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External Costs of Road Traffic Accidents in Türkiye: The Willingness-to-Pay Method

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Abstract

Traffic accidents remain a major global burden, causing mortality, disability, and socio-economic losses that hinder sustainable development. Beyond human suffering, crashes place long-term pressures on health systems, labor markets, and national economies, disproportionately impacting low- and middle-income countries. Estimating the true societal costs of accidents is therefore essential for designing effective, equitable, and sustainable road safety policies. This study applies the Willingness-to-Pay (WTP) method to evaluate the external costs of traffic-related deaths and injuries in Türkiye between 2008 and 2018. By incorporating material and immaterial losses, the WTP framework captures a broader spectrum of impacts than traditional approaches, offering valuable insights into the scale of welfare losses and the value of risk reduction. The findings reveal that external costs rose substantially over the decade, from 1.63% to 2.72% of national Gross Domestic Product (GDP), underscoring that economic losses from road crashes are growing faster than the economy. These results highlight the need for systematic interventions that integrate road safety into national sustainability agendas, including safer infrastructure, behavioral programs, advanced vehicle technologies, and efficient emergency response systems. The evidence presented strengthens the case for prioritizing traffic safety as a fundamental component of sustainable transport and public health strategies.

Keywords: traffic accidents; external costs; willingness to pay; sustainable transportation; road safety policy

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1. Introduction

The World Health Organization (WHO) reports that the annual number of road deaths reached 1.19 million in 2021, while the number of injured individuals in road crashes ranged from 20 to 50 million per year [1–4]. This makes road collisions the eighth leading cause of death worldwide [2,5]. In addition, traffic accidents constitute one of the most significant burdens for national economies, governments, and communities [4,6], resulting in substantial casualties and economic losses [7,8]. According to Chen et al. [9], the estimated societal cost of road traffic injuries to the global economy is approximately 1.8 trillion US dollars, representing about 0.12% of the world's Gross Domestic Product (GDP). Road accidents also have broader societal implications, influencing the health sector, labor market, and government expenditure [10–13]. While the overall societal burden of crashes is recognized, this issue becomes even more critical in urban environments where multiple transport modes coexist. According to the WHO [14], more than half of all road

traffic deaths involve vulnerable road users—pedestrians, cyclists, and motorcyclists—who remain the most exposed participants in traffic. In such urban areas, an essential dimension of sustainable and safe transportation is to ensure the protection of these vulnerable users. Previous research has emphasized that unprotected users often experience the most severe consequences in road traffic accidents. For instance, Macioszek et al. [15] analyzed the safety of cyclists in Poland using road incident maps and identified spatial clusters of high-risk areas, highlighting the need for infrastructure improvements and targeted safety measures for bicyclists. Currently, 93% of global traffic fatalities occur in low- and middle-income countries, even though these nations account for only 60% of registered vehicles worldwide [16]. These countries are experiencing rapid population and economic growth, leading to increased motorization and a corresponding rise in road traffic accidents [17,18]. Although low- and middle-income countries bear the highest health burden from road injuries, they account for only 46.4% of global economic losses, largely due to higher productivity and treatment costs in high-income nations. In such contexts, medical treatment expenses constitute a larger share of the total economic burden [9]. By contrast, cost-of-crash studies are conducted more systematically in high-income countries, where the societal impacts of traffic accidents are assessed in monetary terms and used to justify increased investment in road safety measures [19].

The magnitude of the damage caused by traffic accidents is most commonly assessed using a country's GDP or Gross National Product (GNP). These indicators are widely recognized as appropriate benchmarks for ranking the scale of costs and for enabling international comparisons [20]. Moreover, given the persistently high incidence of road accidents, such costs are particularly significant in developing countries, where they impose a disproportionate burden. This underscores the necessity of rigorous analysis [2]. In general, it is estimated that the cost of traffic accidents corresponds to approximately 1% of gross national income in many countries [21]. The World Bank (WB) has more recently adopted the assumption that traffic accidents account for about 2% of national income to better reflect their true economic magnitude [22]. Similarly, the WHO has reported that traffic accidents correspond to around 3% of GDP in most countries [2,3]. Supporting this, international studies have demonstrated that the socio-economic costs of accidents range between 0.4% and 6.0% of annual GDP [23,24].

Evidence from country-level studies further reinforces these economic burdens. One of the earliest studies conducted in Türkiye was undertaken by the General Directorate of Highways (GDH) in 1998, which found that the cost of traffic accidents amounted to 2.2% of national income [25]. In Iran, it has been reported that approximately 25% of unnatural deaths are attributable to traffic accidents, and that their economic cost is equivalent to about 3% of GDP [26]. Likewise, in the Republic of Tatarstan, traffic accidents resulted in material losses amounting to 2.5% of GDP [27]. In Kazakhstan, the socio-economic cost of road traffic accidents was estimated at 6.8 billion USD in 2012, corresponding to 3.3% of GDP [28]. The situation in African countries also demonstrates wide variation. The estimated cost of road accidents as a percentage of Gross National Product was 0.8% in Ethiopia, 1% in South Africa, 2.3% in Zambia, 2.7% in Botswana, and approximately 5% in both Kenya and Malawi [29]. In Vietnam, the economic cost of traffic accidents during 2006 and 2007 was estimated to be about 2.8% of GDP [30]. Similarly, in the Kingdom of Saudi Arabia, road crashes were estimated to result in economic losses corresponding to nearly 4.3% of GDP [31].

Across the European Union (EU), road traffic accidents killed 18,844 people in 2020, which is 10,847 fewer than in 2010 (−37%) [6]. A total of 6675 people lost their lives as a result of road traffic accidents in Türkiye in 2018 [32]. Türkiye has fewer cars per thousand people than any EU country. However, the country ranks first in road fatalities

with 366 deaths per million vehicles [33,34]. The socioeconomic impact of road accidents is significant, evident in the substantial social costs they generate [4]. Traffic injuries, for instance, place a substantial strain on the Turkish healthcare system, both in terms of treatment costs and resource allocation. Assessing the economic losses resulting from road accidents is essential to grasp the severity of road safety issues in the countries [35]. In addition, the evaluation of road safety programs requires a monetary assessment of safety improvements [36]. Therefore, sound decision-making for safety-related investment programs heavily relies on the economic evaluation of traffic crashes [37].

Road accidents significantly impact individuals by affecting their mental and physical health, work capacity, and income. In addition to causing pain and suffering, road injuries can push families into poverty due to the high costs of medical treatment, rehabilitation, funerals, and lost income [11,38]. Traffic accidents not only result in property damage but also cause physical and psychological harm to both victims and offenders. The associated costs typically include medical expenses, property repair, productivity losses, and compensation for emotional distress [39]. Kasnatscheew et al. [40] stated that the economic burden of road traffic injuries can be assessed through road safety valuation methods, which quantify various cost components in monetary terms.

Given these multidimensional impacts, it is essential to conduct a monetary assessment of traffic safety to evaluate how reducing traffic mortality risk compares with the costs associated with implementing road safety measures [24,41,42]. Research in this field provides critical insights that can be integrated into educational programs, fostering a culture of safety and supporting the development of safety management systems. Such information is vital for traffic management and policymaking, as it facilitates systematic risk mitigation and enhances overall traffic safety [11,39,43,44]. Building on this framework, the present study estimates the annual cost of traffic-related deaths and injuries in Türkiye using the Willingness-to-Pay (WTP) method. It also contributes to the growing body of literature applying WTP to assess traffic risk reduction in Türkiye. The authors previously calculated the external costs of road traffic accidents in the country between 2008 and 2018 using the Human Capital (HC) method, one of the internationally recognized approaches for accident cost estimation. The current study, therefore, allows for a direct comparison between the HC method and WTP approaches within the same dataset, highlighting methodological differences in how economic and social costs are valued. The remainder of this paper is organized as follows. Section 2 presents a comprehensive literature review on the external costs of road traffic accidents and the valuation approaches used to estimate them. Section 3 outlines the theoretical background and conceptual framework of the study. Section 4 describes the data, methodological design, and model applied to assess the WTP for traffic risk reduction in Türkiye. Section 5 presents and discusses the results, while Section 6 concludes with key findings, policy implications, and suggestions for future research.

2. Literature Review

Haddak et al. [11] highlighted that earlier studies often used the HC method to measure the cost of road traffic accidents, focusing primarily on productivity losses while overlooking the intrinsic value of life and suffering. To address this limitation, the WTP approach was developed, emphasizing individuals' preferences and their perceived reduction in accident risk. Within this framework, individuals are asked either directly or indirectly how much they are willing to pay for a reduction in risk, which forms the basis for estimating the Value of a Statistical Life (VSL). Several studies have estimated WTP for reducing fatal accident risks and calculating VSL [45–47], while others have explored individuals' willingness to pay for eliminating the risk of fatal or serious injuries [42,48,49].

The WTP approach thus quantifies the economic value of lost life years and quality of life based on the amount individuals are prepared to pay for risk reduction [40,48,50–52]. In contrast, the HC or Gross Output (GO) method, which estimates the discounted present value of a victim's future productivity lost due to death, has inherent limitations, as it accounts only for tangible (material) losses [53]. The WTP method, on the other hand, incorporates both material and immaterial dimensions by capturing individual perceptions of risk and well-being [54,55]. Although the HC and the WTP methods are sometimes considered alternative approaches for valuing saved human lives, they in fact capture different cost components and are therefore complementary to each other [53].

Wijnen et al. [53] and Wegman [1] noted the complexities in comparing VSL estimates across countries and recommended that each country should periodically update and evaluate its own national VSL. Because of data limitations, the WTP method has been more frequently applied in high-income countries than in low- and middle-income ones [28,38]. The HC and WTP approaches yield different socio-economic cost estimates; in general, values based on the WTP method are approximately twice as high as those derived from non-WTP approaches [24,56–58]. However, despite its wide acceptance, the WTP method remains costly and challenging to implement, not only due to data collection expenses but also because populations in low-income economies may have difficulty expressing their willingness to pay [20]. Therefore, further efforts are needed to develop practical data collection and analytical frameworks that can be reliably applied in low- and middle-income countries [49]. Based on previous studies, income has been found to be significantly and positively correlated with individuals' WTP for safety improvements [48,49,59–61], confirming that safety is considered a normal good [36]. Beyond fatality valuation, the WTP approach is also applied to non-fatal injuries to estimate the monetary value individuals assign to reducing the risk of harm [40]. Despite challenges in eliciting precise WTP estimates, this approach remains the most widely accepted and empirically validated method for quantifying the perceived value of risk reduction and associated pain and suffering [11,38,57,58,62–64].

The allocation of resources for investment can be guided by evaluating the economic burden that road injuries impose on a country's GDP [65]. It is therefore advisable for all countries to conduct a WTP study to determine the value of statistical life in traffic injuries prior to making any investments in road safety [66]. As Elvik [67] emphasized, calculating the cost of road traffic accidents using the WTP method helps to minimize the risk of being involved in such incidents. In line with this, comparative analyses of approaches for estimating the monetary value of human costs indicate that most countries adopt the WTP method [68]. If the cost of road accidents is based solely on police data, the calculation of the cost of road accidents will be inaccurate [69]. Wijnen et al. [24] note that in many European countries, the costs of road accidents are underestimated due to unreported accidents and the failure to account for fatalities. Therefore, the WTP method produces a correct estimate of costs and allows policymakers to reduce the number of traffic accidents and address the associated problems more easily [41,70].

Mon et al. [71] estimated the VSL for motorcyclists, car drivers, and bus passengers in Myanmar using a WTP approach, yielding VSLs of MMK 118.062 million (USD 98,385) and MMK 162.854 million (USD 135,712), respectively, and estimated the 2015 total cost of death at MMK 594.681–820.296 billion (USD 495.567–683.580 million). Abdallah et al. [72], using the WTP method, estimated the cost of road traffic crashes in Egypt at 52 billion EGP (approximately USD 6.6 billion) in 2014, equivalent to 2.27% of GDP. In 2005, Bhattacharya et al. [73] estimated the cost of a traffic injury in Delhi at USD 150,000 using the WTP method. Bhattacharya found that WTP increased as income increased and risk was reduced. It has been estimated that Australian traffic crashes cost at least USD 27 billion per year

using the WTP method in 2006 [74]. In the study by Le et al. [75], the true cost of accidents was assessed using a method reflecting society's WTP, which estimated the statistical value of a life saved at USD 1,874,000 for car accidents, USD 1,711,000 for motorcycle accidents, and $1,426,000 for avoiding a serious injury.

Jomnonkwao et al. [16] examined the VSL and Value of a Statistical Serious Injury (VSSI) in road accidents using the WTP on transport safety. Several studies have calculated the cost of traffic injuries in Iran, but most commonly used the HC or contractual compensation [76]. Ainy et al. [38], using the WTP method, estimated the cost of traffic injuries in Iran in 2013 at about US $39 billion, corresponding to 6.46% of gross national income. Ainy et al. [76] found that by measuring the potential benefit of preventing traffic injuries from causing death and injury, the WTP method is closer to the actual cost of injuries. A study by Subhan et al. [77] found that attitude toward traffic safety responsibility was significantly associated with intention to pay. In addition, drivers who travel high annual mileage seem to prefer lower WTPs for road safety [78]. This may be because highly experienced drivers tend to have lower WTP because they are often more experienced and skilled and believe they can avoid life-threatening situations [37]. It was found in Wisutwattanasak et al.'s [78] study and in Svensson and Johansson's [42] study that drivers with children have more road safety responsibilities, thus resulting in higher WTP. According to Subhan et al. [77], drivers with higher safety intentions show greater WTP for road safety, while those with compelling trips tend to decrease their WTP despite similar annual mileage and driving skills. Behavioral intention has a positive influence on drivers' attitudes toward road accidents, according to Wisutwattanasak et al.'s [78] results. It is also observed to vary across groups of drivers. Additionally, drivers with elders in the household may be more aware of the severity of road accidents, thus increasing their perspective on road safety improvement [36]. In their study, Schoeters et al. [68] highlighted significant differences in crash cost estimates for serious injuries across European countries. They reported that the cost per serious injury ranges from EUR 28,205 to EUR 975,074, while the total costs associated with serious injuries account for between 0.04% and 2.7% of a country's GDP.

Schoeters et al. [79] presented the results of a stated preference study estimating the WTP of respondents in four European countries (Belgium, France, Germany, and the Netherlands) to reduce the risk of fatal and serious injuries in road crashes. Using a mixed logit model, the researchers estimated the VSL at EUR 6.2 million, the VSSI at EUR 950,000, and the Value of Time (VoT) at EUR 16.1 per hour. The study found that the value of preventing a fatal injury is roughly seven times higher than that of preventing a serious injury. In the EU-28 transport sector, road accidents account for an average of 33% of the total external costs [80]. Approximately 156 billion euros have been saved by the national economies of EU member states by preventing road traffic deaths. According to these figures, road safety has a significant impact on a state's economic indicators [81]. Moreover, these findings underscore their importance for various socioeconomic studies, particularly in assessing the socioeconomic costs of road accidents. Consequently, policy makers have recently shifted their focus from transportation and infrastructure projects to assessing and prioritizing road safety measures by monetizing them [11].

The reviewed literature highlights that the WTP approach has become the most widely accepted and comprehensive method for estimating the socio-economic burden of road traffic accidents, as it captures both material and immaterial losses. However, most existing WTP-based studies have been conducted in high-income countries, where data availability and survey implementation are less constrained. In contrast, research in low- and middle-income countries remains limited, often relying on the HC method due to data scarcity and financial constraints. Moreover, significant variations exist across studies in terms of estimated VSL and methodological design, indicating the need for

country-specific assessments. Building on this gap, the present study applies an updated and context-specific WTP framework to evaluate the external costs of road traffic accidents in Türkiye, thereby contributing to a more accurate and locally relevant valuation of traffic safety improvements.

3. Materials and Methods

3.1. Data

An extensive dataset for Türkiye (2008–2018) was utilized in this study. Data on traffic fatalities, injuries, and the age breakdown of the deceased were retrieved from the General Directorate of Security (GDS) (The GDS supplied these data following the formal application made by Gümüşhane University, dated 14 January 2020, and registered with the number 43244757-605.01-E.232). Corresponding figures on per capita gross average wages, employment rates, and statutory retirement age [82], population [83], and GDP [84] were obtained from the Turkish Statistical Institute (TSI), and yearly average exchange rates were provided by the Central Bank of the Republic of Türkiye (CBRT) [85]. All monetary data were inflation-adjusted to reflect real values for the given period. The externalities of road traffic accidents were calculated on an annual basis across the 10-year timeframe.

3.2. Methods

In the literature, the WTP method is a widely used method to determine the external costs of accidents. In this context, external costs refer to the overall socio-economic burden of road traffic accidents, encompassing both direct economic losses (e.g., property damage, productivity losses) and indirect welfare losses (e.g., pain, suffering, and loss of life quality) borne by society [86]. This method is used to facilitate international comparisons in this study as well. This study also employs data transfer techniques (utilizing ratios or values from other studies), particularly for countries with insufficient data in international research. To enable the comparison of GDP Per Capita in Purchasing Power Standard (PPS) terms, Türkiye's values for the relevant years were obtained from TSI (2008–2018) [87]. Based on these values, the unit cost of fatalities, referred to as the VSL, was calculated separately for each year between 2008 and 2018 using the WTP method. According to CE Delft [86], OECD [88], INFRAS [89], and HEATCO [90], the reference VSL value for fatalities due to traffic accidents in OECD and EU countries ranges between USD 1.5 million and 4.5 million (2005 USD) [91]. In this study, a conservative reference value of EUR 1,500,000 corresponding to the lower bound of the OECD-used range and the EU average was adopted and adjusted to the Turkish context through PPS conversion to ensure international comparability [87,92]. It is recommended to adjust this reference value according to each country's Per Capita Gross Domestic Product at Purchasing Power Standards (PPS GDP) and reflect it in the cost calculations [86]. The transfer of this value to the Turkish context was made through a PPS adjustment to ensure international comparability. While this approach implicitly assumes an income elasticity of 1.0, empirical research indicates that the elasticity of the VSL may vary between 0.8 and 1.2 across income levels [93,94]. To address potential over- or under-estimation for Türkiye, a sensitivity analysis using income elasticities of 0.8 and 1.2 was therefore conducted, which found that total external-cost estimates shift modestly but remain robust within this range. These studies also recommend using reference unit costs for injuries, distinguishing between serious and slight injuries. Serious injuries refer to injuries requiring hospital treatment but not resulting in death within 30 days, whereas slight injuries are those that do not require hospital treatment and have short-term effects [90,95]. According to OECD [88], in countries without detailed data on serious and slight injuries, a ratio of 0.25 for serious injuries to 0.75 for slight injuries can be used. Unfortunately, such a distinction between serious and slight injuries

is not available in Türkiye's national accident database. Since the number of fatalities and total injuries is known for each year, the estimated numbers of slight and serious injuries were calculated using the recommended proportions. Based on these estimates, the external cost per injured person was calculated for each year in Türkiye by applying 13% of the VSL for serious injuries and 1% for slight injuries [86,88]. In Türkiye, accident records are maintained by different authorities depending on the location of the crash. Areas within municipal borders fall under the jurisdiction of the Turkish National Police, defined as the Traffic Police Responsibility Zone (TPRZ), whereas areas outside municipal borders are under the jurisdiction of the Gendarmerie General Command, defined as the Gendarmerie Responsibility Zone (GRZ). Accordingly, accident data are collected by different authorities (police and gendarmerie) but have been integrated into a unified national database managed by the TSI since 2015. Following this harmonization, the 30-day fatality definition was adopted, consistent with international statistical standards. Since the TSI dataset reports only total injury counts without distinguishing between serious and slight injuries, the ratio used in the OECD report [88], 0.25 (serious) and 0.75 (slight), was applied uniformly across all years.

4. Research Findings and Results

Between 2008 and 2018, the number of injuries reported by both the TPRZ and the GRZ was adjusted using the ratios provided in the methodology, and the results are presented in Table 1 and Figure 1.

Table 1. Fatalities and injury estimates in road traffic accidents, Türkiye (2008–2018).

Year	Responsible Authority	Number of Fatalities	Number of Injuries	Estimated Number of Serious Injuries	Estimated Number of Slight Injuries	Total Estimated Serious Injuries	Total Estimated Slight Injuries
2008	TPRZ	2948	145,163	36,291	108,872	46,117	138,351
	GRZ	1288	39,305	9826	29,479		
2009	TPRZ	2993	161,719	40,430	121,289	50,345	151,035
	GRZ	1331	39,661	9915	29,746		
2010	TPRZ	2738	171,475	42,869	128,606	52,874	158,622
	GRZ	1307	40,021	10,005	30,016		
2011	TPRZ	2582	194,149	48,537	14,612	59,519	178,556
	GRZ	1253	43,925	10,981	32,944		
2012	TPRZ	2555	221,108	55,277	165,831	67,020	201,059
	GRZ	1195	46,971	11,743	35,228		
2013	TPRZ	2393	224,287	56,072	168,215	68,707	206,122
	GRZ	1292	50,542	12,636	37,907		
2014	TPRZ	2296	233,336	58,334	175,002	71,265	213,794
	GRZ	1228	51,723	12,931	38,792		
2015	TPRZ	2555	250,362	62,591	187,772	76,105	228,316
	GRZ	4975	54,059	13,515	40,544		
2016	TPRZ	2266	249,714	62,429	187,286	75,953	227,859
	GRZ	5034	54,098	13,525	40,574		
2017	TPRZ	2299	246,264	61,566	184,698	75,096	225,287
	GRZ	5034	54,119	13,530	40,589		
2018	TPRZ	2138	249,687	62,422	187,265	76,768	230,303
	GRZ	4537	57,384	14,346	43,038		

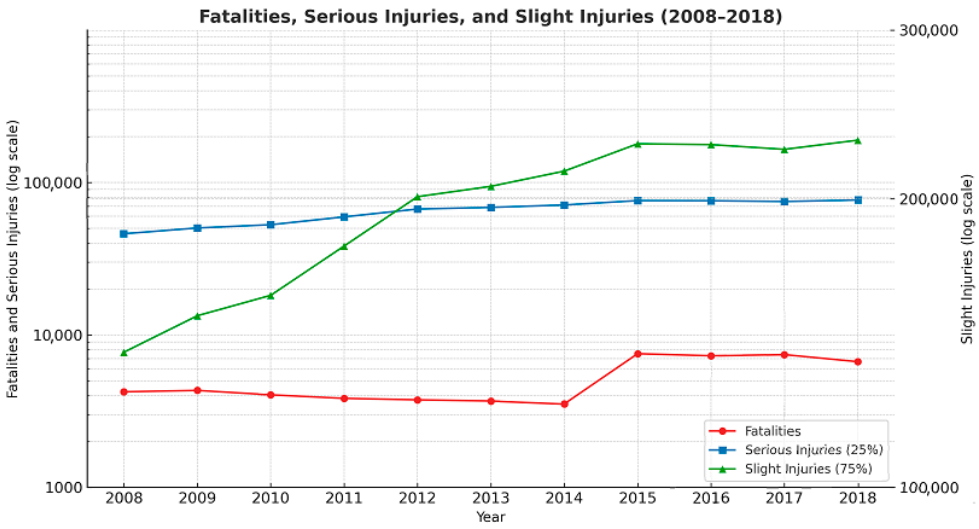


Figure 1. Estimated Fatalities and Injuries in Road Traffic Accidents, Türkiye (2008–2018). Note: The apparent increase after 2015 reflects the adoption of the 30-day fatality definition by TSI; the y-axis is presented on a logarithmic scale to improve the visibility of proportional differences among injury severities.

To enable comparison of PPS GDP Per Capita values, the unit cost of fatalities (VSL) was calculated for each year between 2008 and 2018 using Türkiye's GDP per capita [82] and the reference value of EUR 1,500,000 for VSL, which is based on the EU average [92], as described in the methodology.

For example, for the year 2008, the VSL for Türkiye was calculated as follows:

$$\text{VSL_Türkiye (2008)} = \text{VSL_EU (1,500,000)} \times (\text{PPS Türkiye/PPS EU average}) \text{ (2008)}$$

resulting in:

$$\text{VSL_Türkiye (2008)} = €1{,}500{,}000 \times (0.49)$$

$$= €735{,}000$$

The PPS Türkiye/PPS EU average ratios and the corresponding unit costs of fatalities (€) for the years 2008–2018 are presented in Table 2.

Table 2. PPS Türkiye/EU averages and unit cost of fatalities (€), 2008–2018.

Year	PPS Türkiye/PPS EU Average	Unit Cost of Fatalities (€)
2008	0.49	735,000
2009	0.48	720,000
2010	0.53	795,000
2011	0.57	855,000
2012	0.59	885,000
2013	0.62	930,000
2014	0.65	975,000
2015	0.68	1,020,000
2016	0.66	990,000
2017	0.66	990,000
2018	0.63	945,000

The results are presented in Table 2, while Figure 2 illustrates the trend in VSL over the period.

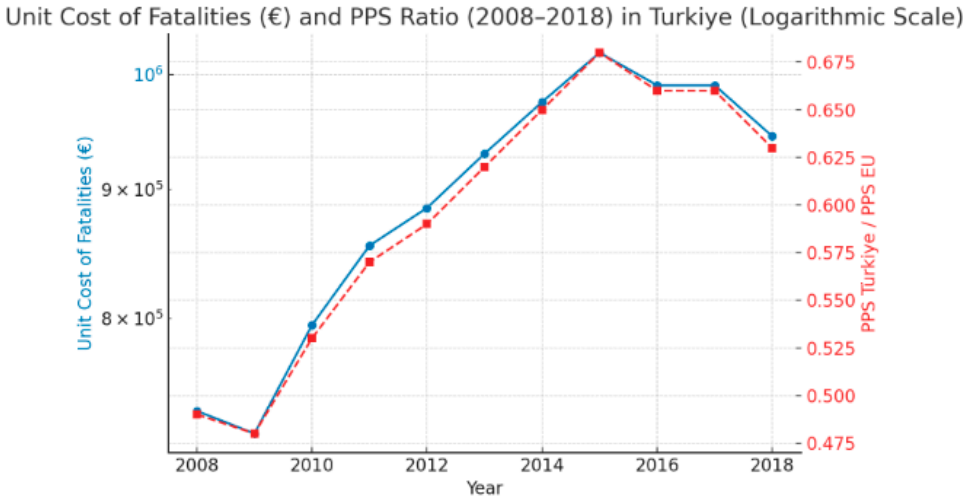


Figure 2. Unit costs calculated for fatalities between 2008 and 2018.

The unit cost calculated for fatalities in Table 2 has been used as 13% for the unit cost of serious injuries and 1% for the unit cost of slight injuries, due to the reasons previously explained in the methodology. Therefore, the unit costs for serious and slight injuries were calculated for the years 2008–2018 following the steps below. The results are presented in Table 3.

Table 3. Unit VSL costs (€) for fatalities as well as slight and serious injuries in Türkiye (2008–2018).

Year	Fatalities (€)	Serious Injuries (€)	Slight Injuries (€)
2008	735,000	95,550	7350
2009	720,000	93,600	7200
2010	795,000	103,350	7950
2011	855,000	111,150	8550
2012	885,000	115,050	8850
2013	930,000	120,900	9300
2014	975,000	126,750	9750
2015	1,020,000	132,600	10,200
2016	990,000	128,700	9900
2017	990,000	128,700	9900
2018	945,000	122,850	9450

For example, for the year 2008:

$$\text{Unit cost for serious injuries} = \text{VSL Türkiye}_{(2008)} \times 0.13$$

$$= €735{,}000 \times 0.13$$

$$= €95{,}550$$

$$\text{Unit cost for slight injuries} = \text{VSL Türkiye}_{(2008)} \times 0.01$$

$$= €735{,}000 \times 0.01$$

$$= €7350$$

The calculations provided for the year 2008 were applied up to 2018 and are presented in Table 3.

The changes in the VSL for serious and slight injuries presented in Table 3 are more clearly illustrated in Figure 3. As shown in the figure, the costs associated with serious injuries exhibit a continuous increase from 2008 to 2015, reaching their peak in that year, and then display a moderate decline in the subsequent period. Slight injuries exhibit a similar trend, albeit at a substantially lower scale, reflecting their relatively smaller economic burden. This distinction between serious and slight injuries is consistent with international findings in the literature, where the severity of injury is strongly correlated with both direct medical costs and broader socio-economic impacts (e.g., productivity losses and long-term care). It should also be noted that until 2015, the number of fatalities included only those deaths recorded at the crash site. This change in reporting standards may also have contributed to the observed shift in VSL.

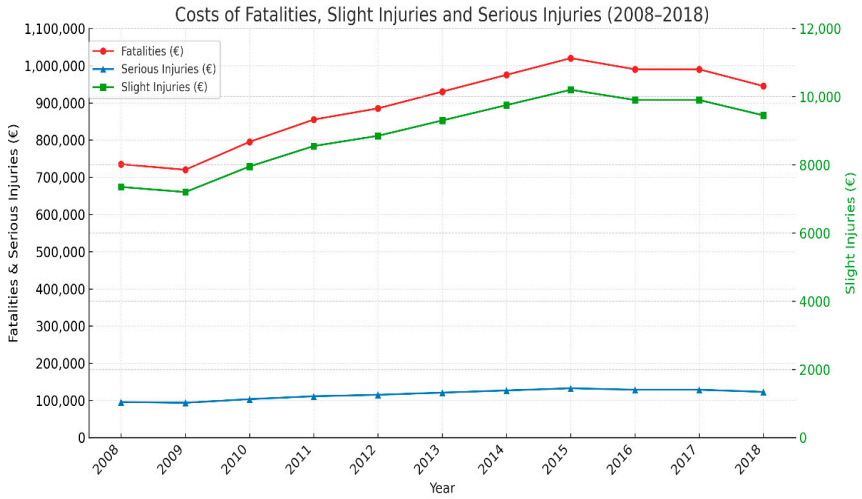


Figure 3. Unit Costs of Serious and Slight Injuries (2008–2018).

The annual total external costs for Türkiye between 2008 and 2018 were estimated by multiplying the calculated unit costs by the corresponding numbers of fatalities, serious injuries, and slight injuries. In 2008, the external costs of fatalities were determined using 4236 fatalities (Table 1) and a unit cost of EUR 735,000 per fatality (Table 2), resulting in:

$$4236 \times 735{,}000 = €3{,}113{,}460{,}000$$

For 2018, using 6675 fatalities from Table 1 and a unit cost of €945,000 from Table 2, the external costs of fatalities were calculated as:

$$6675 \times 945{,}000 = €6{,}307{,}875{,}000$$

The estimated external costs of serious injuries in 2008 were determined using 46,117 serious injuries from Table 1 and a unit cost of EUR 95,550 from Table 3:

$$46{,}117 \times 95{,}550 = €4{,}406{,}479{,}000$$

For 2018, using 76,768 serious injuries and a unit cost of EUR 122,850, the external costs were calculated as:

$$76{,}768 \times 122{,}850 = €9{,}430{,}949{,}000$$

The estimated external costs of slight injuries in 2008 were calculated using 138,351 slight injuries from Table 1 and a unit cost of EUR 7350 from Table 3:

$$138{,}351 \times 7350 = €1{,}016{,}880{,}000$$

For 2018, with 230,303 slight injuries and a unit cost of EUR 9450, the estimated external costs were:

$$230{,}303 \times 9450 = €2{,}176{,}364{,}000$$

In 2008, the external cost of 4236 fatalities was estimated at EUR 3.1 billion, while in 2018, it rose to EUR 6.3 billion for 6675 fatalities. For an estimated 138,351 slight injuries in 2008, the external cost was EUR 1.02 billion, increasing to EUR 2.18 billion for 230,303 slight injuries in 2018. Similarly, the cost associated with approximately 46,117 serious injuries in 2008 was EUR 4.41 billion, reaching EUR 9.43 billion for 76,768 serious injuries in 2018. Consequently, the total external cost of road traffic accidents in Türkiye was calculated as EUR 8.54 billion in 2008 and EUR 17.92 billion in 2018. These findings are consistent with previous studies that demonstrate a strong correlation between traffic accident rates and the associated societal costs [23,65].

The estimated external costs for fatalities, serious injuries, and slight injuries are summarized in Table 4, while Figure 4 illustrates the temporal evolution of these total external costs in Türkiye from 2008 to 2018, thus highlighting the trends and economic implications of the country's road traffic accident burden.

Table 4. External costs of fatalities and injuries, Türkiye (2008–2018, WTP).

Year	Number of Fatalities	Estimated Number of Serious Injuries	Estimated Number of Slight Injuries	External Costs of Fatalities (€)	External Costs of Serious Injuries (€)	External Costs of Slight Injuries (€)	Total External Costs of Traffic Accidents (€)
2008	4236	46,117	138,351	3,113,460,000	4,406,479,350	1,016,879,850	8,536,819,200
2009	4324	50,345	151,035	3,113,280,000	4,712,292,000	1,087,452,000	8,913,024,000
2010	4045	52,874	158,622	3,215,775,000	5,464,527,900	1,261,044,900	9,941,347,800
2011	3835	59,519	178,556	3,278,925,000	6,615,536,850	1,526,653,800	11,421,115,650
2012	3750	67,020	201,059	3,318,750,000	7,710,651,000	1,779,372,150	12,808,773,150
2013	3685	68,707	206,122	3,427,050,000	8,306,676,300	1,916,934,600	13,650,660,900
2014	3524	71,266	213,794	3,435,900,000	9,032,965,500	2,084,491,500	14,553,357,000
2015	7530	76,105	228,316	7,680,600,000	10,091,523,000	2,328,823,200	20,100,946,200
2016	7300	75,953	227,859	7,227,000,000	9,775,151,100	2,255,804,100	19,257,955,200
2017	7427	75,096	225,287	7,352,730,000	9,664,855,200	2,230,341,300	19,247,926,500
2018	6675	76,768	230,303	6,307,875,000	9,430,948,800	2,176,363,350	17,915,187,150

As presented in Table 4, the external costs of road traffic accidents in Türkiye were initially calculated in euros (€) based on the WTP method. To provide a more comprehensive national-level assessment, these costs were subsequently converted into Turkish Lira (₺) using the average EUR/TL exchange rates provided by the CBRT for the period 2008–2018 [85]. The recalculated values are displayed in Table 5, which reports the total external costs of fatalities, serious injuries, and slight injuries in TL terms. In addition, Türkiye's annual GDP is also presented together with the ratio of total external costs to GDP.

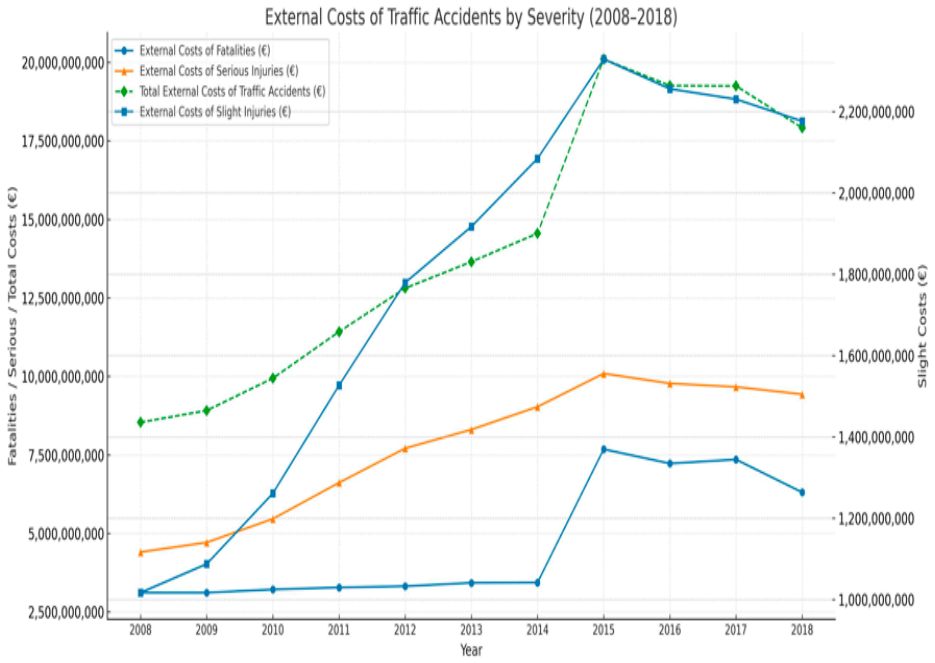


Figure 4. Total external costs in Türkiye (2008–2018), WTP method.

Table 5. Ratio of traffic accident external costs (WTP) to GDP, 2008–2018.

Years	External Costs (€)	EURO/TRY Exchange Rate	External Costs (₺)	GDP (₺)	External Costs to GDP Ratio (%)
2008	8,536,819,200	1.896	16,183,845,734	994,782,858,000	1.63
2009	8,913,024,000	2.151	19,167,636,372	999,191,848,000	1.92
2010	9,941,347,800	1.989	19,776,820,245	1,160,013,978,000	1.70
2011	11,421,115,650	2.322	26,524,398,985	1,394,477,166,000	1.90
2012	12,808,773,150	2.304	29,517,689,636	1,569,672,115,000	1.88
2013	13,650,660,900	2.525	34,472,696,503	1,809,713,087,000	1.90
2014	14,553,230,250	2.906	42,291,250,509	2,044,465,876,000	2.07
2015	20,100,946,200	3.018	60,669,881,877	2,338,647,494,000	2.59
2016	19,257,955,200	3.340	64,317,911,356	2,608,525,749,000	2.47
2017	19,247,926,500	4.116	79,232,357,123	3,110,650,155,000	2.55
2018	17,915,187,150	5.663	101,447,792,818	3,724,387,936,000	2.72

The external costs resulting from fatalities and injuries in traffic accidents have increased steadily over the years. While the total external cost was estimated at TL 16.18 billion in 2008, this figure rose to TL 101.45 billion in 2018, corresponding to a 110% increase in euro terms and a 526% increase in TL terms, driven in part by a 199% rise in the EUR/TL exchange rate. In 2008, the external costs of traffic accidents amounted to 1.63% of Türkiye's GDP. By 2018, this share had risen to 2.72%, highlighting the increasing economic burden of road traffic incidents on the national economy. Figure 5 clearly illustrates the changes in the ratio of the external costs of traffic accidents to GDP over the years, as calculated and presented in Table 5.

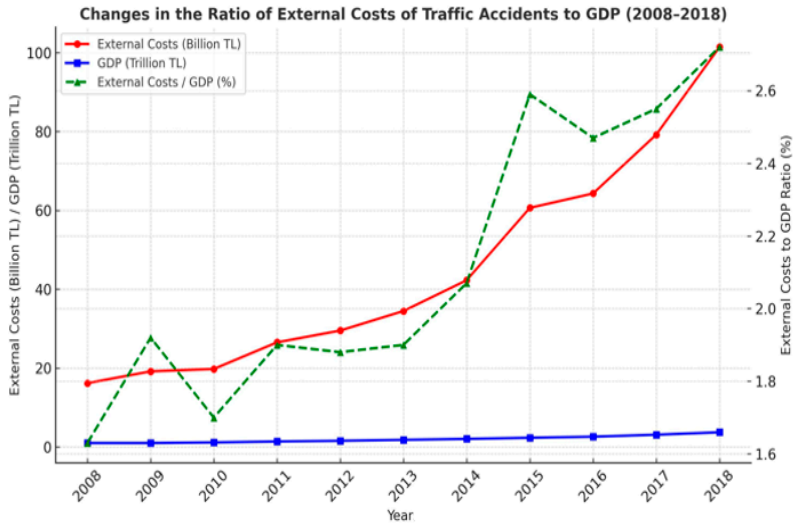


Figure 5. Changes in the ratio of external costs of traffic accidents to GDP (2008–2018).

5. Discussion

This study estimated the external costs of road traffic accidents in Türkiye between 2008 and 2018 using the WTP method, which provides a broader and more comprehensive measure of societal welfare losses compared to the HC method. By incorporating not only fatalities but also serious and slight injuries, the analysis captures a fuller picture of the social and economic consequences of traffic accidents. The results show that the total external costs increased from EUR 8.54 billion in 2008 to EUR 17.92 billion in 2018, corresponding to a rise from 1.63% to 2.72% of GDP. This escalation highlights that the economic costs of accidents have been increasing at a faster pace than overall economic growth, underscoring the urgent need for systemic interventions.

The distinction between fatalities, serious injuries, and slight injuries reveals important dynamics: while the costs of serious injuries peaked in 2015 before declining, fatalities and slight injuries generally increased until 2015 and then stabilized or slightly declined thereafter. Although total external costs continued to rise after 2015, the unit costs expressed in euros show a modest decline, reflecting the normalization effect following the 30-day fatality redefinition and the relatively faster GDP growth during this period. Therefore, the observed increase in post-2015 fatality-related costs largely stems from this statistical redefinition and does not reflect a sudden deterioration in accident severity. By clarifying this effect, the observed increase in costs can be accurately interpreted as a methodological adjustment rather than an actual rise in crash incidence. Moreover, the sharp increase in TL-based costs results not only from rising accident-related expenses but also from currency depreciation. This depreciation further amplifies the financial burden when costs are expressed in national terms. According to the HC method, the external costs of traffic accidents accounted for approximately 0.08% of GDP in 2008, rising to 0.11% in 2018. From a policymaking perspective, the WTP method provides a more comprehensive reflection of the societal benefits of traffic safety investments, capturing direct economic losses, the value of life, welfare losses, long-term socio-economic impacts, and psychological costs. On the other hand, the HC method provides a baseline reference point for decision-makers by indicating the minimum level of costs. Employing both methods together in planning traffic safety policies and assessing the economic effectiveness of preventive measures yields more robust results.

The WTP method highlights the temporal evolution of the economic burden of road traffic accidents and allows for a more accurate assessment of their macroeconomic significance. This burden cannot be overlooked in transport and public health policies. Similar

patterns have been observed in several European studies, where external costs are used to justify investments in road safety interventions. For countries like Türkiye, where VSL estimates are adapted rather than directly calculated, this growing cost ratio strengthens the case for conducting local WTP studies and implementing targeted safety improvements. Moreover, the combined effect of increasing accident numbers and currency depreciation indicates that, without structural interventions, costs will likely continue to grow faster than GDP. This trend could further strain public resources. In addition to accident frequency and exchange rate changes, the rise in the share of external costs from 1.63% to 2.72% of GDP can also be linked to broader structural and policy-related dynamics in Türkiye's transport system. Over the study period, Türkiye witnessed a notable expansion in vehicle ownership, with the number of registered motor vehicles increasing by more than 60%, accompanied by substantial highway investments and road network extensions [96,97]. These developments occurred in parallel with rapid urbanization, which has significantly intensified traffic exposure and congestion levels [98]. Furthermore, the dominance of road transport within the national modal split, supported by policies prioritizing highway infrastructure, has maintained the country's reliance on road-based mobility. Collectively, these factors have amplified both the frequency and socioeconomic impact of road crashes, contributing to the observed upward trend in external costs. This policy-oriented interpretation aligns with previous findings emphasizing the interconnected nature of transport demand, infrastructure growth, and external cost evolution in developing economies [19].

The findings emphasize that the estimated external costs of road traffic accidents in Türkiye—ranging between 1.63% and 2.72% of GDP—are broadly consistent with international evidence. According to the WHO, traffic crashes correspond to approximately 3% of GDP in most countries [2,3], while the WB assumes an average burden of around 2% of national income to better reflect their true economic magnitude [22]. Similar patterns have been reported in comparable middle-income countries: for example, road accidents account for about 3% of GDP in Iran [26], 2.5% in the Republic of Tatarstan [27], 3.3% in Kazakhstan [28], and 2.8% in Vietnam [30]. The estimated ratio for Türkiye, therefore, falls within the internationally observed range (0.4–6% of GDP) [23,24], reinforcing the validity and comparability of the current results within the broader global context.

This study is subject to certain limitations. The VSL estimate is based on the EU average and is transferred to the Turkish context using a PPS adjustment. While this approach enables international comparability, it may not fully capture country–specific differences in willingness to pay or income distribution. Additionally, exchange rate volatility during the study period could introduce estimation biases, as the conversion of euro-denominated VSL into Turkish lira is sensitive to short-term currency fluctuations. Furthermore, Türkiye's national accident database reports injuries as a single aggregated category without differentiating between serious and slight cases. As highlighted by the OECD/ITF [99] report on serious road traffic casualties, many countries, particularly those with limited data systems, face inconsistencies in injury severity definitions and underreporting of serious injuries. To address this limitation, an approximation of 0.25 for serious injuries and 0.75 for slight injuries was applied, following the approach used in the OECD report [88]. While we acknowledge that this assumption may not perfectly reflect the actual Turkish distribution, the resulting external-cost estimates remained consistent with OECD-reported GDP shares [23,24], confirming the methodological robustness of the adopted approach despite existing data constraints. It should be noted that the true social cost of road accidents cannot be directly observed; rather, all valuation approaches provide estimates within a welfare-based framework [91,99]. Consistent with this, the VSL represents not an absolute figure but an estimated indicator for welfare-based decision-

making [91,99]. Therefore, the results of this study should be interpreted as welfare-consistent estimations rather than precise financial calculations.

6. Conclusions

In Türkiye, policy measures such as stricter traffic regulations, enhanced enforcement, and public awareness campaigns have contributed to a gradual decline in the number of individuals killed or seriously injured in road accidents. This improvement is largely linked to safety strategies that promote safer behaviors, leverage technological advancements, and strengthen infrastructure. However, despite this progress, the rising external costs of accidents reveal that these measures remain insufficient and require further enhancement. Strategies to address these burdens include refining the education and training systems for road users, strengthening traffic law enforcement, and enhancing the safety features of road infrastructure and vehicles. Additional measures involve encouraging the adoption of contemporary technologies, improving emergency response services and post-injury care, and strengthening road safety management across all user groups. To effectively curb the economic and social burden of traffic accidents, these efforts should be complemented by comprehensive data collection. Locally tailored economic valuation studies, including WTP assessments specific to the Turkish context, are particularly important.

Future research should also aim to disaggregate the external costs of traffic accidents by road user type, such as drivers, pedestrians, and cyclists, once sufficiently detailed national datasets become available. Such differentiation would provide a more accurate understanding of exposure and vulnerability patterns in Türkiye's evolving transport system. Although road traffic accidents continue to occur at high rates in low- and middle-income countries, limited research on their economic implications indicates notable gaps in the literature and a need for continued investigation. Addressing these gaps through comprehensive valuation studies would provide critical evidence to support road safety investments, which can not only reduce fatalities and injuries but also contribute to sustainable economic growth. Future research should focus on refining VSL estimates through empirical surveys to capture public risk preferences more accurately, thereby improving cost–benefit analyses of road safety interventions. Evaluating the suitability of different valuation methods, taking into account data availability, quality, and management challenges, would improve the reliability of road safety cost assessments. This would also guide more effective policymaking, particularly in countries like Türkiye, where adapted approaches are currently employed. Additionally, integrating advanced traffic monitoring technologies and conducting region-specific risk assessments would provide a stronger evidence base for targeted policies. Ultimately, such efforts will enable Türkiye to develop more effective, data-driven strategies to reduce the human and economic toll of traffic accidents in the coming decades.

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Abbreviations

The following abbreviations are used in this manuscript:

WTP	Willingness-to-Pay
GDP	Gross Domestic Product
WHO	World Health Organization
GNP	Gross National Product
WB	World Bank
GDH	General Directorate of Highways
EU	European Union
HC	Human Capital
VSL	Value of a Statistical Life
GO	Gross Output
VOT	Value of Time
VSSI	Value of a Statistical Serious Injury
GDS	General Directorate of Security
TSI	Turkish Statistical Institute
CBRT	Central Bank of the Republic of Türkiye
PPS GDP	Gross Domestic Product at Purchasing Power Standards
TPRZ	Traffic Police Responsibility Zone
GRZ	Gendarmerie Responsibility Zone
€	Euro
TL (₺)	Turkish Lira

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