Road safety performance indicators for the interurban road network

George Yannis[1a], Wendy Weijermars[b], Victoria Gitelman[c], Martijn Vis[b], Antonis Chaziris[a], Eleonora Papadimitriou[a], Carlos Lima Azevedo[d]

[a] National Technical University of Athens, Greece
[b] SWOV Institute for Road Safety Research, the Netherlands
[c] Technion, Israel Institute of Technology, Israel
[d] LNEC National Laboratory for Civil Engineering, Portugal

Abstract

Various Road Safety Performance Indicators (SPIs) have been proposed for different road safety research areas, mainly as regards driver behaviour (e.g. seat belt use, alcohol and drugs etc.) and vehicles (e.g. passive safety); however, no SPIs for the road network and design have been developed. The objective of this research is the development of an SPI for the road network, to be used as a benchmark for cross-region comparisons. The developed SPI essentially makes a comparison of the existing road network to the theoretically required one, defined as one which meets some minimum requirements with respect to road safety. This paper presents a theoretical concept for the determination of this SPI as well as a translation of this theory into a practical method. Also, the method is applied in a number of pilot countries namely the Netherlands, Portugal, Greece and Israel. The results show that the SPI could be efficiently calculated in all countries, despite some differences in the data sources. In general, the calculated overall SPI scores were realistic and ranged from 81-94%, with the exception of Greece where the SPI was relatively lower (67%). However, the SPI should be considered as a first attempt to determine the safety level of the road network. The proposed method has some limitations and could be further improved . The paper presents directions for further research to further develop the SPI.

Keywords: road safety, performance indicators, road network, pilot studies.

[1] Corresponding author: Ass.Prof. George Yannis
National Technical University of Athens, Department of Transportation Planning and Engineering
5 Heroon Polytechniou str. GR-15773 Athens
Tel: +302107721326, Fax: +302107721454
E-mail: geyannis@central.ntua.gr

1. Introduction

In order to monitor the efficiency of road safety measures and road safety progress in general, the most common indicators are the numbers of accidents, fatalities and injuries. These numbers, however, are often not sufficient to illustrate the level of road safety, as they depict the “worst case” of unsafe operational conditions of the road traffic system. Moreover, counts of accidents and casualties sometimes do not reveal the processes that produce them. Therefore, additional safety indicators are required for assessing the safety conditions of a road traffic system and for monitoring their progress (ETSC, 2001; Wegman et al, 2008).

Road Safety Performance Indicators are defined as measures (indicators) that reflect the operational conditions of the road traffic system that influence the system’s safety performance (Hakkert et al, 2007). The SPIs' purpose is to reflect the current safety conditions of a road traffic system; to measure the influence of various safety interventions and to enable comparisons between different road traffic systems (e.g. countries, regions, etc). SPIs may also provide information about underlying causes of accidents. They may concern particular groups of road users e.g. children, new drivers or professional drivers, or compliance with important safety rules e.g. seat belt use, or cover specific areas such as the urban road network or the trans-European network (EC, 2003).

SPIs have been increasingly researched during the last years, with particular emphasis on methodological and data issues (Wegman et al, 2008; Assum and Sørensen, 2010). Moreover, there is a rapid development of composite indicators e.g. indexes which are a combination of individual indicators (de Leur & Sayed, 2002; Hermans et. al., 2008; Gitelman et al, 2010), since the multidisciplinary character of road safety implies that policymakers should take various influential factors into account.

Within SafetyNet, a 6th FP European Integrated Project, Safety Performance Indicators were developed for seven road safety related areas, namely alcohol and drug-use, speeds, protective systems, daytime running lights, vehicles (passive safety), trauma management and roads (Hakkert and Gitelman, 2007). An exhaustive literature review on SPIs (SafetyNet, 2005) was carried out in the SafetyNet project, and demonstrated that there were no SPIs for road networks in use. However, based on the Sustainable Safety approach (Koornstra et. al., 1992; CROW, 1997), Dijkstra (2003) proposed a framework to assess network and design quality aspects of a safe road infrastructure at the regional level.

The objective of the research presented in this paper was to develop an SPI for the road network, which may be applicable in different countries and may be used as a benchmark for cross-country comparisons. In general, the safety of a road transport system strongly depends on the layout and design of the road infrastructure. Many ongoing practices in infrastructure research apply sampling of casualty data for safety assessment. In addition, accident prevention can be improved by early assessments of safety hazards, i.e. by monitoring the physical appearance of the road environment and the operational conditions of traffic. Thus, SPIs for roads aim to assess the safety hazards in relation to infrastructure layout and road design. Therefore, within SafetyNet, two SPIs were considered for roads: a road network SPI and a road design SPI. The method proposed by Dijkstra (2003) was used as a basis to formulate the road network SPIs, where for road design SPI the European Road Assessment Programme (EuroRAP) experience (Lynam et al, 2003, 2004) was examined. The paper presents the rationale behind the road network SPI, the methodology developed for estimating the SPI and the results of its first application through a number of national pilot studies, each one focusing on a different country region. The SPI is still in the development phase and the proposed methodology is just a first suggestion that could be improved.

2. SPI development for road networks

Wegman and Aarts (2006) discuss five principles that are essential for a safe performance of a road transport system. Four of these principles are relevant for the road network. First, it is important that roads are monofunctional and are part of a road network that is hierarchically structured (functionality principle). Second, in case speeds are high, different types of road users and traffic driving in different directions should be physically separated from each other (homogeneity principle). Third, road course and road user behaviour should be predictable by a recognizable road design (predictability principle). Fourth, the road environment should be forgiving when an accident occurs (physical forgivingness principle).

From this perspective, it is important to assess the safety of a road network at two levels:

- The road network level; the right road should be located at the right place from a functional point of view, i.e. the road category of a road should be appropriate given its function in the road network.
- The road design level: individual roads should be designed in a safe way

Within the SafetyNet project, SPIs were developed for both levels. This results in two SPIs: the road network SPI and the road design SPI. Although this paper focuses on the road network SPI, the road design SPI will be discussed briefly for completeness purposes.

2.1 Road Design SPI

The European Road Assessment Programme (EuroRAP) was designed as a complementary activity to the European New Car Assessment Programme (EuroNCAP), developed in the 1990s. According to EuroRAP (Lynam et al 2003, 2004) a rating system for roads should help optimize the combined effect of road and vehicle safety. EuroRAP was piloted to rate Europe’s various roads for safety, while currently it is distributed throughout the world. One of the tools suggested by the EuroRAP for estimating road infrastructure safety is the EuroRAP Road Protection Score (RPS). The RPS is a measure for the protection that is provided in relation to three main accident types: run-off road, head-on impacts and severe impacts at intersections. EuroRAP designed a method to calculate the RPS for each road segment or route, expressed in one to four stars, depending on a number of road characteristics. The classes or values that are used for the scoring of each road characteristic are: speed limit, median treatment, hard obstacles or barriers (type and placement), road site areas (cut and embankment), junctions and intersections (type and access). For more information on the EuroRAP RPS see Lynam et al (2003), (2004) and iRAP (2009). In this way, the EuroRAP RPS assesses to some extent whether the homogeneity principle (separation of directions at medium and high speeds) and the physical forgivingness principle are met.

The RPS focuses on the road design and appears to relate to the same type of philosophy that is being aimed at in SafetyNet SPIs for roads. Therefore, it was decided to adopt the EuroRAP RPS as a prototype for the road design SPI. The road design SPI was applied to a Dutch case study (Hakkert and Gitelman, 2007), which demonstrated the possibility of calculation of the road design SPI for the road network once the EuroRAP RPS scores are available for each road section. However, further implementation of the EuroRAP RPS scores is required for a co-operative framework to be established between the SafetyNet team and the EuroRAP.

2.2 Road Network SPI

This section firstly describes the concept of the developed SPI (2.2.1) which serves as a guideline for the development of more specific SPI applications. Such an application is subsequently described in sections 2.2.2 and 2.2.3 which present the translation of the SPI concept into a practical method.

2.2.1 Road network SPI concept

The road network SPI is based on a quantitative method for the assessment of network and design quality aspects of a safe road infrastructure at the regional level developed in a Dutch study by Dijkstra (2003). The purpose of this study was to compare the existing road network to the theoretically required roads, defined as those which meet some minimum requirements with respect to road safety. Recently, this method was further improved and used in studying the relationship between network design, route choice and safety (Dijkstra, 2011). The classification method of urban areas in the Dutch study originated from the rather descriptive and qualitative method of the German guidelines for road categories (FGSV, 1988). These guidelines defined a classification of roads and urban centre types in a qualitative way. In the Dutch study the method of FGSV has been adjusted to a more quantitative method for the assessment of the infrastructure.

The road network SPI aims to measure whether the right road is on the right location. It is defined as the percentage of appropriate actual road category length, per road category. This can be mathematically expressed as:

$$SPI(T_i) = \frac{\sum_n \left(L_{t_i}^{T_i} \middle| t_i \geq T_i\right)}{\sum_n L_{t_i}^{T_i}} \qquad (1)$$

where:

T_i : is the theoretically required road category i:{six categories, from AAA to C}

t_i : is the actual road category i:{six categories, from AAA to C}

n : is the number of road connections

$SPI(Ti)$: is the value of the safety performance indicator for road category T_i

L_{ti}^{Ti} : is the actual road length which should theoretically be of category T_i and actually is of category t_i

The basic idea behind the developed SPI is that the traffic demand determines the type of road required. The SPI then measures to what extent the actual roads in a network are appropriate, given the theoretically required roads.

To estimate the above SPI, the theoretically required road categories between centres need to be defined. To achieve this, initially, the traffic demand between pairs of centres *a* and *b* should be obtained. This will be derived by a formula of the following form:

$$D_{ab} = f\left(X_a^1, X_a^2, \dots, X_a^i, \ \ X_b^1, X_b^2, \dots, X_b^i, \ \ X_{ab}^1, X_{ab}^2, \dots, X_{ab}^j\right) \qquad (2)$$

where, variables X_a, X_b and X_{ab} are the determinants of the traffic demand between centres *a* and *b,* while *i* and *j* indicate the number of variables. Variables X_a and X_b concern each of the two centres independently (i.e. population, business, industry, tourism, culture), while variables $X_{\alpha b}$ concern both centres (i.e. distance, terrain, etc)

The actual traffic volume between centres (which is required to define the theoretically required road category) will be derived from the traffic demand. Due to the fact that several connections, with different route costs (distance, time, comfort, safety etc) might exist between pairs of centres, traffic volumes resulting from the respective demand need to be derived from an appropriate traffic assignment model (Sheffi, 1985).

However, the purpose of the road network SPI is to determine whether two centres are connected by an appropriate road, thus only one connection between each pair of centres should be evaluated. The criterion to select the most appropriate connection depends on policy (i.e. fastest route vs safest route). Therefore, the traffic volume resulting from the previous traffic assignment for the selected connection will be used to determine the theoretically required road category for this connection:

$$T_i = f(Q_i) \qquad (3)$$

It should be mentioned that although the above formula implies that the theoretically required road category is only a function of traffic volume, in practice, the way this relationship is established can be determined by additional characteristics like the level of service, the road accident risk, the generalised cost etc.

Once the theoretical road categories required for each connection are determined, and the data concerning the length and category of the actual connections are available, equation 1 can be used for the calculation of the SPI.

2.2.2 Road network SPI development

In order to translate the above theoretical concept into a practical method, which can be applied to several countries (with limitations in comparable data), and to enable cross-country comparisons, a number of assumptions (which will lie at the basis of the developed road network SPI) should be made. In the formulation of the SPI proposed here, these are the following:

Assumption 1: Two centres that are in each other's area of influence generate traffic to and from each other
Assumption 2: The size of centres determines the traffic demand between those centres
Assumption 3: All traffic between two centres uses the same road
Assumption 4: The traffic demand determines the type of road necessary: more traffic requires a higher-level road

Concerning the first and second assumption, there is a need to quantify the relation between centre size and traffic demand. For the rest of this paper, the following definitions are used:

Definition 1: A centre (C) is defined as a geographically localized area where people travel to and from
Definition 2: The size (N) of a centre is defined as the extent to which the centre generates traffic
Definition 3: Traffic demand (D) between two centres is defined as the number of motor vehicles travelling between the centres

Figure 1 to be inserted here

Quantifying the relationship between the size N_1 and N_2 of centres *C1* and *C2*, and the traffic demand D_{12} between these centres means finding the following function D:

$$D_{12}= D(N_1,N_2) \qquad (4)$$

It should be noted that the direction of the traffic flow is not taken into account. Without using measurements, a simple function can be derived by assuming that D_{12} linearly depends on both N_1 and N_2 with the same coefficient (*c*). This yields the following function:

$$D_{12} = c(N_1+N_2) \qquad (5)$$

Assumption 3 states that all traffic between two centres uses the same road. In reality, often multiple routes exist between two centres. However, given the fact that only one connection (the path with the “lowest cost”) between each origin-destination pair will be evaluated (assuming that all traffic is assigned to this path), it can prove valid enough to serve as a starting point. This results in the following function:

$$Q_R = D_{12} \qquad (6)$$

In which Q_R denotes the traffic volume on road *R* between centres C1 and C2. Note that equations 4 to 6 are meant to model traffic *demand*, not the actual traffic expected. Whether or not the actual traffic is free flowing is irrelevant here.

Assumption 2 states that although there are many factors affecting traffic demand between two centres (i.e. population, business, industry, tourism, culture) only the size of centres (population) is used as a proxy in this study, to simplify the process and to demonstrate the calculation of the SPI. More factors can be used in further applications of the method to provide more robust estimations of the demand between centres. In that case a more detailed method for the estimation of the demand should be adopted, using not only the current traffic flows but also the employment, trip rates, travel costs, etc (McNally, 2000).

Assumption 4 states that a larger traffic demand requires a higher road type. Higher road types generally allow for higher traffic volumes, thus this is mostly beneficial for mobility. A road safety performance indicator, though, should determine the level of safety. Therefore, Assumption 4 is valid if a higher road type for the given traffic demand (and resulting volume) is more beneficial for road safety. In this case, the level of unsafety of a road type can be defined as follows:

Definition 4: *The level of unsafety of a road type is defined by its accident density (r), defined as the average yearly number of injury crashes per km*

It is known that, for a given road type (*T*), the above defined accident density (r_T) is a function of traffic volume (*Q*):

$$r_T = r_T(Q) \qquad (4)$$

. Further on, to interpret Assumption 4, some underlying assumptions could be made:

Assumption 4.1 *A higher order road is safer at each given traffic volume*
Assumption 4.2 *A predefined maximum level of acceptable unsafety is required*

Assumption 4.3 *For a given road type T, having a higher traffic flow implies decreases the level of safety (i.e. accident density increases: $r_T(Q)$ is a positive-monotonic function)*

However, it should be noted that although assumption 4.3 holds for accident density, it does not necessarily apply for accident risk. The function of accident risk with traffic volume may not be positive monotonic.

A maximum level of acceptable unsafety should be predefined, because otherwise there is no criterion to allow for any road type lower than the highest-order road. The level of unsafety was defined as the road type accident density, r_T, so let:

r_{max} denote the maximum level of unsafety that is acceptable
M denote the number of possible road types
T_i denote the ith road type, where i = 1, .., M

Then, if r_{max} is chosen high enough, Assumption 4.3 implies that there are traffic flows Q_i (i = 1, .., M) such that $r_T(Q_i)$ equals r_{max}. Figure 2 shows this in a graphical form.

Figure 2 to be inserted here

The function $r_T(Q)$ can have different forms per road type, however, for the scope of this study it can be supposed that a multiplicative factor exists and a common risk function such as: $r_T(Q)= a(T)\ r(Q)$.

Moreover, the general form of these risk functions is provided, however, the specific form in each country can be different. On that purpose calibration of the functional forms with national data is necessary. Additionally, different maximum levels of unsafety can be used for different networks taking into account the existence of different standards due to different landscape, policies etc. in each country. Nevertheless, none of the above affects the comparison using the SPI, because it is dimensionless and reflects only the extent to which each country's national standards are achieved.

Given a maximum level of acceptable unsafety, r_{max}, ranges of traffic volumes (in red cf. Figure 2) are associated with minimally required road types. The following table shows which traffic volume range dictates which minimal road type.

Table 1 to be inserted here

2.2.3 Method for the determination of the road network SPI

The previous section discussed the rationale behind the practical application of the road network SPI. To be able to apply this theory, some steps have to be taken:

1. Decide when centres are in each other's sphere of influence
2. Determination of the traffic volumes Q_R
3. Decide what is the maximum level of unsafety $r_{\max}$
4. Determination of characteristics of road types T_1 to T_4
5. Determination of the accident density functions for the different road types and the corresponding traffic volumes.

Ideally, the areas of influence, the traffic volumes and the accident density functions are known from empirical studies and the maximum level of acceptable unsafety is defined by policy makers. However, in reality, traffic volumes between centres depend on various factors and are difficult to obtain in a simple way. Moreover, knowledge about exact quantitative relations between traffic volumes, road characteristics and accident density is limited. As a result, traffic volumes and road types are unknown. Empirical research on these functions was beyond the scope of this research. Therefore, some choices were made to be able to apply the theory from the previous section.

So, in practice, the steps taken for the estimation of the indicator were the following:

1. Decide when centres are in each other's sphere of influence
2. Determination of the populations P_i, generating the corresponding traffic volumes Q_i
3. Determination of the characteristics of road types T_1 to T_4
4. Determination of theoretical road categories T_i corresponding to the maximum level of unsafety r_{max}, for pairs of urban centres with given population size

To obtain a road network SPI that allows for international comparisons, an internationally harmonized road categorization is proposed. Table 2 shows the minimal requirements for different road categories that are proposed within SafetyNet. Roads are classified into six categories ranging from AAA to C. This classification is restricted to rural roads and motorways.

Table 2 to be inserted here

These road types are assigned to connections between different combinations of centre sizes. Table 3 shows which road categories are assumed to be necessary between different combinations of centre sizes. It is herewith stressed again that this table is not based on empirical evidence, but on expert judgement. Therefore, the classes in table 3 should not be considered as strict classes but as an indication.

Table 3 to be inserted here

The classification of the types of centres is adopted from Dijkstra (2003). He distinguishes five types of centres, based on the number of inhabitants. This implies that only the number of inhabitants is assumed to be relevant for the amount of traffic that is generated by a centre. As mentioned before, in reality, also other factors, such as industry, airports and tourist attractions, affect the amount of traffic that is generated. When applying the method, special consideration should be given to these situations.

To determine which centres should be connected to each other in a given region or country, we used the so-called 'circular search areas‘, in line with hierarchical graph theory (Nystuen J. D., Dacey, 1961, Gross and Yellen 1998). According to this method, for each urban or rural centre examined, a circular search area is drawn. This circular search area is determined by the distance to the closest centre of the same type: the centre of the circular search area is the location of the urban centre assessed and the radius of the circle is described by the shortest distance to the closest centre of the same type. The area within each circle can be seen as the area of influence of that specific town or village. Within this area, connections to other centre types are considered. Table 4 shows which types of centres are searched for. It is suggested that connections between centre types of very different size, for instance 1 and 4, 1 and 5, 2 and 5 etc., are not meaningful to examine. The reason for this is that it is highly unlikely that such connections exist at all. The search area for connections between type 3 and type 5 centres is adjusted (from the centre type 3 to the nearest centre type 4). This prevents taking into account centre types 5 which probably do not have a relation with the centre type 3.

Table 4 to be inserted here

As an example, figure 3 shows the application of the methodology from the Portuguese pilot project. More specifically, the circular areas within which connections are sought are presented according to the criteria of Table 4. The urban centre ‘Albufeira’, for example, is classified as type 3, having thus two different circular search areas for connections with type 4 and type 5 urban centres.

Figure 3 to be inserted here

The next step is the identification and matching of the actual (existing) road connections, in relation to the theoretical ones. In this step, the road categories of the theoretically required connections are compared to the actual ones. In order to perform this step, the actual connections have to be identified and the roads that are part of the actual connection need to be categorized according to the SafetyNet road categories presented in Table 2.

The identification process depends mainly on the specific criteria chosen to represent the route choice by drivers. Based on the Sustainable safety approach, the SafetyNet identification procedure is carried out in two steps. First, all existing connections are filtered using a detour factor that limits the total length of the connection. Initially, it was decided that the actual connection between two cities should be less than 1.6 times the Euclidean distance between the cities. This detour factor is similar to the detour factor applied by Dijkstra (2003) and is evaluated in the pilot studies presented in the next sections. Secondly, it is also possible that more than one connections between two centres are indentified from the previous step. In that case, one of the connections needs to be selected as the actual connection to be evaluated. This can be done in several ways, e.g. using a route planner or a GIS application, depending on the instruments and data available.

For each connection that is finally selected, the SafetyNet road category should be determined by translating the national road categorization into the SafetyNet categorization. An actual connection between two centres can consist of several road sections with different road categories. Moreover, a connection may consist of a part inside the built-up area and an interurban / rural part. In the context of the present research, only the interurban / rural part of the connection needs to be assessed. For each connection, the road categories that make up the rural part of the connection, as well as their lengths, should be determined.

The final step is the calculation of the SPI. This is made by comparing the theoretically desired and the actual road category and by aggregating the scores for each road category. In this way, for each theoretically required road category, the percentage of actual roads that meets the requirements can be calculated. The calculation of the SPI for a given road category was provided in the previous section (2.2.1) by equation 1.

3. Road network SPI application in pilot studies

The developed methodology was evaluated through a number of pilot studies carried out in the Netherlands, Greece, Israel and Portugal. Their characteristics are summarized in Table 5 and are presented in detail below.

3.1. Pilot studies characteristics

For the Netherlands, The Province of South Holland was chosen as the pilot area. The province has 3.455.097 inhabitants. The provincial capital is The Hague which is one of the 82 local authorities in the province. The province has a road network of 15.884 kilometres made up of 740 kilometres of State roads (freeways with speed limits of 100 and 120km/h); 694 kilometres of provincial roads (distributor roads with speed limits of typically 80km/h and sometimes 100km/h); 2.025 kilometres of Water Board roads (rural access roads with speed limits of 60km/h) and 12.425 kilometres of local authority roads (80km/h rural distributors, 50km/h urban distributors and access roads with 30km/h limits).

The region of Peloponnese, situated in south Greece was selected for the calculation of the SPI in Greece. The region has 1,045,000 inhabitants and an area of 21,493 square kilometres. It covers a large geographical area and it includes numerous cities/towns of various sizes and populations. Finally, it includes all types of roads in a relatively “closed” interurban road network (7730 kilometres in total, 6979 kilometres of which were examined) and it has a mountainous mainland, which is interesting to study.

For Israel, the whole country served as a pilot area and the road network SPI was calculated for a sample of the road network. The majority of population is concentrated in Tel-Aviv, Central, Haifa and Jerusalem districts. The Northern district is more densely populated, while the Southern district is the largest and is scarcely-populated. A significant part of the Southern district is covered by deserts. In 2006, the average population of the country was 7,054,000 inhabitants. The total road network is 17,686 kilometres, of which 7,854 kilometres are rural roads. The list of urban areas considered was the whole list of administrative units (municipalities/ towns/ villages/ communities) of the country, which is maintained by the Central Bureau of Statistics. Urban centres for the pilot were sampled based on this list.

For the Portuguese pilot study, the national continental territory bellow Tagus River was chosen as a study area. This area is around 34,000 square km and has a total of 1,700,000 habitants (2006 estimation). This area has several types and sizes of urban areas, various road types and also good conditions for urban areas identification, and thus satisfies the criteria for the implementation of a pilot study. However it is not representative of all urban centres at the country level. The pilot area is characterised by a very disperse human occupation except in the Setúbal Peninsula and the South coast of the Algarve. Both these regions are also characterised by intense industrial, commercial or touristic activities. Data related to territory occupation (geometry, population and number of houses) was collected for a total of 438 Freguesias, the Portuguese smallest administrative unit level, from the National Institute of Statistics and the Portuguese Geographic Institute. The road network data was obtained from the InfoPortugal S.A. geo-referenced data base.

Table 5 to be inserted here

3.2. Data availability

In general no significant obstacles concerning data availability were faced within the pilot studies. However, a number of issues were raised and should be highlighted. Firstly, it was not always possible to define urban and rural centres by the boundaries of the built up area due to lack of data availability on this level. For example, in the Netherlands, data was available for municipalities instead of villages/cities (one municipality may consist of several villages that are separated by rural area). Moreover, in Israel, Portugal and the Netherlands, a number of urban centres are very close to each other such that no rural area exists between them. In order to overcome this obstacle, each centre (village, city) that is surrounded by rural area should be defined as one centre.

Furthermore, despite the fact that the size of the centre is the only measure which defines the centre type, it was revealed that some centres with facilities of special interest (like ports) would not be taken into account in case only the number of inhabitants was considered. These places generate and attract traffic due to their facilities and therefore need to be included as centres. Moreover, in a few cases, using the population as a proxy for demand, centres were classified to a lower category considering the amount of traffic that was generated or attracted by them. In case centres were defined on the basis of other characteristics, like industry and recreational areas, indicators would be needed for these factors, e.g. the surface of industrial area or the number of employees. Data on these indicators were not available (or at least not easy to obtain) in the pilot countries. In Greece and Portugal, the problem was solved in a more pragmatic way; the list of centres was evaluated and centres that were considered missing or misclassified were added or upgraded by experts with local knowledge.

A final issue with regard to the classification of the centres is that the limits of the classes were chosen from the Dutch study of Dijkstra, (2003). By modifying the limits, the distribution of centres across types will change along with the theoretically required network.

3.3 Determination of theoretical connections

In the pilot studies of Israel and Portugal the process for the determination of the theoretical connections through the circular search areas was automated, whereas Greece and The Netherlands determined the theoretically required connections manually. In case some theoretical connections were found to be missing, this was mainly due to missing centres (i.e. points of special interest but with low residing population, being erroneously classified as Type 5). In Portugal, not all relevant theoretical connections were identified by the search areas, due to relatively small search areas (caused by short distances between two centres of the same type). Moreover, some small urban centres (type 5 centres) were not connected to any higher class centre since it was not in any search area. Such connections, which were considered missing, were added manually in the pilot studies.

On the contrary, in some cases, theoretically required connections were determined that could not be found in reality. This was mainly observed when a natural barrier existed between centres. The search circles do not take natural barriers into account and determine the distance on a straight line. In case of a barrier (mountains, rivers, lakes, etc), cities that are geographically close may lack a direct connection. This was the case in several connections in the Greek pilot. As discussed below, these connections were considered with special attention when identifying and matching the actual connections.

Finally, the use of circular search areas may, in rare circumstances, result in excessive connections (that normally should not be assessed). For example, if the distance between two type 4 centres is very long, the radius of the search area will be great and thus will result in meaningless type 4 - type 5 theoretical connections. A possible way to overcome such a problem is to discard this circular area and use a new radius instead, defined by the distance to a closer type 5 centre. Such needs for exceptions could occur easier in areas with mountainous layout as the distribution of centres can be quite uneven.

The theoretical connections resulting from the application of the methodology in each pilot country are shown in Figure 4.

Figure 4 to be inserted here

3.4 Identification and matching of actual connections

Pilot countries used different methods to define the actual connections between centres. Greece and the Netherlands used a route planner to select an actual connection and searched for the fastest route. Portugal built a routing model in a GIS tool for the identification of the fastest route without hierarchy preference. Israel used a GIS tool and searched for the shortest route, going through the highest road classes.

It is important that a safe route (using appropriate road categories) is selected for each connection. In general, the fastest route satisfied this criterion in the Netherlands, Greece and Portugal, while the basic connection was found appropriate for Israel. However, in some cases in the Netherlands, the fastest route was not the safest. Therefore, the actual connections need to be evaluated by an expert with local knowledge and in case a safer route exists that is somewhat longer than the fastest, it should be selected instead of the fastest route.

To specify whether an actual connection should be assigned, a detour factor was applied. This factor is defined as the rate of the actual distance to the Euclidean one. The initial maximum value selected for the detour factor was 1.6. If for a specific connection the detour factor had a value greater than 1.6 the connection would not be assessed. However, it was observed that this initial value was not appropriate for all connections in the pilot areas. More specifically, while the detour factor was found appropriate for the Netherlands, in Greece and Portugal large natural barriers (like mountains and sea) often cause distances between centres to be higher than 1.6 times the Euclidean distance, given that the respective connections do exist. On that purpose, the detour factor should be used in a pragmatic way. In principle, the detour factor should be 1.6 and connections exceeding this detour factor should be further analysed. In case there is a (natural) barrier causing a detour factor to be higher, a detour factor of 2 can be accepted. Another possibility in dealing with natural barriers is to remove a theoretically required connection. This can be done in case the barrier makes travel between these cities unlikely. Finally, in case the detour factor is too high and the conclusion is that an actual connection is indeed missing, this should be noted as a flaw in the road network.

In case a route is selected as an actual connection, the roads that constitute the actual connection should be classified on the basis of the SafetyNet road categorization (see Table 2). This appeared to be possible in all pilot countries, although the data sources and information used differed per country. For some pilots, knowledge of the local situation was necessary in order to determine the road categories.

The actual connections in each pilot country are shown in Figure 5, while the actual road length per road category for these connections is shown in Table 6.

*** Figure 5 to be inserted here ***

*** Table 6 to be inserted here ***

3.5 Calculation of the SPI

The final step, which entails the actual calculation of the SPI value, is straightforward if the preceding steps of the method are applied. For each connection, the length (expressed in km) of the connection that meets the requirement and the length that does not was determined by using equation 1. By summing up the results for each (theoretically required) road category, the proportion of appropriate road category was calculated for each road category. It must be noted that, according to Table 3, class C roads are required only between type 5 centres. However, connections between type 5 centres were only assessed in the Portuguese pilot study therefore no class C roads are stated as theoretically required in the Dutch, Israeli and Greek pilot studies. This section presents the most important findings from the calculation of the SPI for the four pilot countries. Additional information as well as more analytical results concerning each pilot study can be found in Weijermars et. al., 2008.

The theoretically required road network was found to differ significantly between the case study areas. In the case study area of Greece, the largest centre was of type 2 (and there was only one) while several type 5 centres existed. In the pilot area in the Netherlands, two type 1 centres existed and the area is densely populated. This imposes different requirements on the road network and makes it difficult to compare the scores for different countries. In general, the resulting scores seem quite realistic, although the scores of Greece seem low compared to the other pilot areas.

In the Netherlands, the road network SPI was calculated for each road category and the results are presented in Figure 6. It can be observed that for most road categories, the actual roads comply quite well with the theoretically desired road category: 87% of the required AAA roads are in fact AAA roads, 87% of the roads that need to be AA are in reality AA or higher, and 91% of the required B roads are in fact B or higher. However, the requirements for BB road are less often met, with about 22% of the roads being of a lower category. Overall, about 82% of the road network in South Holland meets or exceeds the SafetyNet classification requirements.

Figure 6 to be inserted here

To an extent this score is influenced by the presence of higher order roads fulfilling dual roles, as high order connection but also as lower order connection. If one looks at individual classes, 22% of the roads that should be BB are of a lower category. This is caused by the extensive use of single carriageway rural roads in the Netherlands which, according to SafetyNet, should be double carriageway. Considering the area already occupied by roads, it is hardly likely that the majority of these roads could be rebuilt to comply with these requirements. Besides that, many of these roads have overtaking bans and other traffic management measures which conform to many of the Dutch regulation requirements and which are currently not considered by the SafetyNet approach. Based on the results of the pilot in South Holland consideration should be given to reviewing the functional requirements for the various road types and/or the road categories that are desired for different types of connections.

In the Greek pilot study 6.979 kilometres of road were examined, out of which 4.344 were of appropriate or higher actual road category than the theoretical one, resulting in a total road SPI equal to 66.5% in this study area. This finding is not very satisfactory overall; however a more detailed consideration of the SPI reveals an interesting picture. As shown in Figure 7, theoretical connections of type AA are met only by 10% of the total length of the actual connections. Respectively, around 52% of the total road length meets BB or higher standards. One should take into account, though, that no actual BB connections exist in the study area (dual carriageway is very rare for lower level connections in Greece). If BB and B road categories were merged, the SPI for this connection type would be extremely high in the study area. As regards lower level connections, the SPI is equal to 93% for type B connections. It is also interesting to note that about 10% of the total length of these connections corresponds to AAA and A roads, indicating that a limited number of roads is used for many connections.

Figure 7 to be inserted here

Overall, it is indicated that the total SPI score (aggregated over the road categories) is the result of putting together an increased number of lower level theoretical connections presenting a very satisfactory SPI, with a small number of higher level theoretical connections presenting a poor SPI. A great unbalance of the road network in the Greek study area is thereby revealed possibly explained by the nodes definition taking into account only the population and not other criteria (e.g. touristic attractions).

The results from the Israeli pilot study and the calculation of the SPI is presented in Figure 8.

Figure 8 to be inserted here

It can be observed that for most road categories, the actual road categories comply fairly well with the theoretically desired road category: 85% of the required AAA roads are in fact AAA roads, 89% of the required BB roads are in fact BB or higher road categories, and 81% of the required B category roads are B or higher level roads.

The requirements for AA roads are less often met: only 74.5% of the roads that need to be AA are in reality AA or AAA roads, implying that 25.5% of the connections belong to lower road categories (however the differences between the AA and BB road categories are not strict in Israeli conditions, meaning that actual BB-type connections sometimes have road design characteristics similar to the AA-type roads).

Overall, some 81% of the connections considered for the Israeli road network meet or exceed the SafetyNet classification requirements.

In Portugal, the comparison of the actual road network with the theoretically required and the calculation of the road network SPI is provided in Figure 9. It should be pointed out that no urban centres in the pilot area were classified as type 1, eliminating therefore the possibility of any AAA theoretical road connection.

Figure 9 to be inserted here

It can be observed that 75.5% of all roads that should be AA are in reality AA or higher, 86.5% of all roads that should be BB are in reality BB or higher and 95,8% of all roads that should be B are in reality B or higher. In total, 14.975 km had an actual road category appropriate or higher than the theoretical category needed, resulting in a total road network SPI of 93.7%. Type B connections are the most frequent (381 out of 693 connections). These connections have a high SPI score, justifying the high total network SPI. Type C theoretical connections are always associated with appropriate or higher classes of roads, as this category is the minimum road standard indicated by the SafetyNet classification. When Type C connections are not considered for the calculation, the total road network SPI doesn't change much (92.9%), suggesting that their contribution to the needed network is small (total Type C connection length is relatively small).

3.6 Additional observations

The pilot studies revealed a number of issues that could further improve the methodology and its efficiency on future pilots. More specifically, according to the real conditions and the particularities of each study area, the methodology can be adapted by implementing small modifications.

3.6.1 Theoretical connections

As far as the circular areas for the determination of the theoretical connections are concerned, under certain circumstances the implementation of the methodology could result in theoretical connections that normally should not be assessed. If the distance between two centres of the same type is very large, the radius of the respective circular search area would be very long resulting in connections that normally do not have sense. In that case, either a smaller circular area could be assigned based on a different criterion or the resulting theoretical connections should be logically assessed before any connection is assigned.

A detour factor of 1.6 was concluded not to be suitable for the Greek and Portugese pilot area. Detour factors ranging from 1.8 to 3 were tested. The detour factor of 1,8 seemed to be more realistic in the Portuguse pilot, while in the Greek pilot, for some connections a detour factor of 2 (and in some cases even 3) appeared to be sensible. Therefore, it can be concluded that each connection with a detour factor higher than 1,6 should be analysed separately and it should be decided on the basis of local knowledge whether a connection is theoretically needed and whether the actual connection has an acceptable detour factor.

3.6.2 Calculation of the SPI

From the observation of the results it can be claimed that an overall score estimated from the combination of all results should preferably be avoided as it could provide misleading results. The overall score was highest for Portugal, due to a very high percentage of B roads that have a high score. One overall score may give a biased view. Another possibility is to analyse the score for each connection type (type 1 centre – type 1 centre; type1 centre - type2 centre; etc) as was done in the Israeli pilot. This complicates the calculation and the interpretation of the results, but provides more insight into the exact problems.

When the results are analysed in more detail, there appear to be some road categories that have lower scores. In general, AA roads and BB roads are applied to a lesser extent, whereas the SafetyNet procedure does require this category to be examined, resulting in poorer scores for AA roads in Greece, Israel and Portugal and poor scores for BB roads in Greece and The Netherlands.

With regard to the scores of the individual connections, in some cases relatively short sections of the connections (e.g. the road sections connecting freeways to urban areas) failed. The question arises whether these sections should comply with the SafetyNet requirements or if one should allow a certain percentage of the route to be of a lower category and only base the assessment on the primary part of the connection.

4. Discussion

The pilot studies that were discussed in the previous section reveal some limitations of the proposed road network SPI. This section discusses these limitations and makes some suggestions to improve the method.

Firstly, the definition and classification of centres needs some attention. It seems logical to define a centre that is surrounded by rural area as one centre. However, this is not always possible given the data available. Moreover, the limits of the classes were chosen quite arbitrary, there is no theoretical base for these limits. Besides, also other factors than the number of inhabitants affect the amount of traffic that is generated by a centre. Production and attraction of traffic may provide more appropriate classification variables than the number of inhabitants.

Secondly, also the determination of theoretical connections has some limitations. The connections that were found using the circular search areas do not always correspond to the actual situation. Therefore, we advise to let an expert with knowledge of the local situation judge and if necessary adjust the list of necessary connections. Also, travel demand between different combinations of centres could also be determined using a (macroscopic) traffic model.

Thirdly, in many cases, various routes were possible between two centres but according to the methodology, one had to be selected as the actual connection. This step should be dealt with in a pragmatic way, using the available tools.

When assigning a route as the actual connection, it is important that this route is as safe as possible (using high road categories). Hakkert and Gitelman (2007) suggest both the fastest and safest route (the route via the highest road categories) to be determined. The safest instead of the fastest route should be selected in case this was less than 5% slower than the fastest route. This slightly complicates the method, while from the pilot projects it was generally concluded that the fastest route also uses the higher road categories. Therefore, it is not expected that this criterion would significantly improve the results. We advise to ask someone with knowledge of the local situation if there is a safer route that is just somewhat longer and if so the safest route should be selected.

Fourth, in some cases, multiple connections use the same road. In this case the theoretically desired road category could be upgraded when the estimated daily traffic volume (that follows from the combination of connections) exceeds the maximum capacity of a road category. On that purpose, the connections using each road section should be determined. Upgrading the theoretically desired categories of certain roads will have an impact on the SPI scores. In the pilot studies, this factor was not taken into account and could be considered in a further application of the method.

The resulting scores seem quite realistic in general, although the scores of Greece seem low compared to the other pilot areas. It should be noted, that the theoretically desired road network differs greatly between the case study areas. This puts different requirements on the road network and makes it difficult to compare the scores for different countries. From the results it can also be observed that it may not be wise to combine the results per road category into one overall score. The highest score was recorded for Portugal, due to a high weight of lower level roads in the total SPI score, which have a better score comparing to higher road categories.

Moreover, the theoretically desired road categories between some combinations of centres may be somewhat strict in the current method. The determination of a typical accident density function $r_T(Q)$ per road type, could allow for a more theoretically founded choice for the necessary road type given the traffic demand on a road.

5. Conclusions

This paper presents two SPIs to assess the level of safety of the (interurban) road network. The road design SPI assesses whether individual roads are designed in a safe way and is based on the EuroRAP road protection score. The road network SPI assesses whether the right road is located at the right place from a functional point of view. Mixing the road design with the road network performance indicator could potentially allow for a more complete assessment. Research on this subject is currently under way (Wegman and Oppe, 2010).

The road network SPI is discussed in more detail and is applied in a number of pilot countries. The SPI that is proposed is just a first attempt to determine the safety level of the road network. The methodology could certainly be further improved. From the pilots we conclude that it is possible to calculate the SPI scores. Moreover, the resulting scores seem quite realistic, with the exception of Greece where the SPI was relatively low. However, the method for calculating the SPI has some limitations. Most importantly, some arbitrary choices had to be made concerning the classification of centres, the amount of traffic between centres and the type of road that is necessary given the amount of traffic between two centres. We defined some directions for further research in order to further develop the SPI.

Furthermore, we recommend to investigate the relation between the SPI scores and traffic safety (for example expressed in the number of fatalities per km travelled) in order to obtain more insight into the validity of the road network SPI and the consequences of (changes in) SPI scores. Of course, a country could fit well with the categorisation and still have a high risk because of other structural factors such as unsafe driving behaviour. Therefore, the selection of the areas for such a study would have to be careful so that they have similar structural characteristics.

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Table 1. Traffic volume ranges and associated minimally required road types

Traffic volume range	**Minimally required road type**
0 to Q_1	*T1*
Q_1 to Q_2	*T2*
Q_2 to Q_3	*T3*
Q_3 to Q_4	*T4*

Table 2. Minimal requirements for different road categories

	Rural areas (outside built-up areas)					
SafetyNet road categories T_i	**AAA:**	**AA:**	**A:**	**BB:**	**B:**	**C:**
	Motorway	A-level road 1	A-level road 2	Rural distributor road 1	Rural distributor road 2	Rural access road
Functional road category	Through-road (road with a flow function)			Distributor road		Access road
Separation of opposing directions	Dual carriageway	Dual carriageway	Single carriageway, preferable with lane separation	Dual carriageway	Single carriageway, preferable with lane separation	Single carriageway
Lane configuration	2x2 or more	2x1, 2x2	1x2, 1x3, (1x4)	2x1, 2x2	1x2, 1x3, (1x4)	1x2, 1x1
Obstacle-free zone	Very wide or safety barrier	Wide or safety barrier	Wide or safety barrier	Medium	Medium	Small
Intersections	Grade-separated	Preferable grade-separated	Preferable grade-separated	Preferable roundabout	Preferable roundabout	

Table 3. Minimum required road types T_i connecting two centres of given size

Urban centre type (# inhabitants)	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 5**
Type 1 (P_1>200,000)	AAA	AAA	AA	indirectly	indirectly
Type 2 (P_2: 100,000 to 200,000)		AA	AA	BB	indirectly
Type 3 (P_3: 30,000 to 100,000)			BB	BB	B
Type 4 (P_4: 10,000 to 30,000)				B	B
Type 5 (P_5<10,000)					C

Table 4. Overview of the search for centres

Start centre type	Search for the centre of the same type (radius)	Centres in search area	Assessment of the connections between
1	The nearest 1	2 and 3	1 and 1, 1 and 2, 1 and 3
2	The nearest 2	3 and 4	2 and 2, 2 and 3, 2 and 4
3	The nearest 3	4	3 and 3, 3 and 4
3	The nearest 4	5	3 and 5
4	The nearest 4	5	4 and 4, 4 and 5

Table 5. Characteristics of the study areas

	Netherlands	**Greece**	**Israel**	**Portugal**
Pilot study region	South Holland	Peloponnese	Whole country	Territory bellow Tagus
Area (km^2)	2,818	21,493	22,073	34,000
Population	3,455,097	1,045,000	7,054,000	1,700,000
Interurban road network length (km)	15,884	7,730	17,686	28,000

Table 6. Actual road network in the four pilot countries by road category

Country	Connection type	Length (km)			
		avg	max	min	st.dev.
Netherlands	AAA	14,8	52,9	1,1	11,7
	AA	8,8	20,6	1,5	4,4
	A	6,7	12,1	3,1	3,9
	BB	5,4	18,0	1,2	3,5
	B	5,6	24,7	0,6	4,1
	C	4,3	8,2	2,0	2,3
Greece	AAA	28,6	80,8	0,9	26,8
	AA	16,4	16,5	16,2	0,2
	A	21	66,4	0,4	19
	BB	0	0	0	0
	B	12,7	116,5	0,03	18,2
	C	1,5	16,4	0,01	3,33
Israel	AAA	10,6	34,7	1,4	6,8
	AA	6,5	33,9	0,7	5,5
	A	5,1	30,9	0,5	6,5
	BB	5,2	12,3	0,8	3,1
	B	5,7	19,0	1,1	3,7
	C	2,5	8,5	0,3	1,9
Portugal	AAA	4,1	240,6	3,0	19,6
	AA	0,8	25,4	0,1	2,3
	A	0,1	5,6	0,06	0,5
	BB	0,4	5,7	0,06	0,9
	B	10,6	61,3	0,03	12,5
	C	1,1	28,6	0,02	3,7

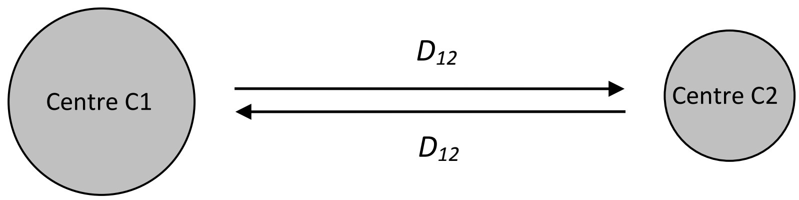

Figure 1. Traffic demand D12 between centres C1 and C2.

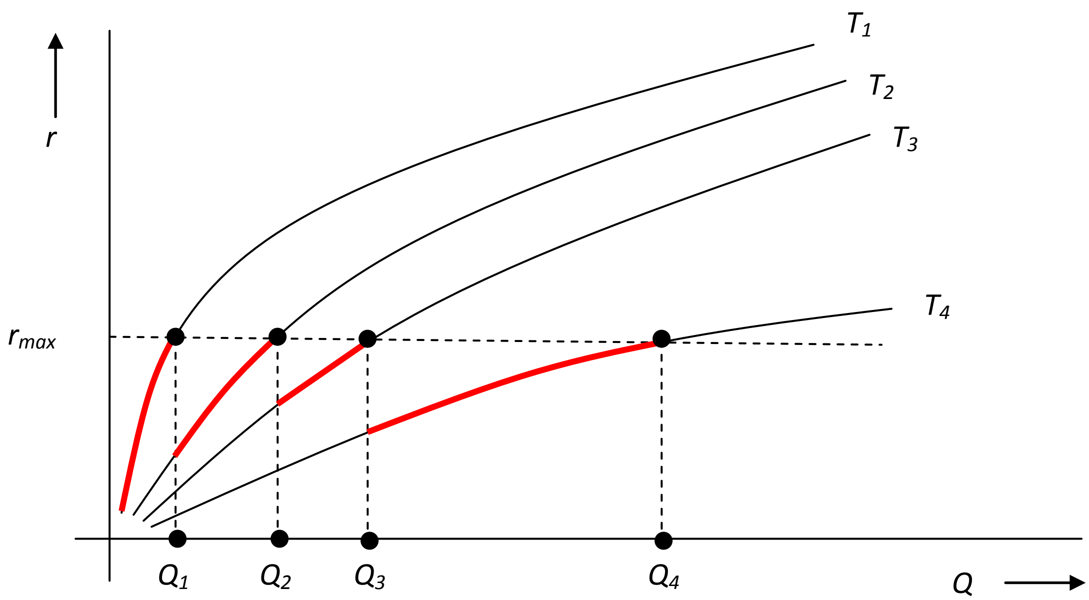

Figure 2. The relation between road accident density, r, and traffic volume, Q, for different road types, T.

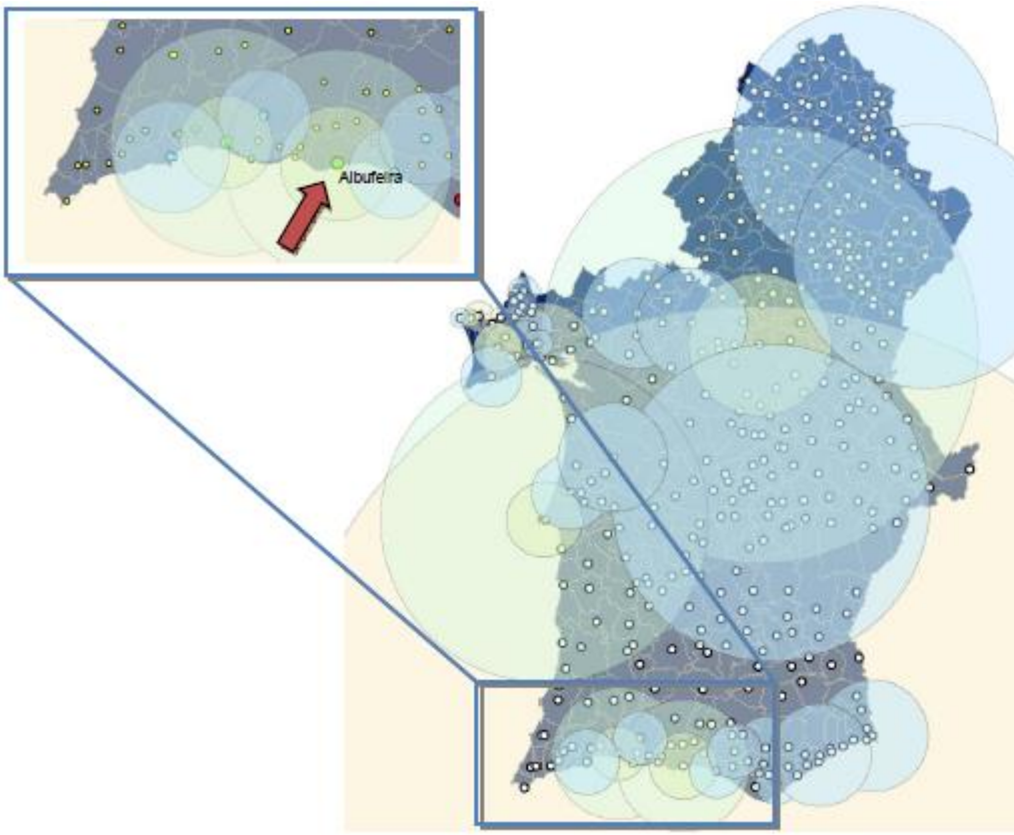

Figure 3. Circular search areas in the Portuguese study area

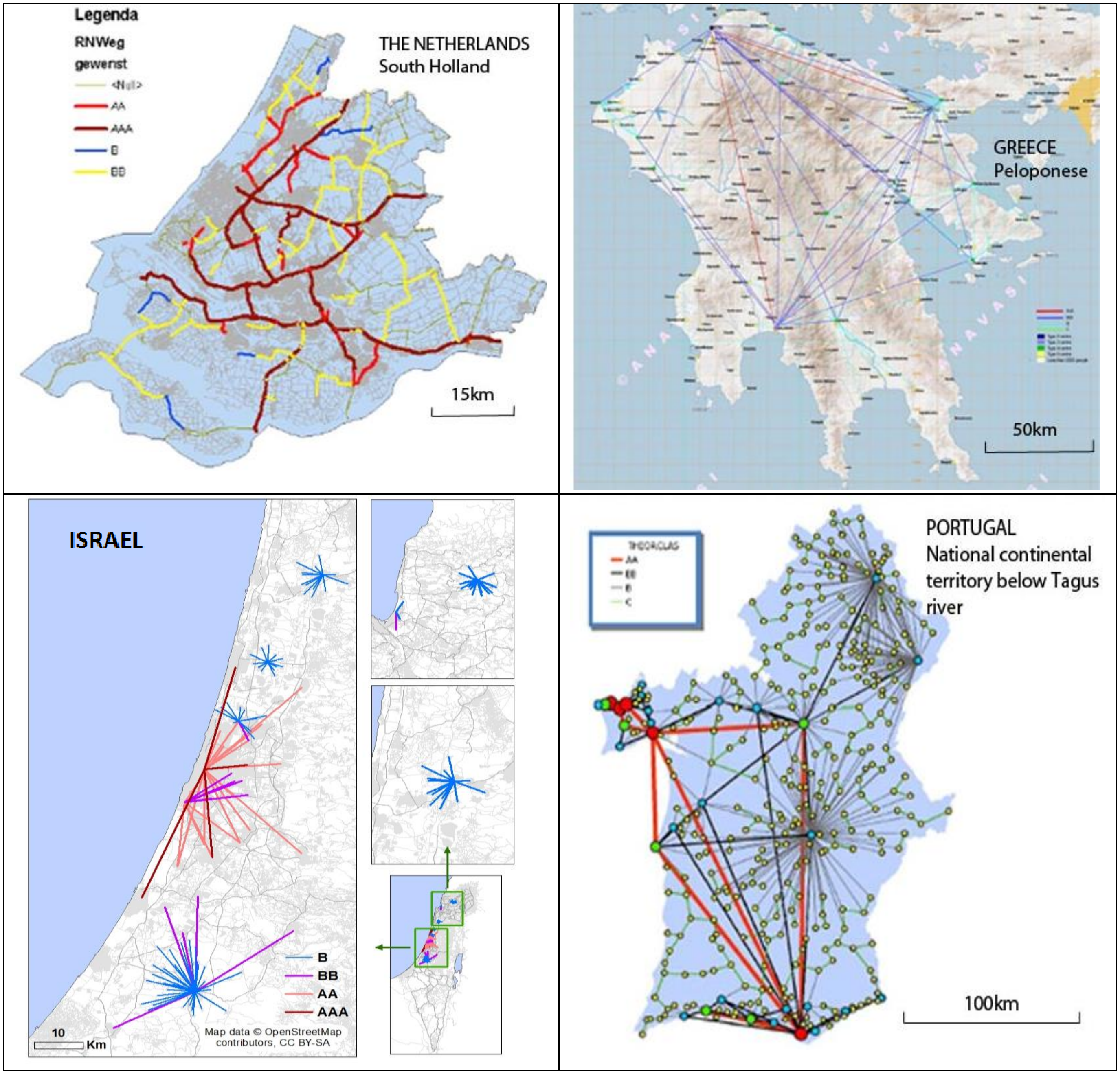

Figure 4. Theoretically required connections in the four pilot countries

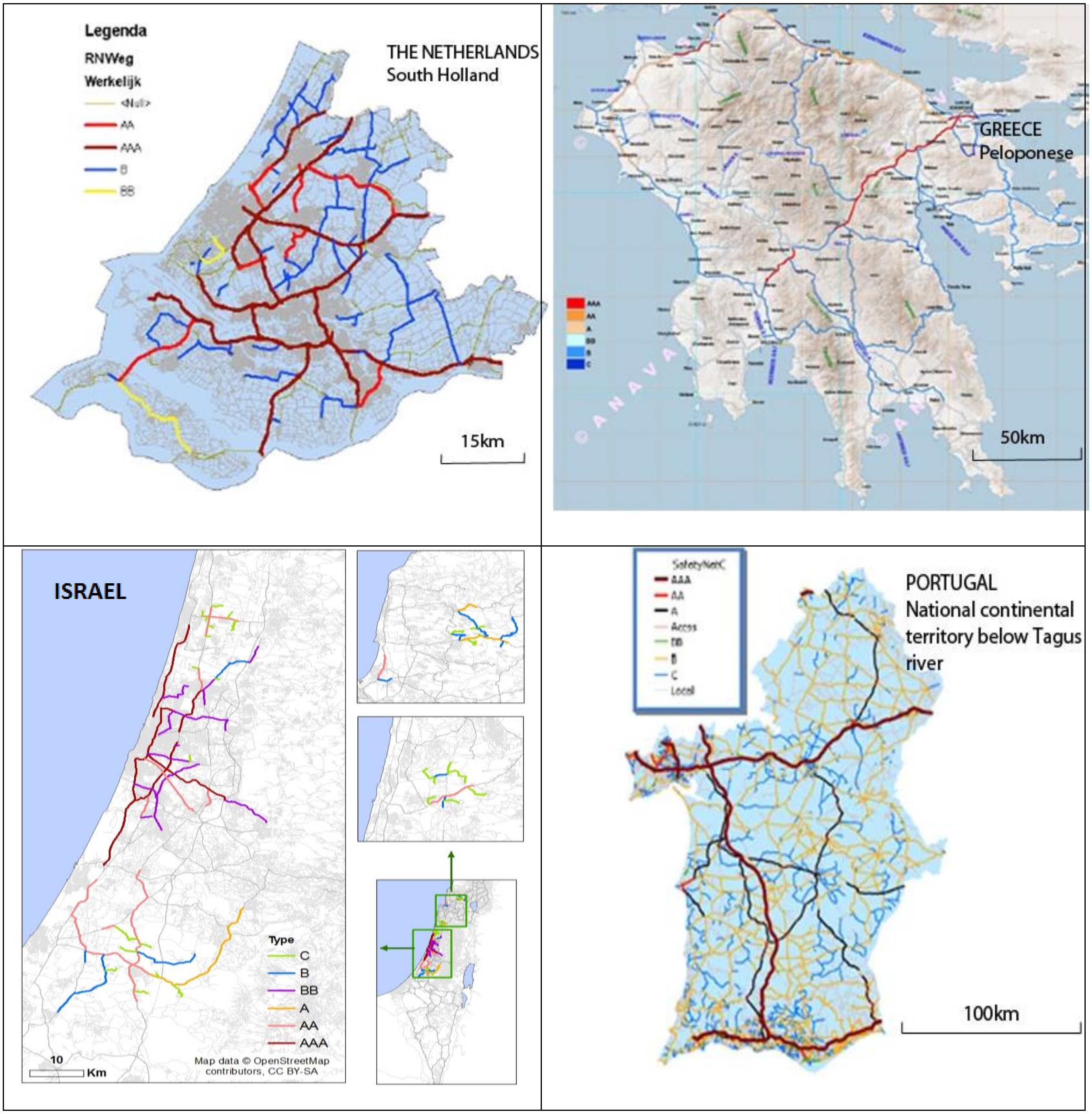

Figure 5. Actual connections in the four pilot countries

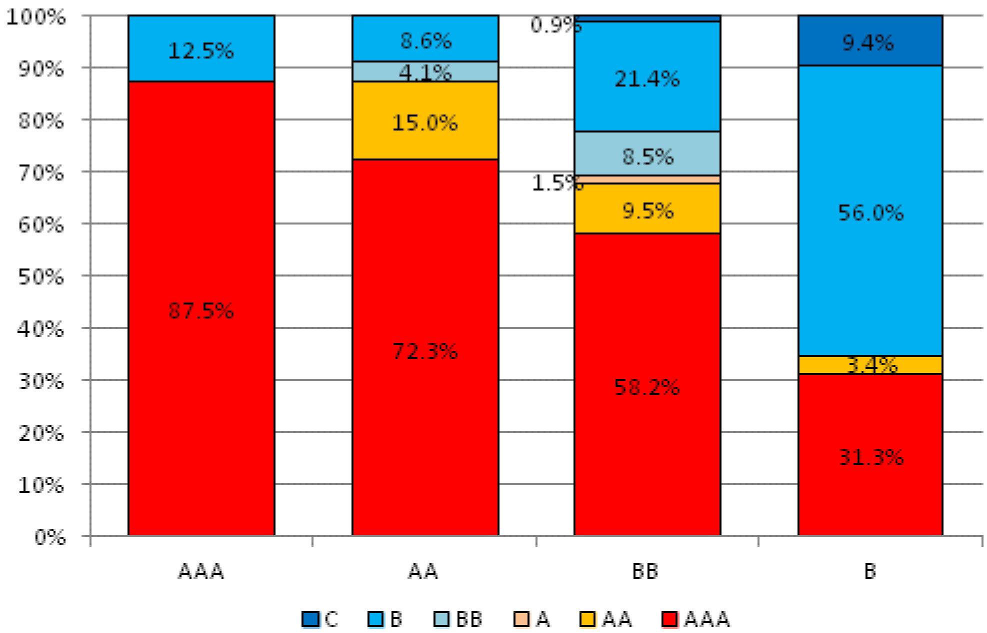

Figure 6. Percentage of roads meeting the requirements in the Dutch pilot study

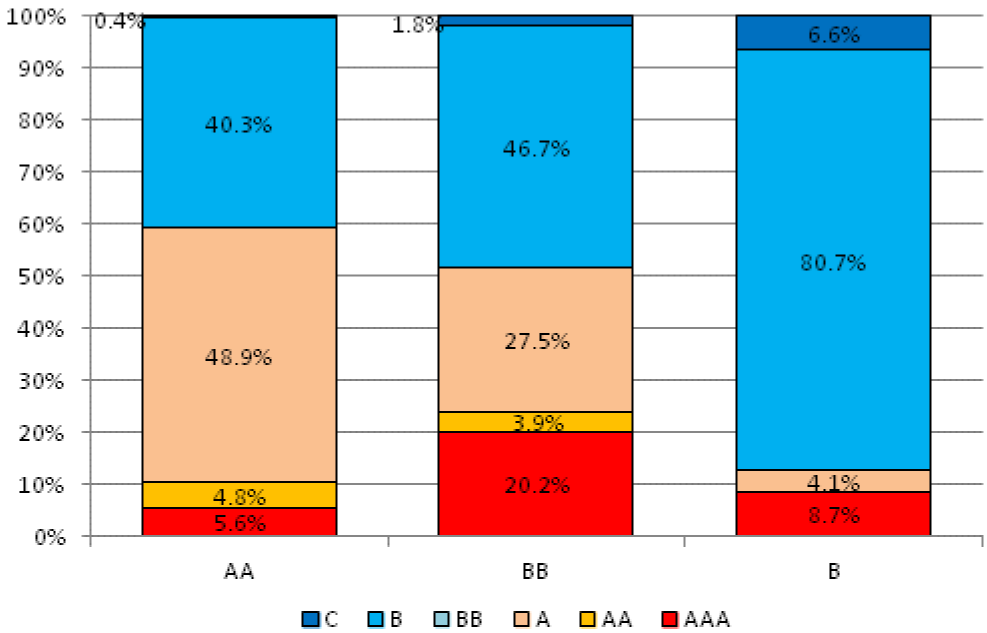

Figure 7. Percentage of roads meeting the requirements in the Greek pilot study

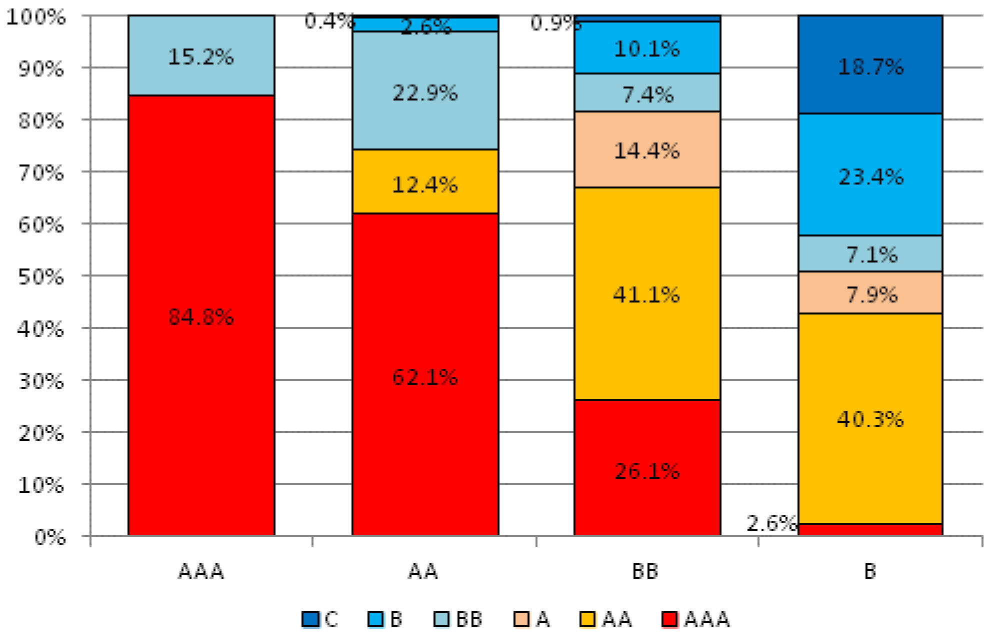

Figure 8. Percentage of roads meeting the requirements in the Israeli pilot study

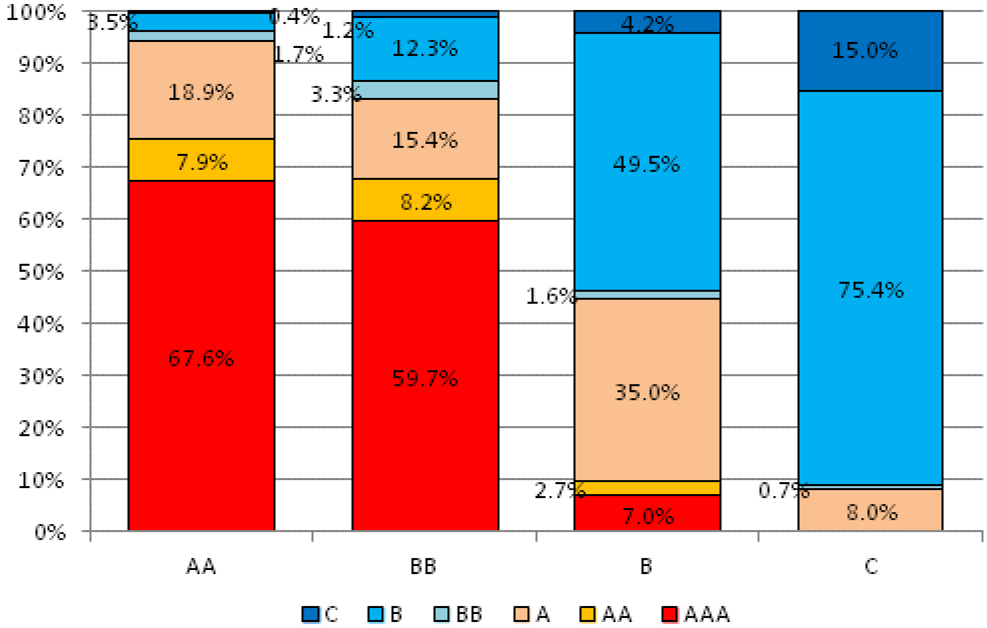

Figure 9. Percentage of roads meeting the requirements in the Portuguese pilot study