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COSTS OF CONGESTION RELATED TO ROAD CRASHES IN IRELAND

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Summary

Objectives and scope

Road crashes have an enormous emotional impact on human lives, and moreover, result in very significant socio-economic costs. Costs of congestion related to crashes is one of the elements in these costs. Although compared with other cost items it is not a major cost component, congestion costs are commonly taken into account in road crash costs studies and international guidelines on estimating road crash costs recommend including these costs. In Ireland, crash cost information is commonly used in economic appraisal of transport, but there is currently no information on congestion costs resulting from crashes. Information on these costs is important to have a complete picture of road crash costs, and it also helps to identify appropriate measures to reduce congestion.

Therefore the Road Safety Authority (RSA) commissioned W2Economics to conduct a study into congestion costs related to road crashes, in the context of Action 123 of the government’s Road Safety Strategy 2013-2020. The aim of the study is to:

- Give an overview of the methods and results of studies on congestion costs related to crashes in other countries, as well as the rationale for estimating these costs and areas of application in these countries
- Give an indication of the potential size of congestion costs related to crashes in Ireland.
- Recommend a method that can be applied to estimate congestion costs related to crashes in Ireland in more detail.

This study

To meet these objectives the following research activities were carried out:

1. A review of studies into congestion costs related to crashes in other countries. Well documented studies on congestion costs related to crashes were identified in five countries: Australia, Austria, Germany, the Netherlands and the United States. The methodologies and outcomes were reviewed in detail. Particular attention was paid to the most recent study on congestion costs related to crashes in the Netherlands. The Dutch approach is unique because the congestion costs were based on direct monitoring of actual congestion instead of using traffic model results.
2. An analysis of road safety and traffic indicators that influence crash-related congestion costs in these five countries and in Ireland. This analysis was aimed identifying the main indicators that affect congestion costs and at explaining differences in costs levels between countries.
3. An estimation of size of congestion costs related to crashes in Ireland, using a ‘value transfer’ approach. This means that the estimate is based on results of best practice congestion cost studies in other countries. Cost estimate from other countries were adjusted to the road safety and traffic situation in Ireland, using the main indicators that affect congestion costs.
4. A discussion on opportunities for estimating congestion costs related to crashes in Ireland in more detail.

Congestion cost regarded as an important road crash cost element
In each of the countries included in the review, congestion costs are regarded as an important element in the socio-economic costs of road crashes, and for that reason they are included as a standard cost item in road crash cost calculations in these countries. Information on the costs of road crashes, and congestion costs as part of that, is used to raise awareness for the socio-economic burden of road crashes. In addition, road crash costs information is used in cost-benefit analysis of road safety projects and broader transportation projects. Road crash costs figures, including congestion costs, are often included in national guidelines for cost-benefit analysis of traffic and transport projects.

Direct time losses are the most important cost item
There are several types of congestion costs resulting from crashes. In all reviewed countries the cost calculations concentrate on direct time losses for vehicle occupants affected by the congestion, which is the most important cost item. In addition, some countries take into account health and environmental costs, additional vehicle operating and fuel costs, costs of adapting travel behaviour (such as detouring and changing departure time), costs of travel time unreliability and time losses due to rubbernecking (congestion without lane closings, also on the opposite side of the road). Health, environmental and vehicle operating costs are generally relatively small, while costs of adapting travel behaviour and costs of travel time unreliability can be very substantial additional costs.

Methods: queuing models versus direct congestion monitoring
In all countries, except the Netherlands, a queuing model is applied to estimate the costs of direct times losses due to crash-related congestion. These models calculate the time losses resulting from crashes using several parameters such as traffic volumes, road capacities, capacity reductions due to a crash and emergency response times. A different approach is used in the Netherlands: time losses due to congestion are measured in a direct way through a congestion monitoring system that records indicators such as length, duration and the cause (including crashes) of a traffic jam. This approach has the advantage that the cost calculations are based on data of actual congestion, so they are not dependent on data limitations and assumptions that need to be made in queuing models. A limitation of the Dutch approach is that only information on congestion on motorways is collected, while the models that are applied in most other countries do include other road types.

Crash-related congestion costs vary widely between countries
The review shows that there are large differences in the size of congestion costs. In Germany and Austria the congestion costs related to crashes are very low: €7 and €1 per registered motor vehicle respectively (2014 price level). In Australia and the Netherlands the cost per motor vehicle are in the same order of magnitude (€43 and €33), whereas in the US the costs are highest (€92 per motor vehicle). Expressed as a percentage of GDP, congestion costs range from 0.001% in Austria to 0.19% in the US. The proportion of congestion costs in total costs of road crashes ranges from 0.04% to 5%.

Cost variation explained by differences in methods and in road safety and traffic situations
Several explanations for these cost differences were identified. Firstly, methodologies to calculate congestion costs are different with respect to the costs items, road types and crash severity

categories that are included. Most studies underestimate congestion costs, because they do not include all relevant cost items, nor congestion on regional and local roads and/or property damage only crashes. Furthermore, the specifications and level of detail of the calculation models are different in each country, which further contributes to different outcomes. Secondly, different road safety levels and traffic and infrastructure circumstances in each country result in different congestion cost levels. Thirdly, the values of time differ considerably between countries.
Given these methodological differences, it is recommended to develop guidelines on the estimation of congestion costs related to crashes and to integrate these in international guidelines for road crash cost calculations.

Congestion costs related to crashes in Ireland: €20-50 million
Two value transfer approaches were applied to estimate congestion costs in Ireland. In the first approach, congestion costs in Ireland were estimated using the congestion costs per capita in other countries. In the second approach, costs per crash in Ireland by severity and road type were derived from studies in other countries and applied to the number of crashes in Ireland. Three main factors that affect the size of the costs in Ireland relative to the other countries were taken into account: the crash rate, traffic volumes and the value of time. The values of each of these three parameters are substantially lower than in most of the other countries, and they all have a downward impact on congestion costs as compared to the other countries. Other parameters that could affect congestion costs did not show any clear differences between Ireland and the other countries. The results of the value transfer calculations show that the cost of congestion related to crashes are likely to be in order of magnitude of €20-50 million (price level 2014). This is 3-7% of total road crash costs in Ireland, which indicates that congestion costs are a relevant, although minor, cost component.

Recommendation: developing a queuing model for a more detailed estimate
The value transfer approach only gives a fairly rough indication of the potential size of congestion cost related to crashes in Ireland, as it is based on results from other countries and several assumptions. For the time being the €20-50 million range can be used to supplement the current estimate of road crash costs in Ireland, but developing a queuing model is recommended to estimate the costs of direct time losses more precisely. The examples in other countries show that this is a feasible approach to estimate costs of direct time losses in Ireland. The key input data for such as model are available in Ireland and for some aspects the model can draw on a recent DTTaS congestion cost study in the Greater Dublin Area. However, some additional data analysis and data collection would be needed. Ideally, other relevant cost times are added to the costs of direct time losses. Given the complexity of estimating some of these impacts and the broader applicability outside road safety, it is recommended studying these impacts in the context of a broader congestion cost study and to apply the results to crash-related congestion.

1. Introduction

Road crashes have an enormous emotional impact on human lives, and moreover, a very significant socio-economic impact. International reviews show that this impact is estimated at 0.5% up to 6% of gross domestic product (Wijnen & Stipdonk, 2016). Costs of congestion related to crashes is one of the elements in these costs. Although compared with other cost items it is not a major cost component, congestion costs are commonly taken into account in road crash costs studies and international guidelines on estimating road crash costs recommend including these costs. For example, recently the ongoing European project SafetyCube concluded, on the basis of a review of these guidelines and best practices, that congestion costs should be regarded as a main element of road crash costs (Wijnen et al., 2017).

In Ireland there is currently no information on congestion costs resulting from crashes, and therefore the Road Safety Authority (RSA) has commissioned W2Economics to conduct a study into these costs, in the context of Action 123 of the government's Road Safety Strategy 2013-2020. The aim of the study is to:

a) Give a detailed description of the most recent study on congestion costs related to crashes in the Netherlands. The Dutch study is unique and only available in Dutch and therefore specific and detailed attention will be paid to this study.
b) Give an overview of the methods and results of studies on congestion costs related to crashes in other countries, as well as the rationale for estimating these costs and areas of application in these countries;
c) Give an indication of the potential size of congestion costs related to crashes in Ireland;
d) Recommend a method that can be applied to estimate congestion costs related to crashes in Ireland in more detail, taking into account opportunities to integrate this in an ongoing study on congestion by the Department of Transport.

This report is structured as follows. Chapter 2 reviews studies into congestion costs related to crashes in five countries. In Chapter 3, road safety and traffic indicators that affect congestion costs due to crashes in Ireland are analyzed and compared with statistics in the five countries included in the review, in order to derive an indication of the size of congestion costs related to crashes in Ireland. Chapter 4 discusses the opportunities for estimating congestion costs related to crashes in Ireland in more detail. In Chapter 5 conclusions and recommendations are given.

2. Congestion costs in other countries

A recent review of studies on road crash costs (Wijnen & Stipdonk, 2016) shows that congestion costs are taken into account in six out of the ten high-income countries that were included in that study. Detailed documentation on the method used to calculate congestion costs is available in five of these countries: Australia, Austria, Germany, the Netherlands and the United States (US). In this chapter the methods and results of the congestion costs calculations in these countries are reviewed. In addition, the rationale for estimating congestion costs in each country as well as the areas of application will be discussed, based on information we received from experts in each country: Mr. T. Risbey (Department of Infrastructure and Regional Development, Australia), Mr. N. Sedlacek (Herry Consult, Austria), Mr. A. Kasnatscheew (Federal Highway Research Institute (BASt), Germany) and Mr. L. Blincoe (National Highway Traffic Safety Administration, US). After discussing the five national studies separately, a comparison of the methods and the results is made.

2.1 Australia

Research on congestion costs and applications

Costs of congestion have been calculated at least since 1988, when the report 'Cost of Road accidents In Australia' was published (Steadman & Bryan, 1988). At that time only direct time losses were included based on a study from the US, whereas in the latest study (BITRE, 2009) Australian data were used and other costs items were added (fuel costs, environmental and health costs). The objective of the crash cost studies is to capture all social costs of crashes, hence the inclusion of costs such as estimated congestion costs from crashes. The studies have two main uses. Firstly, information on the total social cost of crashes is used for general policy making purposes, as it gives information on the socio-economic burden of crashes. Secondly, the cost per crash or per casualty are used for benefit-cost analysis purposes.

Method

In the latest calculation of road crash costs in Australia, three cost items are included:

- Direct time losses
- Health costs of additional local air pollution
- Additional vehicle operating costs

Below we discuss each cost item.

Direct time losses

To estimate the direct time losses resulting from crashes, a queuing model is applied in Australia (see textbox).

Queuing models

Queuing models estimate queue length and traffic delays related to different road designs or traffic scenarios (BTE, 2000). They are used by traffic engineers and traffic planners for road design and traffic control. These models use data or assumptions on the number of vehicles arriving at the crash location ('arrival curve') and on the number of vehicles that can pass the crash site at several points in time after the crash ('departure curve'). For example, the number of departing vehicles may be zero directly after the crash, a certain percentage of the normal road capacity after emergency services have arrived and a higher (and increasing) percentage after the road has been cleared. The arrival curve depends on factors such as road type, time of the day and area (urban/rural). The departure curve depends on the response time of emergency services and the time they need to clear the crash site, which is dependent on factors such as crash severity and area.

The queuing model applied by BITRE (2009) estimates the number of delayed vehicles due to a crash and the associated time losses on the basis of four key parameters:

1. traffic volume (number of vehicles per hour)
2. road capacity without an incident
3. capacity reduction due to a crash
4. duration of the capacity reduction.

The input that was used in the model include:

- Data and assumptions on traffic volumes by five road types, area (metropolitan/non-metropolitan) and day and time of the day (weekday peak/business hours and weekend day/night).
- Data on ambulance response time and the time ambulance services spend on the crash at the crash site (as an indicators of response time of all emergency services), by area (metropolitan/non-metropolitan) and crash severity (injury/ property damage only crash).
- Data on the time ambulance services spend on the crash at the crash site.
- An assumed road capacity reduction (30%) for all road types, areas and crash severities.
- Relative delay times by crash severity (fatal/injury/property damage only crash: 2.7/1.0/0.6), based on data from the U.S.
- Reported number of crashes by severity (fatal/injury/property damage only) and area (Melbourne and Sydney metropolitan/other metropolitan/non-metropolitan)

Based on these inputs the model calculates the time loss by crash severity, road type, area, day and time of the day. To translate time losses into costs, values of time by area are used for six vehicle categories: private car and motorcycle, business car, light commercial vehicle, bus, rigid truck and articulated truck. Different values are used for metropolitan and non-metropolitan areas. The values of time for cars, motorcycles and bus passengers are based on wages and occupancy rates (number of people per vehicle: driver and passengers). Concerning business cars, a percentage of the average wage is taken. For commercial vehicles and bus drivers the value of time is based on wages of the drivers (AustRoads, 2008).

Health costs of additional local air pollution

The Australian calculations include the impact of congestion on health related to an increase in emissions, such as particulate matter (PM) and NO_2. An average value per minute (A$0.03) used in the BITRE (2009) study, which is based on previous detailed studies on emission costs (BTRE, 2007; Watkiss, 2002). In these studies the costs of emissions were estimated using emissions per vehicle type in Australia, the health impacts of these emissions (mortality and morbidity) and the economic valuation of these health impacts. Data on health impacts and economic valuation were taken from the European ExternE project and adapted to the Australian situation, e.g. by taking into account differences in population density. The economic valuation of health impacts was based on studies into the amount people are willing to pay for reducing health risks (fatal and non-fatal), representing the economic valuation of lost life years or lost quality of life. Costs of medical treatment and lost labour productivity were added to that.

Additional vehicle operating costs

Extra time spent in traffic jams results in an increase in vehicle operating costs, particularly fuel costs. BITRE (2009) has estimated these costs at about A$0.03 per minute. These costs are based on data on the relation between speed and fuel consumption as established in a previous report (BTRE, 2007).

Results

The total costs of congestion related to crashes in Australia are estimated at A$893 million (Table 2.1). This is 0.09% of GDP and 5% of total road crash costs (A$17.9 billion). Table 2.2 shows the number of crashes these figures are related to, both the total and number of crashes that (were assumed to) cause congestion. Direct time loss is by far the largest cost item (89% of total congestion costs), while health costs related to additional air pollution and additional vehicle operating cost are relatively small (6% and 5% of total costs respectively). More than half of the costs are related to property damage only (PDO) crashes, while injury crashes also have a major share in total costs (41%). The proportion of fatal crashes in the total costs is only 2% because of the low number of fatal crashes. However, the congestion costs per fatal crash are, as expected, much higher than those of injury and PDO crashes (Table 2.3): the costs of a fatal crash are 2.8 times higher than the costs of an injury crash. The cost difference between an injury crash and a PDO crash is relatively slight (injury 1.2 times higher than PDO). Costs, in particular concerning injury and PDO crashes, were found to be related to the degree of urbanisation: the costs per crash are highest in the largest cities Melbourne and Sydney, while the cost in other metropolitan city areas are lower than in non-metropolitan areas (Table 2.3). Note that the costs per crash in Table 2.3 only refer to crashes that result in congestion. Consequently, the average cost for all crashes are lower.

	Fatal	Injury	PDO	Total
Direct time loss	15.9	323.0	452.8	791.7
Health costs	1.1	21.7	30.6	53.3

Vehicle operating costs	0.1	19.5	27.5	48.0
Total	18.0	364.2	510.9	893.0

Table 2.1: Total congestion cost related to crashes in Australia in 2006 by crash severity (million A$). Source: BITRE (2009)

	Fatal	Injury	PDO	Total
Total number	1,455	213,698	438,700	653,853
Number causing congestion	792	45,141	76,246	122,179

Table 2.2: Number of crashes in Australia in 2006, total and crashes resulting in congestion. Source: BITRE (2009)

	Fatal	Injury	PDO	All
Melbourne and Sydney	22,570	8,350	8,010	8,230
Other capital city areas	21,450	6,290	6,100	6,660
Non-metropolitan areas	24,080	7,430	6,300	7,430
Average all areas	22,660	8,110	6,660	7,330

Table 2.3: Congestion cost per crash in Australia in 2006 (A$). Source: BITRE (2009)

2.2 Austria

Research on congestion costs and applications

In Austria, the methodology to estimate road crash costs was developed in the early 1990s. Congestion costs were included in this methodology, because they are regarded as a relevant component of the socio-economic costs resulting from road crashes. There is no specific interest in the congestion costs apart from being an important element in the total costs of road crashes. The results of the road crash cost studies in Austria are mainly used in cost-benefit analyses of infrastructure projects. The road crash cost figures are integrated in the Austrian Directive for decision making support, in particular the guidelines for cost-benefit research in traffic and transport (FSV, 2010). In addition, the Ministry of Transport uses cost information to justify or assess road safety investments. The latest cost study in Austria was conducted in 2012 (Sedlacek, 2012), in which the costs were estimated for the year 2011.

Method

The Austrian calculation of congestion costs only takes into account direct time losses resulting from crashes. A relatively simple method is applied to estimate these costs. Time losses are estimated using the total number of injury crashes (including fatal crashes), congestion probabilities, duration of congestion, traffic volumes and vehicle occupancy rates. It is assumed that only injury crashes result in congestion, so PDO crashes are not included. The methodology draws on data and assumptions from the previous road crash cost study for the year 2007 (Herry et al., 2008).

The data used to calculate time losses are:

- Congestion probabilities per crash for five road types: 15% for motorways and 3-5% for other road types). These probabilities are based on assumptions.
- Duration of congestion, based on data from traffic monitoring systems. Average traffic jam durations are estimated at 5 to 30 minutes depending on the road type.
- Average traffic volumes per hour by vehicle type (passenger car, truck without trailer, truck with trailer and bus/passenger car with trailer) and road type.

- Number of injury crashes by road type
- Vehicle occupancy rates

The time losses are translated into costs using values of time by trip purpose (business, commuting, leisure, truck without trailer and truck with trailer). Time loss per vehicle is translated into time loss per person using the vehicle occupancy rates.

Results

The total costs of congestion related to crashes is Austria in 2011 are estimated at €4.3 million. These are the costs related to 1,500 injury crashes in Austria that year that (were assumed to) cause congestion, which is a minor proportion of all injury crashes (Table 2.4). Note that PDO crashes are not included in Austrian estimates. The figures only include costs of direct time losses. Congestion costs are a very minor proportion (0.04%) of the total road crash cost in Austria (€10.088 million), and only 0.001% of GDP.

The majority of the costs (75%) is related to congestion on motorways (Table 2.4). About 80% of the costs are associated with passenger traffic (passenger cars and buses), as shown by Table 2.5.

Road type	Costs (million €)	Injury crashes	
		Total	Causing congestion
Motorways	3.22	1,609	241
Other national roads	0.20	215	32
County roads	0.74	11,387	569
Other regional roads	0.06	7,162	215
Other roads	0.07	14,756	443
Total	4.29	35,129	1,500

Table 2.4: Total congestion cost related to crashes in Austria and number of injury crashes (including fatal) in 2011 by road type[1] (million €). Source: Sedlacek (2012)

Journey purpose	
Passenger cars (total)	2.56
- business	0.07
- commuting	0.75
- leisure	1.74
Trucks	0.90
buses/passenger cars with trailer	0.82
Total	4.29

Table 2.5: Total congestion cost related to crashes in Austria in 2011 by journey purpose (million €). Source: Sedlacek (2012)

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[1] The design of national roads (´Schnellstraßen´) is in general identical to motorways (‘Autobahnen’) but some do not have physical lane separation. County roads (‘Landesstraßen B’) can have a national or region function and usually are two-way single carriageways. Other regional roads(‘Landesstraßen L’) are also operated by counties but they have a regional function only. Other roads include local roads.

The average cost per casualty is estimated at €94. The Austrian calculations do not differentiate between injury severity categories.

2.3 Germany

Research on congestion costs and applications

The first estimate of congestion costs related to crashes in Germany was published in 2007 (Listl et al., 2007). The study was initiated by the Federal Highway Research Institute (BASt) and the aim was to quantify travel time losses on motorways due to (long-term) capacity bottlenecks and temporary capacity limitations (accidents, road works, short-term bottlenecks). In this study, collision related congestion costs were estimated at €964 million in the year 2000. In 2010, congestion costs were estimated as an element of a study into the total socio-economic costs of road crashes (Baum et al., 2010). This was the first road crash costs study in Germany that included congestion costs. The motivation for including congestion costs was that the size of these costs was considered to be significant and hence an important element in the total costs of road crashes. No other applications of the congestion costs estimates are known.

The results of the road crash costs studies are used for cost-benefit analyses of road safety measures. An example is a study on daytime running lights, which showed that the safety benefits of daytime running lights outweigh the costs of more fuel consumption and the related emissions (Schönebeck et al., 2005). The road crash cost figures are included in the guidelines on economic efficiency research for roads issued by the Road and Transportation Research Association concerning (FGSV, 2002). Furthermore, the long-term federal plan of strategic investments in infrastructure (Bundesverkehrswegeplan) requires the results of road crash cost studies in the process of prioritizing projects. Finally, road crash costs information is used in political processes with the purpose of raising awareness of road safety and of demonstrating its (economic) relevance.

Method

In Germany, only direct time losses are included in the estimation of congestion costs related to crashes. Costs of direct time losses are calculated for motorways only, because data for other road types are not available. The calculation of the time losses related to collisions in Germany (Baum et al., 2007) is based on a queuing model. The principles of this model are similar to the model used in Australia, which means that congestion costs are calculated on the basis of traffic volumes, road capacity and reduction of road capacity due to a collision. Time losses are calculated on the level of road segments by:

- crash severity: fatal, serious injury, slight injury and property damage only[2]
- day: weekday and weekend/holiday days
- time of the day (hour)

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[2] In Germany two PDO severity categories are distinguished. Only the most severe category is assumed to cause congestion. This category only includes PDO crashes involving towing away vehicles and PDO crashes resulting from offences.

The main inputs for the model are:

- Traffic volume (by road segment, day and time of the day) and the proportion of trucks in the traffic volume. The source of this data is vehicle counts.
- Road capacity (number of vehicles per hour) without an incident by road segment, based on the Highway Capacity Manual from the U.S. (TRB, 2000) and data on the number of lanes by road segment.
- Impact of crashes on road capacity. This impact was estimated on the basis research that modelled the relation between traffic volumes and the number of crashes, using traffic volume data from traffic counts and crash data (Pöppel-Decker et al., 2003; Listl et al., 2007). Based on the results of this research the capacity reduction was estimated at 35% to 58%, depending on number of lanes and crash severity. The duration of capacity reduction was estimated at 35 minutes (slight crashes) to 45 minute (severe crashes). For severe crashes it was estimated that the road is fully closed for 15 minutes.

Based on these data, the model calculates the time loss per road segment (by severity, time of the day and day). The average time loss resulting from a crash for all road segments is then calculated using crash probabilities (by severity, day and time of the day) on a road segment. The probabilities are defined as the number of crashes per vehicle kilometer. They are estimated using the traffic volume per road segment and the results of a study on the relation between the occurrence of crashes and traffic volume (Pöppel-Decker et al., 2003). Total time loss is calculated by multiplying the average time loss per crash by the number of crashes (by severity, day and time of the day).

To translate time losses into costs, monetary valuations of time losses by vehicle type (private passenger car, business passenger car and trucks) and vehicle occupancy rates are used. Values of time for private trips by passenger car are based on productivity statistics, including non-market production such as household work and other unpaid activities. The value of time for trucks is based on the actual costs of freight transport, such as personnel costs and costs related to delay in delivering the freight, and include costs for the clients of transport companies. Traffic volumes by vehicle type are used to derive a weighted average value of time.

The resulting total costs are split into costs related to casualties and costs related to property damage (including property damage resulting from injury crashes). Data on police time spending on the crash location is used for that, as these data include a split into casualty-related time spending and property-related time spending.

Results

Total costs are estimated at €305 million in 2005 (Table 2.6), which is equal to 0.01% of GDP and 1.0% of the total costs of road crashes in Germany (€31.5 billion). Table 2.7 shows the number of crashes on motorways (to which the costs refer) as well as the total number of crashes in Germany. Only direct time losses are included in these costs. The majority of the costs is related to lower severity crashes: slight injuries and PDO crashes have a share of 45% and 38% in total costs respectively.

	Fatal	Serious injury	Slight injury	PDO	Total
Casualty-related	3.02	29.08	84.31	-	116.42
Property-related	1.86	17.82	51.68	116.89	188.24
Total	4.88	46.9	135.99	116.89	304.66

Table 2.6: Total congestion costs related to crashes in Germany in 2005 by crash severity (million €). Source: Baum et al. (2007)

	Fatal	Serious injury	Slight injury	PDO*	Total
Motorways	589	4,383	15,971	16,822	37,765
All roads	4,984	66,627	265,008	100,073	2,153,919

Table 2.7: Number of crashes in Germany in 2005. Source: Baum et al. (2007)

* Only most severe PDO crashes, see footnote 2. The total number of PDO crashes is 1.8 million (all roads).

Interestingly, the costs per fatal crash are larger than the costs per serious injury in Germany (Table 2.8). The costs per slight injury crash are about 30% lower than the costs per serious injury crash and the costs per PDO crash are slightly higher than the costs per slight injury crash.

	Fatal	Serious injury	Slight injury	PDO
Casualty-related	4,572.22	4,961.18	3,180.88	-
Property-related	3,149.65	4,066.09	3,237.00	6,953.09
Total	7,721.87	9,027.27	6,417.88	6,953.09

Table 2.8: Congestion cost related to crashes per crash in Germany in 2005 by crash severity (€). Source: Baum et al. (2007)

2.4 Netherlands

Research on congestion costs and applications

In the Netherlands, a calculation of congestion costs related to crashes was introduced in the 1990s in a study on financing safe infrastructure, that included an estimate of the total costs of road crashes (Poppe & Muizelaar, 1996). Since then congestion costs are included as a standard cost item in road crash cost studies, which are carried out regularly in the Netherlands. The latest study ('Kosten van verkeersongevallen in Nederland': 'Costs of road crashes in the Netherlands') was published in 2012 and was carried out by the Ministry of Infrastructure, in cooperation with several research organizations including SWOV Institute for Road Safety Research (De Wit & Methorst, 2012; Wijnen, 2012). In this study costs of road crashes, including congestion costs, were calculated for the year 2009. The costs are calculated as much as possible according to international guidelines, in particular the European COST313 guidelines (Alfaro et al., 1994), that recommend including congestion costs.[3]

The results of these studies on costs of road crashes are used in the preparation and evaluation of road safety policy, for example in the Strategic Plan Road Safety 2008-2020) that stresses that road crashes have an enormous economic burden (MinVW, 2008). Data on costs of road crashes are also used in cost-benefit analyses of road safety investments and other transport projects, for example in a cost-benefit analysis of investments in Sustainable Safety in the period 1998-2007. This analysis showed that the road safety benefits were about four times higher than the costs of measures (Weijermars & Wegman, 2011). Although congestion costs have a minor share in total road crash costs in the Netherlands (2.4% in 2009), they are considered as a standard element in road crash cost studies. In most applications no specific attention is paid to them however, because of their relatively limited size. Furthermore, road crash cost figures are included in national guidelines for cost-benefit analysis of infrastructure projects (Eijgenraam et al., 2000), which are commonly used for cost-benefit analysis in the Netherlands. For larger projects, a cost-benefit analysis according to these guidelines is compulsory.

Another recent study on the congestion costs related to collision and other incidents, commissioned by the Ministry of Infrastructure, was aimed at estimating the benefits of improved incident management, in particular shortening the time needed between the incident and opening the road lanes again after removing the vehicles etc. (Drolenga et al., 2016). It was estimated that incident management saved about €250 million congestion costs in 2015. About half of these costs was related to crashes, of which more than three quarters were property damage only crashes. The other half of the costs concerned other incidents such as car breakdowns, motor problems etc. Furthermore, the study showed that that the benefits (saved congestion costs) of improving incident management are 5 to 8 times higher than the costs.

Information on congestion costs is also used by transportation organizations to stress the economic losses for transport and shipping companies. They use this information to argue that more investments in reducing congestion should be made.

Method and results

Several cost items related to congestion are taken into account in the latest road crash cost study in the Netherlands:

- Direct time losses
- Costs related to unreliability of travel time
- Costs of adapting travel behaviour, such as detour, changing transport mode or travel times, etc.
- Additional fuel costs
- Indirect costs, such as impact on public transport.

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[3] Recently, new guidelines for estimating road crash costs were developed in the EC project SafetyCube (Wijnen et al., 2017). These guidelines are mainly based on the COST313 guidelines and consider congestion costs as a main cost item.

Below we discuss each cost item.[4]

Direct time losses

In the Netherlands, direct time losses are estimated on the basis of direct measurement of several congestion indicators. Congestion data are collected by a congestion monitoring system, operated by the Traffic Centre Netherlands. In this centre, in cooperation with five regional traffic centres, all traffic flows on motorways are monitored and managed, e.g. by dynamic speed limits, opening/closing lanes, etc.. Direct time losses due to congestion are calculated by comparing the actual speeds with the speed that would have been achieved without congestion (reference speed). In addition to speed data, data on traffic volumes and traffic jam length are used to calculate the time losses (lost vehicle hours). Using vehicle occupancy rates, the time loss per vehicle is translated into time loss per person (MinIE, 2012). This time loss due to congestion on motorways (all causes) in the Netherlands was estimated at 62 million hours in 2009.

To estimate the proportion of this direct time loss that is related to crashes, data on congestion intensity are used. Congestion intensity is defined as the length of a traffic jam multiplied by the duration of the traffic jam. This information on traffic jams is collected by the Traffic Centre Netherlands. In these databases several causes of congestion are distinguished, including crashes, which enables determining the contribution of crashes to congestion intensity. In 2009, 11% of total congestion intensity was attributed to crashes. To determine the travel time loss related to crashes, it was assumed that this percentage also applies to travel time. This implies that travel time loss related to crashes was estimated at 6.6 million hours (11% of 62 million hours).

To transfer time loss into economic costs, the number of hours lost is multiplied by the monetary value of time. Here a distinction is made between freight transport and passenger transport. For passenger transport, three further modes are distinguished: commuting, business and other. Values of time are available from studies into the amount of money people are willing to pay for reduced travel time, using surveys among road users (‘stated preference’ research; HCG (1998) and RAND Europe et al., (2004)).[5] The weighted average value of time is €17,33. On the basis of this value of time and the travel time loss related to crashes, the costs of direct time loss was estimated at €115 million in 2009.

Costs other than the costs of direct time loss are estimated on the basis of the total (all-cause) congestion costs in the Netherlands in 2011. Below we discuss these costs and then the application of these costs in the calculation of congestion costs related to crashes.

Unreliability of travel time

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[4] No information is available about the estimation of additional fuel costs. In recent congestion cost calculations these costs are not included anymore. The impact of fuel costs on total costs is negligible according to the Dutch calculations.

[5] The values of time were updated shortly after the study on road crash costs in the Netherlands was finalized (Significance et al., 2012). The new values of time, that were based on a stated preference survey, did not deviate much from the values found in the previous studies.

In the Dutch study, unreliability of travel time is defined as the extent to which the actual travel time deviates from the travel time that road users expect (KiM, 2012). Unreliability is expressed as the standard deviation of the distribution of travel time in number of minutes. This standard deviation was estimated on the basis of a traffic simulation model called 'Smara' (Strategic model for analyzing reliability of accessibility). In this model unreliability of travel time is estimated on the basis of probabilities of several causes of congestion (e.g. events, crashes and other incidents, weather, road works) and their impact on road capacity and speed, taking into account factors such as time of the day, day and season (Hilbers et al., 2004). The economic valuation of unreliability was based on the value of time and assumptions on road user's reaction on (changes in) travel time unreliability (Van Reisen, 2006).[6] It was concluded that costs of unreliability are 38% of the costs of direct time loss (KiM, 2012).

Adapting travel behaviour

Costs of adapting travel behaviour are based on a study in which a traffic model (the Dutch National Transport Model) was applied to estimate direct time losses due to congestion as well as indirect costs that result from the direct impacts (Koopmans & Kroes, 2004). Travel choices that people make, including choice of destination, transport mode, departure time and route choice, are included in this model. Using this model, two calculations were done. Firstly, costs related to direct time losses due to congestion only were calculated. In the second calculation congestion costs were calculated when also the indirect impacts resulting from changes in travel behaviour are taken into account. The calculations showed that the costs are about twice as high if indirect impacts are included. This result was applied to calculate the costs of travel adaptations related to both direct time loss and unreliability of travel time.

Indirect impacts

There is very little empirical research on the indirect costs of transport projects in general in the Netherlands, and no information on indirect costs related to congestion such as impacts on public transport. In Dutch guidelines on cost-benefit analysis of infrastructure projects (Elhorst et al., 2004), a rough estimate of indirect costs (or benefits) was made: 0-30% of the direct costs (or benefits). This range was applied in the Dutch estimation of congestions, which means that indirect costs were estimated at 0-30% of the costs of direct time loss.

Total costs of congestion

Table 2.9 gives an overview of the total (all-cause) congestion costs in the Netherlands in 2011.

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[6] These values were based on assumptions and rules of thumb. New values of unreliability were derived in the stated preference study by Significance (2012), see previous footnote. These values were lower than the previous values that are used in the road crash cost study, but more in line with international literature.

Cost item	
Direct time loss	0.9
Related adaptation costs	0.9
Unreliability costs	0.3
Related adaptation costs	0.2
Additional fuel costs	0.03-0.06
Indirect costs	0.0-0.7
Total	2.3-3.0

Table 2.9: Total (all-cause) congestion in the Netherlands in 2011 (billion €). Source: KiM, 2012.

Table 2.7 shows that total costs than costs are 2.6 to 3.3 times higher than the costs of direct time loss. This result was used to estimate total congestion costs related to crashes, by multiplying the direct time costs by a factor 2.6. The lower end of the range (2.6) was chosen, to avoid overestimating the costs. However, the indirect costs, particularly costs of unreliability, are likely to be more associated with crash-related congestion than with other types of congestion (particularly daily traffic jams). Consequently, the factor 2.6 probably results in an underestimation of the congestion costs related to crashes.

Results

The resulting costs on congestion related to crashes in the Netherlands are summarized in Table 2.10. Congestions costs related to crashes are estimated at €300 million, which is 0.05% of GDP and 2.4% of total road crash costs (€12.5 billion). Direct time losses have a share of 39% in the congestion costs. Table 2.11 shows the total number of crashes on motorways (to which the costs refer) as well as the total number of crashes in the Netherlands. The proportion of crashes that result in congestion is not available.

Cost item	
Costs of direct time loss	115
Other costs (adapting travel behaviour, unreliability, fuel and indirect costs)	185
Total	300

Table 2.10: Total congestion costs related to crashes in the Netherlands in 2009 (million €). Source: De Wit & Methorst, 2012.

	Fatal	Serious injury	Slight injury	PDO	Total
Motorways	589	4,383	15,971	16,822	37,765
All roads	4,984	66,627	265,008	1,817,300	2,153,919

Table 2.11: Number of crashes in the Netherlands in 2009. Source: Ministry of Infrastructure and Environment.

Accurate estimates of the congestion costs by severity level and costs per crash are not available in the Netherlands, because the congestion data used to estimate the congestion costs related to crashes does not include indicators of crash severity nor the number of crashes.

2.5 United States

Research on congestion costs and applications

In the US congestion costs are including in crash costs estimates since at least 1992 when the report 'The economic cost of motor vehicle crashes, 1990' (Blincoe & Faigin, 1992) was published. Until the latest road crash cost study (Blincoe et al., 2014), only the value of lost travel time was included. In the most recent study, this was expanded to include the added costs from additional fuel burned and environmental and health impacts. Congestion costs are included in these studies because they are a significant proportion of overall road crash costs, so it is considered important to account for these costs in order to provide a comprehensive estimate of the full impact of crashes on society.

The results of these studies have two primary uses. The first is to inform the public and policy makers of the impacts that traffic crashes have on society, which is helpful for policy decisions and the allocation of resources. The second is to establish the value of benefits such as reduced fatalities, injuries, and property damage only crashes that results from the adoption of safety countermeasures through either regulation or behavioural programs. In the US, it is required to conduct cost-benefit analyses of regulations and the costs per crash or casualty, that include congestion costs, are used for this purpose.

In addition to the congestion costs estimates in the road crash cost studies, congestion costs are calculated annually by the Texas Transportation Institute. These studies do not include separate estimates of congestion costs related to crashes however.

Method

In the US the following impacts related to congestion due to crashes are taken into account:

- Direct time losses resulting from lane closings
- Rubbernecking: time loss due to congestion that is not caused by lane closings
- Post-crash queue dispersal
- Detours
- Environmental impacts
- Additional fuel consumption

Below we discuss the methods that are used in the US to estimate each of these impacts.

Direct time losses resulting from lane closings

In the US a queuing model is used to estimate the time losses related to crashes. The basic structure of the model is the same as the models used in Australia and Germany. This means that the time loss is calculated on the basis of traffic volumes, duration of road blockage and reduction of road capacity due to a collision. The main inputs for the model are:

- Traffic volumes ('Annual Average Hourly Traffic') for five road types, based on data from the Highway Performance Monitoring System. This is a comprehensive traffic data collection system covering a sample of over 110,000 highway segments. Traffic volumes are linked to road crashes, using data on traffic volumes and crashes by day (weekday/weekend), time of the day (hour), road type and crash severity. Based on these data, the traffic volume related to each crash severity category and road type was calculated, showing that crashes tend to occur at times when traffic volumes are higher than average.

- Duration of road blockage, which is estimated using crash data on urban interstate expressways in Pennsylvania, that includes the time police spends at the crash site by crash severity (fatal, injury and PDO) and type of road closure (fully, partially, none). Data from Kentucky were used to estimate police time spending on other road types. Estimates of police response time were added to the police time spending estimates, resulting in crash durations of 143-167 minutes for fatal crashes, 38-63 minutes for injury crashes and 35-56 minutes for PDO crashes (depending on the road type, weighted average for road closing types).
- Road capacity reduction. Data on the impact on road capacity if a road lane is blocked and the probability of lane blockage is used to estimate road capacity reduction. The impact of road blockage on capacity is retrieved from a study that estimated road capacity reduction as a function of the number of lanes and the number of lanes closed, and taking into account the number of vehicles involved (Chin et al., 2004). The probabilities of lane blockage due to fatal crashes are derived from the FARS (Fatality Analysis Reporting System) database, and these were also applied to injury and PDO crashes.

In the US model separate calculations are made for reported and unreported crashes, by making assumptions on the duration of road blockage and road blockage probabilities for unreported crashes relative to reported crashes.

Direct time losses (as well as other types of time loss discussed below) that were calculated using these data are transferred into costs using values of time per road type developed by Hagemann et al. (2013). The values of time are based on guidelines from the US Department of Transport (USDOT, 2011), that include values of time for business travel, personal travel, bus drivers and truck drivers. The values were derived from wages (business travel, truck, bus) and household income (private travel).

Rubbernecking

In the US study on road crash costs, rubbernecking is defined as ‘any slowing that affects capacity when a lane isn’t blocked, regardless of specific motivation’ (Blincoe et al., 2014). Rubbernecking can be a result of driver’s curiosity or cautiousness when an incident has happened even when the road capacity is not affected. Rubbernecking can occur either on the side of the road where the incident occurred or on the other side of the road.

Time loss related to rubbernecking on the side of the road where the crash occurred is calculated similarly to the time loss resulting from lane closings, since the data used to calculate crash duration and road capacity reduction include ‘no lane closure’ (or ‘vehicle on shoulder’) as a category. The rate of rubbernecking in the opposite direction was taken from one of the few studies on rubbernecking (Masinick & Teng, 2004). They collected data on crashes on a road section in Virginia and the traffic flow in the opposite direction of the road. From this study it was concluded that about half of the crashes caused rubbernecking in the opposite direction. Capacity reduction was estimated at 13% in that study. These estimates are used, in combination with data on traffic volumes and crash duration, for the calculation of time loss due to rubbernecking in the opposite direction. In addition, capacity reduction figures related to rubbernecking in the same direction (20-24%, depending on road type) were applied as an approximation of the rubbernecking in the opposite direction.

Post-crash queue dispersal

Time losses related to queue dispersal after the road has been cleared are calculated separately in the US methodology (which is different from the models used in the other countries where these time losses are included in the queuing model). Costs of post-crash queue dispersal include waiting time before vehicles can start to move after the crash site is cleared plus the time loss related to the fact that vehicles cannot move at the normal speed for some time when the queue disperses. These time losses are calculated using data and assumptions on several parameters, such as the number of vehicles in the queue, the distance between the vehicles in the queue, the time interval between initiated acceleration of each vehicle in the queue and the acceleration of the vehicles.

Detours

Time losses resulting from detours to avoid traffic jams are estimated using the micro-simulation model TSIS-CORSIM. This model can simulate traffic responses to crashes and one the outputs is vehicle hours lost due to a crash. The model was applied in a study that estimated time loss, including time loss related to detours, resulting from truck crashes (Hagemann et al., 2013). To estimate time loss related to detours of all traffic, Blincoe et al. (2014) applied their own method to estimate direct time losses (as described above) to trucks only, and compared the outcomes with the results found by Hagemann et al. (2013) that included both direct losses and time losses. The resulting factor was used to estimate to estimate the impacts of detours of all traffic.
In addition, the Hagemann et al. (2013) study took into account non-linear congestion impacts related to the interaction between traffic density and road capacity. For example, when traffic density is low, the remaining road capacity after a crash may still be sufficient and direct time losses may be overestimated. This effect is not included in the estimates of direct time losses because these calculations were based on average traffic volumes by road type. However, by applying the results of Hagemann et al. (2013) to estimate detour impacts, these non-linear congestion impacts were automatically included.

Environmental impacts

The study on truck crashes discussed above (Hagemann et al., 2013) included environmental impacts, by linking the results of the TSIS-CORSIM model to the emission model MOVES (Motor Vehicle Emission Simulator) developed by the US Environmental Protection Agency. Using these models, the emissions (tons) of several pollutants (e.g. CO_2, NO_x and PM) per fatal crash were estimated. In the road crash cost study (Blincoe et al., 2014) the emissions per crash are translated into emissions per vehicle hour using the time loss estimates for fatal crashes. The emissions per hour are then used to estimate the emissions per injury crash and PDO crash. The emissions are expressed in terms of money using monetary valuations per ton emission from several studies, that represent the associated health and environmental costs. In addition to the direct vehicle emissions, 'upstream' emissions are included in the calculations. These are emissions related to production and distribution of fuel. Data on these emissions were taken from the 'Corporate Average Fuel Economy Standards' (NHTSA, 2012).

Additional fuel consumption

Extra fuel consumption due to congestion are derived from the estimated CO_2 emissions per crash and studies that have estimated the relation between fuel consumption and CO_2 emissions. The associated costs are calculated using an average fuel price.

Results

Table 2.12 shows the total costs and the number of crashes[7] in the US. Total costs of congestion related to crashes in the US are estimated at 28 billion US$ in 2010, which is 3.2% of the total costs of road crashes in the US (871 billion US$) and 0.2% of GDP. The majority of these costs (71%) is related to PDO crashes, while fatalities have share of only 1% in total congestion costs.

	Fatal	Injury	PDO	Total
Total congestion costs	189	7,903	19,935	28,027
Number of crashes	30,296	2,969,963	10,565,514	13,565,773

Table 2.12: Total congestion cost related to crashes by crash severity in the US 2010 (million US$). Source: Blincoe et al. (2014)

The costs per fatal crash are about six times higher than the costs per injury crash, while the costs per injury crash are a factor 1.3 higher than the costs per PDO crash. Large difference were found between police reported and unreported crashes: costs per police reported crash are five (PDO) to 12 (fatal) times higher than the costs per unreported crash (Table 2.13).

	Fatal	Injury	PDO
Police reported	14,121	3,755	3,673
Unreported	1,130	491	671
All	14,121	2,459	1,881

Table 2.13: Congestion costs per crash by crash severity in the US 2010 (US$), police reported and unreported. Source: Blincoe et al. (2014)

Table 2.14 (costs per crash) shows that time losses dominate the congestion costs, having a share of 91-92% in the costs per crash. This includes time loss related to rubbernecking and detours (separate estimates are not available). Costs of additional fuel consumption (6-7%) and emissions (2%) are relatively low.

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[7] All crashes; the number of crashes that cause congestion was not reported.

	Fatal	Injury	PDO
Time losses	12,855	3,409	3,376
Emissions	342	90	80
Additional fuel	925	255	217
Total	14,121	3,755	3,673

Table 2.14: Congestion cost related to crashes per crash in the US 2010, by cost item (million US$). Source: Blincoe et al. (2014)

There are huge differences in costs per crash between road types (Table 2.15[8]), which are particularly influenced by different traffic volumes per road type.

	Fatal	Injury	PDO
urban interstates/expressways	104,519	14,421	10,147
urban arterials	8,553	1,257	584
urban other	1,154	332	154
rural interstate/principle arterials	7,592	928	748
rural other	543	92	59

Table 2.15: Congestion cost per crash in the US 2010, by road type (US$). Source: own calculations based on Blincoe et al. (2014)

2.6 International comparison

Table 2.16 summarizes the congestion costs related to crashes for the five countries included in this review. In addition to total costs, costs as percentage of GDP, costs per registered motor vehicle and the proportion of congestion costs in total road crash costs are shown for comparison purposes. The costs are converted into Euro and price level 2014.[9] GDP and number of motor vehicles, for the year for which the costs were estimated, were retrieved from the World Bank (2015). The table shows that there are large differences in the relative size of congestion costs. In Germany and in particular in Austria the congestion costs are relatively very low. In Australia and the Netherlands the costs are in the same order of magnitude (particularly the costs per motor vehicle), while the costs per motor vehicle and the percentage of GDP in the US are more than twice as high as in Australia and the Netherlands. Leaving aside Austria, congestion costs are about 1 to 5% of the total costs of road crashes. Logically, this percentage depends on the size of the other components of road crash costs

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[8] Table 11 shows the figures for police reported crashes only. The costs of unreported crashes show similar differences between road types, but the cost levels are much lower.

[9] The year 2014 is chosen because in Chapter 3 an estimate of congestion costs in Ireland is made for 2014, the most recent year for which road safety statistics are available at the time of writing this report. The costs in local currencies were firstly expressed in price level 2014 using GDP deflators from the World Bank (2017) and then adjusted for relative price differences using price level indices from Eurostat which implies that all values are expressed in the average price level of the EU28 countries. Finally Australian and US values are converted into Euro using the exchange rate for 2014 from the World Bank (2017). In the remainder of this report the same procedures are used for converting values expressed in local currencies in a certain base year into Euro and price level 2014.

and the way they are estimated. For example, the US has relative high road crash costs because of a relatively high value for quality of life loss (Wijnen & Stipdonk, 2016). Consequently, the share of congestion costs in total road crash costs in the US is lower than in Australia, while the congestion costs per motor vehicle are much higher.

	Congestion costs (million €, 2014)	% GDP	Costs per capita (€, 2014)	Costs per motor vehicle (€, 2014)	% total road crash costs
Australia	593	0.09%	29	43	5.0%
Austria	4	0.001%	0.5	1	0.04%
Germany	328	0.01%	4	7	1.0%
Netherlands	286	0.05%	17	33	2.4%
US	22,166	0.19%	72	92	3.2%

Table 2.16: Total costs of congestion related to crashes, costs per motor vehicle, percentage of GDP and proportion in total road crash costs.

Table 2.17 shows the costs per crash by severity (fatal, serious injury, slight injury, average for all non-fatal injury crashes, PDO) and the average costs per crash for all crashes (all severity levels).[10] This shows that the average costs per crash in Austria are again extremely low, while in Germany the costs per injury crash and per PDO crash are relatively very high. The high costs per PDO crash in Germany are likely to be explained by the fact that only more severe PDO crashes are included, while in Austria the same costs for all severity categories are assumed. Furthermore, the costs in Germany refer to motorway only, where congestion costs are likely to be higher than average due to much higher traffic volumes.

As expected, more severe crashes result in higher congestion costs, except in Germany and Austria. The costs per injury crash and per PDO crash are generally in the same order of magnitude.

	Fatal	Injury			PDO	All
		Serious	Slight	All		
Australia	9,754	1,355	-	-	-	915
Austria	113	113	-	-	-	113
Germany	10,225	-	11,953	8,498	-	9,207
Netherlands	14,496	7,695	5,306	5,684	9,271	155
US	13,725	2,390	-	-	-	1,828

Table 2.17: Congestion costs per crash by crash severity and the average for all crashes (€, 2014)

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[10] Averages for all crashes are calculated using the total costs and number of crashes as reported in the cost studies. For Germany and the Netherlands only crashes on motorways were used. The number of motorway crashes in Germany was derived from the total costs and costs per crash. The number of crashes in the Netherlands was derived from the BRON crash statistics database (MinIE, 2017). The costs per crash refer for all crashes, regardless of whether they result in congestion. However, in Australia only the costs per crash were only reported for crashes that result in congestion. We have calculated the average costs for all crashes using data on the total number of crashes and the number of crashes that cause congestion (source: BITRE, 2009).

The differences in congestion costs can be explained on the one hand by differences in the methodologies, and on the other hand by differences in road safety and traffic circumstances. Concerning methods, the previous sections showed that there are several differences between the five countries. Firstly, there are differences in the costs items that are included. In Austria and Germany, only direct time losses are included, while the other three countries also include environmental impacts, fuel costs, costs of adapting travel behaviour (e.g. detours) and/or costs of travel time unreliability. Table 2.18 shows that in Australia, Austria and Germany total costs are dominated by direct time losses, because other costs were not included (Austria, Germany) or other costs have a minor share in total congestion costs related to crashes (Australia). However, the Dutch calculations show that impacts on travel behaviour (e.g. detour) and travel time unreliability can result in very significant costs. The inclusion of costs related to travel behaviour adaptions and rubbernecking in the US may contribute to the relatively high costs in the US, while the omission of these costs could (partly) explain the relatively low costs in Austria and Germany. However, differences in the number of costs items included do not explain the relatively high costs in Australia, as Australia only includes health/environmental costs and vehicle operating costs as additional costs, which have a limited share in the total costs.

	Direct time losses	Adapting travel behaviour	Travel time unreliability	Health/ Environment	Vehicle operating / fuel costs
Australia	89%	-	-	6%	5%
Austria	100%	-	-	-	-
Germany	100%	-	-	-	-
Netherlands	39%	39%	22%	-	1%
US	91%		-	2%	7%

Table 2.18: Distribution of total congestion costs over costs items

Secondly, there are differences in the road types that are included in the calculations. In Germany and the Netherlands, only congestion on motorways is taken into account, while the models in the other three countries include all roads. Including motorways only may result in a significant underestimation of total congestion costs related to crashes: in Austria 25% of congestion costs is related non-motorways, while in the Netherlands a rough estimate indicates that including non-motorways would raise the congestion costs by about 50% (Annema & Van Wee, 2004).

Thirdly, in Austria congestion costs resulting from PDO crashes are not taken into account, while in the other countries, PDO crashes contribute very significantly to congestion: 38% (Germany) to 71% (US) of the congestions costs result from PDO crashes. Hence, the exclusion of PDO crashes in the Austrian calculations is one of the explanations for the relatively very low costs in Austria.

Finally, the specifications and level of detail of the calculation models are different in each country. Whereas Austria applies a relatively simple model that includes a few key parameters without distinguishing severity categories, the US for example developed a much more detailed model that uses more parameters such as lane closing probabilities by road type, the resulting road capacity reduction, duration of lane closings by crash severity, emergency services response times, etc. In

Germany time losses were calculated at the level of road segments, while the models in other countries use averages for all road segments. Such differences in level of detail are likely to contribute to differences in the size of the congestion costs.

As mentioned above, other explanations for differences in congestion costs relate to differences in road safety and traffic circumstances, such as the number and severity crashes, traffic volumes and road capacities. In addition, different values of time may contribute to different cost levels. In the next chapter, the road safety and traffic variables that are included in the calculation models as well as the values of time will be assessed in more detail, which will provide additional explanations for the cost differences.

2.7 Summary and conclusions

In this chapter, studies on congestion costs related to crashes in five countries were reviewed. In all of these countries congestion costs are regarded as an important element in the socio-economic costs of road crashes, and for that reason they are included as a standard cost item in road crash cost calculations in these countries. Information on the costs of road crashes, and congestion costs as part of that, is used to raise awareness for the socio-economic burden of road crashes. In addition, road crash costs information is used in cost-benefit analysis of road safety projects or broader transportation projects. Road crash costs figures are often included in national guidelines for cost-benefit analysis of traffic and transport projects. Furthermore, in the Netherlands a study was conducted that used congestion costs related to incidents, including road crashes, for a cost-benefit analysis of incident management. In the other countries no specific applications of congestion cost estimates are known, apart from being one of the elements in the estimation of the total costs of road crashes. However, possibly the congestion cost estimates are used by organizations concerned with traffic flow such as the police or national, regional or local transportation departments. No further information on the use of congestion cost data by such organizations is available however.

In most countries, a queuing model is applied to estimate congestion costs related to crashes. These models calculate the time losses resulting from crashes using several parameters such as traffic volumes, road capacities, capacity reductions due to a crash, emergency response times, etc. The level of detail, e.g. the number of parameters used in the model, differs considerably between countries, which (partly) explains differences in the outcomes. A different approach is used in the Netherlands. Instead of modelling congestion, time losses due to congestion are measured in a direct way through a congestion monitoring system. In this system the cause of congestion, including crashes, is recorded. In addition to these data, models are used in the Netherlands to estimate other impacts, such as travel behaviour adaptions and unreliability of travel times. Direct measurement of congestion indicators, such as length and duration of traffic jams, as applied in the Netherlands enables to provide an accurate estimate of the direct time losses, which is not dependent on data limitations and assumptions that need to be made in queuing models. However, only motorways are included in the Dutch data, while most models that are applied in the other countries do include estimations of congestion on all road types. This implies a significant underestimation of the full congestion costs related to crashes in the Netherlands. Another advantage of the queuing models is that they provide insight in the relations between congestion costs and crash and traffic characteristics, such as the numbers of crashes by severity and traffic density. In the Netherlands information on these relations is not available however.[11]

In all countries the emphasis in the congestion cost calculations is on direct time losses, and in some countries no other costs (Austria, Germany) are taken into account. Other countries include health and environmental costs (Australia, US), additional vehicle operating and fuel costs (Australia, Netherlands, US), costs of adapting travel behaviour (Netherlands, US) and costs of travel time unreliability (Netherlands). In the US time losses due to rubbernecking (congestion without lane closings, also on the opposite side of the road) are explicitly included. The Dutch calculations show that in particular costs of adapting travel behaviour and costs of travel time unreliability can have a substantial impact on the size of the costs. Health and environmental costs as well as vehicle operating costs are relatively low in all countries that include these costs.

The review shows that there are large differences in the size of congestion costs. In Germany and in particular in Austria the congestion costs related to crashes are very low: €7 and €1 per registered motor vehicle respectively (2014 price level). In Australia and the Netherlands the cost per motor vehicle are in the same order of magnitude (€43 and €33), whereas in the US the costs are highest (€92 per motor vehicle). Costs as a percentage of GDP range from 0.001% in Austria to 0.19% in the US. Congestion costs have a share of 1% to 5% of the total costs of road crashes (excluding Austria where this percentage is extremely low: 0.04%).

Several differences in the methodologies that are applied to estimate congestion costs related to crashes were identified, in particular differences in costs items, road types and crash severity categories that are included. Furthermore, the specifications and level of detail of the calculation models are different in each country. These differences contribute to the differences in cost levels.

In addition to methodological differences, different road safety and traffic situations can explain the differences in cost levels. Concerning road safety characteristics, the studies in the five countries show that congestion costs per crash depend on the number of crashes by[12]:

- crash severity
- road type
- day (week/weekend)
- time of the day
- number of vehicles involved (particularly single vehicles crashes versus multiple vehicle crashes)[13]

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[11] In principle it would be feasible to link data on congestion resulting from crashes to crash and traffic statistics. This has not been done in the Dutch study on road crash costs, as the purpose was to only estimate the total congestion costs related to crashes.

[12] The Australian model also distinguishes between several types of urbanization. However, this overlaps with road types.

[13] Only in the US study this aspect was explicitly included. However, also the Australian study notes that some types of single vehicle crashes are likely to cause less congestion than multiple vehicle crashes.

Concerning traffic conditions, the most important parameters that are included in the congestion costs models are:

- Traffic volumes (by road type, day and time of the day)
- Road capacity (by road type)

In addition, congestion costs depend on several indicators affecting the impact of crashes on congestion:

- Congestion probabilities (by crash severity and road type)
- Road capacity reduction due to a crash (by severity and road type)
- Crash duration (by severity)
- Emergency response times

In the next chapter the road safety and traffic parameters will be analyzed in more detail, which will give further explanations for the costs differences. The findings will be linked to data for Ireland, to produce an indication of the potential size of congestion costs related to crashes in Ireland.

3. An estimate of the potential size of congestion costs related to crashes in Ireland

3.1 Introduction

In this chapter an estimate of the potential size of congestion costs related to crashes in Ireland is made. A ‘value transfer’ (or ‘benefit transfer’) approach will be adopted, which in general means that the results of primary valuation studies are used to estimate values in another context (Freeman et al., 2014). In this case it means that congestion costs estimates from studies in other countries, that were discussed in Chapter 2 are used to estimate the costs in Ireland. However, the road safety and traffic situation in Ireland is different from the situation in other countries, so factors affecting the size of congestion costs should be taken into account as much as possible. Firstly, we analyse the main road safety and traffic characteristics that affect congestion costs (as identified in Chapter 2) in Ireland and the four other countries and compare them in a qualitative way (Section 3.2). Austria is not included in the analyses because the results of the Austrian deviate strongly from the results in the other countries, which is most probably due to the fact that the Austrian model was much more simplified than the models used in the other countries. Based on this comparative analysis and cost estimates in other countries, an estimate of the potential size of congestion costs related to crashes in Ireland is made (Section 3.3).

3.2 Road safety and traffic indicators influencing congestion costs

In Chapter 2, several road safety and traffic factors that were found to affect congestion costs:

- the number of road crashes, total and by:
    - number of motor vehicles involved
    - crash severity
    - road type
    - day (week/weekend)
    - time of the day
- traffic volumes by road type
- value of time

The comparative analysis in this section concentrates on these factors, which data are available in Ireland and most of the other countries, provided that accurate data are available. We present figures for both fatal and injury crashes. More weight should be given however to the results on injury crashes, as the previous chapter showed that injury crashes contribute more to congestion costs than fatal crashes because of the higher number of crashes. PDO crashes are not included in this chapter due to the lack of accurate data on PDO crashes in most countries. Data are retrieved from the costs studies in each country and are supplemented by data from national road crash databases and reports on road crash statistics. All data refer to the year for which the congestion costs were estimated in the particular country, unless stated otherwise. Data for Ireland refer to the year 2014 and are taken from the RSA report ‘Road Casualties and Collisions in Ireland - 2014 Tables’ (RSA, 2016). Details on the data sources and data analyses are included in Appendix 1.

Total number of crashes

Table 3.1 presents the number of fatal and serious injury crashes[14] and the crash rates for each country, including the estimated number of unreported crashes. Serious injury crashes are defined as crashes involving at least one casualty who is admitted to hospital with an overnight stay (Australia, Netherlands) or at least for 24 hours (Germany). In Ireland the definition is broader because also casualties with specific injuries (e.g. fractures and concussion) are included, whether or not detained in hospital. Despite potential differences in estimates of unreported crashes, the table indicates that the number of fatal and injury crash rates in Ireland are low compared to the other countries, particularly given the broader definition of serious injuries in Ireland. Obviously, this has a downward impact on the size of congestion costs related to crashes as compared to the other countries.

	Fatal		**Serious injury**	
	Total	**Per 100,000 people**	**Total**	**Per 100,000 people**
Australia	1,455	7.0	25,498	123
Germany	4,984	6.0	66,627	81
Netherlands	667	4.0	16,731	101
US	30,296	9.8	n.a	n.a
Ireland	*179*	*3.9*	*2,261**	*49*

Table 3.1: Number of crashes (including unreported) and crash rates.

* The number of serious injury crashes in Ireland is calculated by multiplying the reported number (646; source: RSA, 2016) by an underreporting factor of 3.5 as outlined in Sheridan et al. (2011).

Crash severity

The review in Chapter 2 showed that the congestion costs per crash depend on crash severity. Consequently, total congestion costs depend on the distribution of the number of crashes over severity categories. Table 3.2 shows that in all countries the number of fatal crashes as a proportion of fatal and serious injury crashes is low, although there are differences between the countries. In particular in the Netherlands the proportion of fatal crashes is relatively low (3.8%), which is related to the high number of bicycle injury crashes in the Netherlands. The distribution of crashes over fatal crashes and serious injury crashes in Ireland is in line with the distribution in the other countries and consequently this variable is assumed not to cause any differences in congestion costs related to crashes.

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[14] We concentrate on serious injury crashes because in Ireland the rate of underreporting is only known for serious injury crashes (not for minor injury crashes).

	Fatal		Serious injury	
Australia	1,455	5.4%	25,498	94.6%
Germany	4,984	7.0%	66,627	93.0%
Netherlands	667	3.8%	16,731	96.2%
Ireland	*179*	7.3%	*2,261*	92.7%

Table 3.2: Number of crashes by crash severity

Number of vehicles involved

Congestion costs related to crashes are likely to depend on the number of motor vehicles involved. Crashes without involvement of motor vehicles (pedestrians and cyclists only) usually do not result in congestion. Furthermore, single vehicle crashes are likely to cause less congestion than multiple vehicle crashes, because the probability of road blockage is smaller in the case of single vehicle crashes (e.g. run-off-road crashes). Figure 3.1 presents the proportions of single vehicle crashes and multiple vehicle crashes. Single vehicle crashes include collisions with a pedestrian. In all countries, the majority (58-68%) of fatal crashes are single vehicle crashes, while most injury crashes (60-75%) are multiple vehicle crashes. The pattern in Ireland is not different from other countries, although the proportion of single vehicle fatal crashes is on the lower end (58%) while the proportion of single vehicle injury crashes (40%) is on the higher end. The latter could have a downward impact on congestion costs (relative to the other countries), taking into account that a large share of congestion cost are related to injury crashes.

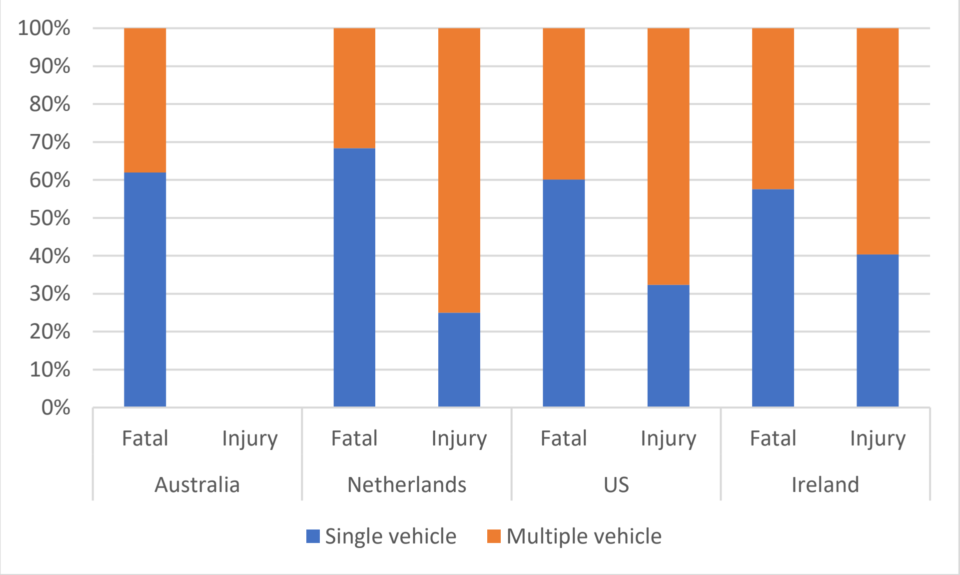

Figure 3.1: Proportion of single and multiple vehicle crashes in all vehicle crashes.

Road types

In general, congestion costs are higher on roads with higher traffic volumes, particularly if the number of lanes is limited so the impact of a crash on traffic flows is more severe. Consequently, congestion costs resulting from a crash depend on the road type. This is confirmed by the results of the US congestion cost study (see Section 2.5; in other countries congestion costs by road are not available). This implies that the distribution of the number of crashes over road types affects the total congestion costs related to crashes.

The five countries in this assessment use different classifications of road types, which complicates comparing the number of crashes by road type. A classification into urban roads, rural roads and motorways can be more for Germany, the Netherlands and Ireland. Figure 3.2 presents the distribution of the number of fatal and injury crashes over these three categories in these countries. This shows that there are relatively more crashes on rural roads and less on urban roads and motorways in Ireland as compared to Germany and the Netherlands. Since traffic volumes are likely to be lower in rural areas, this is expected to have a downward impact on congestion costs in Ireland. There are no data available that allow making the same classification for Australia and US. However, the proportion of injury crashes on urban roads in the US is also slightly lower than in Ireland (66% versus 59%).

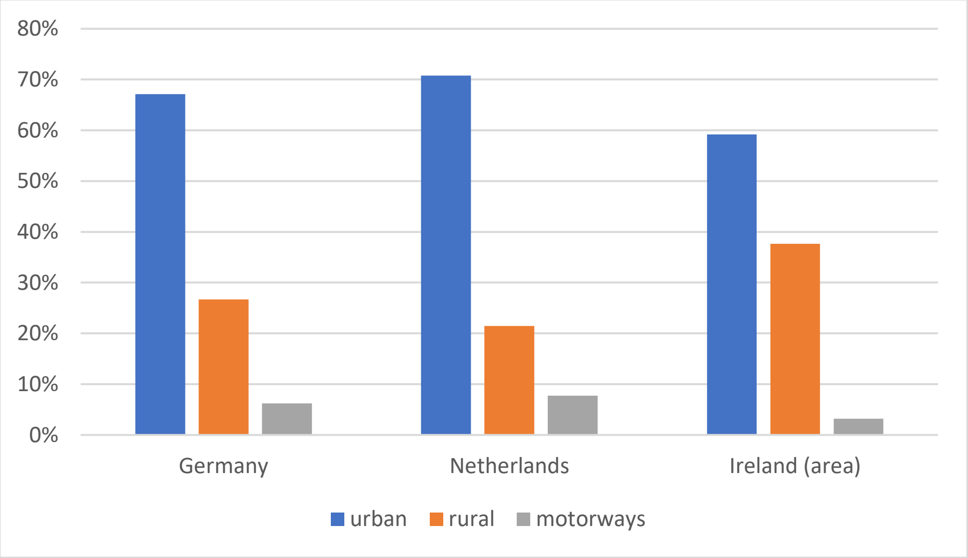

Figure 3.2: Proportion of injury crashes inside built-up areas, outside built-up areas (excluding motorways) and motorways. Source: own calculations based on several sources (see Appendix 1).

Note that the road types in each of these three categories might be substantially different between the countries, for example concerning the number of road lanes. In Ireland, 86% of the crashes occur on two-way single carriageways, which are likely to be more prone to congestion after a crash than dual carriageways (because only one lane might be blocked allowing traffic to keep on flowing to some extent). However, comparing specific road types across countries is not possible because detailed information on crashes by road types, such as two-way single carriageways, is not available in each country or different road type definitions are used.

Day of the week

Congestion costs resulting from crashes are likely to be higher on weekdays than during the weekend because of higher traffic volumes. In addition, higher values of time associated with business travels and commuting contribute to higher costs on weekdays. In Ireland 70% of all fatal crashes and 73% of injury crashes occur weekdays (Figure 3.3). Compared to the other countries this is on the lower end, but still in the same order of magnitude: in other countries 65% to 81% of fatal crashes occur on weekdays and 76% to 84% of injury crashes.

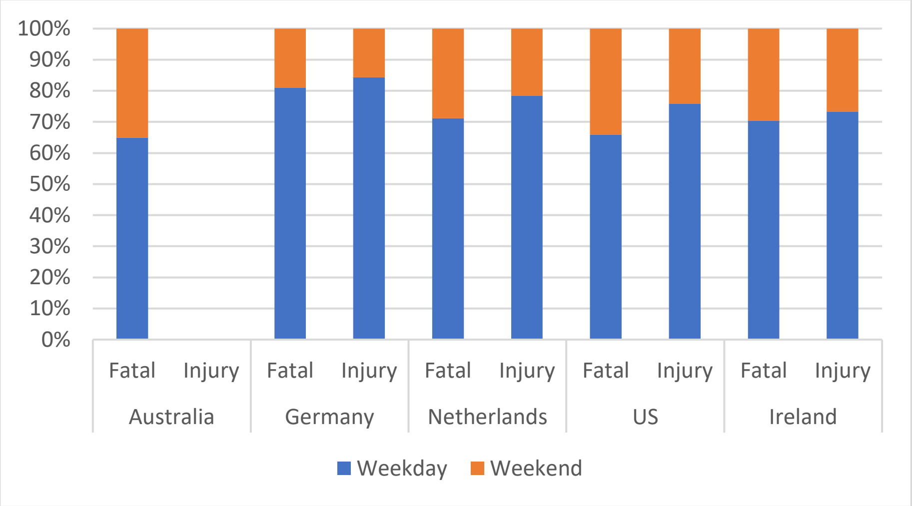

Figure 3.3: Distribution of fatal crashes and injury crashes over weekdays and weekends.

Time of the day

Crashes result in more congestion at times of the day when traffic density is higher. Figure 3.4 presents the number of crashes during traffic peak hours on weekdays (Monday-Friday) as a proportion of the total number of crashes on weekdays. Peak hours are 7-10 am and 4-7 pm in each country, following the DTTaS study on congestion costs (DTTaS, 2017). This shows that the proportion of injury crashes during peak hours in Ireland (40%) is in the same range as in other countries (35-44%). The proportion of fatal crashes during peak hours in Ireland (38%) is higher than in the other countries (23-36%), but the impact on total congestion is expected to be very limited due to the low number of fatal crashes compared to injury crashes.

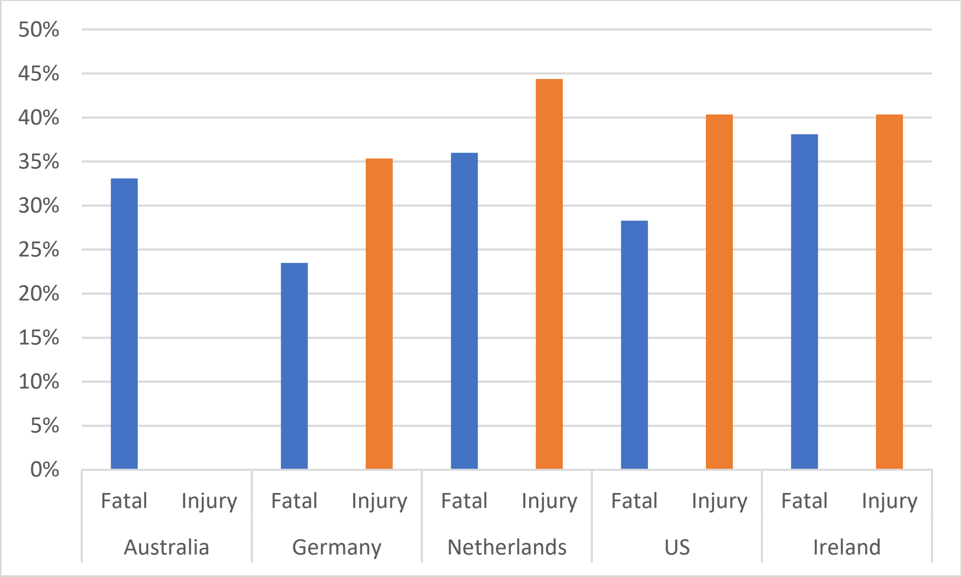

Figure 3.4: Proportion of crashes in peak hours (7-10 am and 4-7 pm)

Traffic volume

Differences in traffic volumes are another potential explanation for congestion cost differences, as congestion and the related costs increase with higher traffic volumes. Table 3.3 shows the traffic volumes (number of vehicles per 24 hours) on motorways for each country (see Appendix 1 for details on data sources). This shows that the traffic volumes on motorways in Ireland are more than twice as low as in the other countries. Traffic volume data for other road types is not available, but the figures for motorways indicate that traffic densities in Ireland are lower than in the other countries. Consequently, the number of vehicles in Ireland that are affected by congestion after a crash, and thus congestion costs, are likely to be lower than in the other countries. On the other hand, usually road capacities are adjusted to traffic volumes, which means that in Ireland the road capacities are expected to be smaller than in the other countries (for examples indicated by fewer lanes per road). This has an upward impact on congestion, which might outweigh the effect of lower traffic volumes to some extent.

Country	Traffic volume
Australia	42,000-68,000
Germany	48,000
Netherlands	49,000
US	26,000-114,000
Ireland	*19,000*

Table 3.3: Traffic volumes on motorways (number of vehicles per day, annual average; rounded at 1,000)

Value of time

Table 3.4 shows the values of time per vehicle hour (cars and trucks) that were used in the cost studies in each country. In particular values per car, which have a much stronger impact on congestion costs than truck values because of their larger proportion in traffic volumes, show substantial differences: the highest value (Australia) is 2 times higher than the lowest value (Netherlands). Logically, this has a strong impact on the size of the congestion costs.

	Car	Truck
Australia	33.1	46.7
Germany	NA	46.2
Netherlands	16.5	53.0
US	22.9	32.0
Ireland	11.4	26.3

Table 3.4: Values of time (per vehicle hour, € 2014)

Summary

Table 3.5 summarizes the results of the comparative analysis of the factors that can influence the size of congestion costs related to crashes. The most distinct differences between Ireland and the other four countries concern the crash rate, traffic volumes and the value of time, which are all substantially lower than in (most of) the other countries. This is expected to have a considerable downward impact on congestion costs as compared to the other countries. In addition, there are less crashes on urban roads and on motorways in Ireland than in the other countries, which has a further downward impact on congestion costs. This could be offset however by a very high proportion of crashes on two-way single carriageways in Ireland, which are likely to be more prone to congestion than other road types. Furthermore, we found a somewhat lower proportion of multiple vehicle crashes in Ireland and less crashes on weekday. However, these are slight differences and the indicators are still in the same order of magnitude as in the other countries. Consequently, the impact on the congestion costs of these factors (as compared to the other countries) is considered to be very slight or negligible.

Factor	Indicator	Ireland compared to other countries	Impact of congestion costs
Crash rate	number of crashes per 100,000 people	++	++
Crash severity	% fatal crashes	No difference	None
Number of vehicles	% multiple vehicle crashes	-	+
Road type	% crashes on urban roads	-	-
	% crashes on motorways	-	-
Day of the week	% crashes on weekdays	-	-
Time of the day	% crashes during peak hours	No difference	None
Traffic volume	Number of vehicles per 24h on motorways	--	--
Value of time	Value of time per vehicle hour (average by journey purpose, car and trucks)	--	--

Table 3.5: Summary factors that influence congestion cost

++: considerably higher in Ireland / considerable upward impact on congestion costs

+: slightly higher in Ireland / slight upward impact on congestion costs
-: slightly lower in Ireland / slight downward impact on congestion costs
--: considerably lower in Ireland / considerable downward impact on congestion costs

3.3 The potential size of congestion costs related to crashes in Ireland

An indication of the potential size of congestion costs related to crashes in Ireland can be given using the 'value transfer' approach. In this case, this means that we use estimates of the congestion cost found in other countries and apply them to Ireland. We adopt two approaches:

- Top-down: here we derive a plausible range of the *costs per capita* from other countries (taking into account differences in methods) and apply this range to Ireland, taking into account differences in road safety and traffic characteristics as identified in Section 3.2.
- Bottom-up: in this approach we derive congestion *costs per crash* from the studies in other countries, and apply this estimate to the number of crashes in Ireland to give an indication of the total congestion costs related to crashes. This approach particularly takes into account the distribution of crashes over severity levels and road types, by using costs per crash and number of crashes by severity and road type.

Top-down approach

In the review in Chapter 2, costs of congestion related to crashes were found to range between €4 and €72 per capita (excluding Austria; Table 2.13). To derive a figure for Ireland from these values, the following factors should be taken into account (see Section 3.2)

- Crash rates in Ireland are lower than in most other countries: both the number of fatal crashes and serious injury crashes per 100,000 people are about 1.5 to 2.5 times higher than in Ireland. Only in the Netherlands the rates of (congestion causing) crashes are in the same order of magnitude as in Ireland (taking into account that the higher serious injury crash rate in the Netherlands is related to a high number of bicycle crashes that do not result in (much) congestion).
- Traffic volumes are lower in Ireland than in the other countries: information for motorways indicates that traffic volumes are more than two times lower than in the other countries.
- Values of time in Ireland are a factor 1.6 to 2.7 lower than in the other countries.

Furthermore, there are differences in methods used to calculate congestion costs, in particular (see Chapter 2):

- Australia and Germany do not include costs of adapting travel behaviour (e.g. detouring). Information from the Netherlands and the US indicates that including this cost items results in considerably higher costs (up to twice as high in the Netherlands).
- In Germany and the Netherlands only congestion on motorways is included. Dutch researchers indicated that including other road types might raise the cost by 50% in the Netherlands (Annema et al., 2004).

- The Netherlands is the only country that takes into account the costs of travel time unreliability, which have a significant share (22%, see Table 2.15) in the total costs.

Taking into account the relatively low crash rates, traffic volumes and value of time in Ireland as well as the omissions in the congestion cost calculations in the other countries, as well as the, we consider €4-€10 per capita as a reasonable, but a rough indication of the potential congestion costs related to crashes in Ireland that includes all relevant cost items except costs of travel time unreliability.[15] Given that Ireland had 4.6 million inhabitants in 2014, this translates roughly into about €20 to €50 million total congestion costs related to crashes Ireland.[16]

Bottom-up approach

In the bottom-up approach, an estimate of the congestion costs per crash, which is derived from studies in other countries and adapted to the Irish situation, is applied to the number of road crashes in Ireland. We use the costs per crash by crash severity and road type, because in Chapter 2 costs per crash were found to depend on these dimensions. Note that the large majority of crashes in Ireland (86%) occurs on one specific road type (two-way single carriageways), which implies that an average for all road types would not be appropriate. In addition, differences in traffic volumes and values of time are taken into account.

Costs per crash by road type are only available for the US. For that reason, we apply the costs per crash per road type from the US to single carriageways in Ireland. Concerning motorways and dual carriageways, the approach draws on congestion cost per crash from Germany and the Netherlands. For all road types we take into account that traffic volumes is Ireland are lower, by using 50% of the costs per crash as a lower limit (and 100% as upper limit). Furthermore, all values are adjusted for the lower the value of time in Ireland as compared to the other countries. Table 3.6 includes the resulting (rounded) costs estimates per crash that we use to calculate congestion costs in Ireland. Appendix 2 provides a more detailed underpinning of these estimates.

	Fatal		Injury		PDO	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
two-way single carriageway	1,700	3,500	150	500	150	300
one-way single carriageway	1,700	3,500	150	500	150	300
dual carriageway	5,000	10,000	2,500	5,000	1,700	3,500
motorway	5,000	10,000	2,500	5,000	1,700	3,500
other road types	1,700	3,500	150	500	150	300

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[15] Although unreliability costs are relevant, it is not standard practice to include them in congestion cost estimates (only in the Netherlands they are included). Moreover, information on these costs related to road crashes is limited.

[16] As explained above, all values are expressed in the average EU28 price level. If the amounts are expressed in the Irish price level, we arrive at the same range due to rounding.

Table 3.6: Assumed congestion costs per crash in Ireland (€, 2014), based on values from other countries

To calculate total congestion costs, the cost per crash are multiplied by the number of crashes by severity and road type in Ireland. Reported numbers of crashes from RSA (2016) are used. For serious injury crashes the reported numbers on each road type is raised by a factor 3.5 to correct for underreporting (based on Sheridan, 2011; see above). Concerning minor injury and PDO crashes, no information on the underreporting rate is available. Therefore, we use the number of reported crashes for these crash categories. Furthermore, we assume the distribution of PDO crashes over road types to be identical to the distribution of slight injury crashes. Table 3.7 summarizes the number of crashes we use in this approach.

	Fatal	Serious injury	Minor injury	PDO
two-way single carriageway	162	1,971	4,250	28,650
one-way single carriageway	3	133	301	2,029
dual carriageway	5	91	186	1,254
motorway	5	49	166	1,119
other road types	4	18	68	458
Total	179	2,261	4,971	33,510

Table 3.7: Number of crashes in Ireland including estimated unreported crashes

Table 3.8 presents the total costs based on the costs per crash (Table 3.6) and the numbers of crashes (Table 3.7) in two scenarios. In the minimum scenario the lower limit crash costs from Table 3.6, assuming relatively low traffic volumes, are used and in the maximum scenario the upper limit values. In this bottom-up value transfer approach, the resulting total costs are in a range of €12 to €23 million. The majority of the costs (73%) is related to PDO crashes, whereas serious and slight injuries have a proportion of 7% and 17% in total costs respectively. Fatal crashes account for only 3% of the costs. Note that the €12-23 million cost range should be regarded as a minimum, and probably an underestimation, since underreporting of slight injury and PDO crashes is not taken into account.

	Low traffic volume scenario					High traffic volume scenario				
	Fatal	Serious injury	Minor injury	PDO	Total	Fatal	Serious injury	Minor injury	PDO	Total
two-way single carriageway	0.3	0.5	1.0	4.1	6	0.6	0.9	2.0	8.1	12
one-way single carriageway	0.0	0.0	0.1	0.3	0	0.0	0.1	0.1	0.6	1
dual carriageway	0.0	0.2	0.5	2.2	3	0.0	0.5	0.9	4.4	6
motorway	0.0	0.1	0.4	1.9	3	0.0	0.2	0.8	3.9	5
*/	96+	0.0	0.0	0.1	0	0.0	0.0	0.0	0.1	0
Total	0.3	0.8	1.9	8.5	**12**	0.7	1.7	3.9	17.1	**23**

Table 3.8: Congestion costs related to crashes in Ireland in the bottom-up value transfers approach (million €, 2014)

Conclusion

The range found in the bottom-up approach (€12-23 million) is lower than the results of the top-down approach (€20-50 million). However, the bottom-up approach is likely to underestimate the costs because underreporting of slight injury and PDO crashes, which have a huge share in the total costs, is not taken into account. Therefore we consider €20-50 million as a plausible range of the congestion costs related to crashes in Ireland.[17] This is 0.01-0.03% of GDP and 3-7% of the total costs of road crashes in Ireland which are estimated at €722 million in 2015 (Wijnen et al., 2017).

3.4. Summary and conclusions

This chapter analyzed the main factors that could explain differences in congestion costs in the countries for which congestion cost estimates are available (as reviewed in Chapter 2) and Ireland. The aim was to identify factors that should be taken into account for making a (rough) estimate of the congestion costs related to crashes in Ireland, using cost values from other countries. The comparative analysis shows that three key parameters shows clear differences: crash rates, traffic volumes and values of time. The values of each of these three parameters are substantially lower than in most of the other countries, and they all have a downward impact on congestion costs as compared to the other countries. Other dimensions, in particular the distribution of crashes over high and low-speed roads, crash type (single/multiple vehicle) day of the week (weekdays/weekend) and time of the day do not show any clear differences.

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[17] As explained above, all values are expressed in the average EU28 price level. If the amounts are corrected for relative price differences between EU28 price level and Irish price level, we arrive at the same range due to rounding.

The results of this comparative analysis were used to give a (rough) indication of the congestion costs related to crashes in Ireland. The estimates were made using cost estimates from the other countries, that we adjusted to the Irish road safety and traffic situation (‘values transfer’ approach). In particular concerning the three factors that were identified to affect congestion costs relative to the other countries (crash rate, traffic volume and value of time) were taken into account. Two value transfer approaches were adopted. In the first approach, congestion costs in Ireland are estimated using the congestion costs per capita in other countries. In the second approach, costs per crash (by severity and road type) in Ireland were derived from studies in other countries and applied to the number of crashes in Ireland to estimate total congestion costs. In both approaches the three factors that were identified to affect congestion costs relative to the other countries (crash rate, traffic volume and value of time) were taken into account, as well as differences and omissions in the methods used to estimate congestion costs in the other countries. The results of the value transfer calculations show that the cost of congestion related to crashes are likely to be in order of magnitude of €20-50 million. This is 3-7% of total road crash costs in Ireland, which indicates that congestion costs are a relevant, although minor, cost component.

The value transfer approach implies that several assumptions need to be made on the applicability of results from other countries in Ireland. Consequently, the outcomes of the value transfer just give a rough indication of the potential size of congestion costs related to crashes in Ireland. To give a more precise estimate, a country-specific study would be needed, which is discussed in the next chapter.

4. An outline for a detailed estimation of congestion costs related to crashes in Ireland

4.1 Introduction

The indication of the potential size of congestion costs related to crashes in Ireland that was made in Chapter 3 provides some guidance on the order of magnitude of these costs in Ireland, but a more detailed study would be needed to estimate the congestion costs more precisely, similar to the studies that are conducted in the countries we reviewed in Chapter 2. This chapter discusses how a more precise estimate can be made, including the data requirements for such a study and the availability of these data in Ireland.

Recently, a study on the costs of congestion (all causes) in the Greater Dublin Area was conducted by the Department of Transport, Tourism and Sport (DTTaS, 2017). Although this study did not pay specific attention to the causes of congestion (such as crashes), a more precise estimate of the congestion costs related to crashes could potentially draw on the method and data that were used in that study. Therefore, we will firstly review the DTTaS study (Section 4.2). Furthermore we discuss methods that could be applied for estimating crash-related congestion costs more precisely (4.3) and the data requirements and availability in Ireland (4.4.).

4.2 The DTTaS congestion cost study

In the DTTaS study, the costs of congestion in the Greater Dublin Area were estimated for the year 2012. In addition, a forecast of the costs for the year 2033 was made. The study was aimed at assessing the economic impact of congestion, and thereby the need for mitigating congestion in the short and long term and providing guidance on allocating public spending on transport. The study was conducted in the context of the Strategic Investment Framework for Land Transport, which addresses DTTaS' future investment priorities including urban congestion. In addition, the study was made in the context of the the Action Plan for Jobs, which notes that investments in transport are important for the economy and for quality of life, and the EU targets on reducing greenhouse gas emissions. The scope of the study is limited, in the sense that it concentrates on the Greater Dublin Area and only addresses the costs of direct time losses. However, the report notes that 'DDTaS envisages this report as being the first element of a national project'. Subsequent calculations may include other cost items, such as environmental and vehicle operating costs, and may adopt a wider geographical scope.

The study concentrates on recurrent congestion, which is defined as congestion resulting from 'factors that act regularly or periodically on the transportation system, such as daily commuting or weekend trips'. The costs of non-recurrent congestion, which is more difficult to assess due to a much greater degree of randomness, is not included in the study. Furthermore, the study concentrates on 'aggravated congestion', which is defined as the difference between 'observed total journey times and those journey times that would have been observed if the road were operating at 80% of its optimum capacity'. The percentage of the optimum capacity was determined on the basis of the relation between speed and traffic volume: average speed falls dramatically when traffic volumes exceed 80% of the road capacity. Note that there is also (some) congestion at lower traffic volumes, but at these volumes the travel benefits of additional traffic are assumed to be higher than the congestion costs. For that reason, such congestion is not regarded as problematic and therefore the study only considers 'aggravated congestion'.

The Eastern Regional Transport Model (ERM) was utilised to estimate congestion costs. This is one of the five regional transport models in Ireland which are operated by the National Transport Authority. The ERM covers the road network in the Greater Dublin Area. Travel demand is modelled by transport mode, journey purpose, time zone and individuals' characteristics (e.g. socio-economic). The model includes the main transport modes (including public transport) and distinguishes between five time zones (morning peak, morning inter-peak, afternoon inter-peak, evening peak, off-peak). The model assigns trips on the road network and one of the outputs of the model is travel time.

Time losses due to congestion, by transport mode and journey purpose, are estimated by firstly calculating travel time for the actual traffic flows (for each of the circa 10,000 links in the road network). Then travel times are calculated for a scenario in which there would be no congestion, that means that traffic volume are below 80% of the road capacity on each link. Travel time losses due to congestion are the difference between the actual travel time and the travel time in the scenario without congestion. Time losses are converted into costs using values of time by trip purpose (car: business/commuting/education/other, bus: general/school/free travel, goods vehicles).

Using the ERM, the costs of direct time losses due to congestion were estimated at €358 million in 2012 and were expected to rise to €2.08 billion in 2033 (both price level 2011), assuming that the road network is the same in 2012 and 2033. The majority of the costs were caused by the morning (7-10 am) and afternoon (4-7 pm) traffic peaks (38% and 43% of the costs respectively). Furthermore, congestion costs were found to be related mainly to personal vehicles (59% of the costs), while 34% of the costs was attributed to goods vehicles and 7% to buses.

4.3 How to estimate costs of direct time losses due to crashes in Ireland in detail

The review of congestion costs estimates in Chapter 2 showed that congestion results in several types of costs:

- Direct time losses
- Costs of adapting travel behaviour (detouring, changing travel times, etc.)
- Costs of travel time unreliability
- Environmental and health costs
- Vehicle operating costs

In this section and the next section we concentrate on direct time losses, since these costs are generally regarded as the most important costs item. Below we discuss potential approaches for estimating these costs in Ireland. The other cost items are discussed in Section 4.5.

Direct congestion monitoring approach

The review in Chapter 2 showed that in principle there are two approaches for making a detailed estimate of direct time losses due to crashes. The first option is to monitor actual congestion and collect data on indicators such as actual speed, length of traffic jams, duration of congestion and the cause of congestion (including crashes). Based on these data, in combination with data on speeds without congestion and values of time, direct time losses due to congestion (including rubbernecking) by cause can be calculated. This approach is applied (only) in the Netherland and has the great advantage that the congestion cost calculations are based on direct measurement of congestion instead of model outcomes. Consequently, the results can be considered as superior to the outcomes of models that usually rely on assumptions on several parameters. Moreover, most models use average traffic volumes (by hour of day, day of the week and road type), while congestion costs are affected by the actual traffic volume at the time the crash occurred. The direct monitoring approach by definition takes into account the actual traffic situation at the location and time of the crash. However, this approach requires a system of traffic monitoring by cameras that cover the full road network as well as traffic monitoring centres. If such a system is already in place for traffic management purposes, as is the case for the main road network in the Netherlands, the data collected by the system can be utilised relatively easily for congestion costs calculations. However, the Dutch approach is unique and in other countries (including Ireland) such a system is not available. Consequently, the direct monitoring approach is not considered as a feasible option for Ireland, at least in the short term.

Congestion modelling approach

The second approach, which is applied in all countries we reviewed in Chapter 2 except the Netherlands, is to develop a model to estimate direct time losses due to crash-related congestion. A standard queuing model, as in used in Australia, Germany and the US, would be appropriate to estimate times losses, which can be translated into costs using values of time. In such a model, direct time losses are estimated using several parameters, in particular traffic volumes, road capacity, reduction of road capacity due to a crash, duration of the road capacity reduction and the number of crashes. Rubbernecking impacts can be included in the model, as has been done in the US, which mainly requires information (or assumptions) on the rate of rubbernecking on the opposite site of the road. Although developing a queuing model requires availability of these data, the level of detail is flexible. For example, in Germany time losses were calculated at the level of road segments, which requires availability of data on traffic volumes, road capacity, etc. for each road segment. In Australia and the US average time losses for a limited number of road types were calculated, using average traffic volumes for these road types (by hour of the day and weekday/weekend). To comply with the data requirements, assumptions can be made for some parameters or data from other countries may be used if needed. For example, the Australian model uses data from the US and assumptions to estimate road capacity reductions after a crash by crash severity. The examples in other countries, and the flexibility in level of detail and data requirements, show that this approach is probably the most appropriate and feasible method to estimate costs of congestion related to crashes in Ireland.

4.4 Data requirements and data availability for a crash-related congestion cost model

As noted above, a model to estimate direct time loss due to crashes requires data on several parameters. To assess the feasibility of developing such a model for Ireland, we discuss below the most important data requirements and availability of these data in Ireland.

Number of crashes
The number of crashes in Ireland are available through police reporting. The crash and injury data are processed by RSA, which compiles the crash databases and publishes reports on road safety statistics. The data include the main factors influencing congestion, such as crash severity (fatal, injury, PDO), day of the week, time of the day and road type. Concerning road type, RSA distinguishes between five categories (motorway, dual carriageway, two-way single carriageway, one-way single carriageway and other). However, the data allow constructing other categorizations of road types can be made since the exact location (including road number) where the crash occurred in known. This is important for developing a congestion cost model, which requires the same categories for all parameters, in particular concerning traffic volume and crash data.

Traffic volume and road capacity
Traffic volume data are essential, since there is a direct (positive) relation between time losses and traffic volume. Traffic volumes and the number of crashes vary considerably by road type, which implies that traffic volumes by road type are needed. Data on traffic volumes in Ireland by day and time of the day are collected by Transport Infrastructure Ireland (TII) on the basis of traffic counts. These data cover the motorways, national roads and a few regional roads that are operated by TII (representing approximately 45% of the total road traffic in Ireland; Source: TII). Average traffic volumes by day of the week and time of the day (hour) for motorways and national roads can be derived from these data and used as an input for queuing model. For regional and local roads, data on traffic volumes are not collected systematically. However, regional traffic models that are operated by the National Transport Authority, such as the Eastern Regional Model that was applied in the DTTaS congestion cost study, contain information on the traffic volumes on the network links in the model. These data can also be used in a queuing model for crash-related congestion. These models also include road capacities of each network link.

Road capacity reduction due to a crash
The reduction of road capacity (by crash severity and road type) can be determined in a study on the relation between the occurrence of a crash and traffic volume (as conducted in Germany, see Section 2.3) or a study on the probability of lane closure due to a crash and the impact of lane closure on traffic volume (as conducted in the US, see Section 2.5). To our knowledge, such studies have not been conducted in Ireland however. The German approach, aimed at establishing the relation between traffic volumes and crashes, is probably most feasible in Ireland. Possibly a study in which TII traffic volume data (which are available for intervals of 5 minutes) are linked to crash data could provide information on road capacity reduction after a crash. The US approach requires information on lane closure probabilities by crash severity and related traffic volume decreases, which is not available in Ireland [correct?}. In case conducting a specific study on this issue is not feasible, an

alternative is to use assumptions on the likely road capacity reduction after a crash (as was done in Australia), e.g. based on data from other countries.

Duration of road capacity reduction

Data on emergency services response times and the time they spend on the crash site can be used as a proxy for the duration of road capacity reduction after a crash. For example, in Australia and the US data on ambulance and police response times and their time spending on the crash site were used. To our knowledge, such data are not available in Ireland however, which implies that some data collection efforts would be needed. An alternative is to derive the duration from data on traffic volume reductions due to a crash (as discussed above).

Values of time

The value of time is an essential input that is needed to translate time losses into monetary costs. Values of time by journey purpose are available in Ireland through the Common Appraisal Framework for Transport Projects and Programmes, which includes monetary values for all relevant parameters in economic appraisal of transport projects (DTTaS, 2016). Information on traffic volume by journey purpose is required to apply these values, which is available in the Eastern Regional Model.

4.5 Estimating other cost items

Besides direct time losses there are several other relevant congestion cost items. Note that these costs are not only relevant for crash-related congestion costs, but for all types of congestion. Therefore, it would make sense to study these impacts in the context of a broader congestion cost study and to apply the results to crash-related congestion, particularly because the estimation of some of these costs is quite complicated and requires applying traffic models. Below we discuss briefly how these costs can be estimated.

Costs of adapting travel behaviour

Studies in the Netherlands and the US show that adapting travel behaviour results in considerable costs. To estimate these costs, information is needed on the travel choices people make and how they are affected by traffic delays (in particular caused by crashes). A microsimulation traffic model, that simulates traffic flows and time losses in situation with and without congestion, is needed to assess such impacts. Results of such models were used in the road crash studies in the Netherlands and the US.

Travel time unreliability costs

Costs of travel time unreliability have (only) been included in the Dutch study on congestion related to crashes, and were derived from a study into the costs of all congestion (all causes). In that study, unreliability was defined as the standard deviation of the distribution of travel time (see Section 2.3). A traffic model can be used to estimate this standard deviation (as was done in the Netherlands), but in principle also other approaches are conceivable, such as deriving the standard deviation from data on actual travel times (e.g. based on in-car data collection systems, such as navigation systems). In addition, a monetary value of travel time unreliability is required. Such a value is not available for Ireland, but studies have been conducted in several other countries. Results from these studies or from meta-analyses (e.g. Carrion & Levinson, 2012) could be used as for estimating unreliability costs in Ireland as an indication.

Environmental, health and vehicle operating costs
Information on vehicles emissions and vehicle operating costs in relation to speed are needed to estimate these costs in relation to congestion, in combination with monetary valuations of environmental and health costs. Information on emissions, vehicle operating costs and monetary values are available through the Common Appraisal Framework for Transport Projects and Programmes (DTTaS, 2016). However, the relation between speed and these impacts would need to be further established, e.g. drawing on studies in other countries.

4.6 Conclusions and recommendations

To estimate costs of congestion related to crashes in Ireland in more detail, we recommend to concentrate firstly on the direct time losses. Developing a queuing model would be needed to estimate direct time losses resulting from crashes, which has been successfully applied in Australia, Germany and the US. A system of direct monitoring of congestion and its causes, which is utilised in the Netherlands to estimate crash-related congestion costs, is not in place in Ireland, implying that such an approach is not feasible in Ireland (at least not in the short term). Current practices in other countries show different levels of details in the queuing models. Consequently, there is some flexibility in choosing the desired level of detail, and thus the data requirements, for developing a new queuing model. The level of detail is mainly reflected in the degree of aggregation. For example, calculations can be conducted for individual road stretches or individual roads, using traffic volumes and road capacities for each single road or road stretch. Alternatively, average figures for a limited number of road types may be used. Similarly, the number of time intervals used in the model is flexible (e.g. a few time intervals reflecting peak and off-peak hours, or hourly intervals). The level of detail depends on the desired accuracy of the model outcomes, data availability and availability of resources develop the model and to collect additional data.

In a queuing model, direct time losses due to crashes are calculated on the basis of a limited number of key parameters, in particular numbers of crashes, traffic volumes, road capacity and the capacity reduction after a crash the duration of this reduction and values of time. Detailed data on numbers of crashes and traffic volumes on national roads is available in Ireland, although efforts on making these data suitable for application in a queuing model would be needed. This concerns in particular the classification of the number of road crashes and traffic volume by road type: data for both parameters should be (made) available for the same road types. Data on road capacity reduction after a crash and its duration is not readily available in Ireland, which implies that additional data analysis (on the relation between crashes and traffic volumes) and data collection (e.g. ambulance or police response time and time spending data) would be needed. Alternatively, assumptions may be made for some parameters (e.g. drawing on data from other countries), which is not uncommon in queuing models. Finally, the model can draw on the DTTaS congestion costs study, for example concerning the definition of congestions and input parameters such as road capacities and values of time. This would also ensure consistency of the queuing model with the DTTaS study.

Direct time losses, which can be estimated using a queuing model, are generally regarded as the most important cost item and we recommend concentrating on these costs. However, there are several other relevant cost items, in particular costs of adapting travel behaviour, costs of travel time unreliability, environmental and health costs and vehicle operating costs. These costs are not only relevant for crash-related congestion costs, but for all types of congestion. Given the complexity of estimating some of these impacts and the broader applicability, we recommend studying these impacts in the context of a broader congestion cost study and to apply the results to crash-related congestion.

5. Conclusions and recommendations

Congestion costs related to road crashes are generally regarded as relevant element in calculations of the socio-economic costs of road crashes. These costs are included in road crash cost studies in several countries and international guidelines on estimating socio-economic costs of road crashes include congestion costs as a standard cost item. Information on the costs of road crashes, and congestion costs as part of that, is used to raise awareness for the socio-economic burden of road crashes in those countries. In addition, road crash costs information is used in cost-benefit analysis of road safety projects or broader transportation projects and is often included in national guidelines for cost-benefit analysis of traffic and transport projects.

Direct time losses are in general the most important cost item related to congestion. In most countries queuing models are used to estimate these costs, using data on crashes, traffic volumes and road capacity reductions after a crash (among others). In the Netherlands congestion costs are based on direct monitoring of congestion. Although this approach has the advantage that the calculations are based on direct measurement of actual congestion at the location and time of the crash, it requires a comprehensive traffic monitoring system which is not in place in most countries. Other costs are added to the direct time losses in some countries, in particular costs of adapting travel behaviour, environmental and health costs, additional vehicle operating costs and costs of travel time unreliability. A variety of sources is used to estimate these costs, such as traffic modelling studies, results from other studies and assumptions. The results in some countries show that in particular costs of adapting travel behaviour, such as detouring, are substantial.

The review of congestion costs related to crashes in five countries shows a very wide range of the size of these costs: €1 to €92 per registered motor vehicle (2014 price level), or 0.001% to 0.19% of GDP. Furthermore, congestion costs have a proportion of 0.04% to 5% in the total costs of road crashes. The differences are firstly explained by differences in the methodologies that are applied to estimate congestion costs related to crashes, in particular differences in costs items, road types and crash severity categories that are included. Most studies underestimate congestion costs, because they do not include indirect costs (such as the cost of adapting travel choices due to congestion), congestion on regional and local roads and/or property damage only crashes. Furthermore, the specifications and level of detail of the calculation models are different in each country. Secondly, different road safety levels and traffic and infrastructure circumstances in each country result in different congestion cost levels. Thirdly, the values of time differ considerably between countries which further contributes to cost differences. Given these methodological differences, we recommend developing guidelines on the estimation of congestion costs related to crashes and to integrate these in international guidelines for road crash cost calculations.

In Ireland, information on costs of road crashes is commonly used in economic appraisal of transport projects and this is integrated in guidelines for economic appraisal (DTTaS, 2016). No specific calculations of congestion costs related to road crashes has been conducted until now, and so congestion costs related to crashes are not included in the economic appraisal. However, congestion costs have gained attention in Ireland, as reflected by the recent publication of a study on congestion cost in the Greater Dublin Area. This study only include costs of recurrent congestion, and thus does not include congestion resulting from crashes. One of the aims of that project was to provide evidence on congestion and the related costs, to help mitigating congestion. In that respect, adding costs of congestion caused by crashes and other incidents is recommended, as this will help to identify appropriate measures to reduce congestion.

Our attempt to quantify congestion costs related to road crashes in Ireland, based on estimates in other countries and taking into account the different road safety and traffic situation in Ireland (‘value transfer’), indicates that the costs are likely to be in the range €20-50 million. This is 3-7% of total road crash costs in Ireland, which indicates that congestion costs are a relevant, though minor, cost component in the total costs of road crashes.

The value transfer approach we adopted only gives a fairly rough indication of the potential size of congestion cost related to crashes, as it is based on results from other countries and several assumptions. For the time being the €20-50 million range can be used to supplement the current estimate of road crash costs in Ireland. However, we recommend developing a queuing model to estimate the costs of direct time losses more precisely. The examples in other countries and the flexibility in the level of detail and data requirements show that this is a feasible approach to estimate costs of direct time losses in Ireland. The key input data for such as model are available in Ireland, although some additional data analysis and data collection would be needed. Ideally, other relevant cost times are added to the costs of direct time losses. As these costs are not only relevant for crash-related congestion but also for congestion due to other causes, and given the complexity of estimating some of these impacts and the broader applicability, we recommend studying these impacts in the context of a broader congestion cost study and to apply the results to crash-related congestion.

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Appendix 1: Data sources and data analyses

This appendix provides information on the data sources and data analyses that were conducted in Section 3.2.

Year
All data refer to the year for which congestion costs were estimated:
Australia: 2006
Germany: 2005
Netherlands: 2009
US: 2010.
Irish data refer to 2014, which is the most recent year for which the data were available when this report was written.

Data sources: general
Crash data that were used in the reports on congestion cost in each country were used as much as possible:
Austalia: BITRE (2009)
Germany: Baum et al. (2007)
Netherlands: De Wit & Methorst (2012)
US: Blincoe et al. (2014)
Data for Ireland were taken from the RSA report ‘Road Casualties and Collisions in Ireland - 2014 Tables’ (RSA, 2016).

More detailed crash statistics for Australia were retrieved from the Australian Road Deaths Database (version September 2017) from the Bureau of Infrastructure, Transport and Regional Economics (BITRE). This database contains details on each police reported fatal crash, including date, weekday, time of the day, crash type (pedestrian, single/multiply vehicle), number of fatalities per crash, involvement of bus/truck and speed limit. This database only includes data on fatal crashes. Similar data for injury crashes are not (publicly) available.
For the Netherlands, the BRON road crash database was used. This database is compiled by the Ministry of Infrastructure and Environment and contains very detailed information on the reported crashes, such as driver characteristics, vehicles involved, crash cause, alcohol involvement, speed limit, etc.

Total number of crashes, crash rates and number of crashes by severity
Total number of crashes are retrieved from the road crash cost studies in each country (see above), except Ireland. In each cost study the number of crashes includes police reported crashes and an estimate of the number of unreported crashes. The number of police reported serious injury crashes in Ireland (646) is taken from RSA (2016), which is corrected for underreporting by multiplying this number by 3.5. The factor 3.5 was found by Sheridon et al. (2011) on the basis of an analysis of hospital data. For the US the number of serious injury crashes is not available (only all injury crashes).

Crash rates were derived by dividing the number of crashes by population. Population was retrieved from the World Bank database ’World Development Indicators’, version 31-01-2015.

Number of vehicles involved

The number of fatal single vehicles and multiple vehicle crashes in Australia was derived from the Australian Road Deaths Database, that includes crash type (pedestrian /single vehicle/ multiple vehicle) as a crash characteristic. For the Netherlands the BRON database was used, which includes the number of pedestrians and the number of vehicles involved by vehicle type (bicycle, moped, motorcycle, car, van, truck, bus and agricultural vehicle). The number of single vehicles and multiple vehicle crashes in the US and Ireland were taken from the report ‘Traffic Safety Facts 2010’ (NHTSA, 2011) and RSA (2016) respectively.

Single vehicle crashes include crashes involving a pedestrian and a single vehicle in each country. Furthermore, bicycles are included as a vehicle, except in the US, because in the Irish data bicycles are included. To enable comparisons with Ireland, bicycles are included in the other countries as well if possible.

Number of crashes by road type

The following data are used to classify crashes into crashes in built-up areas, non built-up areas (excluding motorways) and motorways:

- Germany: number of injury crashes with a breakdown into urban areas (built-up), rural areas (excluding motorways, non built-up) and motorways from the BASt factsheet ‘
- Netherlands: number of injury crashes from the Ministry of Infrastructure and Environment (MinIE, 2017) by speed limit. Speed limits ≤50 km/h are classified as built-up areas, 60-90km/h as non-built up areas and ≥100 km/h as motorways.
- US: number of injury crashes by road type from Blincoe et al. (2014). Their classification includes three urban road types (urban interstates/expressways, urban arterials and other urban roads) and two rural road types (rural interstate/principle arterials’ and other rural roads). The number of crashes on motorways cannot be derived from this classification.

Day and time of the day

The day and time of the day of fatal crashes in Australia was derived from the Australian Road Deaths Database. For the Netherlands the BRON database was used, which includes time and day as crash characteristics. German and US data were taken from reports: Baum et al. (2007) and NHTSA (2011) respectively. The German data only include crashes on motorways. Data for Ireland were provided by RSA. Number of crashes by time of the day refer to the number of casualties instead of crashes. The distribution of crashes over hours of the day is assumed to be quite similar to the distribution of the number of casualties.

Value of time

The values of time are based on the reported values in the cost report in each country. For the US the source is Hagemann et al. (2013, which was also used in the US cost report. We calculated weighted averages using the distribution of traffic volumes over trip vehicle types and/or trip purpose (business, commuting, other) as reported in the cost reports. The averages for trucks in Austria and the US are unweighted averages for several truck types because information on traffic volume per truck type was not reported.

Traffic volume

Data on traffic volumes (annual average daily traffic (AADT): number of vehicles per 24h) were retrieved from the following sources:

- Australia: the road crash cost study by BITRE (2009). This report contains traffic volume per road type for business hours (including the average for all road types) and multipliers for five day/time of the day categories (weekday: peak / business hours / off-peak; weekend: day / night). From these data we derived the AADT for each road type by (1) calculating the AADT for all road types based on the traffic volume for business hours (average all roads) and the multipliers for other days/time of day, weighed by the duration of each day/time of the day category, (2) calculating the average traffic volume for each road type using the average AADT for all road types and the ration of traffic volumes during business hours for each road type.
- Germany: the costs report (Baum et al., 2007) does not include traffic volumes. Thereofore, traffic volume for motorways was derived from vehicle miles travelled on motorways (Autobahn) and the length of motorways as reported by BASt (2017).
- Netherlands: traffic volume on national roads (mainly motorways) was retrieved from the Statline database of Statistics Netherlands.
- US: the road crash costs study (Blincoe et al., 2014) reports AADT by road type. The category urban interstates/expressways consists of motorways whereas rural interstate/principle arterials also include motorways. The AADT of these two road types is used as the range of the AADT on motorways.
- Ireland: traffic count data by road stretch and road type from Transport Infrastructure Ireland (TII) were used to calculate the (unweighted) average ADDT on motorways.

Value of time

Values of time are based on the values of time used in the road crash cost report in each country. For the US the source is Hagemann et al. (2013, which was also used in the US cost report. We calculated weighted averages using the distribution of traffic volumes over trip vehicle types and/or trip purpose (business, commuting, other) as reported in the cost reports. The averages for trucks in Austria and the US are unweighted averages for several truck types because information on traffic volume per truck type was not reported.

For Ireland, values of time (2012 prices) by transport mode were taken from DTTaS (2017). Four types of car travel were distinguished: employer (business), commuting, education and other. Based on NTA’s 2012 travel survey (NTA, 2013), we assumed that roughly 20% of vehicle miles travelled (VMT) is related to business travel, 20% to commuting and 60% to education and other (which have the same value of time). We used 2012 data because more recent travel survey do not distinguish between business and commuting, which is essential given the much higher value of time for business travel compared to the other trip purposes.

All values are adjusted for inflation and purchasing power parities (PPP). PPPs are the rates of currency conversion that take into account differences in relative price levels across countries (EU/OECD,2012).

Appendix 2: Congestion costs per crash in the bottom-up value transfer approach

In the bottom-up value transfer approach (Section 3.3), congestion costs per crash by severity and by road type from other countries are used to give a rough estimate of the total congestion costs in Ireland. Table 3.6 presents the costs per crash that were derived from other countries and that were multiplied by the number of crashes in Ireland. This appendix gives a more detailed underpinning of these congestion costs per crash that are assumed for Ireland.

Costs per crash by road type are only available for the US. For that reason, we apply the costs per crash from the US in the bottom-up approach. Moreover, the average costs per crash in the US are in line with cost estimates in other the countries (except Austria), particularly regarding fatal crashes. This is shown in Table A1. As discussed in Chapter 2, the costs per fatal crash in other countries are in the range €8,000-€11,500. The US estimate (about €11,500) is on the higher end of this range, which is (partly) explained by the fact that more cost item have been included than in most other countries, such as costs of detouring and rubbernecking. Concerning costs per injury crash, the range is much wider: €1,000 to about €9,000. However, the costs in Germany only refer to motorways, where congestion costs are much higher than on other road types because of higher traffic volumes. For that reason the costs in Germany are considered not to be representative for total congestion costs on all road types. The same applies to the average costs per crash (all crashes) in the Netherlands. The cost per injury crash in the US are higher than in Australia which is likely to be explained, at least partly, by the fact that the US included more cost items. The same reasoning applies to the costs per PDO crash. In conclusion, we consider the US cost estimates as the most appropriate estimates for application in the value transfer. In addition, the German and Dutch estimates are applicable to estimate congestion costs on motorways.

	Fatal	Injury	PDO	All
Australia	8,135	1,130	763	901
Germany	8,528	6,418-9,027	7,679	6,755
Netherlands	NA	NA	NA	1,478
US	11,447	1,993	1,525	1,675

Table A1: Costs per crash (€, 2014)

The congestion costs per crash in the US are available for five road types (Table A2).

	Traffic volume	Fatal	Injury	PDO
Urban interstates/expressways	113,814	82,663	11,405	8,025
Urban arterials	23,996	6,764	994	462
Urban other	2,908	913	263	122
Rural interstate/principle arterials	25,579	6,004	734	592
Rural other	1,502	429	73	47

Table A2: Traffic volumes (average number of vehicles per 24 hours) and congestion cost per crash in the US 2010, by road type (€, 2014). Source: own calculations based on Blincoe et al. (2014)

A complication is that the US road type do not match with the road types that are used in the crash statistics in Ireland (RSA, 2016):

- two-way single carriageway
- one-way single carriageway
- dual carriageway
- motorway
- other road types

In the US, most urban arterials and rural interstate/principle arterials are one-way or two-way single carriageways. Therefore we consider the congestion costs per crash on these US road types most appropriate for value transfer to single carriageways in Ireland. However, traffic volumes are likely to be much higher in the US than in Ireland. We use the average costs for the two US road types as upper limits of the costs per crash on single carriageways in Ireland, and adjust these cost for a lower value of time in Ireland as compared to the US (average car and truck, weighted by person kilometers travelled). This results in €3,500 per fatal crash, €500 per injury crash and €300 per PDO crash (rounded). We apply 50% of these values as lower limits, reflecting lower traffic volumes in Ireland. Concerning dual carriageways and motorways, the cost figures on US urban interstates/expressways and motorways in Germany are considered to be most appropriate. However, the cost on US urban interstates/expressways are much higher than the cost on motorways in Germany, particularly regarding fatal crashes. As a rough indication, we use €10,000 fatal crashes to motorways and dual carriageways in Ireland. This is based on the German estimate, taking into account that on the one hand the German figure only includes direct time loss and thus underestimates the full costs, while on the other hand the value of time in Germany is expected to be higher. The value is also expected to be in line with the Dutch results (for national roads only, which are dual carriageways and motorways), given the average value for all crashes. For injury crashes on dual carriageways and motorways we use €5,000 per crash, based on the German figures and taking into different values of time, and we assume that the costs per PDO crash are €3,500 given the fact that in general the costs per PDO crash are about 70% of the costs per injury crash. Since traffic volumes on motorways in Ireland are about twice as low as in the other countries, we use 50% of these values as lower limits. For other roads we use the same values as for single carriageways.