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Assessment of the transferability of European road safety inspection procedures and risk index model to Egypt

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ABSTRACT

Road safety is considered a worldwide issue, especially in developing countries where road fatalities are considered the top cause of death among youth. Generally, three main factors impact road safety including driver, vehicle, and road environment. Statistics show that driver behavior is the major contributory factor to crashes (65%); however, other factors may lead to higher severity crashes such as deteriorated infrastructure, unforgiving roadside design, etc. In this regard, extensive research work has been performed to analyze these crash-contributing factors and propose safety measures. For instance, in North America, researchers developed the Highway Safety Manual (HSM) which provides crash prediction models (CPM) and safety performance functions (*SPFs*) used in implementing effective safety measures. In the European Union (EU), crash data is complementary to road safety inspections as tools for the safety management of the road network in operation.

This research investigates the potential of transferring the European experience, namely the Identification of Hazard Location (IASP) procedures, to Egypt. The analysis shows not only a significant similarity in the safety levels of infrastructure between Egypt and Italy but also in speed behavior. The transferability of the EU IASP procedure is validated by comparing the output of the Risk Index (*RI*) measure as a surrogate measure of safety with the expected crash frequency resulting from HSM's *SPFs*. The comparison is assessed using Spearman's rank correlation coefficient. This process is applied to a case study that examines a 6-km segment of a two-lane, two-way rural road connecting Faraskour and El Mansoura in Egypt, serving as an example of a hazardous rural road in Egypt. The results indicate that the relation between the *RI* outputs and the expected crash frequency at the majority of segments of the road section is significant based on Spearman's rank correlation factor value of 0.75. Few limitations have been identified and presented in the study including the effect of access located on curves or hidden in vegetated areas.

1. Introduction

Road safety is considered a worldwide problem, with fatalities due to road crashes being the leading cause of death among youth aged 15–29 years, especially in Low- and middle-income countries (LMICs) where about 93 % of road crash fatalities occur with about 20 million deaths and serious injuries per year [1]. While statistics show that driving errors are the main contributor to traffic crashes, the "Safe System" approach, now adopted in Europe and worldwide, acknowledges that people make mistakes and are vulnerable. The ethical foundation is to shift the blame of road crash fatalities and injuries from road user behavior to a system of shared responsibility involving safe roads and roadsides, safe speeds, safe vehicles, and safe road users for creating a system whereby accidents do not result in death or serious injury [2].

Specifically, road engineers bear the responsibility for enhancing road safety by implementing self-explanatory conditions that help drivers avoid mistakes and reduce the severity of potential accidents on the roadside. When safer roads and roadsides are the focus, the development of a reliable tool for identifying and prioritizing locations where safety measures are required to improve road safety is essential. In this regard, for the road network in operation, road safety inspections are a well-established tool to identify and manage safety issues where

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Table 1
Taxonomy to Evaluate Crash Categories between Egypt and Italy (2016 – 2020).

Categories	Sub-category	Egypt database terminology	Crash (%)	Italy database terminology	Crash (%)
(1) Vehicles	(1) Deficiencies in the Vehicles	Broken Down Brakes, Deficiencies in the Vehicles, Flat Tire, Detachable Tire	81 (11.1 %)	Breakage or insufficiency of the brakes (a) Deficiencies in the Vehicles (a) Tire blowout or excessive flat (a), Wheel detachment (a)	797 (2.6 %)
(2) Nature of crash	(2) Car Hit Pedestrians Passing	Car Hit Pedestrians Passing	19 (2.6 %)	Pedestrian crash (b)*	323 (1.1 %)
	(3) Car Overturned	Car Overturned, Loss of Vehicle Control, Sudden Turnover	202 (27.8 %)	Run off the road (b)* Heeling (c)** Overtaking (c)**	1427 (4.7 %)
	(4) Collision of two vehicles	Collision of two vehicles	108 (14.9 %)	Head on (b)* Side on (b)* Head-side on (b)* Rear-end (b)*	14,422 (47.5 %)
	(5) Sudden stop	Sudden stop	12 (1.7 %)	Sudden stop (b)*	21 (0.1 %)
	(6) Hit object	Hit object	6 (0.8 %)	Hit obstacle (b)*	1786 (5.9 %)
(3) Circumstances of crash	(7) Driving in the Wrong Direction	Drive-In Wrong Direction	4 (0.5 %)	Driving in the wrong direction (c)**	865 (2.8 %)
	(8) Excessive Speed	Excessive Speed, Excessive Speed Led To Overturn	147 (20.2 %)	Excessive speed (c)**, non-compliance with speed limits (c)**	4152 (13.7 %)
	(9) Wrong Turning	Wrong Turning	3 (0.4 %)	Turning right / left irregularly (c)**	328 (1.1 %)
	(10) Distracted driver	Unaltered Driver	43 (6.0 %)	Proceeding with distracted or indecisive driving (c)**	5310 (17.5 %)
	(11) Sudden Passage (Pedestrian, Animal, etc.)	Sudden Pedestrian -Animal -Child- Passage/ Appearance	34 (4.7 %)	Sudden Pedestrian – Animal crossing (c)**	407 (1.3 %)
	(12) Wrong merging	Wrong merging	26 (3.6 %)	Maneuvering irregularly to stop without respecting the traffic lights or the agent's signals (c)**	60 (0.2 %)
	(13) Wrong overtaking	Wrong overtaking	41 (5.7 %)	Overtaking at intersections, in curves, on bumps or with insufficient visibility, irregularly to the right, without observing the special prohibition sign (c)**, a vehicle that was overtaking another (c)**, a vehicle stopped to allow crossing (c)**	487 (1.6 %)

Note: *: crashes in (b) not included in (a). **: crashes in (c) not included in (a) or (b).

treatments need to be implemented. This procedure is particularly effective when crash data is not available or unreliable as is often the case in Low- and Middle-Income Countries (LMICs), where the WHO estimates an average road death under-reporting of 84 % in LICs and 51 % in MCIs [1]. Nevertheless, conducting a safety inspection may require predefined procedures and experience. Such requirements may be transferred from countries where safety inspection programs have been established and applied for a significant time achieving measurable improvements in road safety and helping in prioritizing treatment projects on road networks to achieve maximum benefit–cost ratio. Europe has been applying safety inspections for over three decades resulting in a reduction of crash costs by approximately 4.1 % of the Gross Domestic Product (GDP) [3]. Thus, it was found of benefit to validate the transferability of the European experience to Egypt to help identify hazardous road sections during safety programs.

This study aims to test and validate the transferability of the Identification of Hazard Location Procedure (IASP) developed in Italy [4]. The IASP procedure was assessed by UK Transport Research Laboratory (TRL) as one of the six most promising safety evaluation models to be tested in the UK [5]. The procedure outlines a methodology for safety inspections on two-lane, two-way roads and defines Risk Index (*RI*) as a surrogate measure of safety to estimate the crash frequency and severity [6]. An inspection vehicle, with a driver and two inspectors, fill out a checklist, supported by a camera, GPS, and tablet to collect road safety information along the drive on the road. This procedure, extensively applied and validated in Italy, was deemed suitable for application in Egypt due to the greater similarity between the infrastructure and user behavior in Egypt. The output of the Risk Index (*RI*) measure has been compared with the expected crash frequency resulting from HSM's *SPFs.* This process is applied to a case study that includes a 6-km segment of a two-way, two-lane rural road connecting Faraskour and El Mansoura in Egypt, serving as an example of a hazardous rural road in Egypt.

Model transferability is defined as the possibility of using a model developed in one country to suit the road context, climate conditions, and user typology and behavior of another country. Both Egypt and Italy are Mediterranean countries that share similarities in context, climate conditions, user typology, and driver behavior as presented in the following section. Such similarities maximize the probability of success of the transferability of the Risk Index (*RI*) model.

Model validation is the process where the performance of the model is checked and evaluated using various performance metrics [7]. According to the result of these performance metrics, the model is considered reliable for prediction when it reasonably fits the data, i.e., it does not overfit the data, or fail to account for general trends, i.e., does not underfit data [7].

In international practice, network screening is a reactive approach that analyzes crash data to identify potentially hazardous sites. According to the Highway Safety Manual [8], network screening employs safety performance functions (*SPFs*), also known as accident prediction models, and empirical Bayes (*EB*) correction to address the potential regression to the mean and account for local factors not considered in the SPF. This method requires a significant amount of good-quality crash data to develop *SPFs* and apply the *EB* correction to the road sections to be analyzed [9,10]. Even though, more simplified practical approaches

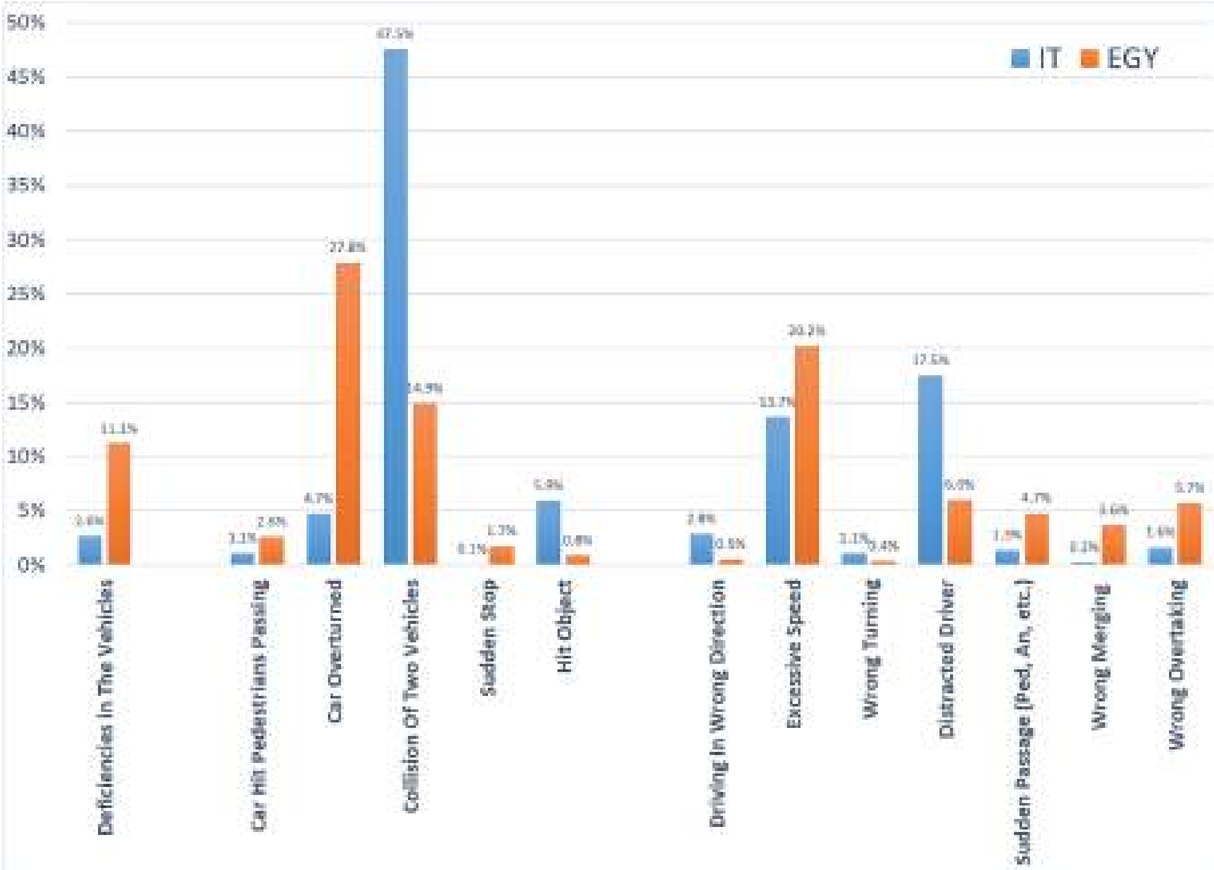


Fig. 1. Distribution of Crash Causes in Egypt and Italy.

have been applied [11], there is always the need for the availability of reliable crash data and road feature measures, which is usually not the case in Egypt. Therefore, there is a need in Egypt to develop an alternative simple and practical methodology for road network screening to identify and prioritize hazardous locations that require the implementation of safety measures.

The Road Safety Inspection (*RSI*) verifies the defects and evaluates the risk of crashes at road sections [12]. In the European Directive, *RSI* is defined as ordinary periodical verification of characteristics and defects that require maintenance for safety reasons [13]. *RSI* is complementary when crash data are available to determine hazardous road sections; alternatively, *RSI* is the only approach that is applicable, while risk assessment and ranking remain a requirement for identifying hotspots and prioritizing hazards for improvement works.

Based on the above, the RSI procedure is a useful approach to apply in Egypt due to the unavailability of accurate crash data and the shortage of qualified road feature data. This paper focuses on this method and proposes a methodology to implement regular inspections to identify potential hazards on the road network. The methodology highlights the need to valide the transferability of the European experience in the inspection, as IASP procedures, which could be considered an effective proactive tool in Egypt. This tool would overcome the challenge of the non-availability of reliable crash data, and increase the efficiency of inspection programs in Egypt. The rest of the paper is organized as follows: Subsection 1.1 illustrates a taxonomy of road crash statistics between Egypt and Italy; Subsection 1.2 conducts a comparison between the speeding behavior in Egypt and Italy; Section 2 presents Background on Safety Programs and Tools in Europe; Section 3 discusses the Transferability Procedure of the *RI* Model; Section 3 includes the Case Study; and Section 4 presents Conclusions and Recommendations.

1.1. Taxonomy of road crash statistics in Egypt and Italy

Road safety is a global concern affecting both developed and developing countries. Worldwide, road crashes result in approximately 1.3 million deaths and cause 20 to 50 million injuries annually [14]. According to the World Health Organization (WHO) statistics for Egypt in 2020, road crashes accounted for 10,141, which represents 1.89 % of the total deaths, a significant proportion. Consequently, the mortality rate is estimated at 11.77 deaths per 100,000 persons, ranking Egypt at 116th out of 183 countries in terms of safety level [1].

In Italy, the National Institute of Statistics (ISTAT) revealed that road crashes are considered a major concern since it is one of the highest causes of death among youth aged 15–25 years. Statistics recorded in 2020 indicate a total number of crash injuries reached about 159,249 [15]. Consequently Italy was ranked 162nd with 4.13 deaths per 100,000 persons. In addition, road crashes accounted for 3,221 deaths, which is equivalent to 0.59 % of total deaths [1].

The application of the IASP procedure involves selecting and using all available and suitable information to classify the proper attributes associated with different crash typologies in the Italian and Egyptian databases. Due to differences in database content and formats, the taxonomy theory is applied to create a comparable structure for the database used in the analysis. The taxonomy is non-exclusive, and the codes represent categorical values, denoting the absence or presence of a certain feature [16].

As a first step, in the Egyptian and Italian crash databases, three categories have been identified:

- Deficiencies in the vehicle; 2- Nature of the crash; and, 3- Circumstances of the crash.

Table 2
Taxonomy for Proportion of Crash. Type (IT) vs. Cause (EGY) (2016–2020).

Crash Type (IT)	IT proportion	Crash Cause (EGY)	EGY Proportion
Head on	22 %	Driving In Wrong Direction, Wrong Overtaking	10 %
Side on	28 %	Collision Of Two Vehicles, Wrong Turning, Wrong Merging	30 %
Rear end	10 %	Sudden Stop	3 %
Run off the road	28 %	Car Overturned, Hit Object	45 %
Others	12 %	Car Hit Pedestrians Passing, Sudden Passage (Ped, An, etc.)	12 %
Total	100 %		100 %

Using this methodology, it was possible to define a common classification based on 3 crash categories and 13 sub-categories, joining the Egyptian [27 crash causes] and Italian [4 vehicle deficiencies (a) + 8 crash typologies (b) + 65 crash events (c)] national crash databases (Table 1).

In Fig. 1, the proportion of crash causes is reported (average value for the period 2016–2020). Fig. 1 shows that the deficiencies in vehicles are predominant in Egypt, possibly due to insufficient vehicle safety features. In addition, the results indicate that the collision of two vehicles is more prevalent in Italy (47.5 %); while the overturning of cars is influenced more by the Egyptian roads and driver characteristics.

However, it is important to emphasize the variation in the distribution of accidents between both countries, attributed not only to differences in road and environmental conditions and driving behavior; but also to variations in the different ways to collect and classify crash data.

Accordingly, to apply the IASP procedure, a comprehensive taxonomy is required encompassing the five main types of accidents; head-on, side-on; rear-end, run-off-the-road, and other crashes. In the Italian database, it was simple to identify these types of crashes; whereas the Egyptian database primarily relates to the circumstances of the crash without providing sufficient details about the crash type. Thus, crash circumstances are associated with the probable accident type as given in Table 2. Only excessive speed and distracted driving have not been specifically associated with a particular accident type due to the high variability of the speed-related scenario. It is noteworthy that the taxonomy produced suitable and comparable results between the typologies classified in the Italian database and the associated crash caused in the Egyptian one. Table 2 highlights the main differences, notably the higher percentage of run-off road and lower head-on related crashes in Egypt.

1.2. Speed behavior in Egypt and Italy

Table 1 shows speed as the main causality factor in crash occurrence in both countries. In this regard, the operating speed (V_{85}) is a parameter that will be used in the safety models presented afterward. Thus, the speeding behavior of drivers can be used to compare the safety levels between the two countries, as well.

The relationship between crash frequency and severity, and the operating speed and its variability which is defined as the 85th percentile of speeds in free flow conditions (V_{85}) is well- established in the literature [17]. Thus, several mathematical models have been developed to calculate (V_{85}) using different road characteristics such as road class, section width, speed limit, etc. Moreover, the horizontal curve radius plays the main role in explaining the variability of V_{85} when other road characteristics remain constant. Furthermore, the development of these models depends on the driver's behavior affected by the rules and environmental, social, and cultural factors that may vary by country.

A model based on data collected in Italy was developed and used in the road safety risk index model that will be later presented in the paper [4]. The model in Equation (1) relates the V_{85} to the radius curvature (1/R) for two-way two-lane rural roads with a paved section ranging from 8 to 9 m.

$$V_{85} = 99.31 - 2923.32/R \quad (1)$$

In addition, the Egyptian model, given in Equation (2), which was chosen for comparison was developed by Hashim et al. (2016). This model was selected since the road characteristics in the area where the model was developed closely resemble the case study employed in this research and similar to the road characteristics used in developing the Italian model. The model was developed for a rural two-lane, two-way road connecting Sohag and Hurghada.

$$V_{85} = 99.885 - 3880.21/R \quad (2)$$

Both models were developed by analyzing speed data collected under standardized real-world conditions, including daylight, free-flowing traffic, and passenger car scenarios. These models were specifically designed for roads in Egypt and Italy, featuring similar geometric characteristics and functional classifications as the road under study in the current paper.

Fig. 2 compares the V_{85} predicted by the two models. Generally, the

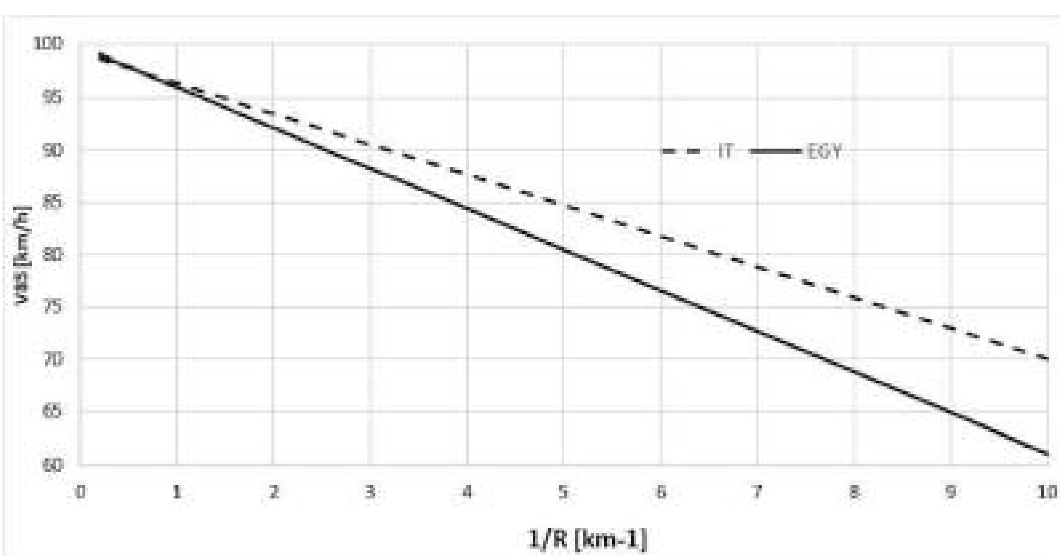


Fig. 2. The Egyptian and the Italian Speed Models Comparison.

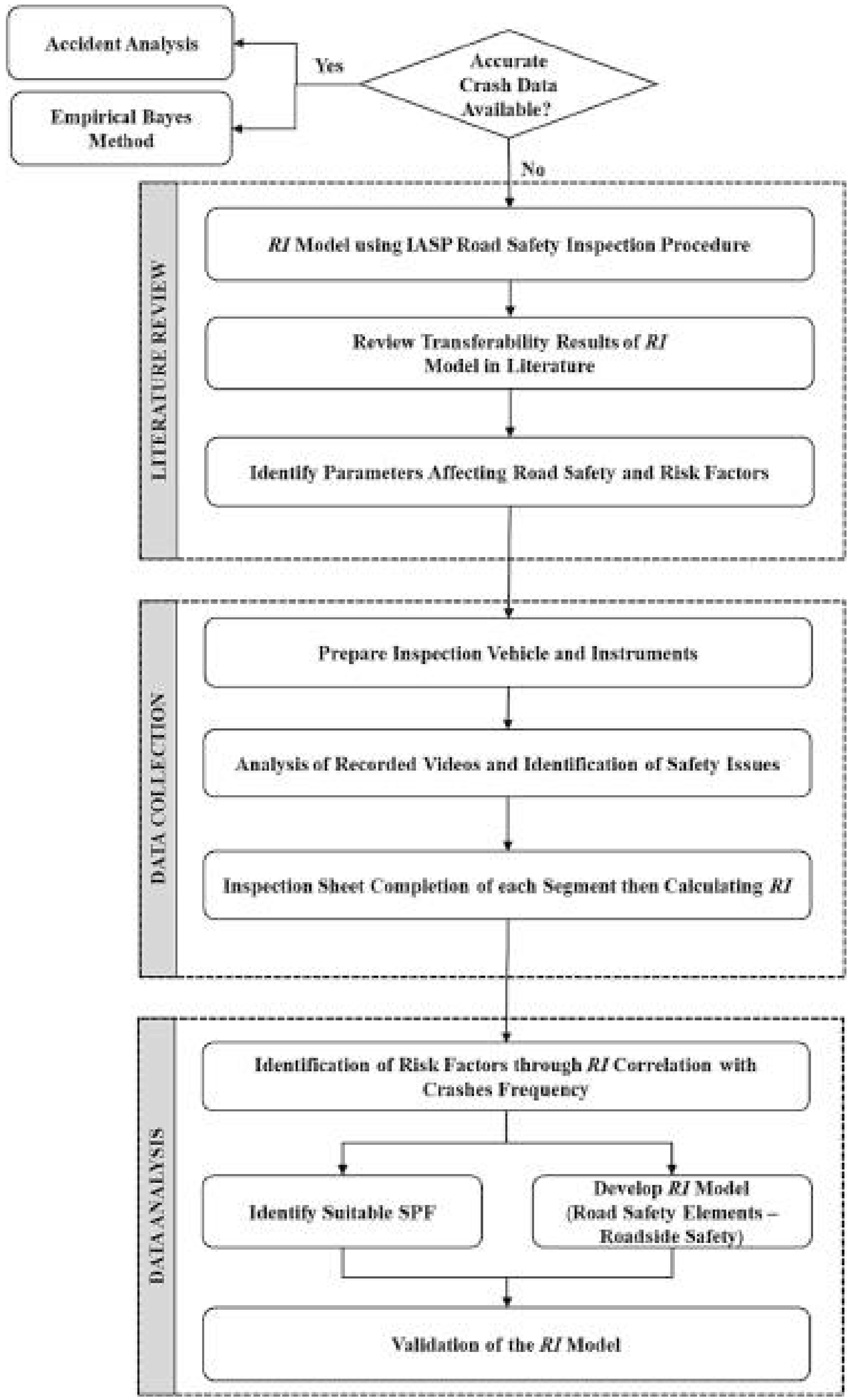


Fig. 3. Methodology for Transferability of *RI* Model.

speed of Italian drivers is higher even if the difference becomes less than 5 % for $1/R < 4\ km^{-1}$ (i.e. $R > 250$ m) making the drivers' behavior in the two countries comparable.

2. Background

The majority of research work has been dedicated to crash prediction on two-lane two-way rural roads since most fatal crashes occur on this type of road. Moreover, two-lane rural roads are more suitable for the application of engineering safety measures (e.g., improving roadside, alignment, sign, marking, etc.) to mitigate risks [10]. The methods developed to identify risk factors and estimate the risk rating by using Safety Inspection are presented in the following sections.

Many approaches were used to identify hot spots along the road segments. The common approach used to identify hazardous road sections will be discussed in the next subsection. Combining two or more approaches may yield more accurate results.

For instance, network screening, based on crash data, is complementary to road safety inspection because the two approaches (network screening and road safety inspection) have different capabilities and targets. Crash analysis is more effective in the identifying high-risk locations and is applied as a reactive procedure. Safety inspections are suitable to identify both specific locations with high-risk profiles, which can be compared with crash analysis results, as well as identifying widespread risk factors affecting the road network. Moreover, safety inspection is proactive in its nature and, therefore, is effective as routine control, as well. The recent revision of the EU Directive on Road Infrastructure Safety Management has emphasized such approach by combining road safety inspection with a new tool called network-wide road safety assessments (NWRSA). These assessments comprise visual inspections, an analysis of traffic volumes, historical accident data assessment, and crash severity assessment. Based on the results of the assessment, all sections of the road network could be classified into no fewer than three categories, according to their inherent safety levels [13]. Nonetheless, despite their need, in low-middle-income countries where effective safety treatments could be carried out, the lack of reliable crash data limits the applicability of the overall safety assessment. Thus, risk assessment, using only safety inspections, becomes a need to provide detailed investigation. Fig. 3 presents the methodology proposed in this study to support the decision-making process in selecting the best approach for hazard identification, to be applied in Egypt.

In 2008, for the first time, the European Commission [13] adopted a directive to be followed by their member states to increase the safety of the network through different safety tools. The tools include road safety impact assessments, road safety audits, management of road network safety, and road safety inspections. A list of these countries is summarized by Cafiso et al. [28]. The countries performed road safety programs, including inspecting road network and identifying hotspots.

In addition, the European Commission encouraged the periodic inspection of road networks to identify safety problems that needed to be treated. Accordingly, [28] defined safety inspection procedures for two-way two-lane rural roads determining the method to evaluate and resolve the safety issues, whether they are at high-level or low-level problems, through specific guidelines and actions.

A risk assessment model was further developed and applied in different EU countries to carry out a quantitative score and safety ranking of road sections consistent with the most recent amendments to the EU RISM [13]. While this model has been tested for transferability in various countries, the primary objective of this research is to assess the applicability of these procedures and the *RI* model specifically to Egypt.

3. The transferability procedures of the *RI* model

3.1. Parameters affecting road safety and risk factors

A relation has been found between crash occurrence and safety factors, such as access density, road geometry, signs, delineation, roadside, etc. However, in many instances, crashes can occur even in the absence of these factors due to other factors such as human error, environmental changes, or vehicle factors. Therefore, it can be challenging to represent all crash circumstances in *RI* models [21,22] which have the goal to relate potential safety hazards to road factors that can be improved to reduce the likelihood and severity of road crashes.

Table 3
Parameters of *RI* Measure in Literature.

Study	Parameters Assessed
Rosolino et al. [25]	Access Density, Pavement Irregularities, Marking, Signs, Roadside, and Barriers.
Cafiso et al. [6]	Curve Radius, Length of Curve, Tangent Length, Width of Lane and Shoulder, Density of Driveways, Marking, Sign, Delineation, Sight Distance, Pavement Conditions, Roadside Hazard, Operating Speed
Nassiri and Mojarad [26]	Road Alignments, Sight Distance, Intersections, Road Lighting, Traffic Capacity, Surface Condition, Roadside, Lane Width, and Pavement Conditions.
Nodari and Lindou [27]	Surface Conditions, Horizontal Curves, Intersections, Vertical and Horizontal Signaling, Longitudinal Elements, Cross Section, Vulnerable Users, Roadside, and General Elements

Therefore, several researchers developed road safety *RI* models. For example, [23] evaluated crash risk at road sections using the Accident Hazard Index (*AHI*), which is a combination of accident frequency and accident severity. They used the Quasi-Poisson model to relate *AHI* to the explanatory variables causing the hazard. In Malaysia, [24] developed a composite index (risk index) that shows acceptable results. The parameters of *RI* measures in the literature are shown in Table 3.

3.2. RI model

Risk Index (RI) is quantified as the product of three components: exposure, crash frequency, and crash severity [18–20]. The following equations are used to quantify the *RI*-given factors (exposure factor, accident severity, and frequency factors). Equation (3) calculates the *RI* through the product of its components. Equation (4) calculates the exposure as a product of AADT with the length of the section. Next, Equation (5) calculates the Accident Frequency Factor as a product of the accident frequency related to the safety inspection of the road issues with the accident frequency related to the geometric design of the road.

$$RI = EF \times AFF \times ASF \tag{3}$$

Where:

EF: Exposure Factor
AFF: Accident Frequency Factor
ASF: Accident Severity Factor

With

$$ExposureFactor = L \times AADT \tag{4}$$

Where:

L: Length of the segment under consideration (in kilometers)
AADT: Average annual daily traffic (in 1,000 vehicles per day)

$$Accident\ Frequency\ Factor = RSI\_AF \times GD\_AF \tag{5}$$

Where:
RSI_AF: The state of degradation of the section in question is assessed based on road safety inspections.
GD_AF: The component related to the design consistency

In the *RI* model, the severity refers to the KABC scale [8] ranging

Table 4
Geometric Design Scores (GDS) [6].

Curves	WS_{GD}	Tangents	WS_{GD}	Related accidents P_{GD}
Good	0.2	Overall standard check	0.0	Run off the road
Fair	0.5	Less than minimum length	0.1	Head on (Partially 50 %)
Poor	1.0	More than maximum length	0.1	

from possible injuries to fatal crashes as a function of operating speed and roadside hazard as given in Equation (6).

$$AccidentSeverityFactor = ASF = \frac{V_{85}}{V_{base}} \times RSI\_AS \quad (6)$$

where:

V_{85}: is the average 85th percentile of speed along the segment (weighted to element length)
V_{base}: is the base speed for two-lane local rural highways (e.g. legal, posted speed)
RSI_AS: The roadside accident severity factor of the segment.

More details on the model and parameters' calculation can be found in [6].

3.3. Road safety inspections

The IASP operative manual [29] provides guidelines for inspecting and evaluating different safety factors, as well as determining the ranking of each safety issue from a high to a low or null score. For each safety factor, a clear definition of the procedure help standardize subjective evaluations among different inspectors [28]. Thus an accident factor evaluation, based on the inspection of safety issues, is calculated for ranking purposes[4].

Roadside hazard *RSI_AS* includes different elements considered during the road inspection. These elements include embankments, bridges, safety barriers, dangerous terminals and transitions, trees, utility poles, rigid obstacles, and ditches.

3.4. Geometric design evaluation

One of the utmost factors that should be considered in road safety is the evaluation of the geometric design of a road.

In the risk model, the geometric design (GD) accident factor is calculated using Equation (11).

$$GD\_AF = 1 + WS_{GD} \times \Delta AF_{GD} \times P_{GD} \quad (11)$$

where.

WS_{GD}: the score of the geometric design safety issue
ΔAF_{GD}: estimated relative increase in accident risk due to issue *GD* (equal to 7)
P_{GD}: the proportion of accidents affected by issue *GD*

Lamm's safety criteria [30,31] provide a well-established framework for estimating the safety performance of road curves which was applied to define the safety score WS_{GD}. The evaluation classifies the safety level of the horizontal curves in two-lane rural roads, in terms of "good", "fair", or "poor", based on three safety criteria which estimate the increasing probability of accidents in curves. However, since Lamm's criteria cannot be applied to tangent sections, the WS_{GD} is calculated according to geometric design standards which define the required minimum and maximum length based on design speed. Further details on the WS_{GD} calculation can be found in [6].

Table 4 shows the values of WS_{GD} and related accident typologies P_{GD}, based on curve and tangent safety criteria assessment.

3.5. Validation and transferability of the risk Index model

Research efforts on *RI* validation confirm that the risk index, based on safety inspections, correlates well with crash occurrence. For instance, Leur and Sayed [22] evaluated road segments using a subjective measure (i.e., risk index). Then, the evaluation procedures were validated by correlating the *RI* measure with an objective measure (i.e., the potential for improvement). The correlation coefficient was 0.318, which assured the procedures. Rosolino et al. [25] studied the factors contributing to accidents in Italy to calculate the *RI* and validity of the selected factors. First, a pilot survey was conducted and then *RI* procedures were validated by correlating the value of *RI* with an objective safety measure. The results assured the validation of *RI* procedures.

To assess the reliability of the IASP procedures, [32] used Kappa statistical test to study the level of agreement among different inspectors. This process was performed after conducting the IASP procedures for inspecting two-way two-lane rural roads calculating the *RI* for each segment. The results showed that the level of agreement between the different inspectors was statistically significant.

Transferability refers to the applicability of using a predicted model/methodology on new conditions different from the ones where the model was developed. This is done to determine whether the model is useful in new conditions and provides accurate results [33].

Considering the framework of the European Directive 2008/96/CE and the strong correlation between crash occurrences and the IASP Risk Index in Italy [34], the transferability of the procedure to another EU country, involving a sample of 184 km of Polish roads [35]. The comparison revealed the main safety issues of the Polish infrastructure and the opportunities to adapt the Polish inspection procedures to the IASP procedures, which involve simple equipment (i.e., checklist, GPS, tablet, and camera). The study demonstrated a strong agreement between both guidelines and the evaluation procedures. The results revealed a high efficiency and success in transferring the Italian road safety inspection procedures to Poland. The coefficient of determination (R^2) between *RI*/*L* and expected crashes per km (calculated using the Empirical Bays method) was 0.8 which was statistically significant [35].

3.6. Safety performance functions

Safety Performance Functions (SPFs) are statistical models, calibrated on historical crash data, used to predict crash frequencies based on related explanatory variables, such as traffic exposure and geometric characteristics of road segments. conducted in different countries. The HSM provides SPFs for most road facilities.

SPF is calculated for two-way rural road segments as per the following equation under base conditions in the last update of HSM [36]:

$$N_{SPF} = e^{-7.463+0(AADT)+ln(L)} \quad (14)$$

Where:

N_{SPF}: predicted total crash frequency for roadway segment base conditions.
AADT: average annual daily traffic volume (vpd)
L: length of roadway segment (miles)

These SPF functions are calibrated for specific base conditions, which can be adjusted to the actual road features by the use of Crash Modification Factors. However, some conditions could not be predicted by the HSM SPFs due to the unique characteristics of some facilities that were not considered in the HSM models [38]. Thus, there would be a need to calibrate the SPF to local conditions or to develop tailored SPFs.

Accordingly, extensive research has been conducted in different countries to develop *SPFs* for two-way rural road segments [39]. The

Fig. 4. Case Study- Faraskour-Mansoura Road.

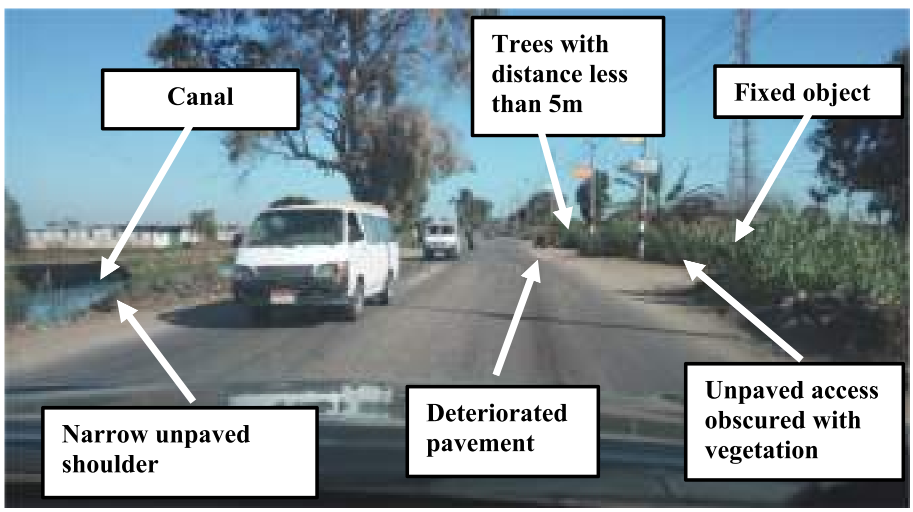


Fig. 5. Road Section Safety Issues.

research has focused on calibrating *SPFs* to address the limitations of existing functions. Most of this research used the negative binomial method because it accurately represents the crash nature where the variance is greater than the mean. There are two types of SPFs: 1) descriptive SPF where AADT is the only variable; 2) multivariate SPF where more variables are used.

Despite research efforts in Egypt, the availability of SPFs, such as those developed for Multi-Lane Rural Divided Highways [40], for undivided two-way two-lane rural roads, is still limited. Nonetheless, considering the alternative safety assessment, road safety inspection should be a suitable approach to be applied to identify hazardous road sections and implementing maintenance programs, especially in the absence of reliable crash database.

Thus, the IASP procedures and the RI model could help in improving safety if successfully transferred to Egypt. However, their procedures need to be validated in the application to Egyptian roads and compared to the alternative HSM approach based on SPF.

4. Case study

This section presents the case study that assesses the transferability of the European experience in road safety inspection to Egypt through the application of IASP procedures on a section of Faraskour –Mansoura Road, Egypt. The road is a two-way two-lane rural road and is one of the main roads in the Mansoura region, Egypt. Its whole length is about 58.5 km long connecting two major cities, Faraskour and Mansoura. The section under study is 6 km long, as shown in Fig. 4. Although limited in the extension, this section of the road was chosen as it contains several safety issues and hazardous features, as shown in Fig. 5.

The proposed methodology includes three phases: calculating the predicted crash frequency using SPFs with CMFs, calculating RI, and finally, noting the comparison procedures, as shown in Fig. 6.

The road section was divided into 58 segments according to the segmentation rules of the HSM. For each segment, the necessary data required for SPFs and CMFs is defined. Furthermore, the data required to calculate the *RI* measure was identified and scored according to the procedure defined in [35] and the IASP manual [32].

4.1. Road segmentation

The road segmentation for the application of the HSM model should fulfill the following rules:

1. Roadway segments should be homogenous and not shorter than 160 m.
2. Roadway homogeneous segments are delimited by:
- Intersections
- Beginning or end of a horizontal curve
- Point of vertical intersection for a vertical curve
- Change of the AADT, and

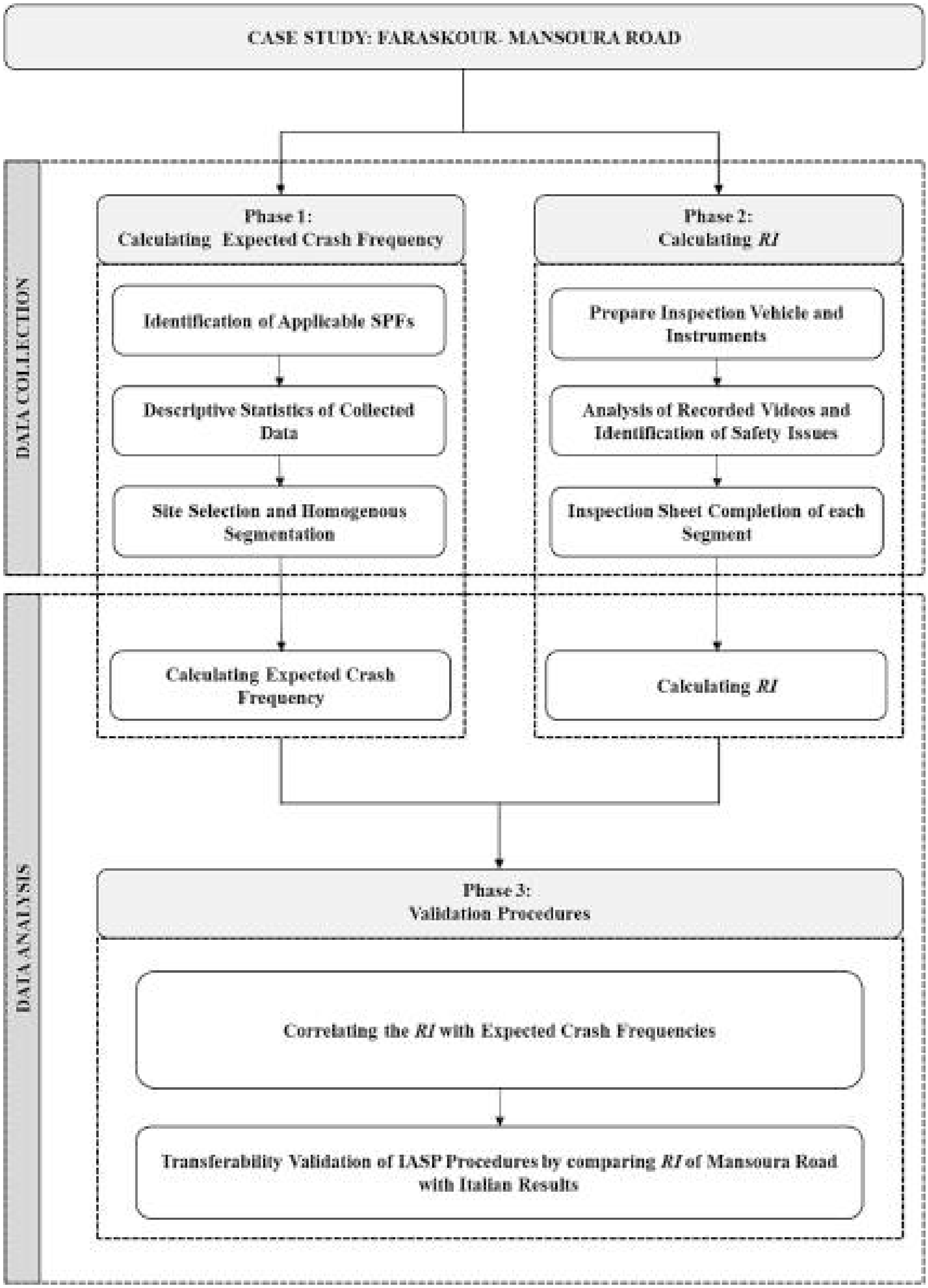


Fig. 6. The Proposed Methodology.

- Other road characteristics (i.e. the lane width, the shoulder width and type, driveway density, and roadside hazard rating).

4.2. Data collection

A portion of the traffic volume data was available, but limited data were collected for the study. Therefore, all the necessary information was collected for the study through video recording during the in-field inspection by car and surveyed data to acquire road geometric data such as horizontal and vertical alignment and within access distance. It is worth mentioning that the AADT data showed limited variations as the selected road section lacks major intersections. Thus, the AADT was

Table 5
Descriptive Summary of the Geometric Parameters of Mansoura Road.

Parameter	Min	Max	Standard deviation	Number of elements
Tangent Length	27.57	319.24	65.58	29
Curve radius	250	5,000	1,048.85	29
Curve length	15.97	351.10	70.54	29
Shoulder Width (m)	0	4	0.8	58
Lane width	2.25	4.5	0.57	58
Gradient	Less than 0.5 %			58
Within access distance (km)	0.082	1.099	0.26066	16

around 22,000 vehicles/day with very minor changes across the entire road section. Table 5 presents the geometric attributes of the sample of road segments.

4.3. Road safety inspection

The inspection of the 6 km of the two-way two-lane rural Faraskour-Mansoura Road, Egypt was conducted in both directions. An inspection Excel sheet was filled assigning a score from ‘0′ to ‘2′ (‘0′ indicates no issue, ‘1′ indicates a low-score problem, and ‘2′ indicates a high-score problem) for each safety issue, following the IASP inspection procedures for road sections with segment with a constant length of 200 m [4].

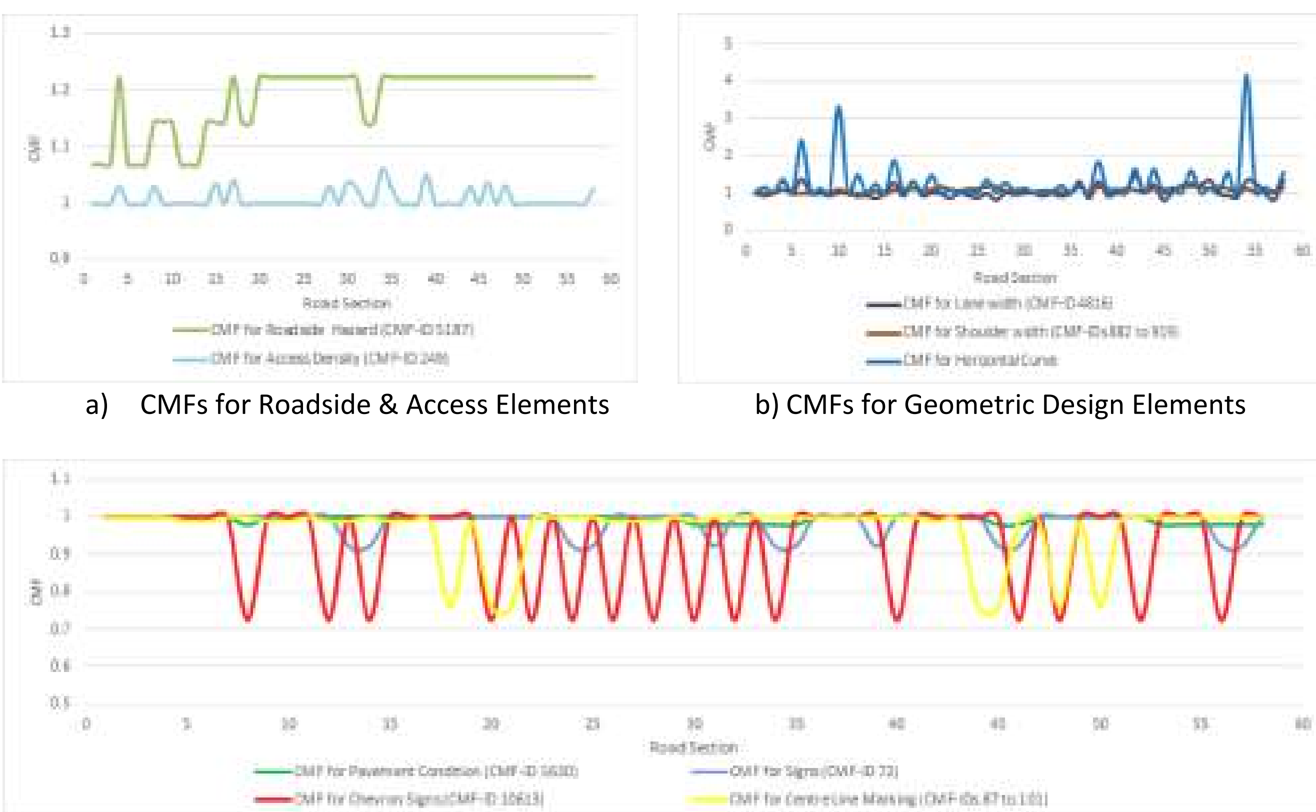
4.4. Analysis of data

The collected data were divided into three main data groups. The first data group was used to calculate the expected crash frequency from the SPFs. The second data group was used to evaluate the road segments. The third data group was used in the *RI* model. Afterward, the correlation between the SPF and RI for the road section was calculated.

4.5. Crash frequency calculation using SPFs

The following steps perform the calculation of the predicted crash frequency: a) road segmentation; b) SPFs for the base condition; c) crash modification factor; and d) the total predicted crash frequency. The predicted crash frequency and the crash modification factors are calculated for the different road segments biased from the base conditions of HSM. The CMFs were retrieved from the Clearinghouse website [37]. Also, the figures show the identification number for each of the used CMFs (i.e. CMF-ID). Then, for each segment, different CMFs were calculated depending on corresponding segment biases from HSM base conditions.

Fig. 7 shows the results for different CMFs along the considered road. In Fig. 7.a, the figure shows Roadside & Access Elements. From the figure, it could be found that the Access density value ranges from 1 to 1.05 indicating that some segments have access spacing less than 200 m (i.e. base condition for SPF). Furthermore, the figure shows the value for CMF values for roadside hazards at different sections. These values range from 1.08 to 1.22 indicating the existing hazards along the side of all sections on the considered road. In addition, Fig. 7.b shows the CMF value for the horizontal curve ranging from 0.9 to 4 highlighting the noticeable variation of curve radius along the road section. Also, the figure shows the variation in the shoulder and lane width which indicates a steady shoulder and lane width along the road section. Next, Fig. 7.c shows the CMF value for Traffic Guidance and Structural Elements including CMF for pavement condition, signs, chevron signs, and centerline marking. The figure shows that the most of sections do not include these features.



a) CMFs for Roadside & Access Elements

b) CMFs for Geometric Design Elements

c) CMFs for Traffic Guidance & Structural Elements

Fig. 7. The Crash Modification Factors Variations Along the Road Section.

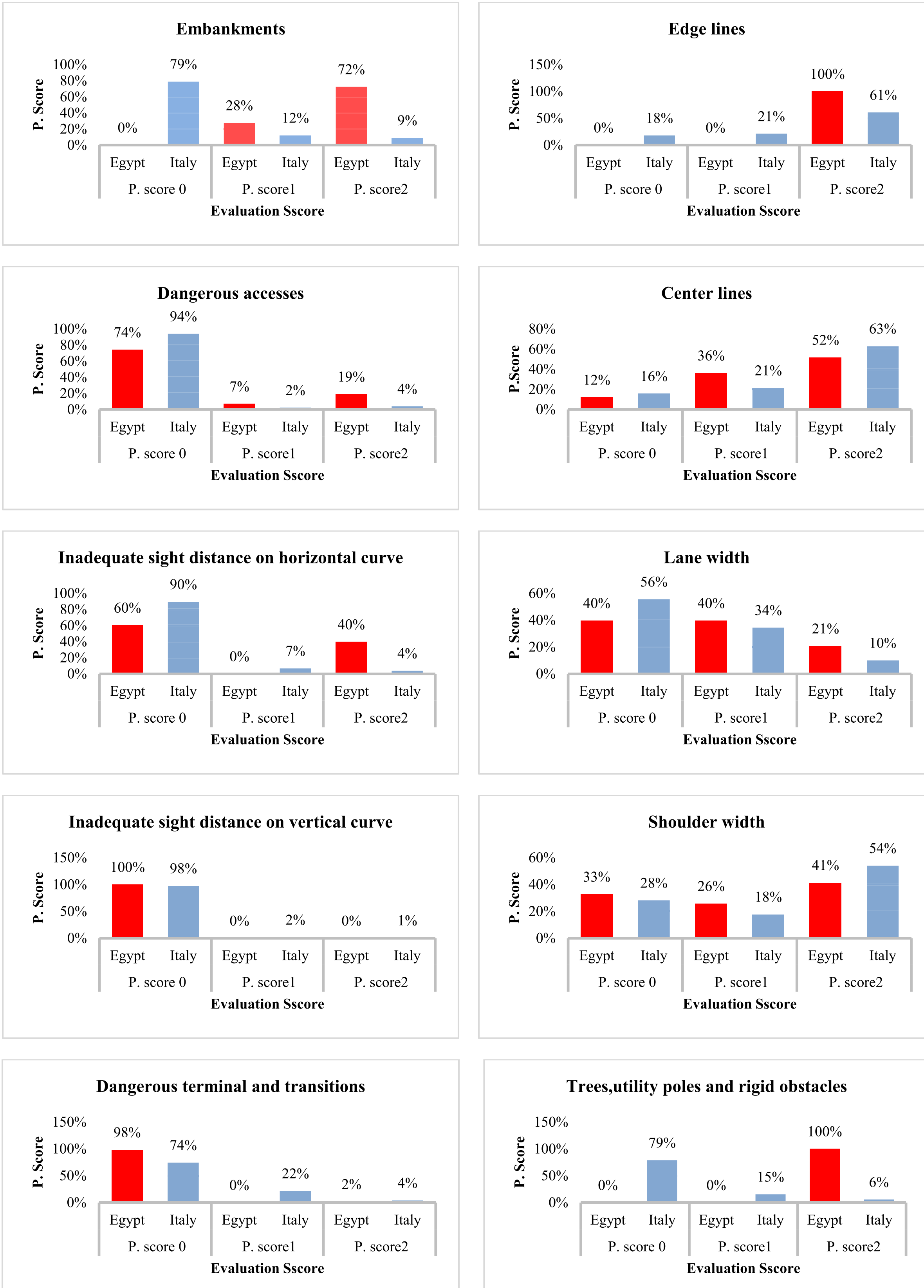


Fig. 8. Safety Issues Score Comparative Summary between Egypt and Italy's Infrastructure.

Table 6
The Percentages of Accidents Corresponding to Each Safety Issue.

Safety Issues	Related Accident	P_j(IT)	P_j(EGY)
Accesses	All	1.0	1.0
Cross-section	Runoff the road Head-on Side on	0.78	0.85
Delineations	All	1.0	1.0
Markings	All	1.0	1.0
Pavement	All	1.0	1.0
Roadside	Runoff the road	0.28	0.45
Alignment	All	1.0	1.0
Signs	All	1.0	1.0
Geometric Design Score (GDF)	Runoff the road Head on (Partially 50 %)	0.39	0.50

4.6. Added safety measures to IASP towards the Egyptian infrastructure adaptation

The pavement condition evaluation was found to be highly affected by the two following issues, which were not initially considered in the IASP. The first issue was defined as the presence of manhole covers raised 5 cm above the pavement level; while the second issue was the presence of asphalt traffic calming bumps. These two issues were added to the IASP methodology to consider local conditions during the safety inspection process on Egyptian Roads. Both safety issues are considered as pavement defects.

In addition, a canal is located along the roadside of Mansoura Road. Although the presence of longitudinal ditches is already considered in the IASP procedure, it was also essential to consider the higher depth of the canal along our road as it directly impacts the severity of crashes. In this regard, the canal depth is considered a high-level problem when exceeds 65 cm.

4.7. Evaluation of road segments hazard

The inspection safety sheets were filled out during the inspection. In addition, video logs were recorded for further analysis and evaluation. In the lab, the recorded photos and videos were analyzed by the inspection team for the completion of the safety issues and inspection sheets.

The road section under study had an average lane width of 3.57 m, a 0.4 m paved shoulder, and 0.5 m unpaved shoulder on each side of the road. In addition, the road lacked average road markings and signs on approximately 80 % of the segment length. The considered road section is bordered by a canal on the west side at a distance less than 5 m from the edge of the unpaved shoulder, and trees on the east side at exactly the edge of the unpaved shoulder. Therefore, in such sections, the roadside hazard is evaluated with a rating of 6 [41]. Additionally, the considered road section included bumps which were considered in the pavement conditions using CMF ID: 5630 for the SPF calculation and bad surface condition for *RI*.

The charts in Fig. 8 present a comparative analysis of safety issue inspection scores between Egypt (Mansoura Road) and a sample of road sections in Italy (Sicily) with similar characteristics, specifically focusing on two-lane rural roads. The quantitative evaluation of safety issues demonstrates the usefulness of this approach.

The results reveal a notable trend: a higher number of road sections in Egypt exhibit higher scores for hazards on the roadside, such as embankments and rigid obstacles. This observation aligns with the later-reported data in Table 6, which indicates a correspondingly higher percentage of accidents related to these specific hazard types. The findings emphasize the significance of the quantitative evaluation in assessing and understanding safety concerns on the roads in both Egypt and Italy, facilitating measures to address these issues effectively.

Based on the above comparison, there is a significant similarity between both the infrastructure's level of safety in Egypt and Italy. On the other hand, the charts show that although geometrics of the road design such as lane width, shoulder width, and horizontal /vertical curves design follow guidelines, more attention may be needed in other safety factors which show high-level scores due to lack of maintenance especially pavement marking, signs, and roadside hazard (i.e. embankment and lateral obstacles). This would help create a more forgiving road environment reducing the severity level of accidents and fatalities even when accidents result from driver errors.

4.8. RI calculation

As previously described, the *RI* is composed of three major components, which are the exposure factor, accident frequency factor, and accident severity factor. Other than inspection and geometric design data, to calculate the risk index, the percentage of crash types (P_j) is required to scale the risk to the proportion accident type directly affected by the different safety issues in Table 6. The values of P_j can calculated from the regional/national crash data for the same road typology. Because of the different crash data collection forms, the values of P_j for Egypt are not directly available from the National statistics, therefore they have been calculated based on the taxonomy correspondence in Table 2. The values of P_j for Egypt and Italy are shown in Table 6, highlighting the higher percentage of accidents related to roadside hazard and geometric design defects in Egypt.

The scores of the safety issues identified during the road inspections were then used to calculate the overall risk index following the model synthetically presented in 3.2. It is worth noting that the *RI* value is a quantitative score without a specific physical meaning, but previous studies have shown a good linear correlation with the expected crash frequency. In any case, the risk values can be used to rank the road sections in order to prioritize further more detailed inspection and treatment works. Fig. 9 presents the evaluated accident risk score (*RI*) of each road segment, with the most dangerous sections being those that combine more than one safety issue.

4.9. Comparing the RI value with the predicted crash frequency

The results of both the *RI* model and the SPFs are presented in Fig. 10. While SPF estimates the predicted number of crashes and RI calculates a risk score, they can be compared because both scalar and ascending prediction of road safety. From the figure, at the majority of the road segments, *RI* and SPF values are found to be visually matched in terms of ranking.

The Spearman's rank correlation coefficient between the SPFs output and *RI* is then calculated using SPSS software. The results show that Spearman's rank correlation coefficient value is 0.75. This value provides insight about the significant relationship between SPF and *RI*. Moreover, this result is consistent with a transferability study conducted in Europe. However, this resulting Spearman's correlation coefficient is lower than the coefficient resulting from [35] research.

However, a few segments experience deviations such as segments 11, 16, 20, 27, 28, 29, 40, 47, 52, 54, 55, and 56. These deviations recognized in the results of *RI* and SPF calculations could be resulting from the effect of the presence of curves evaluated differently in the two approaches, SPF and *RI*. In addition, the CMFs do not include the effect of the location of accesses on safety accurately (i.e., access on curves, and access hidden in vegetation). Additionally, the CMF that calculates the biases of different marking visibility conditions is not precisely determined. For instance, faded marking condition on the pavement does not have a specified CMF, especially in a hazardous roadside environment.

As per Figs. 8 and 10, the most hazardous segments based on *RI* calculations are 58, 50, 48, 44, 4, and 36. On the other hand, the least hazardous segments are 1, 3, 5, 7, and 11. These results highlight the existence of one or more safety issues on the road segments resulting in

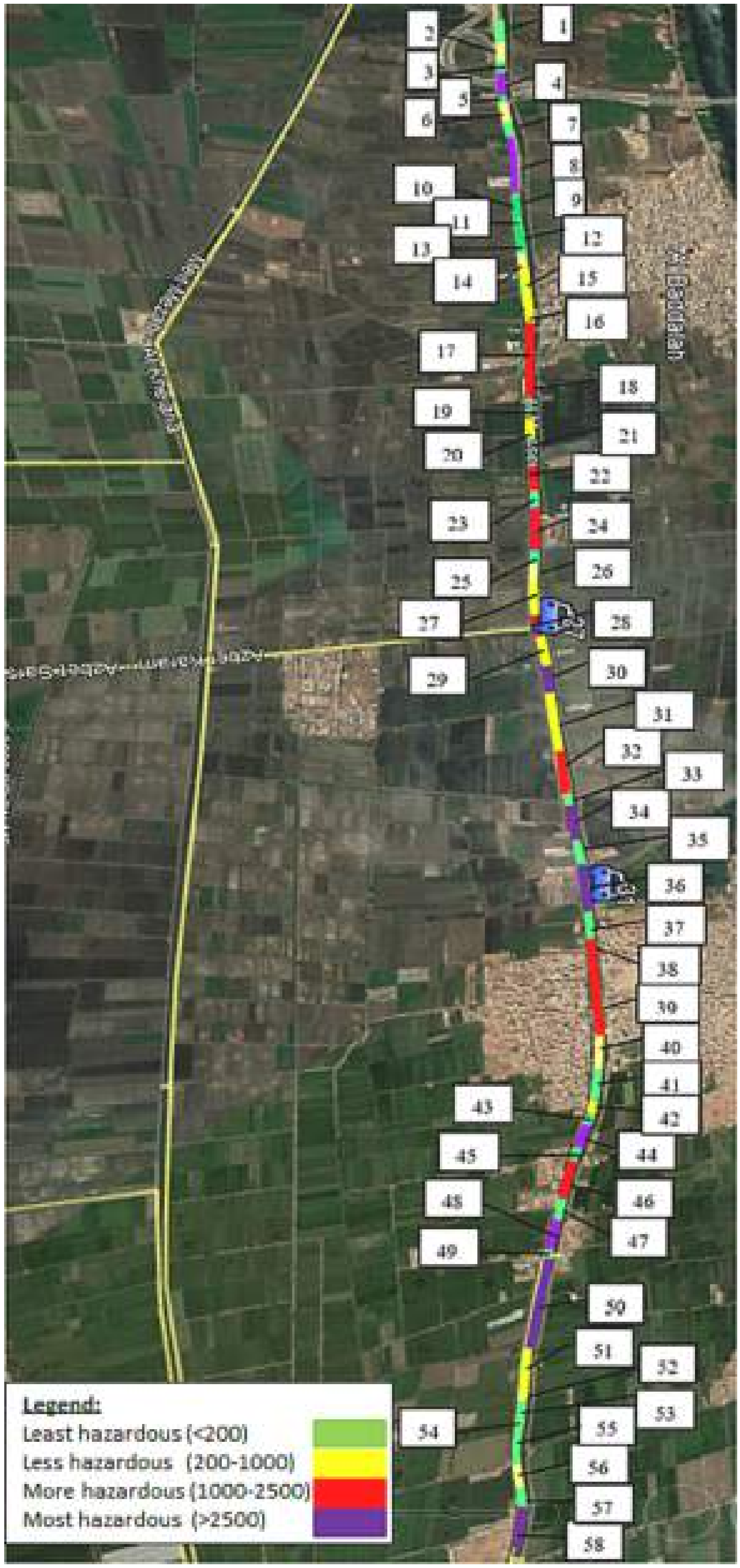


Fig. 9. Hazard Index for the Road Segments.

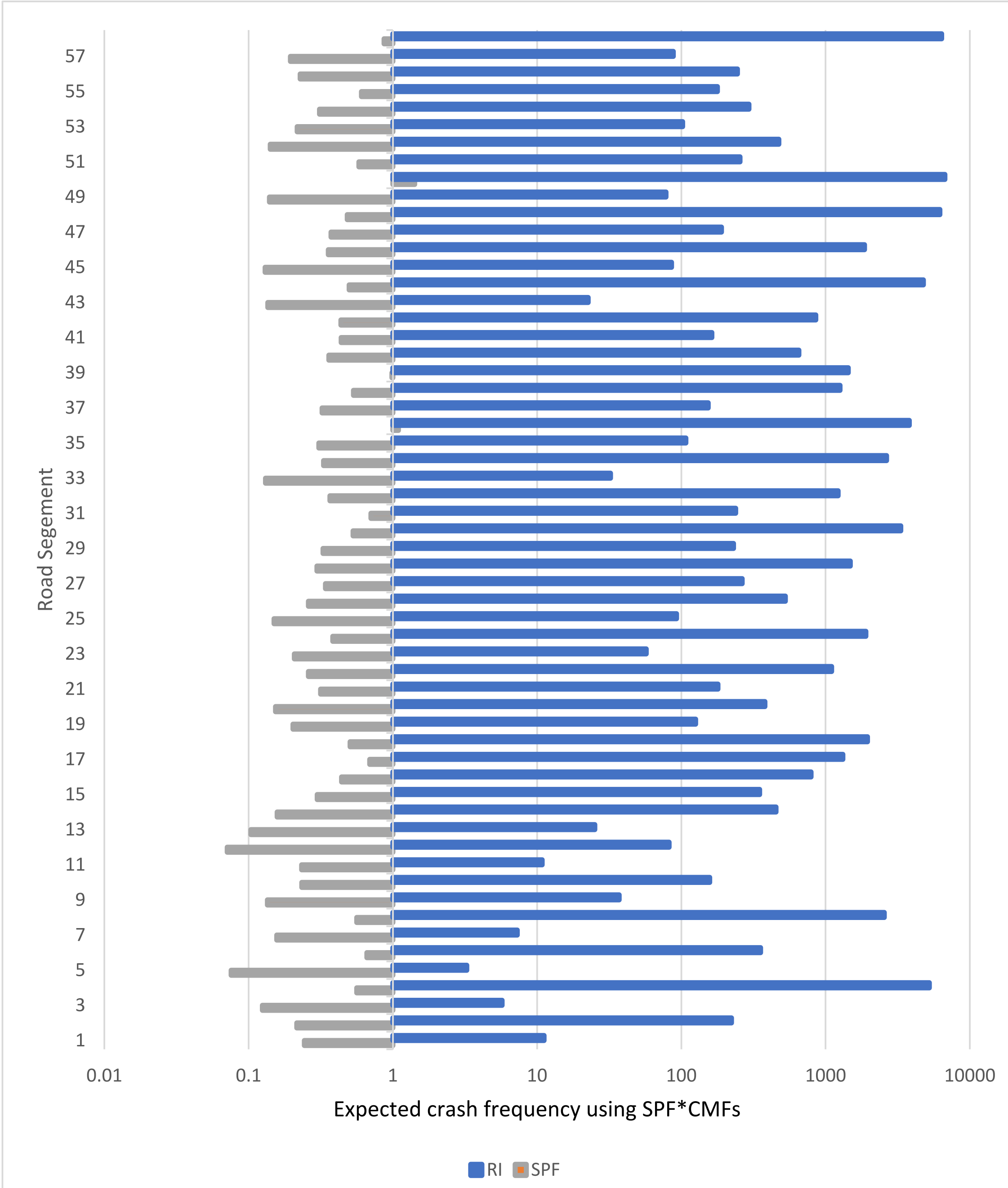


Fig. 10. Relation between *RI* and SPF.

increasing the risk based on their level. For instance, the existence of sharp horizontal curves without prior warning signs after a long tangent road segment, the absence of edge line marking, the presence of traffic calming bumps, and the non-protection of a roadside featured with the hazardous environment (i.e., deep canal). Such an increase in the tendency of the vehicle could result in a probability of high-severity accident occurrence.

5. Conclusions

The continuous rise in road accidents has prompted safety researchers to focus on identifying hazardous road sections. Two common approaches for assessing safety on existing road networks are accident analysis and road safety inspection. In Egypt, the road safety inspection approach is particularly suitable due to the absence of a reliable crash database, and it offers the advantage of proactively pinpointing risky road sections.

Notably, there were no standardized inspection guidelines in Egypt before this research. Hence, this study represents a significant milestone for Egypt as it transfers the methodology of evaluating hazardous road sections based on the IASP (Italian Road Safety Inspection) procedures. IASP is a European procedure initially developed in Italy, incorporating specific guidelines to assess safety issues from low to high severity levels. The output of safety issues' evaluation during the inspection, along with geometric design checks, serves as input for calculating the Risk Index (RI), which provides a quantitative ranking of risky segments in the road network.

The primary objective of this study was to assess the transferability of European road safety inspection procedures to Egypt and compare the results with the SPF (Safety Performance Function) crash prediction.

The research methodology involved three phases applied to the Faraskour-Mansoura Road as a case study: calculating predicted crash frequency using SPFs in Egypt, calculating the RI, and finally comparing RI values with SPF results for the same road.

Data collection encompassed various types, including traditional data like traffic and road characteristics, and non-traditional data sourced from Google Earth. Visual inspections using a regular car and camera were employed to record and evaluate safety issues.

The RI consists of three components: road user exposure, the probability of accidents occurring, and accident severity. Each road segment's risk is determined through inspection and evaluation.

The study found a correlation coefficient of 0.75 between SPF results and RI values for the considered road, which was slightly lower than similar research conducted in Italy and Poland. This finding aligns with existing literature, although the lack of crash data hindered applying a Bayesian correction to SPF predictions.

The results show the promising transferability of the IASP to Egypt, in line with its successful application in European countries with a strong emphasis on prioritizing hazardous locations. The IASP procedure demonstrates great potential in identifying risky road segments, with the added advantage of lower costs and simpler equipment compared to the data-intensive HSM (Highway Safety Manual) method. This makes it particularly suitable for application in low- and middle-income countries with limited crash data, enabling more extensive risk identification at lower costs.

Moreover, the successful application of the method enhances its reliability globally, driven by the inspection rules used in evaluating various safety issues outlined in the IASP manual.

Although the study's aim was not to draw general conclusions about the overall safety conditions of roads in Egypt compared to Italy, and the limited sample size should be noted, some results align with accident conditions and provide useful insights into emerging safety issues. Notably, roadside conditions were frequently classified with the highest scores, and the percentage of related accidents was significantly higher than in Italy.

6. Future extension

Based on the findings of this research, several recommendations can be made for future studies

1. Custimized inspection sheets: It is advised to update the inspection Excel sheet to be tailored to the specific infrastructure and traffic conditions in Egypt. This customization will enhance the accuracy and applicability of the inspection process.

2. Consider trailer trucks traffic: In the case of significant trailer traffic on the road, it is crucial to include cross-superelevation values that indicate when there might be a higher risk of cargo slipping off the road or trailers becoming detached. This risk should also be correlated with the Average Annual Daily Traffic (AADT) for those trailers. By doing so, road safety measures can be better tailored to handle these specific challenges.

3. Correlate *RI* with crash data: To ensure the effectiveness of the inspection Risk Index (*RI*) results, it is recommended to assess them alongside reliable crash data. This evaluation will provide valuable insights into the correlation between identified risks and actual accident occurrences.

4. Develop Egyptian SPFs: Future research efforts could focus on developing Egyptian Safety Performance Functions (SPFs) for all types of roads using cross-validation techniques. This approach will enhance the reliability of the SPFs, especially by considering the percentage breakdown of the traffic composition, particularly the proportion of trucks on the road, which significantly impacts safety.

However, it is essential to acknowledge some limitations of this research.

1. Applicability to different road types: The RI results have been validated mainly in Europe for two-lane rural roads with low to medium traffic flow, and their applicability to other road types and traffic conditions needs to be carefully considered.

2. AADT limitations: The Average Annual Daily Traffic (AADT) for the road segment falls beyond the limits of the HSM SPFs, which might affect the accuracy of certain predictions based on this criterion.

3. Equipments and tools: The lack of specialized tools and equipment, such as tablet checklists connected to GPS and cameras, hindered the road inspection process from being as efficient as the European approach. Implementing these advanced tools could streamline and enhance the inspection process.

4. Crash data availability: The unavailability of comprehensive crash data for Egyptian roads, which may have resulted from underreporting, represents a significant data limitation. Addressing this issue will require improved data collection mechanisms to facilitate more reliable safety assessments.

Addressing these recommendations and limitations will pave the way for more robust and context-specific road safety assessments in Egypt, leading to more effective and targeted safety improvements on its road network.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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