# Risk Analysis of Western Greece road network using the Highway Safety Manual (HSM)

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## Abstract

Road collisions and traffic injuries are global concerns with significant societal and economic implications. The Highway Safety Manual (HSM) was used to estimate the safety performance of highways and guide transportation decision-making. However, its applicability to the European road network remains uncertain. This paper aims to assess the implementation of HSM in the European context, focusing on two major Greek highways: Ionia and Olympia Odos. The study begins with a comprehensive description of the freeways, including geometric profiles, traffic flow, and crash data. HSM is then applied, considering data requirements and availability. The assessment involves predicting crash frequencies using historical data and comparing them to actual crash frequencies. The findings indicate that data requirements align with European practices, but significant disparities exist between predicted and actual crash frequencies. These discrepancies cannot be solely attributed to the HSM methodology, as other factors like data quality may influence the results. Further research is necessary to determine the suitability of HSM for the European context.

***Keywords:*** *safety performance analysis, accident analysis, prediction method, highway safety manual, highways*

# *1. Introduction*

Road safety is influenced by various factors, including the geometric characteristics of the road, the surrounding environment, the vehicle, and the road user. Typically, a combination of these factors contributes to the occurrence of traffic accidents. Research studies [1] indicated that the human factor alone or in conjunction with other factors accounts for 95% of accidents, while the road contributes to 28% and the vehicle to 8.5% of accidents  Recognizing the global significance of this issue, several manuals for predicting road accidents have been developed to effectively decrease accident rates. One prediction method is presented in the Highway Safety Manual (HSM) [2], [3], [4]. The prediction method is a valuable tool which has been designed to assess and predict safety performance on roadways, with the aim of reducing crashes and improving overall safety. The primary objective of this method is to estimate the potential safety outcomes for specific roadway segments or intersections. By analyzing historical crash data, incorporating relevant roadway characteristics such as traffic volume and geometry, and considering the effects of various countermeasures, the prediction method provides a quantitative measure of safety. Its systematic and comprehensive approach helps identify high-risk areas, evaluate design alternatives, and select appropriate safety measures, contributing to safer and more efficient road networks.

The implementation of the Highway Safety Manual (HSM) has been extensively studied. Previous research applied the HSM methodology in Oregon, USA, to calibrate the manual's predictions [5]. However, limitations were identified in data collection, particularly concerning pedestrian and secondary road accidents in rural areas. The predicted accident rates were found to be significantly lower than expected due to reporting and recording procedures in Oregon. Additional efforts have been undertaken for Missouri, USA [6], Louisiana, USA [7], Florida, USA [8], [9] and Maryland [10]. The international transferability of the HSM has attracted research attention [11]. A study conducted in Greece focused on the suitability of the manual for high-speed national highways in Voiotia and Imathia [12]. By analyzing accident data, this study aimed to predict future accidents and propose improvements by identifying problematic areas in the road network. Additionally, other research projects have utilized the Highway Safety Manual to develop models based on specific road types and corresponding data.

In the early 2000, Greece was facing important (eg. challenges in terms of both the quality and quantity of its road infrastructure, resulting in a poor ranking in terms of safety across European countries. However, efforts have been made to improve the situation through various transportation projects. These initiatives have led to a significant reduction in road accidents, bringing Greece closer to the European average. The present paper investigates the applicability of the Highway Safety Manual (HSM) for accident prediction on the Olympia and Ionia Highways in Greece, examining previous research and considering the specific characteristics of the Greek road network. The prediction method proposes an 18-step procedure in order to conduct a safety analysis and assess and improve the safety performance. The prediction models used are regressions models called Safety Performance Factors (SPF) for base conditions. Every difference between the facility of interest and the base conditions regarding lighting conditions, geometric design characteristics, and traffic control features are considered with Accident Modification Factors (AMF). Lastly, calibration factors for jurisdiction adjustments are also considered. This procedure is implemented to the under-study highways. The prediction of each year is based on abovementioned factors of the previous three years. The objective of the present paper is to assess the suitability of the prediction method proposed by Highway Safety Manual on Greek highways schemes. The paper is structured as follows: Section 2 presents the description of the fields regarding the highways' characteristics, traffic flows, and an overview of the accidents of Ionia and Olympia Odos; Section 3 presents the prediction method analysis proposed by HSM of Ionia and Olympia Highways and the results, and Section 4 mentions the conclusions.

# 2. Description of the Field

## 2.1 Olympia Odos Case

The freeway we study is a major transportation artery that connects Central and Western Greece, and it is divided into three sections as presented in Table 1. The total length of the freeway is 201.8km. The first section connects Athens to Corinth. It is a divided highway with three lanes and a road shoulder per direction. Its total length is 63.6km. It starts from Elefsina and ends up at Ancient Corinth. The second section is Korinthos – Patras highway. The total length of this section is 118.5km and it connects Corinth to Patras. The freeway consisted of one lane and a road shoulder per direction. Lastly, the Peripheral of Patras is also examined as the third section. This section is the shorter with 19.7km and two lanes and a road shoulder per direction. There is also a median strip between opposing directions. The crash data analyzed in this study concern the injuries and deaths resulting from collisions in the Achaia, Ilia, and Aitoloakarnania regions during the period 2009-2015. It is important to note that during this time, the largest section of the freeway, Korinthos – Patras, was under in construction, which forms a significant part of the highway under investigation. Consequently, to facilitate a comprehensive safety analysis, road characteristic data were retrieved from Olympia Odos, and are pertained to the completed highway after the reconstruction process (Table 1).

***Table 1:*** *Athens - Patras Highway (Olympia Odos)*

| Section | Cities Connection | Kilometers | Lanes per Direction | Road Shoulder | Central Reservation |
|---|---|---|---|---|---|
| ELKO | Elefsina - Korinthos | 63.6 km | 3 | + | + |
| KOPA | Korinthos - Patras | 118.5 km | 2 | + | + |
| PP | Peripheral Patras | 19.7 km | 2 | + | + |

During the specified period, a comprehensive range of data were retrieved and analyzed to gain insights into the causes and consequences of accidents along the freeway. These data encompass multiple factors related to injuries and deaths, including:

a) Type of Crash: The classification of crashes (e.g., rear-end collision, head-on collision, side impact) occurring,
b) Lighting Conditions: The prevailing lighting conditions (e.g., daylight, dusk, and night) at the time of incidents,
c) Weather Conditions: The prevailing weather conditions (e.g., ideal, rain) during incidents,
d) Type of Vehicle: The categorization of vehicles involved in incidents (e.g., cars, motorcycles, trucks), and
e) Type of Target: The classification of targets involved in incidents (e.g., pedestrians, cyclists, other vehicles).

First preliminary results regarding Athens – Patras Highway report that during 2009 – 2015, a total of 5,954 collisions resulting in injuries or fatalities were recorded. Among these collisions, it was documented that approximately 89% of them led to injuries, out of which around 15% were categorized as severe. Regarding the type of target vehicle, the majority of the incidents were reported to have occurred with another private car. Motorcycles were also frequently involved in the collisions. Furthermore, results indicate that a significant portion of the collisions on the Athens-Patras Highway were classified as sideswipe collisions.

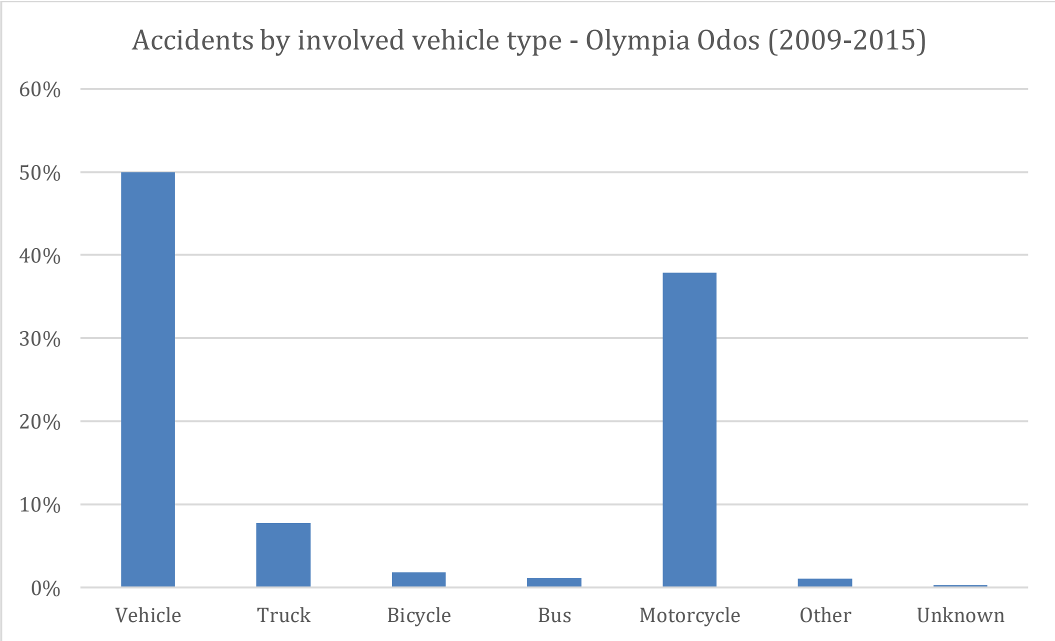


***Figure 1:** Accidents per type of involved vehicle - Ionia Odos (2009-2015).*

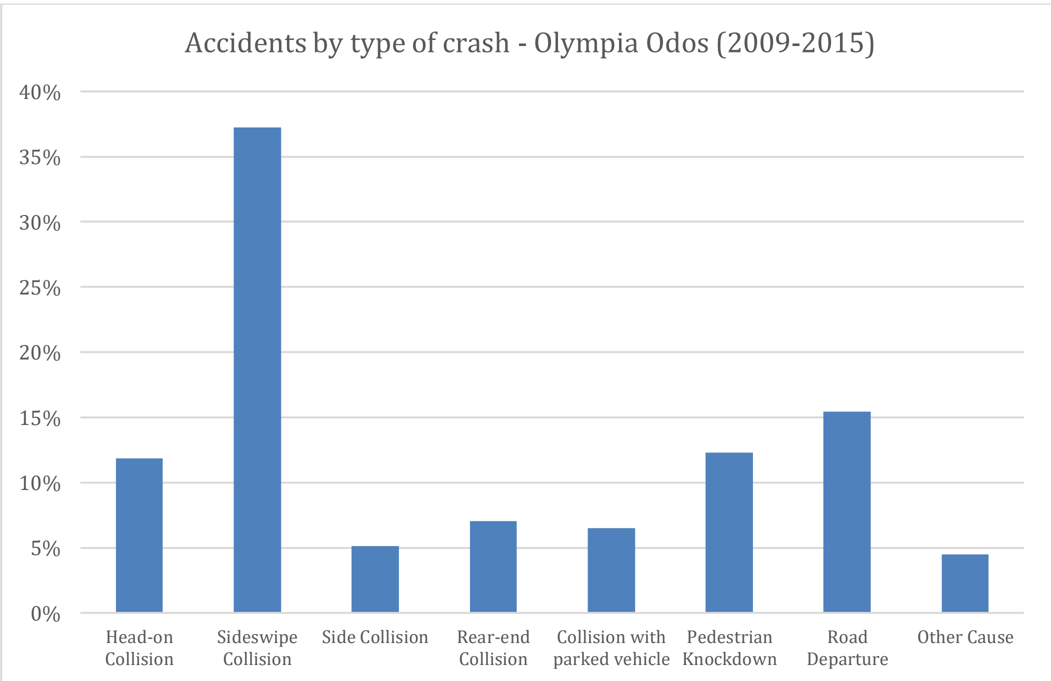


***Figure 2:** Accidents per type of involved vehicle - Olympia Odos (2009-2015).*

In Table 2 the main characteristics of the Athens – Patras Highway collisions are displayed and the fatalities or injuries as well during the period 2009 - 2015. An important observation is that the majority of collisions took place in ideal weather conditions (84%) and during daylight hours (63%).

***Table 2:** Deaths and Injuries reported regarding Type of Crash, Lighting and Weather Conditions, and the Type of Target*

| | Deaths | Injuries | Total Crashes |
|---|---|---|---|
| | | Type of Crash | |
| Head-on Collision | 105 | 601 | 12% |
| Sideswipe Collision | 161 | 2057 | 37% |
| Side Collision | 11 | 295 | 5% |
| Rear-end Collision | 34 | 384 | 7% |
| Collision with parked vehicle | 73 | 314 | 6% |
| Pedestrian Knockdown | 90 | 641 | 12% |
| Road Departure | 164 | 756 | 15% |
| Other Cause | 36 | 232 | 5% |
| | | Daylight Conditions | |
| Daylight | 402 | 3361 | 63% |
| Night | 233 | 1574 | 30% |
| Dusk | 39 | 345 | 6% |
| | | Weather Conditions | |
| Ideal | 547 | 4469 | 84% |
| Raining | 108 | 716 | 14% |
| Other Conditions | 19 | 95 | 2% |
| | | Type of Target Vehicle | |
| Vehicle | 375 | 2602 | 50% |
| Truck | 44 | 416 | 7.7% |
| Bicycle | 16 | 94 | 2% |
| Bus | 7 | 60 | 1% |
| Motorcycle | 211 | 2045 | 38% |
| Other | 19 | 46 | 1% |
| Unknown | 2 | 17 | 0.3% |
| | | Type of Target | |
| Driver | 429 | 3255 | 62% |
| Passenger | 154 | 1433 | 27% |
| Pedestrian | 91 | 592 | 11% |

## *2.2 Ionia Odos Case*

Ionia Odos is the second under study Greek motorway that links Epirus and West Greece, serving as a transportation route for Ioannina, Arta, Agrinio, and Patras. The motorway has a total length of 196 kilometers, and it is a divided highway with two lanes for each direction, including shoulder on both sides?. Firstly, the focus is on analyzing data related to injuries and fatalities caused by collisions during 2012-2019. It is worth noting that the highway was under construction during 2016-2017. In order to conduct a thorough safety analysis, road characteristic data used pertains to the completed highway after the reconstruction process.

***Table 3:*** *Divided Roadway Segments for Ionia Odos*

| Sections | Kilometers | Lanes per Direction | Verge | Central Reservation |
|---|---|---|---|---|
| Egnatia Odos - Per. Artas | 50 | 2 | + | + |
| Per. Artas | 17 | 2 | + | + |
| Per. Artas - Per.Agriniou | 53 | 2 | + | + |
| Per. Agriniou | 34 | 2 | + | + |
| Per. Agriniou - Antirrio | 42,9 | 2 | + | + |

On the same line with Olympia Odos, a comprehensive understanding of collision data information was conducted by examining data pertaining to factors associated with injuries and fatalities, including:

a) Type of Crash: The classification of crashes (e.g., rear-end collision, head-on collision, side impact) occurring,
b) Lighting Conditions: The prevailing lighting conditions (e.g., daylight, dusk, and night) at the time of incidents,
c) Weather Conditions: The prevailing weather conditions (e.g., ideal, rain) during incidents,
d) Type of Vehicle: The categorization of vehicles involved in incidents (e.g., cars, motorcycles, trucks), and
e) Type of Target: The classification of targets involved in incidents (e.g., pedestrians, cyclists, other vehicles).

During the timeframe of interest, initial findings concerning Ionia Odos collision information report a total of 503 accidents with 86% of them leading to injury (categorized as: 76% light injury and 10% severe injury) and 14% resulting in fatalities. The results concerning the target vehicle were consistent with the findings obtained from Olympia Odos. It was observed that the majority of the collisions occurred with another private car. Additionally, motorcycles were frequently implicated in these accidents.

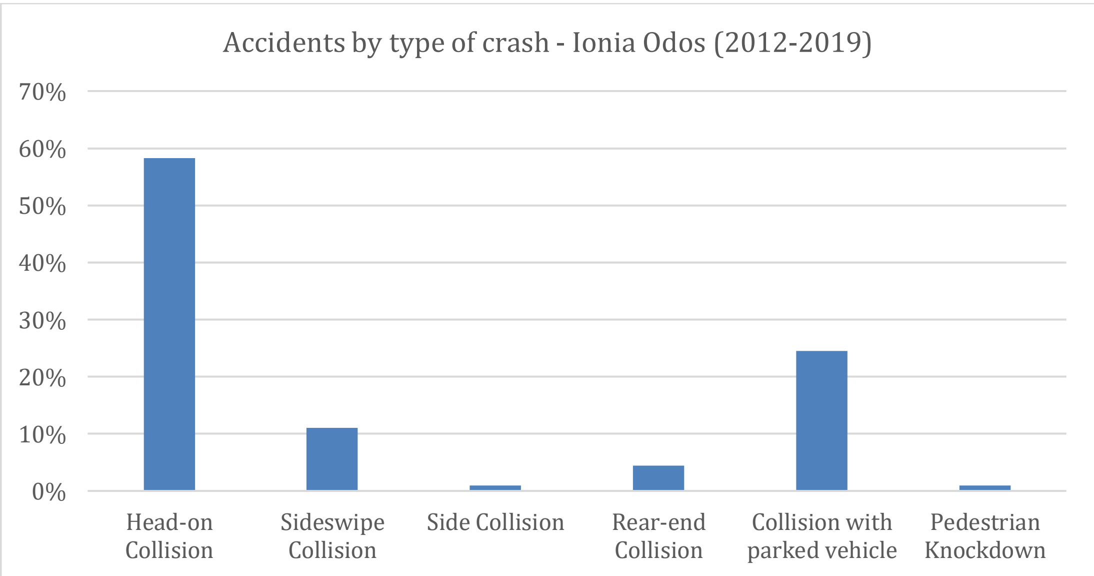


***Figure 3:*** *Accidents per type of crash - Olympia Odos (2012-2019).*

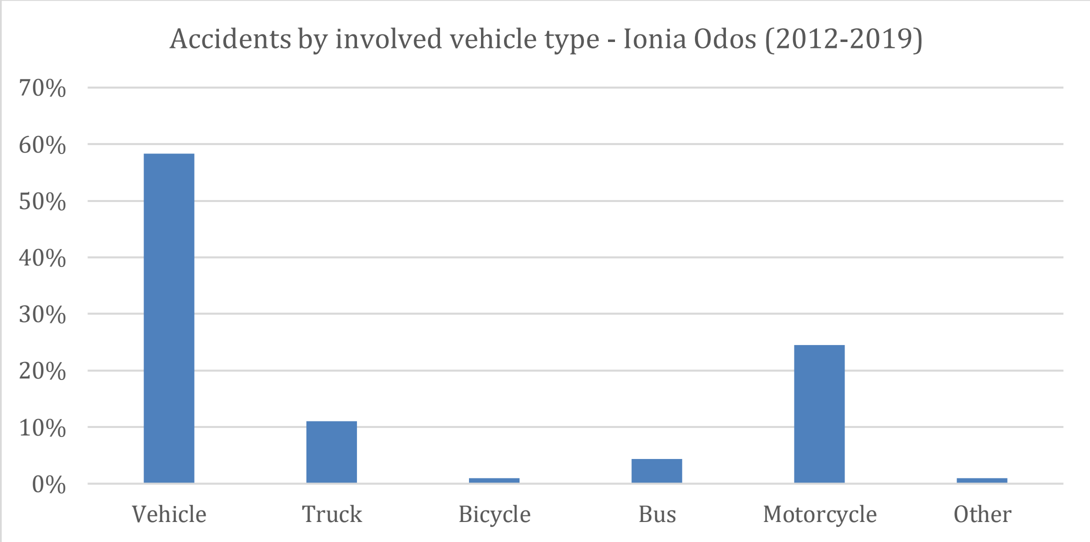


***Figure 4:*** *Accidents per type of crash - Ionia Odos (2012-2019).*

Table 4 presents the primary characteristics of the collisions that occurred on the Ioannina - Antirrio Highway (Ionia Odos), along with the corresponding fatalities or injuries, covering the period from 2012 to 2019. A noteworthy observation, consistent with the findings from Olympia Odos, is that the majority of these collisions occurred under ideal weather conditions (85%) and during daylight hours (76%).

***Table 4:** Deaths and Injuries reported regarding Type of Crash, Lighting and Weather Conditions, and the Type of Target*

| | **Deaths** | **Injuries** | **Total Crashes** |
|---|---|---|---|
| | Type of Crash | | |
| Head-on Collision | 10 | 71 | 16% |
| Sideswipe Collision | 17 | 158 | 35% |
| Side Collision | 2 | 19 | 4% |
| Rear-end Collision | 5 | 50 | 11% |
| Collision with parked vehicle | 1 | 10 | 2% |
| Pedestrian Knockdown | 16 | 19 | 7% |
| Road Departure | 16 | 90 | 21% |
| Other Cause | 2 | 17 | 4% |
| | Daylight Conditions | | |
| Daylight | 44 | 338 | 76% |
| Night | 25 | 96 | 24% |
| | Weather Conditions | | |
| Ideal | 58 | 370 | 85% |
| Raining | 11 | 54 | 13% |
| Other Conditions | 0 | 10 | 2% |
| | Type of Target Vehicle | | |
| Vehicle | 37 | 256 | 58% |
| Truck | 6 | 49 | 11% |
| Bicycle | 0 | 5 | 1% |
| Bus | 3 | 19 | 4% |
| Motorcycle | 22 | 101 | 25% |
| Other | 1 | 4 | 1% |
| | Type of Target | | |
| Driver | 44 | 246 | 58% |
| Passenger | 10 | 170 | 36% |
| Pedestrian | 15 | 18 | 7% |

# *3. Predictive Method Analysis*

## *3.1 Overview*

The predictive method proposed by Highway Safety Manual (HSM) is used for estimating the average crash frequency of a network under a given time period, traffic volume, and geometric design characteristics of the road. Crash severity and collision type are also included. The proposed method can estimate the long-term crash frequency of an individual site. The cumulative sum of all sites results in the average crash frequency of the entire network. The predictive method is a tool not only for evaluating any traffic flow changes, countermeasures implementation, or proposed design features of an existing network but also for evaluating and assessing the design of a new proposed network using forecast traffic volumes.

The Highway Safety Manual (HSM) presents a systematic 18-step procedure for conducting safety analysis to assess and improve the safety performance of roadway facilities. This procedure is applied for the time period of interest in years with known annual traffic volume and unchanged geometric design. The predictive model for the predicted average crash frequency is a regression model which has been developed from data for a number of similar sites for specific conditions regarding flow and geometric design and is known as Safety Performance Factor (SPF) for base conditions. For undivided and divided rural multilane highway the SPF for expected average crash frequency is given from equation 1 and 2, respectively.

$$N_{spf\ ru} = e^{(a+b\times\ln(AADT)+\ln(L))} \tag{1}$$

$$N_{spf\ rd} = e^{(a+b\times\ln(AADT)+\ln(L))} \tag{2}$$

Where:

$N_{spf\ rd}$ is the base total number of accidents per year at a divided road segment;

$N_{spf\ ru}$ is the base total number of accidents per year at an undivided road segment;

$AADT$ is the annual average daily traffic (vehicles/day) on the roadway segment;

$L$ is the length of the road segment (miles);

$a, b$ are regression coefficients.

For existing roadways with available crash data, empirical Bayes (EB) method is applied. EB method combines the predicted with the observed crash frequency of a specific site in order to provide a more reliable estimate of the expected crash frequency. For the EB method an overdispersion parameter k is also used. The parameter provides an indication of the reliability of the SPF. The closer the overdispersion parameter is to zero the more statistically reliable the SPF. The equations of the overdispersion parameter for undivided and divided multilane highways are as follows.

$$k = \frac{1}{e^{(c+\ln(L))}} \tag{3}$$

$$k = \frac{1}{e^{(c+\ln(L))}} \tag{4}$$

Where:

$k$ is the overdispersion parameter of the roadway segment;

$c$ is the regression coefficient;

$L$ is the length of the roadway segment.

In order to account for differences between base conditions and the road network of interest and adjustments, Accident Modification Factors (AMFs) are applied. For each SPF the appropriate AMF should be applied. AMFs are separated in terms of lighting conditions, shoulder width, side slopes, lane length, and traffic control features. For each roadway segment the right AMF is applied. Lastly, calibration factors $C_x$ for jurisdiction adjustments for the local network are implemented, too. It is worth noting the significance of the separation of the roadway of interest into homogenous roadway segments and the thorough documentation of the design elements, traffic control methods, traffic volume, and collisions occurred including the deaths and the severity of injuries. The method can be applied to many types of roadways with different geometric design characteristics. Finally, the predicted average crash frequency for undivided and divided highway roadway segments are given from the equations 5 and 6, respectively.

$$N_{predicted\ rs} = N_{spf\ ru} \times (AMF_{1ru} \times AMF_{2ru} \times \ldots \times AMF_{5ru}) \times C_r \qquad (5)$$

$$N_{predicted\ rs} = N_{spf\ rd} \times (AMF_{1rd} \times AMF_{2rd} \times \ldots \times AMF_{5rd}) \times C_r \qquad (6)$$

where,

$N_{predicted\ rs}$ is the estimate of the expected average crash frequency for a specific year and segment;

$N_{spf\ ru}$ is the expected average crash frequency for undivided road segment at base conditions;

$AMF_{1ru} \ldots AMF_{5ru}$ are the Accident Modification Factors for undivided road segment;

$C_r$ is the calibration factor for road segment;

$N_{spf\ rd}$ is the expected average crash frequency for divided road segment at base conditions;

$AMF_{1rd} \ldots AMF_{5rd}$ are the Accident Modification Factors for divided road segment.

### *3.2 Olympia Odos Case Study*

For the predictive method proposed by Highway Safety Manual (HSM), each of the abovementioned segments has been separated into several distinct sections (Table 5 - Table 7). This division was implemented to aid in modeling framework, allowing for a more detailed examination of the predictions related to injuries and deaths. The abovementioned methodology is then applied to Olympia Odos. Geometric design characteristics were extracted from Google Maps and the data regarding the annual traffic volume and collisions at each segment were retrieved from Hellenic Statistical Authority. Annual traffic volume was assigned to each roadway segment taking into account the vehicle kilometers (Table 8). Korinthos – Patra is the only section of the roadway which is undivided, and the particular methodology was applied to.

***Table 5:** Supplementary Divide Roadway Segments for Athens - Korinthos*

| | Sections | Length(km) |
|---|---|---|
| 1 | Eleysina - Peramos | 12 |
| 2 | Peramos - Megara | 5.3 |
| 3 | Megara - Pachi | 2.5 |
| 4 | Pachi - Kineta | 14.6 |
| 5 | Kineta - Ag. Theodoroi | 8.6 |
| 6 | Ag. Theodoroi - Loutraki | 10.5 |
| 7 | Loutraki - Epidaurus | 1.4 |
| 8 | Epidaurus - Korinthos | 6.4 |
| 9 | Korinthos - Archea Korinthos | 2.3 |

***Table 6:** Supplementary Divide Roadway Segments for Korinthos - Patras*

| No | Sections | Length(km) |
|---|---|---|
| 1 | Archea Korinthos - Kiato | 14.4 |
| 2 | Kiato - Xylokastro | 18.7 |
| 3 | Xylokastro - Derveni | 21.2 |
| 4 | Derveni - Akrata | 6.8 |
| 5 | Akrata - Kalavryta | 9.9 |
| 6 | Kalavryta - Aigio | 13.5 |
| 7 | Aigio - Paralia Aigiou | 6 |
| 8 | Paralia Aigioy - Selianitika | 4.5 |
| 9 | Selianitika - Arachovitika | 22 |
| 10 | Arachovitika - Rio | 1.5 |

***Table 7:** Supplementary Divide Roadway Segments for Peripheral of Patras*

| No | Sections | Kilometers |
|---|---|---|
| 1 | Rio – Patras | 2.3 |
| 2 | Patras - Eglikada | 6.6 |
| 3 | Eglikada - Glafkos | 2.9 |
| 4 | Glafkos - Ovria | 5.1 |
| 5 | Ovria - Mintilogli | 2.8 |

***Table 8:*** *Traffic Volume at Olympia Odos*

| TRAFFIC VOLUME (veh/year) | | | | | | | |
|---|---|---|---|---|---|---|---|
| ELKO | | | | | | | |
| Sections | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
| Eleysina - Peramos | 75199 | 67742 | 58608 | 50237 | 47293 | 42219 | 43013 |
| Peramos - Megara | 71890 | 64758 | 56014 | 48011 | 45194 | 40422 | 41187 |
| Megara - Pachi | 64070 | 57713 | 49911 | 42778 | 40267 | 37222 | 37926 |
| Pachi - Kineta | 65418 | 58923 | 50935 | 43650 | 41083 | 36306 | 36996 |
| Kineta - Ag. Theodoroi | 57501 | 51787 | 44742 | 38339 | 36079 | 35760 | 36010 |
| Ag. Theodoroi - Loutraki | 55906 | 50352 | 43509 | 37283 | 35087 | 34346 | 34587 |
| Loutraki - Epidaurus | 50193 | 45211 | 39094 | 33506 | 31538 | 28362 | 28562 |
| Epidaurus - Korinthos | 50210 | 45226 | 39107 | 33517 | 31548 | 29788 | 30001 |
| Korinthos - Archea Korinthos | 40540 | 36516 | 31573 | 27059 | 25469 | 21110 | 20253 |
| ELKO | 58992 | 53136 | 45944 | 39375 | 37062 | 33948 | 34282 |
| KOPA | | | | | | | |
| Ancient Corinth - Kiato | 28057 | 24433 | 20160 | 17027 | 15953 | 15804 | 15862 |
| Kiato - Xylokastro | 25639 | 22392 | 18519 | 15652 | 14652 | 14505 | 14549 |
| Xylokastro - Derveni | 20096 | 17560 | 14528 | 11494 | 11494 | 11378 | 11411 |
| Derveni - Akrata | 19649 | 17170 | 14206 | 11239 | 11239 | 11125 | 11157 |
| Akrata - Kalavryta | 19649 | 17170 | 14206 | 11239 | 11239 | 11125 | 11157 |
| Kalavryta - Aigio | 19379 | 16932 | 14008 | 11083 | 11083 | 10971 | 11002 |
| Aigio - Paralia Aigiou | 19255 | 16836 | 13936 | 11026 | 11026 | 10912 | 10942 |
| Paralia Aigioy - Selianitika | 19255 | 16836 | 13936 | 11026 | 11026 | 10912 | 10942 |
| Selianitika - Arachovitika | 19578 | 17131 | 14189 | 11225 | 11225 | 11108 | 11136 |
| Arachovitika - Rio | 18976 | 16610 | 13762 | 10887 | 10887 | 10772 | 10799 |
| KOPA | 20953 | 18307 | 15145 | 11982 | 11982 | 11861 | 11896 |
| PP | | | | | | | |
| Rio - Patras | 47393 | 41240 | 34005 | 28715 | 26910 | 26665 | 26767 |
| Patras - Eglikada | 34005 | 29709 | 24578 | 20775 | 19445 | 19249 | 19305 |
| Eglikada - Glafkos | 34005 | 29709 | 24578 | 20775 | 19445 | 19249 | 19305 |
| Glafkos - Ovria | 24908 | 21765 | 18008 | 15222 | 14247 | 14103 | 14143 |
| Ovria - Mintilogli | 31977 | 27968 | 23157 | 19578 | 18320 | 18130 | 18178 |
| PP | 34458 | 30078 | 24865 | 21013 | 19673 | 19479 | 19540 |

Overdispersion parameters were computed for the separated segments of each roadway section and are displayed at Table 9. The values are close to zero which shows the statistical reliability of the SPF models used later. Regression parameters used were retrieved from HSM. AMFs were also determined, according to the methodology provided by HSM, for each specific roadway segment. Lastly, calibration factors were determined. Firstly, the factor was defined considering collision data during 2009-2011. The average of these years was used for the prediction step of 2012. This procedure was repeated for the upcoming years. The abovementioned methodology was repeated for every year and for each roadway segment and the results are displayed at **Error! Reference source not found. - Error! Reference source not found.**.

***Table 9:*** *Overdispersion Parameter (k)*

| Overdispersion Parameter (k) | |
|---|---|
| Sections | ELKO |
| Eleysina - Peramos | 0.02 |
| Peramos - Megara | 0.05 |
| Megara - Pachi | 0.12 |
| Pachi - Kineta | 0.02 |
| Kineta - Ag. Theodoroi | 0.03 |
| Ag. Theodoroi - Loutraki | 0.03 |
| Loutraki - Epidaurus | 0.2 |
| Epidaurus - Korinthos | 0.04 |
| Korinthos - Archea Korinthos | 0.13 |
| | KOPA |
| Ancient Corinth - Kiato | 0.02 |
| Kiato - Xylokastro | 0.01 |
| Xylokastro - Derveni | 0.01 |
| Derveni - Akrata | 0.03 |
| Akrata - Kalavryta | 0.02 |
| Kalavryta - Aigio | 0.02 |
| Aigio - Paralia Aigiou | 0.04 |
| Paralia Aigioy - Selianitika | 0.05 |
| Selianitika - Arachovitika | 0.01 |
| Arachovitika - Rio | 0.15 |
| | PP |
| Rio - Patras | 0.13 |
| Patras - Eglikada | 0.04 |
| Eglikada - Glafkos | 0.1 |
| Glafkos - Ovria | 0.05 |
| Ovria - Mintilogli | 0.1 |

| Ionia Odos | 2012 | | | 2013 | | | 2014 | | | 2015 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nobserved | Npredicted | % | Nobserved | Npredicted | % | Nobserved | Npredicted | % | Nobserved | Npredicted | % |
| Eleysina - Peramos | 5.6 | 5.01 | -11.8% | 4.5 | 3.42 | -31.6% | 3.44 | 2.83 | -21.6% | 3.64 | 7.34 | 50.4% |
| Peramos - Megara | 2.37 | 2.12 | -11.8% | 1.9 | 1.44 | -31.9% | 1.45 | 1.25 | -16.0% | 1.54 | 3.1 | 50.3% |
| Megara - Pachi | 0.99 | 0.89 | -11.2% | 0.8 | 0.61 | -31.1% | 0.63 | 0.59 | -6.8% | 0.67 | 1.35 | 50.4% |
| Pachi - Kineta | 5.92 | 5.3 | -11.7% | 4.76 | 3.61 | -31.9% | 3.6 | 3.44 | -4.7% | 3.81 | 7.68 | 50.4% |
| Kineta - Ag. Theodoroi | 3.07 | 2.74 | -12.0% | 2.46 | 1.87 | -31.6% | 2.06 | 2.03 | -1.5% | 2.17 | 4.4 | 50.7% |
| Ag. Theodoroi - Loutraki | 3.64 | 3.25 | -12.0% | 2.92 | 2.22 | -31.5% | 2.42 | 2.48 | 2.4% | 2.55 | 5.16 | 50.6% |
| Loutraki - Epidaurus | 0.44 | 0.39 | -12.8% | 0.35 | 0.27 | -29.6% | 0.27 | 0.33 | 18.2% | 0.28 | 0.57 | 50.9% |
| Epidaurus - Korinthos | 1.99 | 1.78 | -11.8% | 1.6 | 1.22 | -31.1% | 1.29 | 1.51 | 14.6% | 1.35 | 2.73 | 50.5% |
| Korinthos - Archea Korinthos | 0.58 | 0.52 | -11.5% | 0.46 | 0.35 | -31.4% | 0.33 | 0.54 | 38.9% | 0.33 | 0.66 | 50.0% |
| Ancient Corinth - Kiato | 5.47 | 5.17 | -5.8% | 5.61 | 4.24 | -32.3% | 5.07 | 3.77 | -34.5% | 4.98 | 5.19 | 4.0% |
| Kiato - Xylokastro | 6.53 | 6.18 | -5.7% | 6.69 | 5.05 | -32.5% | 6.04 | 4.89 | -23.5% | 5.94 | 6.18 | 3.9% |
| Xylokastro - Derveni | 5.81 | 5.49 | -5.8% | 5.95 | 4.49 | -32.5% | 5.37 | 5.55 | 3.2% | 5.28 | 5.49 | 3.8% |
| Derveni - Akrata | 1.82 | 1.72 | -5.8% | 1.87 | 1.41 | -32.6% | 1.69 | 1.78 | 5.1% | 1.66 | 1.72 | 3.5% |
| Akrata - Kalavryta | 2.65 | 2.51 | -5.6% | 2.72 | 2.05 | -32.7% | 2.45 | 2.59 | 5.4% | 2.41 | 2.51 | 4.0% |
| Kalavryta - Aigio | 3.56 | 3.37 | -5.6% | 3.66 | 2.76 | -32.6% | 3.3 | 3.53 | 6.5% | 3.24 | 3.37 | 3.9% |
| Aigio - Paralia Aigiou | 1.58 | 1.49 | -6.0% | 1.62 | 1.22 | -32.8% | 1.46 | 1.57 | 7.0% | 1.43 | 1.49 | 4.0% |
| Paralia Aigioy - Selianitika | 1.18 | 1.12 | -5.4% | 1.21 | 0.92 | -31.5% | 1.09 | 1.18 | 7.6% | 1.07 | 1.12 | 4.5% |
| Selianitika - Arachovitika | 5.88 | 5.57 | -5.6% | 6.03 | 4.56 | -32.2% | 5.44 | 5.75 | 5.4% | 5.35 | 5.56 | 3.8% |
| Arachovitika - Rio | 0.39 | 0.37 | -5.4% | 0.4 | 0.3 | -33.3% | 0.36 | 0.39 | 7.7% | 0.35 | 0.37 | 5.4% |
| Rio - Patras | 0.27 | 0.17 | -58.8% | 0.31 | 0.33 | 6.1% | 0.3 | 0 | - | 0.16 | 0.67 | 76.1% |
| Patras - Eglikada | 0.55 | 0.35 | -57.1% | 0.64 | 0.69 | 7.2% | 0.62 | 0 | - | 0.34 | 1.38 | 75.4% |
| Eglikada - Glafkos | 0.24 | 0.15 | -60.0% | 0.28 | 0.3 | 6.7% | 0.27 | 0 | - | 0.15 | 0.61 | 75.4% |
| Glafkos - Ovria | 0.31 | 0.2 | -55.0% | 0.36 | 0.39 | 7.7% | 0.35 | 0 | - | 0.19 | 0.78 | 75.6% |
| Ovria - Mintilogli | 0.22 | 0.14 | -57.1% | 0.26 | 0.28 | 7.1% | 0.25 | 0 | - | 0.14 | 0.55 | 74.5% |
| Olympia Odos | 61.06 | 56 | -9.0% | 57.36 | 44 | -30.4% | 49.55 | 46 | -7.7% | 49.03 | 69.98 | 29.9% |

The expected values for the Road Patras - Korinthos shows variances of -5.7%, -31.6%, -4.1%, and 3.9% in relation to the observed values for the first, second, third, and fourth years, respectively. The prediction method tended to underestimate the outcomes during the first three years, although there was a slight overestimation in the fourth year. In the case of the Elefsina - Korinthos Road, the predicted values deviated by -11.8%, 31.6%, -3.3%, and 50.5% compared to the observed values for the first, second, third, and fourth years, respectively. Overall, the method displayed mixed performance, with a significant over-prediction for the second year. Regarding the Peripheral of Patras, there are notable differences for the first, second, and fourth years, with no reported accidents in the third year. The predicted values exhibited variances of -57.4%, 7%, and 75.4% in relation to the observed values for the first, second, and fourth years, respectively. Generally, the Patras – Korinthos route resulted in better predictions for crash frequency. Geometric design factors, such as the length and width of road segments, as well as differentiations in traffic volumes may have played an important role for the prediction method, as the shortest road with the minimum traffic volume and accident occurrence (PP) showed the highest deviations between predicted and observed crash frequency.

### *3.2 Ionia Odos Case* Study

For the predictive method proposed by HSM analysis conducted Ionia Odos Highway was divided into five homogenous roadway segments. The geometric design characteristics of the segments were obtained from Google Maps, while the data regarding the annual traffic volume and collisions were retrieved from the tolls administration and the Hellenic Statistical Authority, respectively. The annual traffic volume for each roadway segment was determined by considering the vehicle kilometers traveled. The Table 10 displays the geometric characteristics and the traffic volume for the period of 2013 to 2019.

***Table 10:** Roadway segments of Ionia Odos and Traffic Volume assigned.*

| | | TRAFFIC VOLUME (veh/year) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Kilometers | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| Egnatia Odos - Per. Artas | 50 | 5370,12 | 5427,22 | 5536,85 | 5646,48 | 5820,58 | 5930,74 | 6160,01 |
| Per. Artas | 17 | 9423,27 | 9611,73 | 9805,89 | 10000,05 | 10236,76 | 10587,93 | 10909,52 |
| Per. Artas - Per.Agriniou | 53 | 5125,07 | 5435,92 | 5578,97 | 5655,53 | 5812,31 | 5975,8 | 6169,88 |
| Per. Agriniou | 34 | 7329,87 | 7630,91 | 7864,45 | 8097,99 | 8190,63 | 8454,96 | 8834,47 |
| Per. Agriniou - Antirrio | 42,9 | 9405,21 | 9593,31 | 9787,09 | 9980,88 | 10146,12 | 10456,91 | 10888,61 |
| Ionia Odos | 154 | 36653,54 | 37699,09 | 38573,25 | 39380,93 | 40206,4 | 41406,34 | 42962,49 |

The methodology regarding HSM predictive method mentioned earlier is also applied to Olympia Odos. The regression parameters utilized in the analysis were obtained from the Highway Safety Manual (HSM). The Accident Modification Factors (AMFs) were computed for each specific roadway segment according to the methodology. Lastly, calibration factors were determined. Initially, the calibration factor was defined based on the collision data collected during the period of 2013-2015. The average value of these years was then utilized to predict the outcomes for the subsequent year, 2016. This process was repeated for each subsequent year, allowing for the generation of predictions for each year. The methodology described above was systematically applied to each roadway segment and for every year in the analysis and the findings obtained are presented at Table 11.

The results for Ionia Odos are characterized by significant underestimation of the predicted values. The first year shows an underprediction with the highest deviation of 37.6%. At the third year the smallest deviation is reported 11.8%. It is interesting to observe that significant fluctuations are reported at each segment, with instances of -150% underestimation. In conclusion the findings for Ionia Odos suggest consistent under-prediction by the prediction method for each year, with deviations ranging from -11.8% to -37.6%. The fluctuations in the predicted values regarding individual segments indicate potential limitations in the prediction method.

***Table 11:** Predicted Crash Frequency and Observed Crash Frequency for Ionia Odos during 2016-2019*

| Sections | 2016 | | | 2017 | | | 2018 | | | 2019 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nobserved | Npredicted | % | Nobserved | Npredicted | % | Nobserved | Npredicted | % | Nobserved | Npredicted | % |
| Egnatia Odos - Per. Artas | 7 | 4.12 | -69.9% | 6 | 4.52 | -32.7% | 5 | 4.31 | -16.0% | 2 | 2 | 0.0% |
| Per. Artas | 3 | 1.72 | -74.4% | 3 | 1.75 | -71.4% | 3 | 1.9 | -57.9% | 4 | 1.6 | -150.0% |
| Per. Artas - Per.Agriniou | 5 | 3.79 | -31.9% | 7 | 4.02 | -74.1% | 8 | 4.11 | -94.6% | 8 | 3.98 | -101.0% |
| Per. Agriniou | 2 | 2.45 | 18.4% | 2 | 2.59 | 22.8% | 1 | 2.92 | 65.8% | 2 | 3.1 | 35.5% |
| Per. Agriniou - Antirrio | 1 | 1 | 0.0% | 1 | 2.12 | 52.8% | 1 | 2.86 | 65.0% | 1 | 2.97 | 66.3% |
| Ionia Odos | 18 | 13.08 | -37.6% | 19 | 15 | -26.7% | 18 | 16.1 | -11.8% | 17 | 13.65 | -24.5% |

## *4. Conclusions*

In this study, a comprehensive analysis of collisions and safety on the studied freeways, including the Athens-Patras Highway (Olympia Odos) and Ionia Odos, was conducted. The findings provide valuable insights into the factors contributing to accidents, injuries, and fatalities, as well as the performance of predictive methods. For the Athens-Patras Highway, it was observed that a significant number of collisions occurred, resulting in injuries and fatalities. The majority of incidents involved private cars and motorcycles, with sideswipe collisions being a common type. Lighting conditions and weather were found to have minimal influence, as the majority of collisions occurred during daylight hours and under ideal weather conditions. The predictions generated using the Highway Safety Manual (HSM) methodology displayed mixed performance, with some deviations from the observed crash frequency. Geometric design factors and traffic volumes were identified as potential contributors to the prediction discrepancies. Regarding Ionia Odos, a consistent pattern of under-prediction was observed in the predicted values of collisions. Despite some fluctuations across individual segments, the overall trend indicated a tendency to underestimate the number of accidents. The limitations or shortcomings of the prediction method require further investigation to improve the accuracy of future predictions.

Overall, While the data requirements of the HSM align with European practices, the observed disparities between predicted and actual crash frequencies raise concerns. It is important to note that these disparities cannot be solely attributed to the HSM methodology itself. Other factors, such as data quality issues, may have influenced the results. The accuracy and reliability of data play a crucial role in the prediction process, and any inconsistencies or inaccuracies in the collected data can affect the outcomes. The predictive methods used provide a valuable framework for estimating collision frequency. To improve the utilization of the HSM prediction method it is crucial to enhance the quality and comprehensiveness of data collection as well as the time period of study. By collecting comprehensive and high-quality data, the prediction models can be better calibrated and provide more accurate results. Additionally, the separation of the segments plays an important role for the SPF regression models and hence, the overall accuracy of the method. Optimal segment size, homogeneity, and a well-distributed traffic volume within each segment contribute to obtaining more accurate outcomes.

## *4. References-Bibliography*

[1] "THE FLORIDA DEPARTMENT OF TRANSPORTATION RESEARCH OFFICE on Project 'Development and Calibration of Highway Safety Manual Equations for Florida Conditions,'" 2011.

[2] "Highway Safety Manual-1 st Edition Current as of HIGHWAY SAFETY MANUAL PART A PREFACE TO THE FIRST EDITION," 2009.

[3] Hughes, W., Eccles, K., Harwood, D., Potts, I., & Hauer, E. (2004). Development of a Highway Safety Manual. *NCHRP Web Document 62 (Project 17-18 [4]): Contractor's Final Report*.

[4] Part, D. (2010). Highway safety manual. *American Association of State Highway and Transportation Officials: Washington, DC, USA*, *19192*.

[5] F. Xie, K. Gladhill, K. Dixon, and C. Monsere, "Calibration of highway safety manual predictive models for oregon state highways," *Transp Res Rec*, no. 2241, pp. 19–28, Dec. 2011, doi: 10.3141/2241-03.

[6] Sun, C., Brown, H., Edara, P. K., Claros, B., & Nam, K. (2013). *Calibration of the highway safety manual for Missouri* (No. MATC-MU: 177). Mid-America Transportation Center.

[7] Sun, X., Li, Y., Magri, D., & Shirazi, H. H. (2006). Application of highway safety manual draft chapter: Louisiana experience. *Transportation research record*, *1950*(1), 55-64.

[8] Srinivasan, S., Haas, P., Dhakar, N. S., Hormel, R., Torbic, D., & Harwood, D. (2011). *Development and calibration of highway safety manual equations for Florida conditions* (No. TRC-FDOT-82013-2011). University of Florida. Transportation Research Center.

[9] Abdel-Aty, M. A., Lee, C., Park, J., Wang, J. H., Abuzwidah, M., & Al-Arifi, S. (2014). *Validation and application of highway safety manual (part D) in Florida* (No. BDK78-977-14). Florida. Dept. of Transportation.

[10] Shin, H., Lee, Y. J., & Dadvar, S. (2014). *The development of local calibration factors for implementing the highway safety manual in Maryland* (No. MD-14-SP209B4J). Maryland. State Highway Administration.

[11] Sacchi, E., Persaud, B., & Bassani, M. (2012). Assessing international transferability of highway safety manual crash prediction algorithm and its components. *Transportation research record*, *2279*(1), 90-98.

[12] G. Yannis and N. Yannis, “Economic Assessment of Road Infrastructure Safety Schemes in Greece Using Crash Prediction Methodology 2 3.”