimation of the population size of France, by Laplace, and that of London, by Graunt (R. Huggins & Hwang, 2011). Later these models have been successfully used in the estimation of animal populations (Otis et al., 1978), but also in traffic analysis to determine under-reporting. An example is Samuel et al. (2012) where a capture-recapture model was used to estimate the amount of under-reporting of road traffic mortality in developing countries. Similar models have been used in Amoros et al. (2007) or Janstrup et al. (2016) whose results were described in Section 1.1.1.

The general idea behind these methods is that on two or more occasions samples of individuals in the population of interest are recorded and that individuals, once captured in a sample for the first time, are somehow marked such that they can be recognised if they show up in a sample at a later occasion. A *capture history* can be constructed for every individual caught at least once (R. M. Huggins, 1989). These are usually denoted as a sequence of 0's and 1's for every individual, such as `0 0 1 0 1` if there were five sampling occasions and the individual was recorded in sample 3 and 5. To estimate the population size as a whole it is thus necessary to estimate the amount of individuals which did not appear in any of the samples.

As explained in Hook and Regal (1992) capture-recapture methods can also be used for lists which have been created concurrently, as long as certain assumptions are fulfilled. In Hook and Regal (1995) the applicability of these methods for lists in an epidemiological study is demonstrated.

The assumptions that are generally made to derive standard capture-recapture models are, as described in Chao (2001):

1. The population is *closed*, i. e. there is no change in the population between one sampling occasion and the next. In ecological circumstances this often meant that no animals were born or died between multiple trapping occasions.
2. The population is *homogeneous*, i. e. each individual is equally likely to appear throughout a fixed sample.
3. The samples are assumed to be independent.

Using these assumptions and following Brittain and Böhning (2008) an estimate for the population size based on two samples can be derived as follows:

Let $f_{a,b}$ be the amount of individuals, which have the capture history `a b` where $a, b \in \{0, 1\}$, e. g. f_{10} is the amount of individuals in the first but not in the second sample (see Table 1.2). Note that f_{00} is unobservable. Otherwise, the true population size could simply be calculated by $N = f_{11} + f_{10} + f_{01} + f_{00}$. To estimate the population size it is therefore necessary to estimate f_{00}. Additionally, let f_k, for $k = 1, 2$, be the amount of individuals recorded exactly k times. If the assumption of independence between samples holds, then the odds ratio

$$\frac{f_{11} f_{00}}{f_{10} f_{01}} \approx 1. \tag{1.1}$$

Table 1.2: Illustration of a two sample capture-recapture configuration.

		Sample 2	
		yes	no
Sample 1	yes	f_{11}	f_{10}
	no	f_{01}	f_{00}

From this relation f_{00} can be estimated as

$$\hat{f}_{00} = \frac{f_{10} f_{01}}{f_{11}}. \tag{1.2}$$

This gives an estimate for the population size

$$\hat{N}_P = f_{11} + f_{10} + f_{01} + \hat{f}_{00} = \frac{n_1 n_2}{m_2}, \tag{1.3}$$

the *Lincoln-Petersen estimator*, where n_i is the amount of individuals in the i-th sample and m_2 is the amount of individuals in both samples. Since the case $m_2 = 0$ is possible this estimate does not have finite moments, i. e. it's theoretical mean and variance are infinite and thus the *Chapman estimator* was proposed in Chapman (1951). The estimator was constructed to overcome the problems of the Lincoln-Petersen estimator and is defined as

$$\hat{N}_{CPM} = \frac{(n_1 + 1)(n_2 + 1)}{m_2 + 1} - 1. \tag{1.4}$$

Chapman additionally showed that this estimate is practically unbiased, i. e. $E\left(\hat{N}_{CPM}\right) = N$, as long as

$$\frac{n_1 \cdot n_2}{N} > \log N \tag{1.5}$$

and where N is the true population size. In Robson and Regier (1964) it was additionally shown that the estimate is unbiased if $n_1 + n_2 \geq N$ and that the bias is negligible when $m_2 \geq 7$.

The Chapman estimator, as well as the Lincoln-Petersen estimator, can be derived under the additional assumption that capture probabilities of individuals are different in each sample, which is in accordance with above assumptions (Chao, 1989). If p_{ij} is the probability of individual i to be captured on the j-th trapping occasion then this amounts to $p_{ij} = p_j$ for all i and j. Capture-recapture models under this premise are often called M_t models, since probabilities are allowed to vary with *time* (Otis et al., 1978).

Seber (1970) showed that the variance of the population size estimator given in Eq. 1.4 can be estimated approximately unbiasedly by

$$\text{Var}\left(\hat{N}_{CPM}\right) = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2 (m_2 + 2)}. \tag{1.6}$$

Seber showed additionally that the bias is non-negative and depends on n_1 and n_2 in relation to the true population size N. The variance is unbiased if $n_1 + n_2 \geq N$.

2 Methodology

2.1 Data selection criteria

The data that was used for this thesis was taken from the STRADA Access database dump retrieved on 2015-10-06.

2.1.1 Under-reporting of road crashes

Selection

Road crashes reported in police and/or hospital data were used. Only crashes following the criteria below were considered.

1. Crash date was in the timespan 2003-01-01 to 2013-12-31
2. Crash involved at least one personal injury, but no fatalities
3. Crash involved at least one
    - car,
    - truck,
    - bus,
    - motorcycle,
    - moped or
    - bicycle
4. Crash occurred on a
    - road crossing
    - road
    - pavement
    - pavement and bicycle path
    - interchange
    - roundabout

Justification

The object of interest in the investigation of under-reporting was the number of crashes not reported by the police even though they fall within the official definition of a road crash as described in Section 1.3.3. This entails that hospital reports are not used separately but their information is considered per crash as matched by the matching algorithm described in Section 1.3.1.

The time span was chosen since STRADA was officially started on 1st January, 2003 and there are known technical problems in the police reported data as of late 2013 and early 2014 in some counties. All data as of 2014 has thus been excluded. The data at the end of 2013 has been kept since the technical problems started late in 2013 and only affected parts of Sweden.

As described in Section 1.3.3, a road crash must involve at least one personal injury and thus only crashes with this characteristic were included. Crashes with fatalities were excluded since these are generally considered to be fully reported in police data (Howard & Linder, 2014). The choice of vehicles was based on the definition in Section 1.3.3 but was simplified to focus on those vehicles which are in general use for the transportation of people and goods. For road type, the chosen types were those that were available in police as well as hospital data and were public traffic environments.

These criteria lead to the selection of 293977 road crashes in total, whereof 181773 were police reported and 180464 were hospital reported. 68260 crashes appeared in both sources amounting to about 23% of the considered road crashes.

When only those road crashes that occured after a county achieved complete hospital coverage (see Section 1.3.1) were considered then the criteria lead to the selection of 184953 road crashes whereof 93217 were police reported and 137214 were hospital reported. 45478 crashes appeared in both sources amounting to about 25% of the considered road crashes. This last selection was used for the analysis of under-reporting.

2.1.2 Consistency of injury severity classifications

Selection

Injury severity classifications were compared per people who appeared in police as well as hospital data. Individuals whose reports followed the following criteria were considered.

1. Police and hospital reports are linked with a high certainty (`Q` ≥ 90).
2. Crash date was in the timespan 2007-01-01 to 2013-12-31.
3. The hospital record stated that the person had $0 \leq$ ISS ≤ 75 and was not marked as killed.
4. The police recorded injury severity was slight or severe or the individual was marked as uninjured.

Justification

In the investigation of the consistency of injury severity classifications the comparison focused on individuals which were recorded by the police as well as a emergency hospital. A high value of `Q` was chosen, since it was considered worse to encounter faulty linkage than loosing cases. The start date was chosen such that it coincided with the adoption of AIS 2005 Update 2008 in STRADA.

An ISS larger than 0 and less or equal to 75 indicates that a person has sustained at least one injury which has been recorded during a hospital examination. It is necessary to combine this with information about whether the patient died or not as ISS does not account for that. An ISS of zero means that the person did not sustain any injuries.

This selection amounted to 64283 individuals which were available in police and hospital data.

2.2 Estimation of under-reporting of road crashes

2.2.1 Comparison of total amounts

To calculate a lower bound for under-reporting a direct comparison of the total amounts of police and hospital reported crashes was used. Let in the following be

P number of crashes only known by *police*,
H number of crashes only known by *hospitals*,
B number of crashes known by *police* and *hospitals*.

$P + B + H$ is the total amount of crashes which is known and in comparison to the actual amount of crashes N it holds that $P + B + H \leq N$. A lower bound for the under-reporting of road crashes in the police data was then calculated by

$$\hat{p}_{lb} = 1 - \frac{P+B}{P+B+H} = \frac{H}{P+B+H}. \tag{2.1}$$

2.2.2 Capture-Recapture method

To estimate the actual under-reporting it was necessary to estimate the total amount of crashes N. This was done using the capture-recapture method described in Section 1.3.5.

To apply this method to the context of data from STRADA the police data was considered as the first sample of the population while the hospital data was considered as the second sample. Then P, as defined in Section 2.2.1 corresponded to f_{10} from Section 1.3.5, H corresponded to f_{01} and B corresponded to f_{11}.

The population size was then estimated with the Chapman estimator $\hat{N}_{CPM}$ as in Eq. 1.4 and under-reporting of road crashes in the police data was estimated by

$$\hat{p}_{cr} = 1 - \frac{P + B}{\hat{N}_{CPM}}. \tag{2.2}$$

The variance of $\hat{p}_{cr}$ was determined by bootstrapping, i. e. by repeated resampling with replacement of the original dataset and calculation of the under-reporting $\hat{p}_{cr}^{(k)}$ for the resampled dataset. The variance of the resulting sample of $\hat{p}_{cr}^{(k)}$'s was then used as an approximation to the variance of $\hat{p}_{cr}$.

2.2.3 Longitudinal behaviour and the influence of factors

To investigate the change in under-reporting over time, the complete dataset was investigated visually in a resolution per month.

The data was then stratified by the factors daytime, crash severity and crash participant. The considered crash participants were those presented in Section 2.1.1 as well as pedestrians. The latter type was only considered when combinations of crash participants were considered. For this part of the analysis several periods of time were considered, namely

- 2003-2006,
- 2007-2009 and
- 2010-2013.

In each period under-reporting was estimated monthly with the amount method and the capture-recapture method. The median μ_p of all resulting estimates from one method in the respective time period was taken and the spread of the monthly values around the median was quantified by

$$s^{max} := \max_{1 \leq k \leq n} \left(\left| p^{(k)} - \mu_p \right| \right) \text{ as well as } s^{mean} := \frac{1}{n} \sum_{k=1}^{n} \max \left(\left| p^{(k)} - \mu_p \right| \right), \tag{2.3}$$

where the months are labelled 1 to n in the considered time period.

If not enough data was available to sensibly calculate monthly estimates, i. e. no reported crashes in some months, then yearly estimates were calculated and the median as well as the measures of spread described above were applied to the yearly estimates.

If there was not enough data for yearly estimates either, then all data per time period was used to calculate one estimate per period.

2.3 Investigation of the consistency of injury severity classifications

2.3.1 Factor groupings

To compare hospital AIS coded injuries to police reported injury classifications the AIS coding was translated to the categories *uninjured*, *slight* and *severe*.

ISS values reported in the hospital reports in STRADA were used and converted according to:

- ISS 0: uninjured
- ISS 1 - 8: slightly injured
- ISS 9 and higher: severely injured

This is similar to how AIS coding is translated to police injury severity classifications in STRADA and was also used in the determination of the crash severity in the part of this thesis dealing with underreporting. When police and hospital injury severity classifications are combined nine combinations are possible (e. g. severe/severe, severe/slight, …).

The variables gender, age, transport (ambulance or helicopter), daytime, crash participant type, number of involved crash participants in the crash and traffic environment were investigated as possible influencing factors.

Daytime was taken as any time between 7.00 to 18.59 o'clock. Age was divided into the categories

- 0-17, (12.75%)
- 18-24, (24.25%)
- 25-40, (24.48%)
- 41-60 and (25.21%)
- > 60, (13.31%)

where the percentages after the age group state how large the group was with respect to the dataset.

The number of involved crash participants was either one, in case of a single vehicle crash, or two or more if there were multiple crash participants, where at least one of them was a vehicle. This variable was grouped as "single", "two" and "more than two". Considered crash participant types were, similar to the selection in Section 2.1.1,

- car,
- truck,
- bus,
- motorcycle,
- moped,
- bicycle,
- pedestrian and
- other.

The traffic environment was used as coded by the police. This means that traffic environment was coded as urban if the posted speed limit on the road, on which the crash occurred, was 50 km/h or below, otherwise the traffic environment was coded as rural (Mattsson & Ungerbäck, 2013).

2.3.2 Similarity of injury severity classifications for individuals in the same vehicle

It was investigated if being in the same vehicle leads to more similar injury severity classifications.

For this the number of different combinations of police and hospital injury severity classifications were assigned to 1, 2, 3, 4 or 5 individuals per vehicle. A combination of police and hospital injury severity classifications can be, for example, a police injury severity of *severe* and a hospital injury severity of *slight*. When considering, for example, two individuals per vehicle then there can never be more than two different combinations of police and hospital injury severity classifications. It was not investigated which combinations occurred how many times but rather how many different combinations occurred regardless of which.

First, for each vehicle with a certain number of individuals in the same vehicle it was counted how many different combinations of police and hospital injury severity classifications occurred and this was summarized in a frequency table.

In a second step, all people who were alone in/on the vehicle or were pedestrians in a crash with a vehicle were randomly divided into groups of 1, 2, 3, 4 or 5 individuals. This was done for the purpose of simulating that individuals were in the same vehicle together with the chosen number of other people. Then, as in the first step, it was counted how many different combinations of police and hospital injury severity classifications occurred and this was summarized in another frequency table.

Finally, the theoretical frequencies were calculated as if being in the same vehicle would not lead to more similar combinations of police and hospital injury severity classifications. This was done as follows: From the available data for people who were alone in/on the vehicle or were pedestrians involved in a crash with a vehicle the probabilities $p_{\text{police severity}/\text{hospital severity}}$ for an individual to have the combination of injury severity classifications *police severity / hospital severity* (e. g. severe / slight) were approximated by the frequencies of the combination in the restricted dataset.

As a shorthand these combinations were written as *a / b*, e. g. a = severe and b = slight and C was the set of all possible combinations *a / b*. Then the probability for the case of two individuals in/on the same vehicle to get the same combination of injury severity classifications was

$$\sum_{a/b \text{ in } C} p_{a/b}^2 \tag{2.4}$$

while the probability that each of them got a different combination was

$$\sum_{a_1/b_1 \text{ in } C} \quad \sum_{\substack{a_2/b_2 \text{ in } C \\ a_2/b_2 \text{ not equal } a_1/b_1}} p_{a_1/b_1} p_{a_2/b_2}. \tag{2.5}$$

Similarly all other probabilities for 3, 4 or 5 individuals in/on the vehicle were calculated. Note that this calculation was possible since it was assumed that being in the same vehicle does not lead to more similar combinations of injury severity classifications among the involved individuals. The resulting probabilities were summarised in the same way as the frequency tables acquired in step 1 and 2.

If being in the same vehicle would not lead to more similar combinations of injury severity classifications then the frequency table from step 1 should be very similar to the table of theoretical frequencies while the frequency table from step 2 should be similar to the table of theoretical frequencies, since in step 2 people were randomly grouped and therefore their combinations of injury severity classifications should not be more similar than by chance.

2.3.3 Influence of factor levels

To get a first overview over possible influences of factor levels the frequencies of the data across available factor levels (see Section 2.3.1) were given for all those individuals who were alone in the vehicle or were a pedestrian in a crash with a vehicle:

1. by all possible combinations of police and hospital injury severity classifications.
2. by whether the individual was assigned equal or different classifications from the police and a hospital.
3. by whether the individual was assigned a more or less severe injury classification by the police than the medical examination stated (in case police and hospital classified the injury severity differently)

Cases two and three were then analysed with statistical methods. Here only the analysis for case two is explained. The analysis for case three was analogous.

First a Pearson's chi-squared test of independence (Agresti, 2007) was performed on the factor tabulated against either equal/different classification or more/less severe police classification, to determine if the factor had a significant influence. Note that here all levels of the factor were used.

In a second step, odds ratios of all possible combinations of two factor levels were considered. The information was summarised in 2×2 tables as in Table 2.1. The *sample odds ratio* is then defined as

$$\widehat{\theta} = \frac{n_{11}/n_{12}}{n_{21}/n_{22}} = \frac{n_{11}n_{22}}{n_{12}n_{21}} \tag{2.6}$$

and states how likely it is that the classification turns out equal if the individual falls into factor level 1 as opposed to factor level 2.

Table 2.1: Illustration of a 2×2 table for one factor and equal/different police and hospital classifications.

		Classification	
		equal	different
Factor	Level 1	n_{11}	n_{12}
	Level 2	n_{21}	n_{22}

Following Agresti (2007) it holds that $\log\left(\widehat{\theta}\right)$ is approximately $\mathcal{N}\left(\log\theta, SE^2\right)$ distributed where θ is the true odds ratio and

$$SE = \sqrt{\frac{1}{n_{11}} + \frac{1}{n_{12}} + \frac{1}{n_{21}} + \frac{1}{n_{22}}}. \tag{2.7}$$

A true odds ratio of 1, respectively $\log(\theta) = 0$, means that it is equally likely to be classified equal by police and hospital no matter into which of the two selected factor levels the individual falls. In this case it holds approximately that

$$z := \frac{\log\left(\widehat{\theta}\right) - \log(\theta)}{SE} = \frac{\log\left(\widehat{\theta}\right)}{SE} \sim \mathcal{N}(0,1). \tag{2.8}$$

The two-sided p-value

$$p = P(X \geq |z|) + P(X \leq -|z|) = 1 - P(X < |z|) + P(X \leq -|z|) = 2\Phi(-|z|), \tag{2.9}$$

where $X \sim \mathcal{N}(0,1)$ and Φ is the cumulative distribution function of $\mathcal{N}(0,1)$, was then calculated and the hypothesis of no factor influence was rejected if $p < 0.05$.

A sample odds ratio which is significantly different from 1 and smaller/larger than 1 can be interpreted as factor level 1 is $\widehat{\theta}$ times less/more likely as factor level 2.

3 Results

3.1 Estimation of under-reporting of road crashes

3.1.1 Affirmation of the necessity of complete hospital coverage

In Figure 3.1 the percentage of under-reporting calculated for each year from 2003-2013 is shown. The figure visualizes the effect of using only those crashes that occurred after the last emergency hospital in the respective county, in which the crash was located, started to report to STRADA (right hand side) compared to using all available crashes (left hand side). Additionally, the figure shows the sensitivity of the amount method (top row), which calculates a lower bound for the percentage of under-reporting, and the capture-recapture method (bottom row), which estimates the true percentage of under-reporting, to this exclusion criterion.

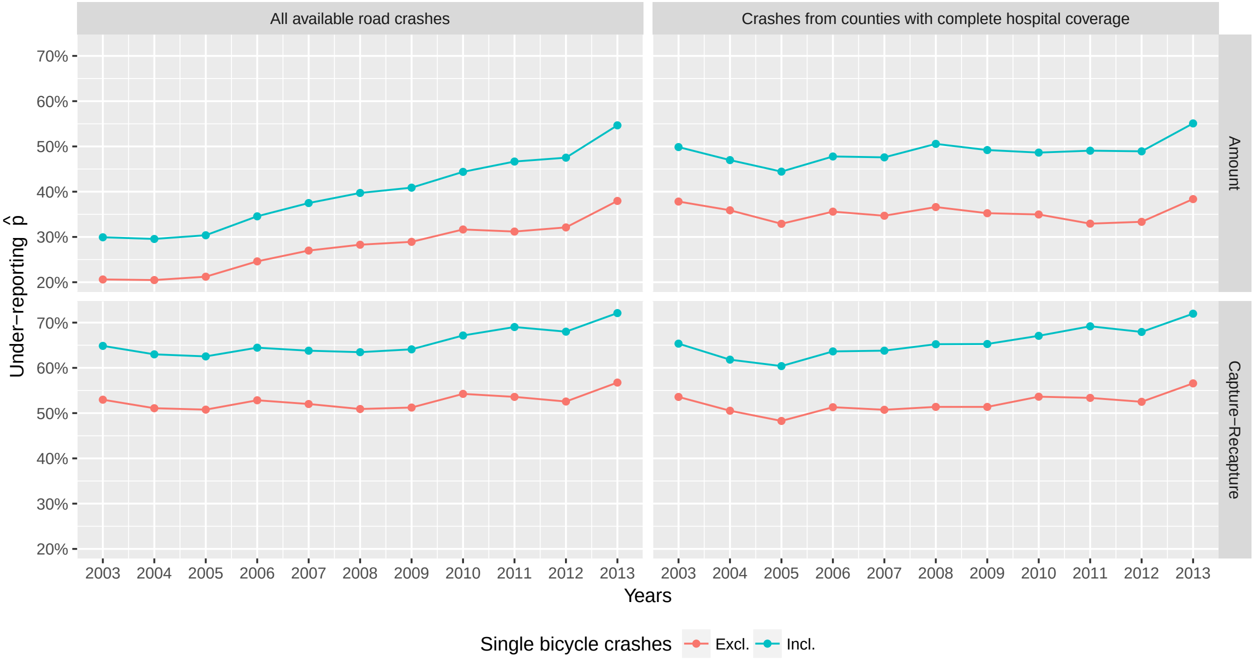

Figure 3.1: *Percentage of under-reporting for the years 2003-2013 including and excluding single bicycle crashes respectively. The graphs on the left show under-reporting when all available crashes are used, while the graphs on the right show under-reporting when crashes are only selected from counties with complete hospital coverage. Under-reporting has been calculated with the amount method (top) and the capture-recapture method (bottom).*

It was found that the largest difference in under-reporting for the amount method (top row in Figure 3.1) when using all data compared to only using data fulfilling the complete hospital coverage in a county (left hand side of Figure 3.1 compared to its right hand side) was an increase in 2003 of 20% when including single bicycle crashes and 17% when excluding single bicycle crashes. Additionally, an upward trend was identified when all available road crash data was used. This trend shows an increase in under-reporting by 25% when including single bicycle crashes and 17% when excluding single bicycle crashes. When only crashes from counties with complete hospital coverage were used then no such trend was identifiable.

For the capture-recapture method the graphs in the bottom row of Figure 3.1 show that the inclusion of all available data did not have a severe impact. The largest difference between the left compared to the right hand side was a decrease in 2005 of 2.1% when including single bicycle crashes and 2.5% when excluding them.

In the following only those road crashes were considered that occurred after the last emergency hospital in the respective county, where the crash was located, started to report to STRADA.

3.1.2 Single bicycle crashes

In Figure 3.2 the percentage of under-reporting of single bicycle crashes is shown. It was found that the lower bound for under-reporting calculated by the amount method was at least 93%, with the lowest under-reporting in late 2004 and mid 2005, and the estimate of the true under-reporting of single bicycle crashes was at least 96%. There was some variation but no clear pattern visible in the range of 93% to 100% in the amount method and 96% to 100% in the capture-recapture.

Single bicycle crashes accounted for about 4% of all crashes reported to STRADA during the years 2003-2009 and about 13% during the years 2010-2013.

In the following single bicycle crashes were excluded from the dataset, with the exception of Figure 3.5.

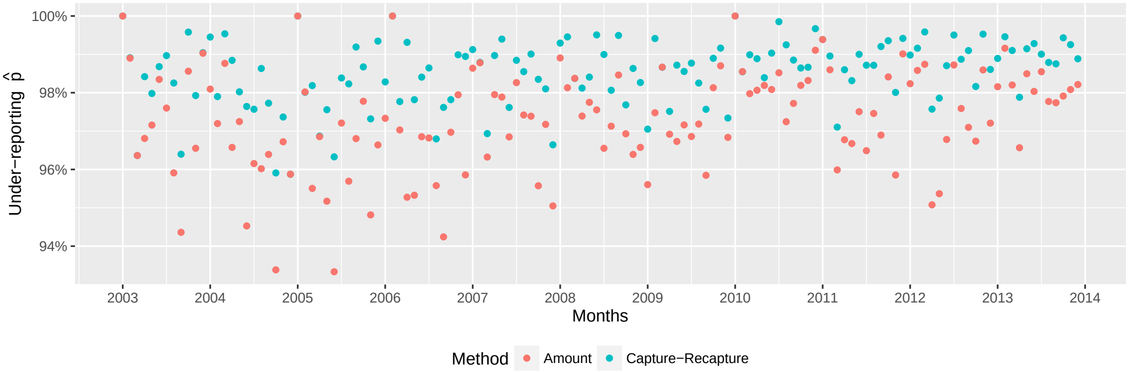

Figure 3.2: *Percentage of under-reporting of single bicycle crashes for all months and the years 2003-2013 calculated with the amount method and the capture-recapture method.*

3.1.3 Standard errors of capture-recapture estimates

The monthly development of the standard errors of the capture-recapture estimates of the true percentage of under-reporting for the years 2003 to 2013 is presented in Figure 3.3. A seasonal pattern with increased standard errors during winter months compared to summer months was recognized. Additionally, the standard errors decreased annually. The largest standard error was observed in March 2004 and was 2.7% which is 5.6% of the corresponding estimate of 47.9%. The smallest was observed in August 2013 and was 1.3% which is 2.2% of the corresponding estimate of 57.8%.

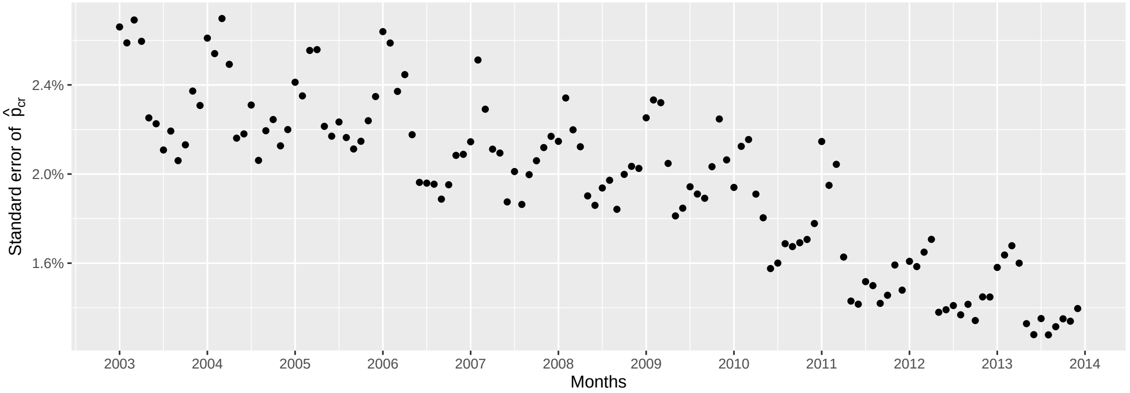

Figure 3.3: *Standard errors for the percentage of under-reporting for all months and the years 2003-2013 excluding single bicycle crashes calculated with the capture-recapture method.*

The standard errors have been found to be small compared to the seasonal behaviour of the estimated under-reporting. Figure 3.4 shows point estimates of the under-reporting and an additional interval for each estimate that covers one standard error upwards and one downwards. The underlying seasonal behaviour is still visible with differences between months often larger than the sum of both of their standard errors.

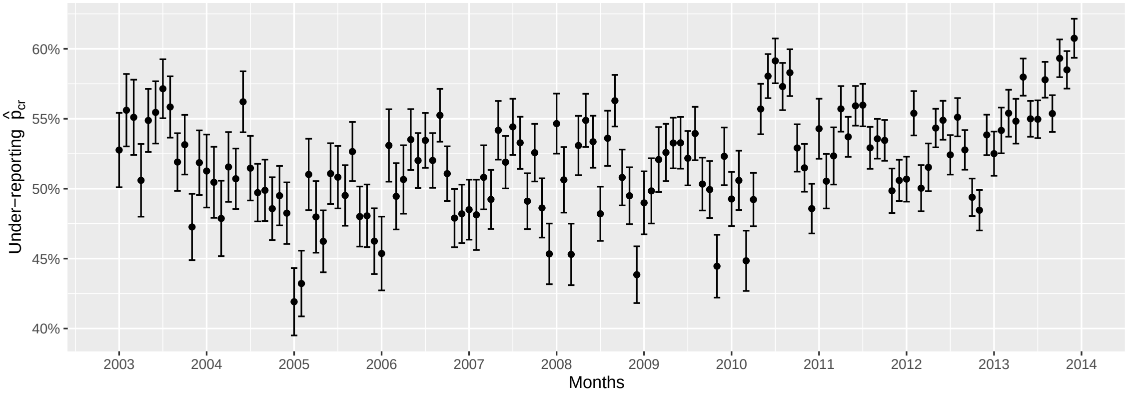

Figure 3.4: *Percentage of under-reporting for all months and the years 2003-2013 calculated with the capture-recapture method. The error bars show the deviation of the point estimates for under-reporting by one standard error.*

3.1.4 Longitudinal behaviour

Figure 3.5 shows the percentage of under-reporting calculated for each month in the years 2003-2013. The calculated lower bound for under-reporting (red dots) as well as the estimated true percentage of under-report (blue dots) are shown and single bicycle crashes were included. In Figure 3.6 under-reporting was calculated excluding single bicycle crashes.

A seasonal behaviour was recognized, particularly in Figure 3.5. It was found that months during the middle of the year, i. e. close to June and July, exhibited increased under-reporting compared to months closer to the turn of a year. The reduced prevalence of this pattern in Figure 3.6, where single bicycle crashes were excluded, showed that the influence of the inclusion of single bicycle crashes was greater during the summer. This seasonal pattern was inverse to the one observed for the standard errors of the capture-recapture estimates in Section 3.1.3.

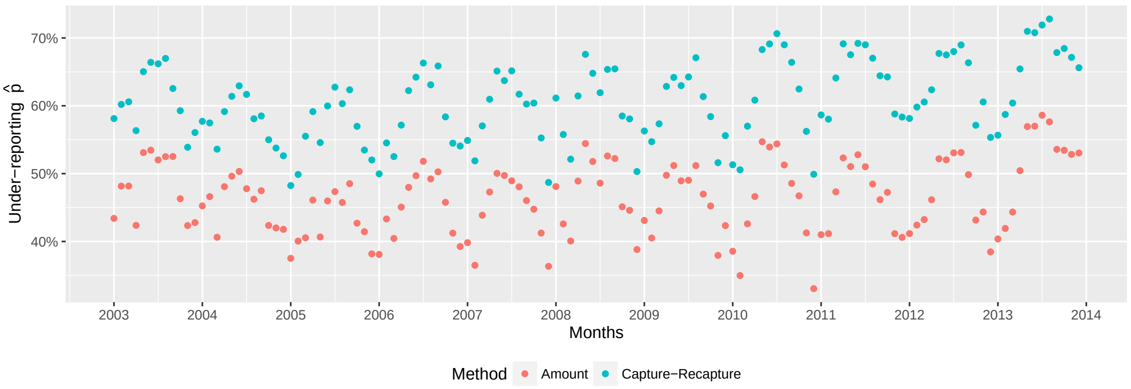

Figure 3.5: *Percentage of under-reporting for all months and the years 2003-2013 including single bicycle crashes calculated with the amount method and the capture-recapture method.*

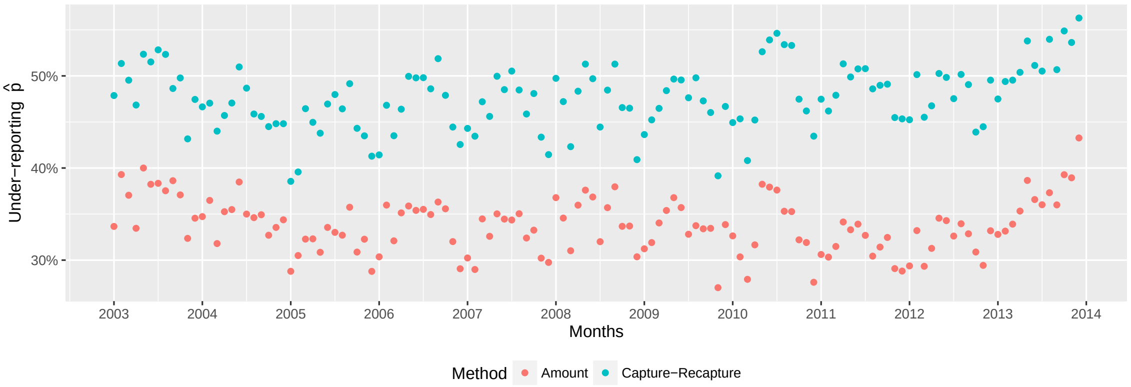

Figure 3.6: *Percentage of under-reporting for all months and the years 2003-2013 excluding single bicycle crashes calculated with the amount method and the capture-recapture method.*

Maximum and minimum percentages of under-reporting per year and their differences are presented in Table 3.1. The largest difference in under-reporting was in the year 2010 with a 11% and 14% difference between the maximum and minimum percentage of under-reporting for the amount method and the capture-recapture method respectively. The least difference in under-reporting calculated with the amount method was 6% in 2012 and for capture-recapture method it was 6% in 2011. The maximum under-reporting overall was in December 2013 with a lower bound of 44% and an estimated 61%. The lowest bounds for under-reporting were in January 2005, November 2009, December 2010 with 28-29% while the lowest estimated under-reporting was found in January 2005 with 42%.

The maximum had been attained in all but two years in the months May to September, while the minimum had been attained in the months November to March in all years. 2013, being the year with the highest observed under-reporting with respect to both methods, additionally had the largest difference in under-reporting between months January and December.

Under-reporting during the months May to September was generally higher than from November to March, while months April and October generally fell between both groups (see Figures 3.7 and 3.8). In 2013 however the months October, November and December exhibited a considerably higher percentage of under-reporting than during the years before (5-10% increase compared to previous years). There was also a strong upward trend in 2013 which could not be seen in any other year and was not as clear when single bicycle crashes were included (see Figures 3.7 and 3.8).

Table 3.1: Maximum and minimum percentage of under-reporting for the years 2003-2013 excluding single bicycle crashes as well as their difference. Additionally, the months in which the maximum and minimum occur are presented.

Year	Amount					Capture-Recapture				
	Maximum [%]		Minimum [%]		Difference [%]	Maximum [%]		Minimum [%]		Difference [%]
2003	May	40.36	November	33.65	6.71	July	57.15	November	47.26	9.83
2004	June	39.65	March	32.34	7.31	June	56.21	March	47.87	8.30
2005	September	37.20	January	29.38	7.82	September	52.65	January	41.92	10.67
2006	September	38.15	December	30.82	7.33	September	55.25	January	45.37	9.84
2007	August	37.49	February	30.11	7.38	July	54.42	December	45.34	8.97
2008	September	40.97	December	31.09	9.88	September	56.29	December	43.85	12.43
2009	May	38.37	November	28.22	10.14	August	53.94	November	44.46	9.52
2010	May	39.92	December	28.62	11.30	July	59.14	March	44.85	14.29
2011	April	36.23	December	29.79	6.44	July	55.97	November	49.85	6.15
2012	May	35.68	January	30.03	5.65	February	55.39	November	48.46	6.91
2013	December	44.15	January	33.65	10.49	December	60.75	January	52.51	8.23

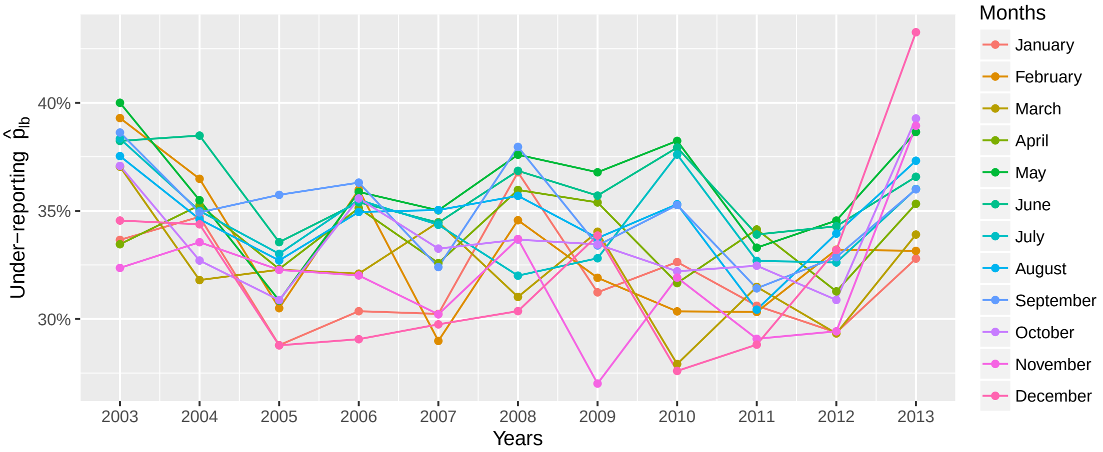

Figure 3.7: *Percentage of monthly under-reporting for the years 2003-2013 excluding single bicycle crashes and calculated with the amount method.*

In the following, months May to October and November to April have been grouped. The separation between the groups was not clearly visible for the amount method (see Figure 3.9) but months May to October accounted for a larger part of the upper range of under-reporting in each year while months November to April accounted for a larger part of the lower range.

When the estimates from the capture-recapture method were considered then the separation between the groups was considerably clearer (see Figure 3.8). As for the amount method, months May to October represented most of the upper range and November to April accounted for most of the lower range. However, for the capture-recapture method the estimates were spread further apart and thus there was less overlap between the two groups.

In both, Figures 3.9 and 3.10, the smoothing lines, which roughly approximate the average of each year but also take previous and following years into account, show that under-reporting in the summer and autumn months, May to October, stayed above that of November to April.

However, in 2013 the results for both groups were closer together and the smoothing lines are only separated by 2-3%.

Figure 3.8: *Percentage of monthly under-reporting for the years 2003-2013 excluding single bicycle crashes calculated with the capture-recapture method.*

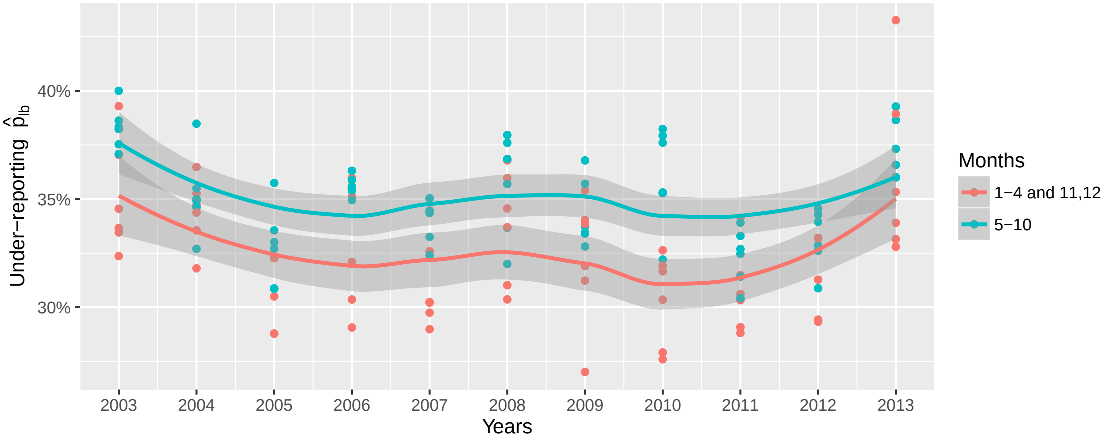

Figure 3.9: *Percentage of monthly under-reporting for the years 2003-2013 excluding single bicycle crashes calculated with the amount method. The months have been divided into summer and autumn months (May to October) as well as winter and spring months (November to April). The approximate development of under-reporting in each group is shown as a locally smoothed trend line.*

3.1.5 Influence of factors

As described in Section 2.2.3 the data was stratified by the factors crash severity, participant types and day-/night-time. The results for the years 2010-2013, the most recent data used for this thesis, are presented in Table 3.2. Additional results for the years 2003-2006 and 2007-2009 are available in the appendix in Tables B.1 and B.2.

The tables present the median of under-reporting over all months in the years that the respective table covers and which was calculated with the amount method ($\mu_{p_{lb}}$) or capture-recapture method ($\mu_{p_{cr}}$). Additionally, the measures of spread (s^{max} and s^{mean}), described in Section 2.2.3, and the relative size of the sub-population in the total population (n/N) as well as the relative size of the amount of crashes in the sub-population which are available in police and hospital data (B/n) are presented.

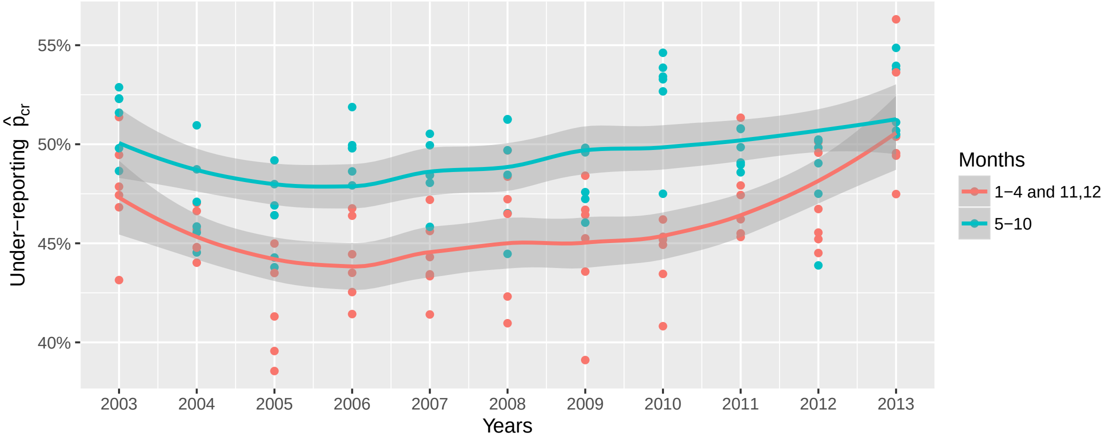

Figure 3.10: *Percentage of monthly under-reporting for the years 2003-2013 excluding single bicycle crashes calculated with the capture-recapture method. The months have been divided into summer and autumn months (May to October) as well as winter and spring months (November to April). The approximate development of under-reporting in each group is shown as a locally smoothed trend line.*

Most of the selected data (56%) was available for the years 2010-2013, while there was less than half of the amount available for the years 2003-2006 (23%) and 2007-2009 (21%). A lower bound for the total percentage of under-reporting in the period 2010-2013 was 48% when including single bicycle crashes and 33% when excluding single bicycle crashes. The estimated under-reporting for those years was 65% including single bicycle crashes and 49% excluding single bicycle crashes. As in Section 3.1.2 the high under-reporting of single bicycle crashes was reflected in this table with 98% as a lower bound for under-reporting and 99% as the estimated under-reporting. Thus in the following single bicycle crashes were excluded again.

The number of considered sub-populations, in which the amount of crashes known to both police and hospitals was larger than 50%, was eight for the years 2010-2013. This was less than half of the sub-populations compared to 14 in the years 2003-2006 and 16 in the years 2007-2009.

There was a considerable difference in under-reporting for severe and slight crashes. The under-reporting of severe crashes was at least 8% and estimated to be 11% for the years 2010-2013, while for slight crashes it was at least 36% and estimated to be 54%.

There was no relevant difference in under-reporting between day- or night-time for the years 2010-2013. For severe crashes under-reporting was at 8% during daytime as well as night-time and the estimated percentages were 11% for daytime and 13% for night-time. Considering the mean spread of 3% in case of daytime and 5% in case of night-time however, there was not enough evidence to consider these estimates to be different. When considering slight crashes there was an increase in the estimate of under-reporting during night-time compared to daytime by about 6%. The maximum spread for night-time (18%) was however found to be quite high compared to the maximum spread for daytime (8%).

Under-reporting of crashes which involved one or more trucks was found to be low compared to the involvement of any of the other motor-vehicles under consideration. For the years 2010-2013 the percentage of under-reporting of crashes involving trucks was at least 17% and estimated to be about 28%. When at least one car was involved in the crash then under-reporting was at least 28% and estimated to be 43%.

For crashes involving buses, motorcycles, mopeds and bicycles under-reporting was at least 37% and particularly high for mopeds (52%) and bicycles (81%). Estimated under-reporting for crashes involving one of these vehicles was at least 54% and highest for bicycles with 90%.

When crashes with the involvement of exactly two different participant types were considered then for the years 2010-2013 car-truck, car-moped, car-bicycle and car-pedestrian crashes were the only sub-populations with a size larger than 1% of the available dataset. Compared to the years 2003-2009 this was an increase as for those years only car-bicycle crashes were in size larger than 1%. It was found that all other considered sub-populations were also larger during the years 2010-2013 compared to 2003-2009.

The least lower bound for the under-reporting of crashes involving two different participants was observed for crashes between trucks and pedestrians. For the years 2010-2013 this was at least 8% and estimated to be 18%. Additionally, under-reporting was low for crashes involving trucks and motorcycles (at least 11% and estimated 16%) and trucks and mopeds (at least 10% and estimated 18%). For crashes between cyclists and pedestrians on the other hand under-reporting was at least 61% and estimated to be 84%.

Crashes between buses and motorcycles have only been considered for all years 2003-2013 since there was little data available (29 crashes between 2003-2013). Under-reporting was at least 10% and estimated to be 15%.

The results for 2003-2006 in Table B.1 and 2007-2009 in Table B.2 confirmed the results for 2010-2013 about the difference in total under-reporting, high under-reporting of single bicycle crashes, the gap between the under-reporting of severe and slight crashes as well as that there was no difference in under-reporting found between day- and night-time. Considering these factors there was no compelling difference between the under-reporting rates when the median was considered in combination with the average and maximum spread.

For the years 2003-2009 crashes involving trucks had the lowest under-reporting rate (at least 16% and estimated 23-24%), as was the case for 2010-2013. Crashes involving at least one cyclists and one pedestrians but no other vehicles exhibited high under-reporting (at least 58-61% and estimated 73-76%) with a similar lower bound as was found for 2010-2013 but lower estimated under-reporting.

For crashes which involved exactly two different participant types the least under-reporting for the years 2003-2006 was for crashes involving trucks and mopeds (at least 7% and estimated 11%), trucks and pedestrians (at least 7% and estimated 15%) as well as motorcycles and mopeds (at least 10% and estimated 15%). For the years 2007-2009 the least under-reporting was found for crashes involving trucks and motorcycles (at least 3% and estimated 5%), buses and mopeds (at least 8% and estimated 12%) as well as buses and bicycles (at least 9% and estimated 16%).

Table 3.2: Estimates of under-reporting for different sub-populations of size n for the years 2010-2013. These are taken from the total population of crashes selected for under-reporting of size $N = 184953$. The number of crashes in each sub-population which is available in police and hospital data is denoted B.

Sub-population	Amount method			Capture-Recapture method			Proportions	
	$\mu_{p_{lb}}$ [%]	s_{lb}^{max} [%]	s_{lb}^{mean} [%]	$\mu_{p_{cr}}$ [%]	s_{cr}^{max} [%]	s_{cr}^{mean} [%]	n/N [%]	B/n [%]
All crashes	47.89	14.84	5.38	64.94	15.02	5.02	56.10	26.42
All crashes[a]	33.01	10.26	2.57	49.47	8.67	2.78	42.72	34.34
Single bicycle crashes	97.89	3.17	0.85	98.79	1.81	0.47	13.38	1.12
Severe crashes	17.58	14.35	3.64	23.12	18.72	4.66	5.06	56.68
Slight crashes	50.86	15.61	5.74	68.76	15.29	5.20	51.04	23.42
Severe crashes[a]	7.94	8.46	2.20	10.99	10.22	2.97	4.44	63.44
Slight crashes[a]	35.83	10.78	2.87	53.75	8.07	3.15	38.29	30.97
Daytime[a,b,d]	8.00	9.44	2.23	10.80	10.89	2.99	3.07	64.95
Daytime[a,c,d]	35.14	9.51	2.50	52.33	7.63	2.78	27.57	31.87
Night-time[a,b,e]	8.38	10.37	3.83	12.65	13.46	5.03	1.36	60.03
Night-time[a,c,e]	38.12	13.58	4.24	57.70	17.84	4.81	10.72	28.64
Car involved	27.80	13.93	2.64	42.79	12.07	2.92	34.01	37.42
Truck involved	17.15	7.03	2.75	27.98	12.53	3.77	4.32	44.47
Bus involved	36.84	37.07	7.15	57.09	26.12	7.92	1.22	27.11
Motorcycle involved	39.39	60.61	11.27	53.65	46.35	10.52	2.74	36.08
Moped involved	52.14	24.33	6.40	68.46	18.71	5.22	3.73	23.59
Bicycle involved	80.96	9.08	3.05	89.99	7.09	2.01	19.12	8.83
Bicycle involved[a]	38.65	23.65	7.74	59.28	38.28	9.11	5.74	26.82
Pedestrian involved[l]	24.00	21.83	4.87	44.99	20.63	7.77	2.99	29.19
Car-Truck crashes[k]	18.89	9.09	3.22	29.51	12.58	4.28	2.65	46.08
Car-Bus crashes[f,k]	28.06	5.48	3.39	41.35	4.53	2.37	0.43	38.08
Car-Motorcycle crashes[f,k]	16.75	4.43	2.57	25.88	5.94	3.29	0.76	47.44
Car-Moped crashes[k]	19.42	30.58	6.58	30.84	30.84	8.72	1.03	40.72
Car-Bicycle crashes[k]	22.02	18.89	4.65	37.87	20.27	6.81	3.31	36.24
Car-Pedestrian crashes[k]	18.30	18.91	4.10	35.02	24.11	6.17	2.08	33.41
Truck-Bus crashes[f,k]	20.80	9.26	4.50	29.94	11.14	6.90	0.06	43.69
Truck-Motorcycle crashes[f,k]	10.76	6.88	3.01	15.66	8.69	4.08	0.07	55.56
Truck-Moped crashes[f,k]	10.30	7.88	3.89	18.21	14.31	6.10	0.07	51.18
Truck-Bicycle crashes[f,k]	18.93	8.16	3.36	32.36	18.26	5.52	0.18	36.83
Truck-Pedestrian crashes[f,k]	7.70	4.07	2.08	18.17	8.77	3.73	0.13	34.87
Bus-Motorcycle crashes[h,k]	10.34	–	–	14.76	–	–	0.02	58.62
Bus-Moped crashes[g,k]	17.24	–	–	34.24	–	–	0.02	31.03
Bus-Bicycle crashes[f,k]	13.66	5.72	2.97	24.57	10.32	4.40	0.10	42.70
Bus-Pedestrian crashes[f,k]	15.31	3.54	1.88	44.73	11.21	4.85	0.20	18.51
Motorcycle-Moped crashes[g,k]	30.00	–	–	43.85	–	–	0.02	36.67
Motorcycle-Bicycle crashes[f,k]	16.37	12.20	7.57	23.00	23.13	11.86	0.03	48.39
Motorcycle-Pedestrian crashes[f,k]	17.14	8.81	4.35	29.49	17.56	11.97	0.03	35.19
Moped-Bicycle crashes[f,k]	29.03	9.52	3.77	50.72	12.42	6.76	0.19	27.09
Moped-Pedestrian crashes[f,k]	23.98	6.95	4.05	46.28	9.42	5.64	0.10	25.81
Bicycle-Pedestrian crashes[f,k]	60.77	10.66	4.85	83.88	4.56	1.93	0.42	12.02

[a] single bicycle crashes excluded

[b] only severe crashes are considered

[c] only slight crashes are considered

[d] 7.00 to 18.59 o'clock is considered as *daytime*

[e] 19.00 to 6.59 o'clock is considered as *night-time*

[f] results are averages of yearly estimates of under-reporting

[g] results are estimates of under-reporting for the combined data from 2010-2013

[h] results are estimates of under-reporting for the combined data from all years 2003-2013

[k] crashes involving at least one of each of the mentioned participant types are considered

[l] crashes involving at least one of the vehicles listed in Section 2.1.1

3.2 Consistency of injury severity classifications

It was found that in the selected data only four cases occurred in which the police reported an individual as uninjured while in the hospital data the person was reported as severely injured. As can be seen in Table 3.3, the available amounts for each other combination was at least more than 100 times larger. For this reason the *severe* and *slight* injury classifications for the hospital data were combined if the police had classified the individual as *uninjured*.

Table 3.3: Total amounts of combinations of injury severity classifications in the selected data. (years 2007-2013, $N = 64283$)

Police	Hospital	Total [%]
Severe	Severe	3.71
	Slight	12.82
	Uninjured	1.26
Slight	Severe	1.46
	Slight	63.01
	Uninjured	14.16
Uninjured	Severe	0.01
	Slight	2.40
	Uninjured	1.17

3.2.1 Similarity of injury severity classifications for individuals in the same vehicle

Individuals who were in/on the same vehicle during a crash were found to be classified more similarly by police and hospitals. In Table 3.4 the observed frequencies of the number of different combinations of police and hospital injury severity classifications for 1, 2, 3, 4 or 5 individuals per vehicle are shown. Table 3.5 shows the frequencies when individuals per vehicle are simulated by random grouping of individuals who were alone in/on the vehicle or were pedestrians involved in a crash with a vehicle. Finally, Table 3.6 shows the theoretical frequencies which are expected if being in/on the same vehicle does not lead to more similar classifications. The frequencies in Table 3.4 are higher for small numbers of different combinations and lower for higher numbers of different combinations compared to Table 3.5 and Table 3.6. This shift of frequencies to the smaller numbers of different combinations shows that combinations of injury severity classifications are more similar among people in the same vehicle. For example, for two individuals in/on the same vehicle it has been observed that 61% had the same combination while 39% had two different combinations. Theoretically however 45% should had the same combination while 55% should had two different combinations.

The frequencies for randomly grouped individuals were however similar to the theoretically calculated frequencies (see Tables 3.5 and 3.6), as was expected (see Section 2.3.2). The largest difference was 1.34% in case of five individuals in the vehicle and three different combinations of injury severity classifications.

Table 3.4: Observed frequencies for the number of different combinations of police and hospital injury severity classifications by the number of individuals per vehicle. (years 2007-2013, $N = 64283$)

Individuals per vehicle	Different combinations [%]				
	1	2	3	4	5
1	100.00	0.00	0.00	0.00	0.00
2	60.51	39.49	0.00	0.00	0.00
3	41.36	50.55	8.09	0.00	0.00
4	27.57	59.40	10.78	2.26	0.00
5	22.02	55.96	19.27	2.75	0.00

Table 3.5: Observed frequencies for the number of different combinations of police and hospital injury severity classifications when people who were alone in/on the vehicle are randomly split into groups of 1, 2, 3, 4 or 5 to simulate the respective number of individuals per vehicle. (years 2007-2013, $N = 45543$ individuals per row)

Individuals per vehicle	Different combinations [%]				
	1	2	3	4	5
1	100.00	0.00	0.00	0.00	0.00
2	45.93	54.07	0.00	0.00	0.00
3	27.95	53.49	18.56	0.00	0.00
4	17.95	48.68	29.37	4.00	0.00
5	12.00	41.85	36.67	8.96	0.52

Table 3.6: Theoretical probability for the number of different combinations of police and hospital injury severity classifications by the number of individuals per vehicle, if being in the same vehicle would not lead to more similar combinations of police and hospital injury severity classifications.

Individuals per vehicle	Different combinations [%]				
	1	2	3	4	5
1	100.00	0.00	0.00	0.00	0.00
2	44.63	55.37	0.00	0.00	0.00
3	26.73	53.70	19.57	0.00	0.00
4	16.90	48.37	30.32	4.41	0.00
5	10.80	41.82	37.32	9.43	0.64

3.2.2 Influence of factor levels

For this investigation only individuals who were alone in/on the vehicle or were pedestrians involved in a crash with a vehicle were considered.

In Table C.1 a detailed overview of the frequencies of the data across the factor levels described in Section 2.3.1 is shown. The combination slight / slight occurred most often (65%), followed by severe / slight (13%) and slight / uninjured (12%), while the combination uninjured / uninjured occurred least (1%). Police and hospital classifications were equal for 70% of all observed individuals (see Table 3.7). If police and hospital classified an individual differently it was found that the police classified more severely in 88% of the time (see Table C.2).

With Chi-squared tests it was found that there is no evidence available in the data that suggests that day- or night-time had a significant influence on whether the individual was classified equally or differently by police and hospital (see Table C.3). If the classifications were different however then day- or night-time had a statistically significant influence on being classified more severely by the police than by a hospital (see Table C.4).

All other factors had a statistically significant influence on whether classification was equal or different and on whether the police classified more severely than a hospital. The influence of factor levels on being classified equally by police and a hospital has been investigated for statistically significant differences with odds ratios (see Table 3.8). The found odds ratios however were in the range of 0.56 to 1.65 which are overall low effects. The same investigation was done for those individuals which were classified differently by police and hospital and the influence of factor levels on whether the police classified the individuals more severely was investigated for statistically significant differences with odds ratios (see Table C.5). In this case odds ratios between 0.41 to 5.17 were observed.

These results are also reflected in Tables 3.7 and C.2 but it was not possible to investigate the statistical significance or strength of a difference between two factor levels.

When considering gender then the odds for a woman to be classified equally by the police and a hospital are greater than those for a man ($OR = 1/0.92 = 1.09$). If a woman however was classified differently by police and hospital then the odds for her to be classified more severely by the police compared to the odds of a man were larger as well ($OR = 1/0.65 = 1.54$).

Individuals from the age group > 60 were more likely to be classified differently by the police and a hospital compared to any of the other age groups (odds ratios between 1.08 and 1.65), while individuals from the age group $0 - 17$ were more likely to be classified equally by police and hospitals compared to any other age group (odds ratios between 1.45 and 1.65). There was no evidence for the age groups $18 - 24$, $25 - 40$ and $41 - 60$ to have an influence on whether an individual was classified equally by police and hospitals.

In case individuals from the age group > 60 were classified differently however their odds to be classified less severe by the police than by a hospital were greater compared to all other age groups (odds ratios between 1.15 and 2.03). For the age group $0 - 17$ individuals which are classified differently are more likely to be classified more severely by the police compared to all age groups (odds ratios between 1.41 and 2.03).

If a person is transported by an ambulance or a helicopter to a hospital then their odds of being classified equally by police and hospital were lower than without transport ($OR = 0.63$). In case of transport and a different classification it was more than five times as likely for the individual to be classified as more severe by the police than by a hospital ($OR = 5.17$).

There was no evidence in the data that day- or night-time had an influence on whether an individual was equally or differently classified by police and hospital. In case of different classifications however individuals were more likely to get classified more severely by the police during night-time ($OR = 1/0.77 = 1.30$).

For an individual involved in a crash which occurred in a rural traffic environment it was more likely to be classified differently by the police compared to a crash in a urban traffic environment ($OR = 1/0.72 = 1.39$). Additionally, in case of different injury severity classifications it was more likely in a rural traffic environment that the police classified the individual as more severely injured ($OR = 1.44$).

Considering the participant type, cyclists were more likely to be classified equally by police and hospitals compared to individuals in cars, trucks, motorcycles and pedestrians (odds ratios between 1.24 and 1.64). For individuals on buses it was found that they were more likely to be classified differently compared to individuals in cars or trucks ($OR = 1/0.64 = 1.56$ and $OR = 1/0.62 = 1.61$). In case of different classifications individuals on buses, compared to individuals in cars or trucks, were then more likely to be classified less severe by the police than by the hospitals ($OR = 1.89$ and $OR = 1.36$). Pedestrians had greater odds of being classified more severely than individuals who were in/on a car, truck, bus, motorcycle, moped or bicycle (odds ratios between 1.29 and 2.44)

In case of exactly two traffic participants (i. e. vehicles or pedestrian) involved in the crash the odds for being classified equally by police and hospital were higher compared to individuals who were in a crash involving a single or more than two traffic participants ($OR = 1/0.81 = 1.23$ and $OR = 1.29$). In case of different injury severity classifications an individual in a single vehicle crash was twice as likely to be classified as more severe by the police compared to the case of exactly two involved traffic participants ($OR = 2.13$). For individuals involved in a crash with exactly two traffic participants it was almost twice as likely to be classified more severe by the police compared to individuals in a crash with more than two traffic participants ($OR = 1.93$). Compared to individuals involved in crashes with more than two involved traffic participants it was about four times as likely for individuals in single crashes to be classified more severely ($OR = 4.12$).

Table 3.7: Frequencies of factor levels across equal or different police and hospital classifications for people alone in/on the vehicle or pedestrian involved in a crash with a vehicle. (years 2007-2013, $N = 45543$)

Factor	Level	Equal [%]	Different [%]
Total		69.69	30.31
Gender	Male	68.96	31.04
	Female	70.69	29.31
Age Group	0-17	76.93	23.07
	18-24	68.59	31.41
	25-40	69.44	30.56
	41-60	69.72	30.28
	> 60	66.89	33.11
Transport[a]	Yes	67.87	32.13
	No	77.07	22.93
	Unknown	73.58	26.42
Daytime[b]	Yes	69.80	30.20
	No	69.35	30.65
Traffic Environment	Rural	65.93	34.07
	Urban	72.82	27.18
	Unknown	73.64	26.36
Participant Type	Car	67.22	32.78
	Truck	66.44	33.56
	Bus	76.19	23.81
	Motorcycle	70.30	29.70
	Moped	78.04	21.96
	Bicycle	76.69	23.31
	Pedestrian	72.64	27.36
	Other	71.20	28.80
# Traffic Participants[c]	Single	67.14	32.86
	Two	71.56	28.44
	More than two	66.18	33.82

[a] Ambulance or helicopter transport
[b] Any time from 7.00 to 18.59 o'clock is considered daytime
[c] Amount of traffic participants involved in the crash

Table 3.8: Odds ratios for being classified equally by the police and a hospital comparing the influence of factor levels. (years 2007-2013)

Factor	For	Against	OR (95% CI)	log(OR)	Std. Err.	z-value	p-value
Gender	Male	Female	0.92 (0.88, 0.96)	-0.0819	0.0207	-3.9535	< 0.001[*]
Age Group	0-17	18-24	1.53 (1.41, 1.66)	0.4232	0.0419	10.1028	< 0.001[*]
		25-40	1.47 (1.35, 1.59)	0.3835	0.0412	9.3150	< 0.001[*]
		41-60	1.45 (1.34, 1.57)	0.3700	0.0408	9.0718	< 0.001[*]
		> 60	1.65 (1.51, 1.80)	0.5009	0.0448	11.1895	< 0.001[*]
	18-24	25-40	0.96 (0.91, 1.02)	-0.0397	0.0293	-1.3549	0.175
		41-60	0.95 (0.90, 1.00)	-0.0531	0.0287	-1.8486	0.065
		> 60	1.08 (1.01, 1.16)	0.0777	0.0342	2.2758	0.023[*]
	25-40	41-60	0.99 (0.93, 1.04)	-0.0135	0.0277	-0.4863	0.627
		> 60	1.12 (1.05, 1.20)	0.1174	0.0333	3.5287	< 0.001[*]
	41-60	> 60	1.14 (1.07, 1.22)	0.1309	0.0328	3.9901	< 0.001[*]
Transport[a]	Yes	No	0.63 (0.59, 0.66)	-0.4648	0.0280	-16.5880	< 0.001[*]
		Unknown	0.76 (0.64, 0.90)	-0.2765	0.0874	-3.1642	0.002[*]
	No	Unknown	1.21 (1.01, 1.44)	0.1883	0.0904	2.0834	0.037[*]
Daytime[b]	Yes	No	1.02 (0.97, 1.07)	0.0209	0.0237	0.8821	0.378
Traffic Environment	Rural	Urban	0.72 (0.69, 0.75)	-0.3255	0.0210	-15.5241	< 0.001[*]
		Unknown	0.69 (0.63, 0.76)	-0.3671	0.0491	-7.4842	< 0.001[*]
	Urban	Unknown	0.96 (0.87, 1.06)	-0.0416	0.0492	-0.8457	0.398
Participant Type	Car	Truck	1.04 (0.94, 1.14)	0.0350	0.0480	0.7285	0.466
		Bus	0.64 (0.47, 0.88)	-0.4451	0.1625	-2.7385	0.006[*]
		Motorcycle	0.87 (0.80, 0.94)	-0.1438	0.0416	-3.4547	< 0.001[*]
		Moped	0.58 (0.53, 0.63)	-0.5499	0.0455	-12.0898	< 0.001[*]
		Bicycle	0.62 (0.58, 0.67)	-0.4731	0.0352	-13.4384	< 0.001[*]
		Pedestrian	0.77 (0.71, 0.84)	-0.2582	0.0398	-6.4941	< 0.001[*]
		Other	0.83 (0.65, 1.06)	-0.1871	0.1249	-1.4986	0.134
	Truck	Bus	0.62 (0.44, 0.86)	-0.4800	0.1685	-2.8488	0.004[*]
		Motorcycle	0.84 (0.74, 0.94)	-0.1787	0.0609	-2.9338	0.003[*]
		Moped	0.56 (0.49, 0.63)	-0.5848	0.0636	-9.1920	< 0.001[*]
		Bicycle	0.60 (0.54, 0.67)	-0.5080	0.0567	-8.9549	< 0.001[*]
		Pedestrian	0.75 (0.66, 0.84)	-0.2932	0.0597	-4.9134	< 0.001[*]
		Other	0.80 (0.62, 1.04)	-0.2221	0.1326	-1.6754	0.094
	Bus	Motorcycle	1.35 (0.97, 1.87)	0.3013	0.1668	1.8064	0.071
		Moped	0.90 (0.65, 1.25)	-0.1048	0.1678	-0.6246	0.532
		Bicycle	0.97 (0.70, 1.34)	-0.0280	0.1653	-0.1695	0.865
		Pedestrian	1.21 (0.87, 1.67)	0.1868	0.1663	1.1232	0.261
		Other	1.29 (0.87, 1.93)	0.2579	0.2042	1.2632	0.207
	Motorcycle	Moped	0.67 (0.59, 0.75)	-0.4061	0.0590	-6.8872	< 0.001[*]
		Bicycle	0.72 (0.65, 0.80)	-0.3293	0.0515	-6.4000	< 0.001[*]
		Pedestrian	0.89 (0.80, 0.99)	-0.1145	0.0547	-2.0934	0.036[*]
		Other	0.96 (0.74, 1.24)	-0.0434	0.1304	-0.3327	0.739
	Moped	Bicycle	1.08 (0.97, 1.20)	0.0768	0.0546	1.4056	0.160
		Pedestrian	1.34 (1.20, 1.50)	0.2916	0.0577	5.0569	< 0.001[*]
		Other	1.44 (1.11, 1.86)	0.3627	0.1317	2.7544	0.006[*]
	Bicycle	Pedestrian	1.24 (1.12, 1.37)	0.2149	0.0500	4.2998	< 0.001[*]
		Other	1.33 (1.03, 1.71)	0.2859	0.1285	2.2252	0.026[*]
	Pedestrian	Other	1.07 (0.83, 1.38)	0.0711	0.1298	0.5474	0.584
# Traffic Participants[c]	Single	Two	0.81 (0.78, 0.85)	-0.2082	0.0228	-9.1517	< 0.001[*]
		More than two	1.04 (0.97, 1.12)	0.0434	0.0356	1.2214	0.222
	Two	More than two	1.29 (1.20, 1.37)	0.2516	0.0333	7.5651	< 0.001[*]

[a] Ambulance or helicopter transport

[b] Any time from 7.00 to 18.59 o'clock is considered daytime

[c] Amount of traffic participants involved in the crash

[*] Log odds ratio is significantly different from 0 on a $\alpha = 0.05$ significance level, i. e. odds ratio is statistically significantly different from 1.

4 Discussion

4.1 Estimation of under-reporting of road crashes

4.1.1 Assumptions of the capture-recapture model

For the capture-recapture model to be applicable certain assumptions (see Section 1.3.5) need to be fulfilled. The assumption of a closed population seems reasonable since for each road crashes there is the possibility that it is reported to either data source.

The assumption of homogeneity in the population is likely to be violated in the available data, since not every sub-population is equally likely to be under-reported. This observed heterogeneity in the data could lead to problems when estimating the overall under-reporting. As described in Chao (2001), this so called local dependence can lead to dependence between the data sources and therefore to over- or under-estimation of the population size and then in turn to over- or under-estimation of under-reporting. It could however not be determined in which direction this possible bias might lead.

The assumption of independence between the capture and the recapture sample is quite central to the traditional formulation of the problem. However, when road crash data from the police and hospitals is considered as two separate samples then it seems reasonable to assume that they exhibit some dependence. It is plausible that a person known to either police or hospital because of a road crash is more likely to show up in the other source as well. This is called *positive correlation* and leads to the under-estimation of the total population size, as mentioned in Chao (2001), and thus to an underestimation of under-reporting.

4.1.2 Matching algorithm

The matching algorithm which is used in STRADA to link police and hospital reports to road crashes (see Section 1.3.1) was not researched in detail. For this a thorough study of how the matching works and manual comparison of a sufficient amount of reports would be necessary. No further inquiries were made into this topic. It was assumed that the algorithm was properly developed and the matching indicator `Q` $\geq 60\%$ was used.

4.1.3 Affirmation of the necessity of complete hospital coverage

b The results in Section 3.1.1 showed that the lower bounds for under-reporting acquired with the amount method changed drastically when the selection was restricted to those crashes that occurred in a county with complete hospital coverage. However, the effect on the capture-recapture method, which estimates the true amount of under-reporting, was little. This suggests that the trend that is visible in the upper left of Figure 3.1 is a consequence of the growing number of hospitals that report to STRADA and not an actual increase in under-reporting (see Section 1.3.1). This finding lead to the decision to solely consider crashes from counties that had reached complete hospital coverage.

The restricted dataset was used for the amount method as well as the capture-recapture method even though it was found that there is little effect on the estimates acquired from the capture-recapture method. This was done to use consistent data for both methods and thus make the results comparable.

4.1.4 Single bicycle crashes

Under-reporting of single bicycle crashes for 2003-2013 was at least 93% (see Section 3.1.2) and the exclusion of single bicycle crashes lead to a reduction of 15% in the lower bound for under-reporting of all crashes in the years 2003-2013 (see Section 3.1.5). A possible reason for the high rate of under-reporting could be that it seems less likely that the police is notified when a single cyclist falls and gets injured in a road traffic environment without the involvement of another vehicle or pedestrian.

4.1.5 Small standard error of individual under-reporting estimates

The standard deviations of the capture-recapture estimates are small compared to the seasonal variations that occur throughout a year (see Section 3.1.3). Additionally they shrink in size and thus are even less important compared to the general spread of the estimates. A possible explanation for the shrinkage of the standard errors is that the amount of available data per year grows over time as more and more counties reach complete hospital coverage. Since the standard errors are small compared to the actual under-reporting estimates ($\max(\sqrt{\mathrm{Var}(\hat{p}_{cr})})/\hat{p}_{cr} = 5.6\%$ in Figure 3.5) and seasonal patterns are much more prevalent the standard errors of the individual estimates were not given any further consideration. Rather the monthly or alternatively yearly measures of spread described in Section 2.2.3 were used.

4.1.6 Seasonal patterns

Under-reporting was generally highest during the months May to September and lowest during the months November to March, while the months April and October stayed mid-range (see Section 3.1.4). A possible explanation for this is that during the warmer months May to September the usage of bicycles, mopeds and motorcycles as means of transport is popular and crashes involving one of these vehicles exhibit high under-reporting (see Section 3.1.5). During winter motorcycles are scarcely driven and bicycle as well as moped traffic is reduced. Another possibility is that, since summer is a popular holiday time in Sweden, the police might have less resources during that time. There was however no further inquiry into this topic.

4.1.7 Systematic errors

Under-reporting in the months October, November and December in 2013 was higher than in previous years (by about 5-10%). Furthermore, 2013 was the only year where the maximum and minimum percentage of under-reporting both occurred in a winter month, explicitly between January and December (see Section 3.1.4). This is because 2013 was the only year with a clear upward trend without the usual anticipated decent at the end of the year (see Figure 3.6).

In late 2013 and early 2014 the police experienced technical problems that had consequences for STRADA (see Section 2.1.1). It is likely that the observed bias of higher under-reporting towards the end of the year 2013 was caused by these difficulties.

Additionally, the largest difference in under-reporting within one year was in 2010. In October 2010 the police and hospitals switched to a web client to report to the STRADA database. It is thus possible that some crashes during the transition period have not been reported because of technical problems. This was however not investigated.

4.1.8 Influence of factors

The percentage of under-reporting which was determined for the available dataset was found to be at least 48% (amount method) and estimated to be 65% (capture-recapture method) in the years 2010-2013 and the years 2003-2009 did show similar results. The percentage of under-reporting found in Larsson and Björketun (2008) for the period 2003-2005 was 53% (see Section 1.1.1) which is higher than the lower bound found here but lower than the estimated rate of under-reporting. The reason for this discrepancy could be that there were eight more years of data available for this thesis and that STRADA was still in an early stage during the years 2003-2005.

Under-reporting of severe crashes when excluding single bicycle crashes was found to be lower than that for slight crashes (see Section 3.1.5). This confirms the frequent intuition that availability of police data for severe crashes is quite comprehensive, as long as single bicycle crashes are not considered (see Section 3.1.2). Increasing under-reporting with decreasing injury severity is in line with the result found in Amoros et al. (2006). This also confirms results from Larsson and Björketun (2008) where they found that under-reporting of slight crashes is 1.5 to 2 times as high as for severe crashes (see Section 1.1.1).

It was unexpected that under-reporting did not show any relation to daytime. The only difference was a slight increase of under-reporting for slight crashes during night-time (by about 6%). This difference could be due to more people (especially pedestrians and cyclists) being under the influence of alcohol at night-time, making it less likely that they call the police in case of a crash, and that there are generally less people under way who could report a crash to the police.

The size of the considered sub-populations, e. g. crashes between cars and bicycles, has increased for the years 2010-2013 compared to 2003-2009. Additionally more than half of the available data was for crashes reported between 2010-2013 (see Section 3.1.4). A possible explanation for this is that during the years 2010-2013 the possible number of counties from which road crashes are accepted due to the restriction to complete hospital coverage almost doubled (see Table 1.1). This especially entailed Västra Götaland county and Stockholm county with Sweden's two largest cities Gothenburg and Stockholm, which account for a large portion of Sweden's urban traffic.

When a moped or bicycle was involved in the crash under-reporting rates were particularly high and even for the involvement of motorcycles high under-reporting was observed (see Section 3.1.5). This confirms results from Janstrup et al. (2016) where it was found that the involvement of motorcyclists and cyclists lead to an increase in under-reporting.

Crashes involving at least one truck had the lowest under-reporting rate in relation to crashes involving one of the other considered participant types (see Section 3.1.5). Additionally it has been found that crashes between trucks and pedestrians, mopeds or motorcycles had a low under-reporting rate. This could be due to the fact that crashes involving a truck are usually quite severe, especially if the crash involved pedestrian or a person on a moped or motorcycle. Under-reporting of severe crashes however was comparatively low and thus the under-reporting of trucks should be as well. Truck crashes also take longer to clean and often traffic needs to be re-directed. This makes police presence at a crash involving a truck even more important.

4.2 Consistency of injury severity classifications

4.2.1 Similarity of injury severity classifications for individuals in the same vehicle

It was determined that individuals in/on the same vehicle were more likely to have the same combination of police and hospital injury severity classifications then people who were alone in/on the vehicle or were pedestrians involved a crash with a vehicle.

A possible explanation for the dependence might be that, since the considered people occupied the same vehicle they experienced similar forces during the crash and thus might sustain injuries of similar severity. Additionally, since there is only one crash scene for all individuals it will be investigated by the same police officers and the rescue team and/or ambulance that is at the scene is the same.

4.2.2 Influence of factor levels

The comparison of injury classifications between police and hospital data was based on the idea that the threshold ISS ≥ 9 is reasonable to classify a person as severe by the same standards as the police does (see police guidelines in Section 1.3.4). For this thesis no additional investigation of the feasibility of this translation was made.

While hospitals and police agreed on the injury severity classification in more than two out of three cases, police classified more severely in almost 90% of all cases where the classifications were different. In the UK Morris, Mackay, Wodzin, and Barnes (2003) investigated how consistent police injury severity classifications were compared to a person's maximum AIS score (MAIS) and the ISS. They found that for their data it was not possible to declare a clear translation between ISS scores and the police injury classifications slight and severe. They rather found that there was a considerable amount of people who were classified as severe by the police but were assigned AIS values 1 or 2 by a hospital. The reason for the police to classify many individuals more severely could therefore have been that the translation of ISS values to police injury severity classifications was not correct in all cases. As mentioned above, no further inquiry into this topic has been made.

Older people (age group > 60) had higher chances of being classified differently by the police and hospitals and in case they classified differently they were usually classified less severe by the police (see Section 3.2.2). A possible explanation for this could be that older people are often more fragile and easily sustain internal injuries or broken bones which might however not always be visible to the police.

Individuals who were transported by an ambulance or a helicopter were more often classified differently and in that case more severely by the police (see Section 3.2.2). This could be due to the fact that the police should classify an injury as severe whenever the individual is expected to be hospitalized (see Section 1.3.4). The police might therefore take ambulance or helicopter transport as a cue for possible hospitalization and classify the person as severely injured.

Individuals involved in a crash in a rural traffic environment were more likely to be classified more severely by the police. By definition a rural traffic environment is any road with a posted speed limit above 50 km/h (Mattsson & Ungerbäck, 2013). Therefore a possible reason for the police classifying individuals more severely in rural crashes could be that these crashes happen at higher speeds and thus it is likely that their appearance is worse compared to urban crashes.

The odds to be classified more severely by the police for individuals in crashes with a single participant compared to those with two and those with more than two were in a $4:2:1$ relation. A possible explanation for this could be that the police classify the injury severity of an individual in relation to the injury severities of the other individuals involved in the same crash. Maybe the most severely injured person is taken as a baseline and the other individuals are classified in relation to this person. It then could happen that people, who would be rated *severe* in a single participant crash get rated *slight* if there are multiple other individuals which are injured even more severely. Another explanation could be that it is possible that the police arrives after the rescue and ambulance and the injured individuals might not be at the crash scene any longer. The more traffic participants and thus individuals were involved in the crash the less likely it is that a full reconstruction of their injury severity is possible.

5 Conclusion

In this thesis under-reporting in police reported road crash data from STRADA as well as the consistency of police and hospital injury severity classifications were investigated.

It was confirmed that known technical problems in the police reporting system at the end of 2013 were visible in the under-reporting especially when single bicycle crashes were excluded.

For the total dataset the rate of under-reporting was at least 48% and estimated to be 65%. About 98% of single bicycle crashes were under-reported in police crash data and thus their inclusion biases the under-reporting noticeably.

It was found that the percentage of under-reporting exhibits a seasonal pattern throughout the years with higher results in the months May to September compared to lower results in November to March. The differences between monthly lower bounds of under-reporting varied in the range of 6% to 11% while the differences between monthly estimates of under-reporting varied between 6% and 14%. The most severe difference between monthly under-reporting estimates excluding single bicycle crashes was found in 2010.

When single bicycle crashes were excluded then the under-reporting of severe crashes was at least 7-10% and estimated to be 10-14%. On the contrary the under-reporting of slight crashes was at least 35-38% and estimated to be 51-54%.

Under-reporting was also investigated for the involvement of different vehicles. For crashes involving cars it was found that under-reporting was at least 28% and estimated to be 43%. For crashes involving trucks the lowest rate of under-reporting was found (at least 17% and estimated to be about 28%). Particularly high rates of under-reporting were found for crashes involving mopeds (at least 52%) and bicycles (at least 81%).

For the investigation of the consistency of police and hospital reported classifications of injury severity it was found that male gender, age above 60, ambulance or helicopter transport and rural traffic environments lead to higher odds for different classifications by the police and hospitals compared to their alternatives.

Furthermore, it was found that individuals who were in/on the same vehicle were more likely to be assigned the same combinations of police and hospital injury severity classifications.

6 Future work

The focus in this thesis was police data and the under-reporting of road crashes. There are other circumstances under which under-reporting is possible.

As the capture-recapture estimates in this work already suggest, there is a possibility for under-reporting in the hospital data as well. This topic could be particularly interesting to investigate in the future, since all emergency hospitals in Sweden report to STRADA as of 2016. Such an analysis could be based on comparisons to police data or other data sources like insurance data.

A different type of under-reporting which could be investigated in the police data is the under-reporting of uninjured people.

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A Variable coding and conversions

In the following, the data selection process according to the criteria in Sections 2.1.1 and 2.1.2 is described in detail. All of the data was taken from the STRADA Access database dump retrieved on 2015-10-06.

A.1 Under-reporting of road crashes

A.1.1 Police data

Separation into crashes

There are three crashes which were connected to two police reports each. Manual inspection showed that the police reports did not describe the same crash leading to the exclusion of these six reports.

Crash date and time

The time-stamp in the variable `acc_date` available in the table `report`, which was available for every police reported crash, was used to determine the crash date and time.

Crash severity

The crash severity was determined by use of the variable `injury_extent`, which is coded in Table A.1, of all people linked to the crash, i. e. all entries in the table `person` linked to the police report. A crash was selected if at least one person was severely or slightly injured but none was killed. The crash severity was chosen as the worst of these two possibilities. This lead to the exclusion of 6088 crashes.

Table A.1: Coding of the variable `injury_extent` in the table `person`.

Code	Description	Translation
1	Dödad	Killed
2	Svårt skadad	Severely injury
3	Lindrigt skadad	Slightly injured
4	Oskadad	Uninjured
9	Uppgift saknas	Missing
20	Anonymiserad	Anonymised*

* Codes other reasons of death not included in official crash statistics

Crash participant types

The variable `sub_elem_type` from the table `traffic_elements` was used to determine the types of traffic elements involved in the crash. The original coding, which can be seen in Table A.2, was simplified according to Table A.3. Applying the selection criterion from Section 2.1.1 lead to the exclusion of 2101 crashes.

Place type

The variable `place_type` in the table `police_report` describes the traffic environment in which the crash occurred. The coding of this variable is described in Table A.4. The type *Other* was excluded, which lead to the exclusion of 5468 crashes.

Swedish county

The variable `municipality` in the table `report` was used to determine the Swedish municipality[1] in which the crash occurred. Therefore the Swedish county[2] was known as well, since municipalities are part of exactly one county. The variable was available for every police report.

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[1] *kommun*, in Swedish

[2] *län*, in Swedish

Table A.2: Coding of the variable `sub_elem_type` in the table `traffic_element`.

Code	Description	Translation
1	Personbil	Car
2	Lastbil (tung)	Truck (heavy)
3	Lastbil (lätt)	Truck (light)
4	Buss	Bus
5	Motorcykel (tung)	Motorbike (heavy)
6	Motorcykel (lätt)	Motorbike (light)
7	Moped (klass 1)	Moped (Class 1, max. 45 km/h)
8	Moped (klass 2)	Moped (Class 2, max. 25 km/h)
9	Okänt fordon	Unknown vehicle
11	Moped (okänd)	Moped (unknown type)
12	Cykel	Bike
13	Fotgängare	Pedestrian
16	Motorcykel (okänd)	Motorcycle (unknown type)
17	Lastbil (okänd)	Truck (unknown type)
21	Traktor	Tractor
22	Motorredskap	Heavy equipment
23	Snöskoter	Snowmobile
24	Terrängvagn	Off-road vehicle (over 400kg)
25	Terrängskoter	Off-road vehicle (max. 400kg)
26	Terränghjuling	All-terrain vehicle (ATV)
27	Övrigt fordon	Other vehicle
28	Släp	Trailer
31	Tåg	Train
32	Spårvagn	Tram
51	Älg	Elk
52	Rådjur/Hjort	Roe deer/Deer
53	Ren	Reindeer
54	Dovhjort, kronhjort	Fallow deer, Red deer
57	Vildsvin	Boar
59	Övrigt vilt	Other quarry
61	Häst	Horse
62	Nötkreatur	Cattle
69	Övriga tamdjur	Other domestic animal
79	Okänt djur	Unknown animal
80	Uppgift saknas	Missing

Table A.3: Conversion of the variable `sub_elem_type` to simplified categories.

Category	`sub_elem_type` coding
Car*	1
Truck*	2, 3, 17
Bus*	4
Motorcycle*	5, 6, 16
Moped*	7, 8, 11
Bicycle*	12
Pedestrian	13
Vehicle on rails	31, 32
Other vehicles	21 to 28
Quarry	51 to 59
Domestic animal (including riders)	61, 62, 69
Unknown	9
Missing	80

* Crash must involve at least one of the starred vehicles

Table A.4: Coding of the variable `place_type` in the table `police_report`.

Code	Description	Translation
1	Gatu-/Vägkorsning	Road crossing
2	Gatu-/Vägsträcka	Road
3	Gångbana/trottoar	Pavement
5	Gång- och cykel-bana/väg	Pavement and bicycle path
21	Trafikplats	Interchange
23	Cirkulationsplats	Roundabout
100	Annan	Other

A.1.2 Hospital data

Separation into crashes

The pre-linked road crashes from STRADA were used, since hospital reports describe individuals instead of crashes. As described in Section A.1.1 crashes were excluded from the police data and thus 4511 corresponding road crashes in the hospital data were excluded. All remaining reports (with very few exceptions mentioned below) are linked together with `Q` ≥ 60, as is also the recommended level in Howard and Linder (2014).

In three cases hospital reports were matched to the crash but were assigned different `Q` values. There was one or two reports matched with `Q` $= 0$ to other reports that were assigned `Q` ≥ 80. The reports with `Q` $= 0$ were excluded in the retrieval of crash specific information, but no further road crashes were excluded since other hospital reports for the crash were available.

Crash date and time

The hospital reports are self-reported by the patients and therefore the time-stamps available from hospital reports are considered less accurate compared to police data. Since matched hospital reports did not always state the same date and time it was necessary to harmonise this information.

1. The police report's time-stamp was used if available
2. If no police report was available, the time-stamp from the hospital reports was used if there was only one report or the time-stamps were equal
3. If no police report was available and the time-stamps were unequal for matched hospital reports, then the average of the available time-stamps was used

Crash severity

The crash severity was determined in the same way as it was defined in Section A.1.1. The injury severity classifications *slight* and *severe* were taken from the variable `injury_extent_hosp` from the table `hospital_report` and the coding is described in Table A.5. The categories slightly and moderately injured from the table were jointly considered as slightly injured.

A crash was considered if nobody involved was marked as dead, and at least one person was marked as slightly or severely injured. For crashes which appear in both sources the crash severity from the police data has been used. This results in the exclusion of 23217 crashes from the hospital data.

Crash participant types

The types of traffic participants involved in the crash were determined with the variables `was` and `against` available in the table `hospital_report`. The first variable, `was`, contains information about the kind of traffic participant the person was or which kind of vehicle the person occupied during the crash. The second variable, `against`, contains the type of the opposing crash participant.

The two variables have similar coding that can be found in Table A.6 and A.7. Similarly to police data the participant types were the case of traffic participants from police reports (see section above) variables were divided into fewer categories. This is described in Table A.8 and A.9.

Only crashes that involve at least one of the vehicles listed in Section 2.1.1 or can be found in police data are kept. This lead to the exclusion of 94389 crashes.

Table A.5: Coding of the variable `injury_extent_hosp` in the table `hospital_report`.

Code	Description	Translation
1	Död, till följd av olyckan	Dead, as a consequence of the crash
2	Måttligt skadad (ISS 4-8)	Moderately injured (considered as slightly injured in this study)
3	Lindrigt skadad (ISS 1-3)	Slightly injured
4	Oskadad	Uninjured
5	Allvarligt skadad (ISS 9-)	Severely injured
8	Osäker skada	Uncertain injury
9	Okänd skada	Unknown injury
11	Död, annan orsak	Dead, other cause
12	Död, osäkert	Dead, uncertain cause
13	Död vid ankomst, till följd av olyckan	Dead at arrival, as a consequence of the crash
14	Död vid ankomst, annan orsak	Dead at arrival, other cause
15	Död vid ankomst, osäker orsak	Dead at arrival, uncertain cause

Place type

The traffic environment was determined with the variable `place_type_hosp` in the table `hospital_report`. The coding of this variable is given in Table A.10 and the chosen place types have been marked. Since hospital reports are per individual instead of per crash different reports usually have different place types. A crash has therefore been kept if the place type of at least one of the reports was in the list of possible ones or if the corresponding police report has been kept, i. e. the police specified a suitable place type.

This selection lead to the exclusion of 17709 crashes.

Swedish county

As described in Section A.1.1 the variable `municipality` from the table `report` can be used to determine the county. In about 3% of hospital reported crashes this variable was missing and in less than 1% the municipality was set to *abroad*.

Only reports where the county could be determined and the crash was not marked as abroad were kept. This lead to the exclusion of 3192 crashes.

A.2 Consistency of injury severity classifications

Individuals in both sources

To determine misclassification, the injury rating of individuals who show up in both sources have to be compared. There are 48862 road crashes which show up in both sources in the desired time frame which are linked with at least $\texttt{Q} \geq 90\%$. Linked to these crashes are 105887 entries in the `person` table as well as 68072 hospital reports. Among these 66003 matched uniquely.

ISS and injury severity

For the police injury severity classification the variable `injury_extent` in the table `police_report` was used, while the variables `iss` and `dead` in the table `hospital_report` were used to determine the hospital injury severity classification. In the latter case an individual was kept if $0 \leq \texttt{iss} \leq 75$ and `dead` wasn't set. This lead to the exclusion of 1720 individuals.

Age groups

Information about age and gender is available from both the `person` and the `hospital_report` table. Both variables existed for every selected person in the hospital reported data and were consistent the police data. Therefore this information was taken from hospital data.

Table A.6: Coding of the variable `was` from the table `hospital_report`.

Code	Description	Translation
10	Fotgängare	Pedestrian[1]
11	Inlinesåkare	In-line skater[1]
12	Rullstolsburen	Wheelchair user
13	Skateboardåkare	Skateboarder[1]
14	Sparkcykelåkare	Footbiker[1]
15	Sparkstöttingsåkare	Kicksledder[1]
16	Annan	Other[1]
20	På cykel	On a bike
30	På moped	On a moped
31	På EU-moped	On a moped (Class 1, max. 45 km/h)
40	På motorcykel	On a motorcycle
41	På tung motorcykel	On a heavy motorcycle
42	På lätt motorcykel	On a light motorcycle
50	I personbil	In a car
60	I lastbil	In a truck
61	I tung lastbil	In a heavy truck
62	I lätt lastbil	In a light truck
70	I buss	In a bus
80	Övrigt	Other vehicle
81	På snöskoter	On a snowmobile
82	I spårvagn	On a tram
83	I traktor	In a tractor
84	I tåg	On a train
85	Ryttare	Rider
86	På fyrhjuling	On an all-terrain vehicle (ATV)
90	Okänt	Unknown

[1] Considered as a pedestrian

Table A.7: Coding of the variable `against` from the table `hospital_report`.

Code	Description	Translation
10	Fotgängare	Pedestrian[1]
11	Inlinesåkare	In-line skater[1]
12	Rullstolsburen	Wheelchair user[1]
13	Skateboardåkare	Skateboarder[1]
14	Sparkcykelåkare	Footbiker[1]
15	Sparkstöttingåkare	Kicksledder[1]
16	Annan	Other[1]
20	Cykel	Bicycle
30	Moped	Moped
31	EU-moped	Moped (Class 1, max. 45 km/h)
40	Motorcykel	Motorcycle
41	Tung motorcykel	Heavy motorcycle
42	Lätt motorcykel	Light motorcycle
50	Personbil	Car
60	Lastbil	Truck
61	Tung lastbil	Heavy truck
62	Lätt lastbil	Light truck
70	Buss	Bus
80	Övrigt	Other vehicle
81	Snöskoter	Snowmobile
82	Spårvagn	Tram
83	Traktor	Tractor
84	Tåg	Train
86	Fyrhjuling	All-terrain vehicle (ATV)
90	Okänt	Unknown
801	Rådjur eller hjort	Roe deer/Deer
802	Älg	Elk
803	Ren	Reindeer
804	Annat vilt	Other quarry
805	Häst	Horse
806	Annat tamdjur	Other domestic animal
807	Vildsvin	Boar
810	Fordon	Vehicle
811	Träd	Tree
812	Stolpe	Post
813	Berg/Stor sten	Large rock
814	Vägtrumma	Culvert
815	Hus	House
816	Brofundament	Bridge foundation
817	Räcke	Handrail
818	Mur	Wall
819	Annat/Ej spec	Other/Not specified

[1] Considered as a pedestrian

Table A.8: Conversion of the variable `was` to simplified categories.

Category	`was` coding
Car[*]	50
Truck[*]	60, 61, 62
Bus[*]	70
Motorcycle[*]	40, 41, 42
Moped[*]	30, 31
Bicycle[*]	20
Pedestrian	10
Vehicle on rails	82, 84
Other motorized vehicle	80, 81, 83, 86
Other VRU	11 to 16, 85
Unknown	90

[*] Crash must involve at least one of the starred vehicles

Table A.9: Conversion of the variable `against` to simplified categories.

Category	Element type codes
Car[*]	50
Truck[*]	60, 61, 62
Bus[*]	70
Motorcycle[*]	40, 41, 42
Moped[*]	30, 31
Bicycle[*]	20
Pedestrian	10
Vehicle on rails	82, 84
Other motorized vehicle	80, 81, 83, 86
Wildlife	801 to 804, 807
Domesticated animal	805, 806
Other VRU	11 to 16
Object	810 to 818
Unknown	90, 819

[*] Crash must involve at least one of the starred vehicles

Table A.10: Coding of the variable `place_type_hosp` in the table `hospital_report`.

Code	Description	Translation
50	Okänd	Unknown
51	Gatu-/Vägsträcka[1]	Straight road
52	Gatu-/Vägkorsning[1]	Road crossing
53	Cirkulationsplats/Rondell[1]	Roundabout
54	Gång- och Cykelbana (-väg)[1]	Walkway or bicycle path on road
55	Gångbana/Trottoar[1]	Separate walkway
56	Buss-/Spårvagnshållplats	Bus or tram stop
60	Banvall	Trackbed
70	Privat område	Private area
71	Naturområde	Mostly untouched natural area, not used for resource acquisition
72	Trafikplats[1]	Interchange
81	Park	Park
82	Torg	Open space
83	Parkeringshus	Car park
84	Separat P-plats	Separate parking space
85	Bensinstation	Fuel station
86	Taxistation	Taxi station
87	Industriområde	Industrial area
88	Hamnområde	Harbour
89	Tomt/Gård/Enskilt område	Private premises
90	Skolgård	School yard
91	Idrottsplats	Sports ground
92	Skogsstig	Forest road or trail
93	Kyrkogård	Graveyard
94	Annan	Other

[1] Considered in this thesis

B Results: Under-reporting of road crashes

Table B.1: Estimates of under-reporting for different sub-populations of size n for the years 2003-2006. These are taken from the total population of crashes selected for under-reporting of size $N = 184953$. The number of crashes in each sub-population which is available in police and hospital data is denoted B.

Sub-population	Amount method			Capture-Recapture method			Proportions	
	$\mu_{p_{lb}}$ [%]	s_{lb}^{max} [%]	s_{lb}^{mean} [%]	$\mu_{p_{cr}}$ [%]	s_{cr}^{max} [%]	s_{cr}^{mean} [%]	n/N [%]	B/n [%]
All crashes	45.88	8.36	3.67	58.25	10.00	3.95	22.73	31.86
All crashes[a]	34.67	5.89	2.22	46.79	8.21	2.65	18.49	38.80
Single bicycle crashes	96.59	3.59	1.27	98.12	1.90	0.84	4.25	1.65
Severe crashes[a]	9.45	8.64	2.38	13.57	11.63	3.40	2.31	62.26
Slight crashes[a]	37.71	7.51	2.50	51.12	9.45	2.91	16.17	35.44
Daytime[a,b,d]	9.09	10.03	2.77	12.94	11.92	3.63	1.61	63.49
Daytime[a,c,d]	37.40	7.72	2.62	50.53	10.55	3.10	12.00	35.93
Night-time[a,b,e]	9.88	9.88	4.65	13.93	17.02	6.58	0.71	59.46
Night-time[a,c,e]	39.31	11.38	4.12	53.08	12.73	4.52	4.17	34.03
Car involved	29.04	7.89	2.23	40.54	8.09	2.47	14.87	42.45
Truck involved	16.12	12.69	4.15	23.39	16.72	6.13	1.50	49.63
Bus involved	33.33	33.33	9.75	46.32	46.32	13.08	0.44	39.44
Motorcycle involved	35.88	64.12	13.93	48.14	51.86	14.26	1.08	40.45
Moped involved	51.08	28.92	8.68	65.86	18.89	7.51	2.28	27.46
Bicycle involved	74.78	8.92	3.59	84.45	8.12	2.86	6.82	13.25
Bicycle involved[a]	38.76	15.23	5.52	52.56	19.04	6.74	2.57	32.39
Pedestrian involved[l]	26.25	17.68	5.98	41.17	27.93	8.46	1.11	34.91
Car-Truck crashes[k]	15.05	18.29	4.37	22.29	20.93	5.59	0.89	51.89
Car-Bus crashes[f,k]	21.31	7.07	2.48	28.68	10.60	4.11	0.16	52.38
Car-Motorcycle crashes[f,k]	15.54	2.45	1.14	23.23	4.90	1.56	0.35	52.94
Car-Moped crashes[k]	21.43	21.43	5.79	33.27	33.27	7.42	0.83	45.79
Car-Bicycle crashes[k]	26.28	16.28	4.05	38.85	25.89	6.28	1.55	40.49
Car-Pedestrian crashes[k]	21.05	20.88	6.72	34.94	29.94	9.64	0.79	37.81
Truck-Bus crashes[f,k]	19.64	20.36	12.68	31.10	31.10	12.57	0.02	45.45
Truck-Motorcycle crashes[f,k]	14.17	10.83	7.98	19.45	13.40	8.68	0.03	58.00
Truck-Moped crashes[f,k]	6.55	22.02	8.04	10.65	35.85	12.94	0.04	49.30
Truck-Bicycle crashes[f,k]	21.83	10.47	4.03	29.35	7.30	3.86	0.08	46.10
Truck-Pedestrian crashes[f,k]	6.80	24.45	7.69	14.79	57.08	18.89	0.04	34.67
Bus-Motorcycle crashes[h,k]	10.34	–	–	14.76	–	–	0.02	58.62
Bus-Moped crashes[g,k]	17.39	–	–	23.07	–	–	0.01	56.52
Bus-Bicycle crashes[f,k]	13.04	0.00	0.00	20.76	3.15	2.06	0.05	47.83
Bus-Pedestrian crashes[f,k]	18.51	13.74	6.69	32.74	21.24	11.51	0.05	32.22
Motorcycle-Moped crashes[g,k]	9.52	–	–	14.89	–	–	0.01	52.38
Motorcycle-Bicycle crashes[f,k]	16.25	16.25	9.57	19.55	19.55	10.75	0.02	60.00
Motorcycle-Pedestrian crashes[f,k]	15.56	24.44	12.22	21.76	33.22	16.84	0.01	42.86
Moped-Bicycle crashes[f,k]	27.95	5.57	2.72	43.68	7.64	5.73	0.14	34.94
Moped-Pedestrian crashes[f,k]	31.84	5.66	3.09	51.19	19.09	7.77	0.06	25.22
Bicycle-Pedestrian crashes[f,k]	58.20	9.98	5.12	73.44	3.47	2.86	0.13	19.91

[a] single bicycle crashes excluded
[b] only severe crashes are considered
[c] only slight crashes are considered
[d] 7.00 to 18.59 o'clock is considered as *daytime*
[e] 19.00 to 6.59 o'clock is considered as *night-time*
[f] results are averages of yearly estimates of under-reporting
[g] results are estimates of under-reporting for the combined data from 2003-2006
[h] results are estimates of under-reporting for the combined data from all years 2003-2013
[k] crashes involving at least one of each of the mentioned participant types are considered
[l] crashes involving at least one of the vehicles listed in Section 2.1.1

Table B.2: Estimates of under-reporting for different sub-populations of size n for the years 2007-2009. These are taken from the total population of crashes selected for under-reporting of size $N = 184953$. The number of crashes in each sub-population which is available in police and hospital data is denoted B.

Sub-population	Amount method			Capture-Recapture method			Proportions	
	$\mu_{p_{lb}}$ [%]	s_{lb}^{max} [%]	s_{lb}^{mean} [%]	$\mu_{p_{cr}}$ [%]	s_{cr}^{max} [%]	s_{cr}^{mean} [%]	n/N [%]	B/n [%]
All crashes	46.51	10.17	4.01	60.68	11.95	4.16	21.17	30.53
All crashes[a]	33.72	6.71	1.95	47.23	8.07	2.35	16.85	37.97
Single bicycle crashes	96.90	2.92	0.92	98.44	3.54	0.70	4.31	1.46
Severe crashes[a]	7.18	7.18	1.98	10.32	10.32	2.90	1.89	63.78
Slight crashes[a]	36.84	6.93	2.15	51.50	7.81	2.51	14.96	34.70
Daytime[a,b,d]	6.70	6.70	2.32	8.79	9.95	3.28	1.32	65.70
Daytime[a,c,d]	36.44	7.42	2.21	50.93	8.28	2.59	10.93	35.31
Night-time[a,b,e]	6.56	11.62	4.23	9.34	18.21	6.13	0.57	59.35
Night-time[a,c,e]	37.03	10.34	3.93	51.97	11.94	4.22	4.02	33.05
Car involved	27.36	8.26	2.12	38.67	9.08	2.52	13.09	42.20
Truck involved	16.00	13.17	3.28	23.85	19.27	5.16	1.30	50.37
Bus involved	34.52	27.01	9.67	46.73	33.16	11.36	0.35	35.97
Motorcycle involved	40.45	39.55	10.87	49.67	42.72	11.15	1.04	36.91
Moped involved	48.28	19.11	5.07	63.76	18.51	4.74	2.47	27.15
Bicycle involved	77.12	10.92	3.18	86.55	9.99	2.41	6.70	12.07
Bicycle involved[a]	38.70	15.71	5.87	54.49	21.77	6.33	2.38	31.26
Pedestrian involved[l]	24.76	12.08	5.16	41.31	24.68	8.80	0.94	35.72
Car-Truck crashes[k]	16.54	13.09	4.46	22.38	22.51	6.61	0.74	53.31
Car-Bus crashes[f,k]	24.19	2.77	1.53	34.51	4.12	1.75	0.12	48.17
Car-Motorcycle crashes[f,k]	17.54	1.43	0.60	24.13	2.65	1.03	0.29	51.72
Car-Moped crashes[k]	20.47	20.47	6.00	30.94	33.81	8.68	0.81	42.87
Car-Bicycle crashes[k]	21.85	13.45	3.85	33.73	16.95	5.52	1.42	40.80
Car-Pedestrian crashes[k]	19.62	18.48	5.87	34.18	21.55	9.75	0.65	39.21
Truck-Bus crashes[f,k]	28.57	8.57	4.44	28.27	12.41	5.72	0.01	57.14
Truck-Motorcycle crashes[g,k]	3.23	–	–	5.12	–	–	0.02	58.06
Truck-Moped crashes[f,k]	11.76	5.31	3.23	21.51	12.63	4.87	0.05	52.08
Truck-Bicycle crashes[f,k]	15.00	7.86	4.29	23.60	10.54	6.64	0.06	50.43
Truck-Pedestrian crashes[f,k]	19.23	13.97	6.85	36.84	26.64	11.73	0.04	32.89
Bus-Motorcycle crashes[h,k]	10.34	–	–	14.76	–	–	0.02	58.62
Bus-Moped crashes[g,k]	7.69	–	–	12.10	–	–	0.01	53.85
Bus-Bicycle crashes[f,k]	9.09	6.29	3.68	16.24	13.57	7.30	0.04	43.48
Bus-Pedestrian crashes[f,k]	14.29	2.38	0.79	30.79	6.49	3.24	0.04	34.25
Motorcycle-Moped crashes[g,k]	15.62	–	–	23.26	–	–	0.02	50.00
Motorcycle-Bicycle crashes[f,k]	28.57	3.57	1.19	42.90	6.70	2.35	0.01	31.82
Motorcycle-Pedestrian crashes[f,k]	20.00	20.00	11.11	23.48	23.48	13.30	0.01	50.00
Moped-Bicycle crashes[f,k]	26.39	3.48	1.72	44.73	4.65	2.90	0.13	32.48
Moped-Pedestrian crashes[f,k]	24.39	0.61	0.23	42.28	4.17	1.57	0.07	30.33
Bicycle-Pedestrian crashes[f,k]	60.56	4.91	1.71	76.14	5.23	2.39	0.12	19.72

[a] single bicycle crashes excluded

[b] only severe crashes are considered

[c] only slight crashes are considered

[d] 7.00 to 18.59 o'clock is considered as *daytime*

[e] 19.00 to 6.59 o'clock is considered as *night-time*

[f] results are averages of yearly estimates of under-reporting

[g] results are estimates of under-reporting for the combined data from 2007-2009

[h] results are estimates of under-reporting for the combined data from all years 2003-2013

[k] crashes involving at least one of each of the mentioned participant types are considered

[l] crashes involving at least one of the vehicles listed in Section 2.1.1

C Results: Consistency of injury severity classifications

Table C.1: Frequencies of factor levels across different combinations of police injury severity classifications (severe, slight, uninjured) and hospital injury severity classifications (severe="ISS ≥ 9", slight="ISS 1-8", uninjured="ISS 0") for people alone in/on the vehicle or pedestrians involved in a crash with a vehicle. (years 2007-2013, $N = 45543$)

Factor	Level	Severe [%]			Slight [%]			Uninjured [%]	
		ISS ≥ 9	ISS 1-8	ISS 0	ISS ≥ 9	ISS 1-8	ISS 0	ISS ≥ 1	ISS 0
Total		4.03	13.39	1.14	1.58	64.68	12.00	2.20	0.98
Gender	Male	5.02	14.08	1.06	1.88	62.82	11.45	2.56	1.12
	Female	2.65	12.42	1.26	1.17	67.26	12.77	1.69	0.79
Age Group	0-17	3.70	12.97	0.64	1.31	73.13	7.59	0.55	0.09
	18-24	3.05	12.56	1.26	0.89	64.50	14.12	2.57	1.04
	25-40	3.11	12.73	1.31	0.97	65.09	12.75	2.80	1.24
	41-60	4.31	13.61	1.06	1.82	64.41	11.53	2.25	1.00
	> 60	6.93	15.74	1.13	3.53	58.99	11.22	1.49	0.97
Transport[a]	Yes	4.97	15.68	1.37	1.93	62.21	12.28	0.88	0.68
	No	0.35	4.28	0.19	0.21	74.59	10.87	7.38	2.13
	Unknown	0.29	5.99	1.17	0.58	71.09	11.68	7.01	2.19
Daytime[b]	Yes	3.69	12.88	1.20	1.56	65.06	12.17	2.41	1.05
	No	5.09	14.98	0.97	1.67	63.51	11.49	1.53	0.76
Traffic Environment	Rural	4.47	13.69	1.49	1.52	60.32	15.28	2.10	1.13
	Urban	3.66	13.11	0.88	1.67	68.27	9.21	2.31	0.89
	Unknown	3.49	13.33	0.47	1.41	69.68	9.20	1.96	0.47
Participant Type	Car	2.40	10.97	1.50	0.77	63.48	16.48	3.06	1.35
	Truck	3.05	11.55	1.77	1.29	60.95	15.04	3.91	2.43
	Bus	4.29	10.48	0.48	0.95	68.10	8.10	3.81	3.81
	Motorcycle	11.50	20.62	0.26	5.31	58.77	2.98	0.52	0.03
	Moped	4.54	14.51	0.49	2.35	73.40	4.05	0.56	0.10
	Bicycle	4.87	16.68	0.33	2.83	71.78	3.24	0.23	0.04
	Pedestrian	8.72	21.27	0.54	2.45	63.92	3.02	0.08	0.00
	Other	11.39	18.99	0.32	2.22	58.86	6.01	1.27	0.95
# Traffic Participants[c]	Single	4.66	14.53	1.52	2.11	62.36	14.57	0.13	0.12
	Two	3.99	13.25	0.87	1.53	66.42	10.50	2.29	1.14
	More than two	2.45	10.99	1.64	0.39	61.28	13.38	7.42	2.45

[a] Ambulance or helicopter transport

[b] Any time from 7.00 to 18.59 o'clock is considered daytime

[c] Amount of traffic participants involved in the crash

Table C.2: Frequencies of factor levels across more or less severe police classification compared to the hospital classification for people alone in/on the vehicle or pedestrians involved in a crash with a vehicle that were given different classifications by the police and a hospital. (years 2007-2013, $N = 13805$)

Factor	Level	More severe [%]	Less severe [%]
Total		87.53	12.47
Gender	Male	85.69	14.31
	Female	90.24	9.76
Age Group	0-17	91.92	8.08
	18-24	88.99	11.01
	25-40	87.67	12.33
	41-60	86.54	13.46
	> 60	84.85	15.15
Transport[a]	Yes	91.27	8.73
	No	66.90	33.10
	Unknown	71.27	28.73
Daytime[b]	Yes	86.88	13.12
	No	89.55	10.45
Traffic Environment	Rural	89.38	10.62
	Urban	85.38	14.62
	Unknown	87.24	12.76
Participant Type	Car	88.32	11.68
	Truck	84.50	15.50
	Bus	80.00	20.00
	Motorcycle	80.35	19.65
	Moped	86.76	13.24
	Bicycle	86.86	13.14
	Pedestrian	90.72	9.28
	Other	87.91	12.09
# Traffic Participants[c]	Single	93.20	6.80
	Two	86.55	13.45
	More than two	76.89	23.11

[a] Ambulance or helicopter transport

[b] Any time from 7.00 to 18.59 o'clock is considered daytime

[c] Amount of traffic participants involved in the crash

Table C.3: Pearson's Chi-squared test for independence between equal or different classification and multiple factors for the years 2007-2013.

Factor	χ^2 statistic	dfs[†]	p-value
Gender	15.5518	1[‡]	< 0.001
Age Group	137.5864	4	< 0.001
Transport[a]	283.6986	2	< 0.001
Daytime[b]	0.7574	1[‡]	0.384[*]
Traffic Environment	261.0120	2	< 0.001
Participant Type	332.8684	7	< 0.001
# Traffic Participants[c]	114.7175	2	< 0.001

[a] Ambulance or helicopter transport

[b] Any time from 7.00 to 18.59 o'clock is considered daytime

[c] Amount of traffic participants involved in the crash

[*] Not significant on $\alpha = 0.05$ significance level

[†] degrees of freedom

[‡] Pearson's Chi-squared test with Yates' correction

Table C.4: Pearson's Chi-squared test for independence between higher or lower classification, in case of different classification, and multiple factors for the years 2007-2013.

Factor	χ^2 statistic	dfs[†]	p-value
Gender	62.6958	1[‡]	< 0.001
Age Group	41.4893	4	< 0.001
Transport[a]	961.5639	2	< 0.001
Daytime[b]	16.4815	1[‡]	< 0.001
Traffic Environment	48.1804	2	< 0.001
Participant Type	66.4801	7	< 0.001
# Traffic Elements[c]	306.0634	2	< 0.001

[a] Ambulance or helicopter transport

[b] Any time from 7.00 to 18.59 o'clock is considered daytime

[c] Amount of traffic participants involved in the crash

[†] degrees of freedom

[‡] Pearson's Chi-squared test with Yates' correction

Table C.5: Odds ratios for being classified more severely by the police than by a hospital comparing the influence of factor levels for the years 2007-2013.

Factor	For	Against	OR (95% CI)	log(OR)	Std. Err.	z-value	p-value
Gender	Male	Female	0.65 (0.58, 0.72)	-0.4344	0.0550	-7.9003	< 0.001[*]
Age Group	0-17	18-24	1.41 (1.09, 1.81)	0.3420	0.1290	2.6512	0.008[*]
		25-40	1.60 (1.25, 2.05)	0.4703	0.1265	3.7185	< 0.001[*]
		41-60	1.77 (1.39, 2.26)	0.5713	0.1250	4.5698	< 0.001[*]
		> 60	2.03 (1.57, 2.63)	0.7093	0.1308	5.4223	< 0.001[*]
	18-24	25-40	1.14 (0.98, 1.32)	0.1283	0.0760	1.6880	0.091
		41-60	1.26 (1.09, 1.45)	0.2293	0.0736	3.1177	0.002[*]
		> 60	1.44 (1.23, 1.70)	0.3673	0.0830	4.4242	< 0.001[*]
	25-40	41-60	1.11 (0.97, 1.27)	0.1011	0.0690	1.4645	0.143
		> 60	1.27 (1.09, 1.48)	0.2391	0.0790	3.0249	0.002[*]
	41-60	> 60	1.15 (0.99, 1.33)	0.1380	0.0767	1.7988	0.072
Transport[a]	Yes	No	5.17 (4.62, 5.80)	1.6437	0.0580	28.3146	< 0.001[*]
		Unknown	4.22 (3.04, 5.85)	1.4389	0.1675	8.5899	< 0.001[*]
	No	Unknown	0.81 (0.58, 1.14)	-0.2047	0.1711	-1.1966	0.231
Daytime[b]	Yes	No	0.77 (0.68, 0.87)	-0.2577	0.0632	-4.0808	< 0.001[*]
Traffic Environment	Rural	Urban	1.44 (1.30, 1.60)	0.3659	0.0529	6.9148	< 0.001[*]
		Unknown	1.23 (0.96, 1.58)	0.2082	0.1264	1.6469	0.100
	Urban	Unknown	0.85 (0.67, 1.09)	-0.1577	0.1258	-1.2533	0.210
Participant Type	Car	Truck	1.39 (1.12, 1.72)	0.3275	0.1091	3.0005	0.003[*]
		Bus	1.89 (0.94, 3.79)	0.6367	0.3550	1.7933	0.073
		Motorcycle	1.85 (1.55, 2.20)	0.6145	0.0897	6.8509	< 0.001[*]
		Moped	1.15 (0.92, 1.46)	0.1434	0.1183	1.2121	0.225
		Bicycle	1.14 (0.96, 1.37)	0.1344	0.0911	1.4758	0.140
		Pedestrian	0.77 (0.62, 0.97)	-0.2571	0.1153	-2.2294	0.026[*]
		Other	1.04 (0.55, 1.96)	0.0389	0.3232	0.1202	0.904
	Truck	Bus	1.36 (0.66, 2.81)	0.3092	0.3686	0.8390	0.401
		Motorcycle	1.33 (1.03, 1.73)	0.2870	0.1336	2.1483	0.032[*]
		Moped	0.83 (0.61, 1.13)	-0.1840	0.1543	-1.1926	0.233
		Bicycle	0.82 (0.63, 1.07)	-0.1931	0.1345	-1.4351	0.151
		Pedestrian	0.56 (0.41, 0.75)	-0.5846	0.1520	-3.8458	< 0.001[*]
		Other	0.75 (0.39, 1.45)	-0.2886	0.3380	-0.8538	0.393
	Bus	Motorcycle	0.98 (0.48, 1.99)	-0.0222	0.3633	-0.0612	0.951
		Moped	0.61 (0.29, 1.26)	-0.4933	0.3714	-1.3280	0.184
		Bicycle	0.61 (0.30, 1.23)	-0.5023	0.3636	-1.3813	0.167
		Pedestrian	0.41 (0.20, 0.85)	-0.8938	0.3705	-2.4127	0.016[*]
		Other	0.55 (0.22, 1.40)	-0.5978	0.4779	-1.2509	0.211
	Motorcycle	Moped	0.62 (0.47, 0.82)	-0.4710	0.1412	-3.3355	< 0.001[*]
		Bicycle	0.62 (0.49, 0.78)	-0.4801	0.1193	-4.0241	< 0.001[*]
		Pedestrian	0.42 (0.32, 0.55)	-0.8716	0.1387	-6.2838	< 0.001[*]
		Other	0.56 (0.29, 1.08)	-0.5756	0.3323	-1.7324	0.083
	Moped	Bicycle	0.99 (0.75, 1.31)	-0.0090	0.1421	-0.0636	0.949
		Pedestrian	0.67 (0.49, 0.91)	-0.4006	0.1587	-2.5234	0.012[*]
		Other	0.90 (0.46, 1.76)	-0.1046	0.3411	-0.3066	0.759
	Bicycle	Pedestrian	0.68 (0.51, 0.89)	-0.3915	0.1396	-2.8046	0.005[*]
		Other	0.91 (0.47, 1.74)	-0.0955	0.3326	-0.2872	0.774
	Pedestrian	Other	1.34 (0.69, 2.62)	0.2960	0.3401	0.8703	0.384
# Traffic Participants[c]	Single	Two	2.13 (1.86, 2.43)	0.7558	0.0684	11.0436	< 0.001[*]
		More than two	4.12 (3.50, 4.86)	1.4158	0.0838	16.8899	< 0.001[*]
	Two	More than two	1.93 (1.70, 2.21)	0.6600	0.0675	9.7778	< 0.001[*]

[a] Ambulance or helicopter transport

[b] Any time from 7.00 to 18.59 o'clock is considered daytime

[c] Amount of traffic participants involved in the crash

[*] Not significant on $\alpha = 0.05$ significance level