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A COMPREHENSIVE ANALYSIS OF EXTERNAL COSTS OF ACCIDENTS

Andrea Maternová[1,a*], Andrej Dávid[2,b,], Vlatka Stupalo[3,c] and Matúš Materna[4,d]

[1]Department of Water Transport, University of Zilina, Univerzitna 8215/1, 010 26 Zilina, Slovak Republic
[2]Department of Water Transport, University of Zilina, Univerzitna 8215/1, 010 26 Zilina, Slovak Republic
[3]Department of Water Transport, University of Zagreb, Vukelićeva 4, HR-10000, CROATIA
[4]Air Transport Department, University of Zilina, Univerzitna 8215/1, 010 26 Zilina, Slovak Republic

[a]andrea.maternova@uniza.sk, [b]andrej.david@uniza.sk, [c]vlatka.stupalo@fpz.unizg.hr, [d]matus.materna@uniza.sk
[*]Corresponding author

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Abstract:
Research background: This paper focuses on the concept of external costs in transportation and the implications of incorporating them into decision-making processes. It highlights that external costs of transport encompass the disparity between social costs, representing all expenses associated with transport infrastructure provision and usage, and private costs borne by individual transport users. The absence of market incentives prevents transport users from considering external costs, leading to account for only a part of social costs when making transport decisions, which ultimately leads to suboptimal outcomes. Thus, internalisation of external costs represents a crucial part of the decision-making process for transport users.
Purpose of the article: The purpose of this article is to provide a theoretical approach to the research problem of internalisation of external costs into decision-making processes in transportation. It aims to define the concept of external costs, the methods used for quantification of externalities and show current state of transport accident costs in EU and non-EU countries.
Methods: This study was conducted through a research design and methodology that involved existing literature analysis, collecting input values on external costs of transport, and assessing the current stage of internalisation of externalities in various countries and transport modes. The sample size included relevant countries and a specific period of time.
Findings & Value added: The paper provides an overview of the input values and methodologies used to provide estimates for the external costs of transport. Moreover, the paper presents total, average and marginal external costs for all relevant countries. The current extent of internalisation of external costs by current taxes and charges for all countries and transport modes. It also investigates recommended options for further internalisation.

Keywords: external costs; externality; transportation; GHG; marginal costs; emissions

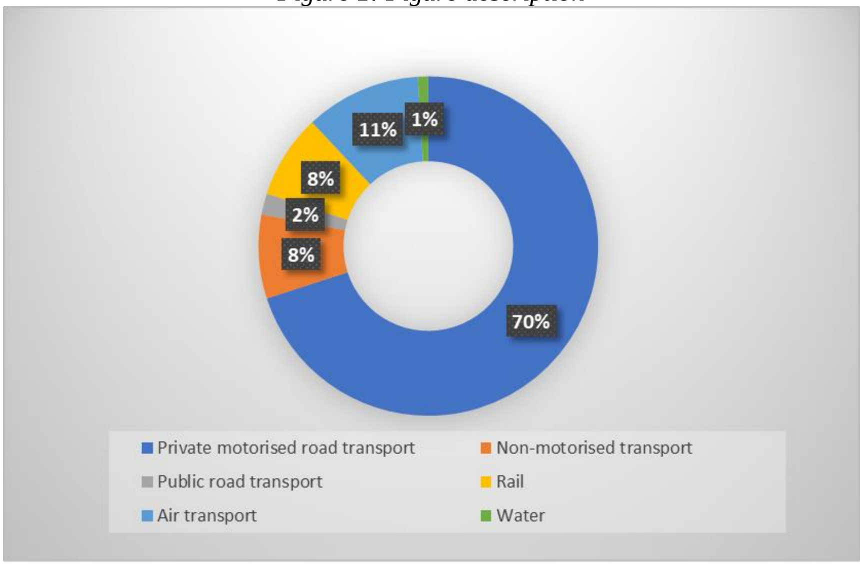
JEL Classification: D61; R41; L91

1. Introduction

Transportation is a purposeful process that brings obvious advantages and benefits to people. Its main advantage is the connection of communities, moving of goods and passengers on big distances, supporting global trade and providing access to public services. The transportation sector plays a vital role in ensuring the sustainability of every national economy (Durana et al., 2022).

Apart from the advantages, transport generates by-products that can have an adverse effect on the population. These impacts are called external costs of transport and are associated with the negative effects of transport activity on the environment and human life, such as air, water, and soil pollution, disruption of ecosystems, noise emissions, traffic accidents, occupation of territory, as well as overcrowding. Road transport, as the largest producer of externalities in transport (noise, emissions, severe congestion, frequent accidents) is the main cause of the uneven development of transport. Individual car transport is experiencing rapid growth. Currently, CO2 emissions from the road sector have risen by 30% compared to 1990, and it is the only transportation mode expected to experience further increases in CO2 emissions in the future, and various other burdens and disruptions, all of which impose substantial costs on the economy and society. The white paper mentions not only the congestion of main roads and highways but also railway lines and junctions, especially in urban agglomerations and airports.

Figure 1: Figure description



Source: Authors based on Handbook on the ECs, 2019.

Despite the fact that most of the bottlenecks apply to cities, the trans-European network is permanently congested. One of the partial plans leading to solving the insufficient capacity of the transport infrastructure and the ecological impacts of transport is the internalization of external costs (objectification of costs to the entities that caused them). This will create an incentive for reducing negative externalities from each activity and increasing environmental quality at the same time. Therefore, it is crucial to develop transportation systems that not only provide efficient connectivity and access but also minimize their ecological footprint and mitigate the negative effects on the environment and human well-being.

Several significant studies, including Bongardt et al. (2011), Haghshenas and Vaziri (2012), TUMI (2018), Bassi et al. (2022), and Lizbetin et al. (2019), have contributed to the definition of sustainable transportation as a system that simultaneously achieves economic, social, and environmental objectives. These studies recognize the interconnectedness of these dimensions and highlight the need for a comprehensive approach to transportation planning and management.

From an economic perspective, sustainability in transportation entails various requirements. The transportation system must be affordable, ensuring that it remains accessible to all members of society. Moreover, fairness and equity considerations play a crucial role, aiming to distribute the costs and benefits of transportation in a just and balanced manner. To achieve this, it is necessary to internalize external costs, which refers to incorporating the societal costs resulting from transportation activities into the pricing and decision-making processes (Grzelakowski, 2020). The Center for Sustainable Transportation provides guidance on how to account for and address these external costs.

The environmental dimension of sustainable transportation centers around the reduction and mitigation of negative environmental impacts. This includes minimizing emissions of air pollutants and greenhouse gases, which contribute to climate change and degrade air quality. Additionally, attention is given to managing and reducing noise pollution caused by transportation activities. The sustainable transportation paradigm emphasizes the importance of waste reduction and proper waste management practices to minimize environmental harm.

The social dimension of sustainable transportation recognizes the fundamental role that transportation plays in enabling individuals to meet their basic needs and participate in society. Safety is a critical aspect, as transportation systems must ensure the well-being and security of users. The promotion of safety measures and the reduction of accidents and injuries are of paramount importance. Furthermore, sustainable transportation seeks to promote fairness and equality by providing equal access to transportation services and opportunities for all individuals, irrespective of their socio-economic status or geographic location. Consideration is also given to future generations, emphasizing the need to ensure sustainable transportation systems that can meet the needs of both the present and future populations.

By understanding and addressing these economic, environmental, and social dimensions, policymakers and transportation practitioners can work towards a more sustainable transportation system that effectively balances the needs of society, the environment, and the economy. In this context, the focus of this scientific paper is on examining and quantifying the external costs associated with transport accidents, which have significant implications for all three dimensions of sustainability.

The main aim of this paper is to provide an overview of the input values and methodologies used to estimate the external costs of transport. It aims to present the total, average, and marginal external costs for all relevant countries and investigate the current extent of internalization of these costs. Moreover, the paper aims to explore recommended options for further internalization. Furthermore, the paper focuses on examining and quantifying the external costs associated with transport accidents, which have significant implications for the economic, environmental, and social dimensions of sustainability.

2. Methodology

The paper provides overview of various external costs, such as noise, air pollution, water pollution, congestions, vibrations, and other externalities resulting from the transportation process. The existing literature is analysed in order to identify the methodologies, models, and input values in estimating these external costs from transport. The next step of methodology includes the identification the necessary input values required for estimating external costs, with a particular focus on monetary terms. These input values may include the value of time, population exposure data, health effects, infrastructure costs, accident rates, and other relevant parameters. Review and analyze available data sources, studies, and reports to identify the most appropriate input values for each specific external cost category.

Based on presented data, the external costs can be given for different transport modes. This step involves quantifying the external costs in monetary terms, allowing for easier comparison and evaluation across different cost categories and transport modes. For road, rail and inland waterway transport, input and output data are provided for the EU28 countries (as data is following from the Study (Van Essen et al., 2019), using data from 2016, Norway, Switzerland, Canada, the United States, and Japan. For Canada and the United States, external costs are considered at the province/state level, including California, Missouri; British Columbia and Alberta). For aviation and maritime transport, external cost output values are not provided at the national level, but at the level of individual (air)ports. From all considered countries the largest international airport is analysed, in Canada and the US, the two largest airports are included. In Europe, the five largest international airports are also considered. In the case of maritime transport, 24 maritime ports considered (European Comission, 2020); ten ports were included to cover the main maritime ports for all European countries with an additional ferry/RoPax German port. Five overseas ports in the US, Canada and Japan have been selected.

Finally, the estimated external costs are compiled for different transport modes and external cost categories into a comprehensive report. The findings include methodologies employed, input values utilized, and the resulting external costs.

3. External costs

Schroten et al. (2019) states that external costs (so-called externalities), arise when the economic or social activities of individual or group of persons have an impact on another individuals or groups and when that impact is not fully accounted, or compensated for involved individuals or groups. In other words, external costs refer to the difference between social costs (all costs to society due to the provision and use of transport infrastructure) and private costs of transport (the costs directly carried by the transport user) (Handbook on the European Comisssion).

In the context of transportation, these costs to society are generated by transport users who, without policy intervention, do not consider or bear these costs themselves (Schroten et al., 2019). For example, in transportation, these costs encompass the expenses associated with air and noise pollution, which individual users do not take into account when deciding how many journeys to undertake. External costs in the transport sector emerge due to limited infrastructure capacity (resulting in congestion) and the adverse effects imposed on other users, such as accidents and environmental impacts.

The market does not motivate transport users to consider the additional costs associated with their choices, resulting in sub-optimal outcomes. To address this, it is necessary to incorporate these costs into the decision-making process. This can be achieved through either regulations or market-based tools like taxes, charges, and emission trading. Combining these approaches, such as implementing differentiated taxes based on Euro emission classes, is also feasible.

Using market-based tools to internalize external costs is widely recognized as an effective way to minimize the negative consequences of transportation and potentially generate government revenue. However, accurate estimations of these external costs are crucial for the efficient application of these tools. External cost figures also serve as valuable parameters for various applications, such as Cost Benefit Analyses.

Before delving into a detailed analysis of the approaches and methodologies used to estimate external transport costs, it is important to address some methodological considerations, such as the choice between marginal and average costs and the components that should be included when estimating external costs. In the analysis, these aspects will be determined and the definitions will be given.

External costs can be divided into seven categories: accident, noise, congestion, habitat damage, air pollution, climate change and well-to-tank emissions (see Table 1).

Table 1: Types of external costs from transportation

Type of EC	Description
Accident costs	Material or immaterial damage resulting from accidents that are not covered by insurance payments (e.g., human costs, administrative costs, medical costs, loss of production)
Noise costs	Costs from unwanted noise due to its varying duration, intensity, or other qualities, causing physical or psychological harm to humans.
Congestion costs	Delay costs resulting from congestion due to traffic jams, including delays and the negative impact on overall well-being.
Costs of habitat damage	Costs arising from the adverse effects of transportation on nature and landscapes encompass the loss of habitats, habitat fragmentation, and degradation caused by emissions.
Air pollution costs	External costs from the four types of impacts caused by the emission of transport-related air pollutants: health effects, crop failures, material and construction damage, loss of biodiversity
Climate change costs	The costs related to all the effects of global warming: crop failures, sea level rise, health costs, damage to buildings and materials (weather damage), loss of biodiversity and problems with wat supply.
Cost of well-to-tank emissions	Other words the cost of energy production, covers includes the production of all types of energy sources leading to other externalities. This includes the extraction of energy sources, processing (such as refining or electricity generation), transportation and transmission, as well as the construction of energy plants and related infrastructure.

Source: Authors based on Hofbauer & Putz (2020).

Mentioned external costs from transport can be classified to two main categories – external costs from traffic accidents and environmental external costs; total, average and marginal costs (see Table 2).

Table 2: Description of external costs

Type of EC	Description
Total external costs (TECs)	all external costs within a geographical boundary (e.g. EU27 or an individual country) caused by specific mode of transport (usually presented in billions or millions €);
Average external costs (AECs)	average costs are calculated by dividing the total costs by the total transport performance (€-cent/pkm, €-cent per tkm and/or €-cent/vkm; or €-cent/LTO (aviation) or €-cent per port call (maritime transport).
Marginal external costs (MCs)	AECs resulting from additional transport activity. In the short run - linked to constant infrastructure capacity, long run MCs do take the construction of additional traffic infrastructure into account (short run marginal congestion costs are higher than long run marginal congestion costs) (€-cent/pkm, €-cent/tkm, €-cent/vkm).

Source: Authors based on Hofbauer & Putz (2020).

4. Results

The values presented in the paper results from the various studies which estimate Willingness to Pay (WTP) values for the different external costs under the particular conditions. Following chapter shows comprehensive analysis of externalities from transport accidents.

4.1 Analysis of external costs from transport accidents

Accidents occur in every transport mode, resulting in significant costs, consisting of two main elements: material costs (such as vehicle damages, administrative and medical costs) and immaterial costs (including reduced lifespans, emotional distress, pain, and grief). While market prices can be used to quantify material costs, such market prices do not exist for pricing immaterial costs. Furthermore, a portion of the overall accident costs is already internalised through mechanisms like insurance premiums or accounting for foreseeable risks.

Human costs refer to the monetary estimation of pain and suffering caused by traffic accidents, covering both injuries and fatalities. Medical costs encompass expenses related to medical treatment, including hospitalization, rehabilitation, medication, and medical devices. Administrative costs include expenses associated with emergency services, such as police and fire departments, as well as legal costs, prosecution expenses, insurance, and administrative tasks related to vehicle and health insurance. Production losses account for the impact on work productivity, including reduced working time, human capital replacement costs, and the inability to engage in non-market activities like household work or volunteering. Material damages refer to the monetary value of vehicle, infrastructure, freight, and personal property damage resulting from accidents. Other costs encompass congestion, vehicle unavailability, and funeral expenses associated with road crashes (excluding this cost category from consideration).

External costs from transport accidents are calculated using a top-down approach, starting with total accidents and then allocating them to different types of vehicles. The analysis of external costs from transport accidents involves the information on the number of casualties per vehicle category and the associated costs per category[1]. The cost per casualty consists of six components, four of which (human costs, production costs, medical costs, and administrative costs) are partly external. To estimate the total external accident costs, the number of casualties is multiplied by the cost per casualty, and transfers from liability insurance systems and gratification payments are deducted.

When accidents occur within the same transport mode, allocation to different vehicle categories is based on their damage potential (intrinsic risk). This method, used in studies like CE Delft & VU Amsterdam, 2004; and CE Delft, INFRAS & Fraunhofer ISI, 2011, involves assigning the victims in the opposing vehicle type involved in the crash to each other. For example, if a fatal accident occurs between a heavy goods vehicle (HGV) and a car, where the driver of the HGV sustains slight injuries while the driver of the car dies, the cost of the fatality is allocated to the truck, and the cost of the slight injury is allocated to the car.

For accidents involving different modes, such as those between a train and a car, the casualties are allocated to the party responsible for the accident (the road user is usually responsible for these accidents) (Jonsson and Björklund, 2015). These steps help determine the total and average accident costs per vehicle category in each country. The accident statistics for road transport are obtained from the EU's Community Road Accident Database (CARE). This detailed database provides information on fatalities, serious injuries, and slight injuries, including the vehicles involved and the road type.

4.1.1 Total and average accident costs

Costs per Casualty

The cost components per casualty are primarily derived from SafetyCube (2017), which estimates standard values for each cost component based on international guidelines developed by Alfaro et al. (1994). However, it is important to note that the values presented in Wijnen et al. (2017) represent social costs of accidents and require adjustments to reflect external costs. The human cost, the largest component of accident costs is resulting from the Value of

[1] data provided for rail accidents does not include suicides.

Statistical Life (VSL), the basis for measuring the costs of traffic accidents. The value of statistical life (VSL) represents the local tradeoff rate between the risk of death and monetary compensation. It serves as a measure of how much individuals are willing to pay to reduce the risk of mortality and reflects the marginal cost of enhancing safety. Due to its crucial economic role, policy analysts consider the VSL as the appropriate metric for evaluating the benefits individuals gain from improvements in health and safety. Currently, the issue of monetary valuation of human life is being addressed by several organizations that have developed studies in which participants were asked to assess their own willingness to pay for reducing the risk of an accident. According to individual study participants, the estimate of the value of statistical life varies not only in individual countries but also according to age. The calculation of the value of human life was first calculated across the EU, but later individual countries agreed that it is necessary to approach this individually - each country should have a different value of statistical life.

Representative Estimates

The average value of a human life according to OECD (2012) was €3.6 million for EU28 countries. To avoid double counting with gross production loss, consumption loss is subtracted from the VSL to determine human costs for fatalities. Consumption loss is calculated by combining data on per capita annual consumption expenditure with the number of life years lost due to an accident (average of 42 years). As a result, the average consumption loss for a fatality in the EU28 is €668,000. Therefore, the human costs for fatalities in the EU28 amount to €2.9 million. The human costs for injuries are valued at 13% and 1% of the VSL for serious and slight injuries, respectively, following the HEATCO (2006) guidelines. No consumption loss is deducted from the injury cost values.

In the United States, estimated rate of the VSL was approximately $10 million (in 2017), whereas estimates in other countries tend to be lower due to the positive income elasticity of the VSL. Given that reducing mortality risk is often a primary objective of government policies, the VSL plays a crucial role in cost-benefit analyses conducted as part of the regulatory process.

Furthermore, the concept of the VSL is closely connected to related notions such as the value of a statistical life year (VSLY) and the value of a statistical injury (VSI). Thus, similar measure approaches can be utilized to assign monetary values to non-fatal injuries and even to mortality risks that have negligible impacts on life expectancy.

According to a study conducted by Schlander et al. (2017), the value of a statistical life year (VSLY) in Europe was estimated to be €158,448. This estimation was based on a systematic review of empirical economic studies published between 1995 and 2015, focusing on European data. The study utilized a comprehensive literature search using the EconBiz and EconLit databases and identified 41 European studies that provided original data. These studies resulted in 49 estimates for the value of a statistical life (VSL). The European median VSLY was €158,448. VSLY estimates showed large heterogeneity by methodology (continental Europe, €158,448; United Kingdom, €117,956; Nordic countries, €161,052).

Following tables provides overview of accident costs components per casualty for EU and non-EU countries, based on the VSL value.

Table 3: Accident costs components per casualty for the EU28 (€, 2016)

	Human costs	**Production loss**	**Medical costs**	**Administrative costs**	**Total external cost per casualty**
Fatalities	2,907,921	361,358	2,722	1,909	**3,273,909**
Serious Injuries	464,844	24,055	8,380	1,312	**498,591**
Slight Injuries	35,757	1,472	721	564	**38,514**

Source: Handbook on the external costs of transport – January 2019 – V1.1

Table 4: Accident costs components per casualty for the non-EU contries (€, 2016)

Country		Human costs	Production loss	Medical costs	Administrative costs	Total external cost per casualty
Norway	Fatalities	2,860,780	535,129	4,031	2,826	**3,402,766**
	Serious injuries	523,348	35,622	12,410	1,944	**573,324**
	Slight injuries	40,258	2,179	1,068	836	**44,341**
Switzerland	Fatalities	3,860,318	554,838	4,179	2,930	**4,422,265**
	Serious injuries	707,624	36,934	12,867	2,015	**759,440**
	Slight injuries	54,433	2,260	1,107	866	**58,666**
Canada (Alberta; British Columbia)	Fatalities	6,975,748	838,700	6,318	4,430	**7,825,196**
	Serious injuries	906,848	55,830	19,450	3,046	**985,174**
	Slight injuries	69,758	3,416	1,674	1310	**76,158**
USA – (California & Missouri	Fatalities	7,968,552	887,154	6,682	4,686	**8,867,074**
	Serious injuries	1,035,912	59,056	20,574	3,222	**1,118,764**
	Slight injuries	79,686	3,612	1,770	1,386	**86,454**
Japan	Fatalities	3,400,821	409,621	3,085	2,163	**3,446,690**
	Serious injuries	442,107	27,268	9,500	1,488	**480,363**
	Slight injuries	34,008	1,668	818	640	**37,134**

Source: *Handbook on the external costs of transport – January 2019 – V1.1*

Following table provides an overview of total and average external accident costs in the EU for all transport modes (road, rail, inland waterway transport). Average costs are calculated by dividing the total costs by the transport performance data. The costs of motorcycles do not include the costs for mopeds. Moped accidents are 1% of EU fatalities and cca3% of EU injuries. Allocation of mopeds cannot be carried out as there is no transport performance data specifically for mopeds available.

Table 5: Total and average costs for EU countries

Total costs EU28		**Average costs**	
Passenger transport	**Billion €**	**€-cent per pkm**	**€-cent per vkm**
Passenger car	210.2	4.5	7.2
Motorcycle	21.0	12.7	13.3
Bus/Coach	5.3	1.0	18.9
Total passenger road	**236.5**	**Total passenger road transport**	
Speed passenger train	0.1	0.1	17.3
Conventional passenger train	2.0	0.5	52.2
Total passenger rail	**2.0**	**Total passenger rail**	
Total passenger transport	**238.5**	**Total passenger transport**	
Freight transport	**Billion €**	**€-cent per tkm**	**€-cent per vkm**
LCV	19.8	6.0	4.1
HGV	23.0	1.3	15.5
Total freight road	**42.8**		
Train	0.3	0.1	34.1
Inland Vessel	0.1	0.1	86.3
Total freight transport	**43.1**		
Total road, rail, inland waterway	**281.7**		

Source: Handbook on the external costs of transport – January 2019 – V1.1

Results show that total costs for EU28 were 281.7 billion of €. As the external costs of accidents are logically higher in the terms of passenger transport (238.5 billion of €), accident costs of freight transport (hinterland) is still quite high (43.1 billion of €). The biggest producer of accident costs is road transport. On the other hand, inland waterway transport produces negligible amount of external costs of accidents. However, this type of transport produces the biggest amount of accident costs when counting €-cent per vehicle-kilometer.

Table 6 shows the average external accident costs for freight and passenger aviation. Passenger aviation values are provided per LTO[2], passenger and pkm (for freight aviation are provided per LTO, tonne and tkm).

Table 6: Accident costs for freight and passenger aviation

Aviation	Total Costs million €	Average Costs			
		€/LTO	€/Passenger	€/tonne	€-cent/PKM
Short Haul	75.01	22.95	0.18	0.81	0.04
Medium Haul					0.01
Long Haul					0.001

Source: Handbook on the external costs of transport – January 2019 – V1.1

Table 7 illustrates the average external costs of maritime accidents. For ferries, the costs are calculated per port of call, passenger and pkm (for freight maritime transport are provided per port call, tonne and tkm).

Table 7: Accident costs for maritime transport

Maritime transport	Total costs million €	Average costs	
		€/port of call	€/million passenger €/million tonnes
Passenger transport	3.3	26	40,996
Freight transport	63.3	318	36,524

Source: Handbook on the external costs of transport – January 2019 – V1.1

4.1.2 Marginal accident costs

This type of costs is only calculated for road transport. For all other transport modes, the marginal accident costs are assumed to be the same as the average costs. The rationale behind this is that these other modes operate as scheduled services, meaning that the risk of accidents is less influenced by the volume of traffic they experience. The marginal accident costs are extra costs, occurred introducing an additional vehicle into the traffic flow. The primary factors considered when calculating marginal accident costs include the accident risk associated with each vehicle type and road type, the costs per casualty, and the risk elasticity. It is worth noting that the costs per casualty utilized in the computation of total and average costs remain consistent for marginal accident cost calculations as well.

Degree of risk internalization

The degree of risk internalization is crucial when determine the share of human costs, internalized by road users. This factor depends on the vehicle types (logically, some types of vehicles are more vulnerable than others). It is calculated by dividing the number of fatalities within a specific vehicle type by the total number of fatalities in accidents involving that particular vehicle type, including victims in other vehicles involved in the accidents (CARE, 2020). This calculation provides valuable insight into a vehicle's comparative vulnerability among other vehicle types.

This approach implies that when a vehicle carries multiple passengers (beyond just the driver), the human costs associated with all these passengers are fully internalized by the driver or the vehicle itself. For instance, if a vehicle causes a fatal crash involving another vehicle carrying four passengers, the human costs of all four passengers are externalized, not borne by the original vehicle. The degree of risk internalization value ranges from 0 to 1, with lower

[2] Landing and Take-off (LTO) cycle covers four modes of engine operation, namely idle, approach, climb out and take-off, each of which is associated with a specific engine thrust setting and a time in mode (ICAO, 2016). LTO cycle representspollutant emissions in the vicinity of airports consists of four mentioned operating modes.

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values indicating a smaller portion of costs being internalized. Generally, occupants of passenger cars and motorcycles are expected to have a relatively higher degree of cost internalization (closer to 1) compared to individuals in heavy goods vehicles (HGVs).

Table 8: The degree of risk internalization

Vehicle type	Risk internalisation factor
Passenger car	0.61
Motorcycle	0.93
Bus	0.16
Coach	0.16
LCV	0.28
Heavy Goods Vehicle	0.14

Source: CARE database (2020)

Based on Ricardo-AEA, TRT, DIW Econ & CAU (2014) the combination of risk elasticity (E) and the degree of risk internalisation (θ) lead to following results:

- if $\theta - E > 1$, the marginal costs are negative and average accident costs decreases with each vehicle entering the road;
- if $\theta - E < 1$, the marginal costs are positive and the accident costs always increases with each additional vehicle.
- a risk elasticity set at -0.25 (motorways and other roads), passenger cars, buses, heavy goods vehicles, coaches, LCVs, and other vehicles all have positive marginal costs.

Table 9 shows marginal external costs of accidents for road transport (EU28). The marginal external costs of accidents of remaining transport modes are identical to the average external accident costs.

Table 9: marginal external costs of accidents for road transport (EU28)

	Motorway	Urban road	Other road
Passenger transport (€-cent per pkm)			
Passenger car	0.25	1.41	0.63
Motorcycle	-0.65	4.42	-3.21
Bus/coach	0.05	0.80	0.19
LCV (€-cent per vkm)			
LCV	0.37	0.76	0.84
Freight transport (€-cent per tkm)			
HGV	0.07	0.10	0.13

Source: Handbook on the external costs of transport – January 2019 – V1.1

The marginal external accident costs for motorcycles are in some cases negative because traffic tends to slow down with each extra driver. This fact enhances safety for all other participants in the traffic flow. However, the additional road user still carries a higher accident risk compared to the absence of risk if they choose not to participate in traffic.

Negative marginal external costs arise when the reduction in accident risk for other traffic users is less significant than the increase in external accident risk caused by the presence of additional traffic users. It is worth noting that negative marginal external costs are primarily observed among vulnerable road users like motorcyclists, as they have largely internalized their own risk (Table 8).

It is important to emphasize that the costs being discussed here are marginal external accident costs. While these costs may occasionally turn negative, this does not imply negative marginal accident costs overall (van Essen et al., 2019).

The largest component of accident costs is the human costs, which heavily depend on the value of a statistical life (VSL). Currently, there is a wide range of VSL values available. For this paper, the VSL figures from the OECD (2012) were used, as it provides the most recent and reliable evidence for the research purposes. Nevertheless, it is important to note that estimating the VSL still carries a degree of uncertainty.

An important aspect we encountered when compiling the output values was determining the portion of accident costs that transport users internalize in their decision-making. Regarding the external portion of human costs, we assumed that individuals internalize their own human costs once they choose to use transportation, while considering the human costs of individuals in other vehicles as entirely external.

5. Discussion

The goal of this paper is a review and state-of-the art analysis of external costs of accidents and calculation methods for different types of transport. A several categories of external costs from transport were analyzed and characterized.

The main document used for the examination of the accident costs quantification was "Handbook on External Costs of Transport". The calculation of different cost components within accident costs adheres to international guidelines.

Human costs are determined using the willingness-to-pay (WTP) value of the value of statistical life (VSL). The VSL for EU28 is €3.6 million, derived from OECD (2012) and adjusted at the country level. To obtain human costs, the consumption loss is subtracted from the VSL. The consumption loss is based on annual market consumption and life years lost due to accidents. Drivers consider the human costs of individuals within their own vehicle as internal, while those of individuals in other vehicles are considered external.

Medical costs are calculated using the restitution costs method. It is assumed that 50% of the medical costs are not covered by insurance, thus considered external. It is assumed that 50% of the administrative costs are not covered by insurance, hence considered external. Production loss points to the fact that the human capital approach is utilized to estimate production loss costs. Approximately 55% of the production loss costs are considered external. All material damage costs are considered fully internalized.

When evaluating the marginal costs, there are several significant facts authors point to. When a driver enters traffic, they expose themselves to the average accident risk. However, the presence of additional vehicles can alter the accident risk for other road users. For example, more vehicles increase the likelihood of encounters and thus raise the accident risk. Conversely, increased traffic may result in more cautious driving or reduced vehicle speed, potentially lowering the accident risk. Consequently, marginal accident costs can significantly differ from average accident costs (either higher or lower) depending on the road type (e.g., motorway, urban) and traffic flow (dense or light).

Marginal accident costs are only calculated for road transport. Rail, aviation, inland waterway, and maritime marginal accident costs are assumed to be equal to the average accident costs since these modes operate on scheduled services. Therefore, the size of the traffic flow does not influence accident costs for these modes, unlike road transport, where accident risk is highly dependent on road congestion.

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6. Conclusions

The costs imposed on society and the environment by transportation activities are often not fully considered in the decision-making process of transport users. Even when policies and regulations have been implemented to address air pollution and GHGs at the EU and international level, other costs involving congestion, accidents, and noise have received much less attention until recently. This problem started to be serious as transport demand is estimated to triple in the next 30 years. Therefore, congestion costs are expected to rise by approximately 50% in 2050, along with increased costs associated with accidents and noise (European Commission, 2011).

Road freight transport in the EU represent the biggest producer of external costs among all modes of transportation. It contributes significantly to road infrastructure degradation, air pollution, and a significant number of fatalities resulting from accidents. Despite this, over 70% of freight is still transported by the means of road transport (in hinterland). Therefore, a key objective of EU transport policy has been to achieve a substantial shift of freight transport from roads to other modes (European Commission, 2019).

Multimodality in freight transport is seen as a solution for long distances and needs to become more attractive for shippers (Raza et al, 2020). While rail transport can be an appealing alternative, substantial investments are still required to upgrade the rail network in Europe, making waterborne alternatives more favorable. The sustainable mobility strategy of the European Commission (EC) aims to increase the use of inland waterways and short sea shipping transport (SSS) by 25% by 2030 and 50% by 2050 (European Commission, 2020). The strategy also recognizes the necessity of fully incorporating the impacts of transportation into pricing as a crucial step in developing a greener, more efficient, and fairer transport system.

The European Commission emphasizes that internalizing external costs by implementing the principles of "polluter pays" and "user pays" is crucial for accounting for the full impact of transport. This entails making transport users accountable for the complete costs of their transportation decisions. The EU strategy sets milestones, including the aim for rail and waterborne intermodal transport to compete on equal footing with road-only transport in terms of internalized external costs by 2030 (European Commission, 2020). Additionally, all external costs of transport within the EU should be covered by transport users no later than 2050.

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