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EVALUATION OF ROAD SAFETY PERFORMANCE INDICATORS USING OWA OPERATORS

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Road safety performance indicators have recently been proposed as a useful instrument in comparing countries on their performance of road safety risk factors. New insights can be gained in case one road safety index is composed of all risk indicators. The safety performance can be evaluated, countries can be ranked, trends identified and the impact of measures assessed. However, the aggregation process is still unclear in this context. In this paper, the use of ordered weighted averaging (OWA) operators will be experimented for an evaluation of road safety performance indicators. More specifically, several basic and more advanced aggregation operators will be applied to our indicator data set and the final index scores are then compared to the number of road fatalities per million inhabitants. It is demonstrated that compensation should not be allowed too much in the road safety context. All indicators should be incorporated in the final index to some extent and weaker performances should be stressed more.

1. Problem Statement

During the past decades, there has been a steady increase in traffic volume, which resulted in continuously increasing traffic problems. Worldwide, an estimated 1.2 million persons are killed in road crashes every year and as many as 50 million are injured [1]. Besides analyzing the number of accidents and casualties, attention should be given to the underlying risk factors (e.g., speed). In the end, we want to have an idea of which measures to take to enhance the level of road safety in a country. Safety performance indicators (SPIs) are very useful in this respect. SPIs enable us to indicate the (relative) safety performance of a country and to understand the process that leads to accidents [2].

The advantage of creating one overall composite indicator over a large set of individual indicators is that a summary statistic – the road safety index – can be used for prioritizing road safety actions and benchmarking as it reduces the complexity of the road safety problem. Furthermore, ranking countries based on their index score attracts attention. In the end, we aim for a road safety index which consists of several risk factors and which is a good approximation for the number of road fatalities in a country. However, several methodological phases

need to be gone through to combine all the information, i.e., selecting appropriate indicators, normalizing the data, imputing missing values, weighting and aggregating, performing a robustness analysis, etc [3].

In this paper, we mainly focus on an essential methodological aspect, namely aggregating road safety indicators. As the concept of indicators and indexes is relatively new in the road safety field, not much attention has been paid to this topic so far. In practice, indexes are often composed using linear aggregation [4]. Nevertheless, the field of aggregation is very broad and several classes of aggregation operators are worth evaluating. Therefore, we will investigate some basic as well as more complex operators. The focus will be on ordered weighted averaging (OWA) operators, an often used and comprehensible class of operators that is interesting for this road safety problem.

After briefly describing the data set in Section 2, we will focus in Section 3 on some general concepts of OWA operators; apply minimum, maximum and average operators; and illustrate the use of expert's opinions regarding aggregation. In Section 4, the results from several aggregation options are discussed, leading to conclusions and topics for further research in Section 5.

2. Data Set

The European SafetyNet project [5] on indicators mentions seven essential road safety risk factors: alcohol and drugs; speed; protective systems; visibility; vehicle; infrastructure; and trauma care. Each domain should be measured by a set of relevant, comprehensive, reliable, specific and quantifiable indicators. The availability of consistent data for a large set of countries is a large limitation.

We collected data related to 2003 for seven indicators (one for each risk domain) for 21 European countries, from several international sources. As we are aware of the fact that the end result is influenced to some extent by the indicators chosen to evaluate a specific risk domain, we use rank numbers instead of raw values. We are more interested in the relative ordering than the exact scores and have more confidence in these robust figures. Moreover, to enhance the interpretability, we normalize all values between 0 (the worst performance) and 1 (the best performance).

The information from the seven indicators will be composed in one index. First, the data are reordered. For each country, the best performance obtains position 1, followed by the 2nd best performance, etc. Next, a road safety index score is computed for each country by multiplying the seven ordered values with the weighting vector. To assess the value of the obtained scores, we will compute the Spearman correlation between the 21 index scores (for a number of

weighting coefficient scenarios) and the number of road fatalities per million inhabitants. In the end, we want to use an acceptable operator which results in a road safety index that is able to predict the road safety output to a desirable extent. In this respect, a negative sign of all correlation coefficients is to be expected as a higher index score results in a better level of road safety, and thus fewer fatalities.

3. Aggregations

3.1. *General Concepts*

Aggregation operators are characterized by certain mathematical properties and aggregate in a particular manner. In general, aggregation operators can be roughly divided into three classes [6]: conjunctive, disjunctive and averaging operators. In this research, we focus on OWA operators [7,8]. An OWA operator of dimension n is a mapping indicated as $F : R^n \rightarrow R$ that has an associated n vector $W=[w_1,w_2,\ldots,w_n]^T$ such that $w_i \in [0,1]$ and $\sum w_i = 1$. Furthermore, $F(a_1,\ldots,a_n)=\sum w_j b_j$ with b_j the jth largest of the a_i.

There are a number of methods to obtain aggregation weights of which linguistic quantifiers [9] is a very common one. Decision makers provide a linguistic quantifier Q (e.g., many). Q can be represented as a fuzzy subset of the unit interval I where for each $r \in I$, $Q(r)$ indicates the degree to which the proportion r satisfies the concept denoted by Q. If Q is a regular increasing monotonic quantifier the aggregation weights can be obtained as follows [6]:

$$w_i = Q(i / n) - Q((i-1) / n) \text{ for } i = 1,\ldots,n. \tag{1}$$

$$Q(r) = r^\alpha \text{ with } \alpha \geqslant 0 \tag{2}$$

is one of the most simple and common methods to define the parameterised subset of the unit interval. In case of seven weights this results in:

$$w_1 = [1/7]^\alpha \text{ ; } w_2 = [2/7]^\alpha - [1/7]^\alpha \text{ ; } w_3 = [3/7]^\alpha - [2/7]^\alpha \text{ ; } w_4 = [4/7]^\alpha \tag{3}$$
$$-[3/7]^\alpha \text{ ; } w_5 = [5/7]^\alpha - [4/7]^\alpha \text{ ; } w_6 = [6/7]^\alpha - [5/7]^\alpha \text{ ; } w_7 = [7/7]^\alpha - [6/7]^\alpha \text{ .}$$

3.2. *Basic operators*

Some of the most common aggregation operators are maximum, minimum and average. In fact, they are special cases of the OWA operator.

- Max: $W=[1,0,\ldots,0]^T$ only considers the best rank (optimistic point of view)

- Min: W=$[0,0,\ldots,1]^T$ only considers the worst rank (pessimistic point of view)
- Average: W=$[1/n,1/n,\ldots,1/n]^T$ considers each rank equally.

The correlation coefficient of the maximum and minimum operator is -0.508 respectively -0.181 indicating that these operators are improper in this context. The average operator results in a rather high correlation (-0.670).

3.3. *Linguistic Formulations*

The weighting vector and index scores can be calculated for each α within the interval [0,∞[(i.e., max and min operator). The higher α, the more emphasis on weaker performances; the lower the final score; and the less compensation allowed. However, it is more correct to select a set of acceptable values for aggregating indicators. In this section, we will discuss a rule-based way for deriving α and aggregation weights. A panel of road safety experts expressed their aggregation policy in natural language, leading to the following principles:

1. in case a country scores bad on more than two of the seven indicators, its final road safety index score should be small;
2. in case a country scores bad on maximum two of the seven indicators, its final road safety index score should be between small and average.

On the one hand, it is another option to consider the rules of each expert separately. On the other hand, linguistic guidelines stressing the interval of the index score in case of good performances (e.g., a country scores well on five indicators) can also be formulated. However, conflicting formulations and constraints for α are common in case of several rules. Therefore, an order of importance should be assigned to the rules; restrictions from a next rule will only be considered in case they are compatible with all former restrictions.

We first classify the scores into three groups as we aim for a rough impression of good, average and bad performances. In [10] an interesting application of OWA operators is given. First, the linguistic formulation is translated numerically. Subsequently, the formula of the weights is used (Eq. (3)). Finally, a constraint for α is found. The same approach will be used, but a different scale. As we use value 1 for 'good', 0.5 for 'average' and 0 for 'bad', the final index score lies in the interval [0,1]. The term 'small', used by the experts, is translated into an index value of 0.25 while an 'average' score equals 0.5 in this case. For guidelines 1 and 2, the restrictions for α are deduced below.

1. $F_\alpha(1,1,1,1,0,0,0){<}0.25 \Leftrightarrow w_1 + w_2 + w_3 + w_4 < 0.25 \Leftrightarrow (\frac{4}{7})^\alpha < 0.25 \Leftrightarrow$

    $\alpha > 2.477$ (4)

2. $F_\alpha(1,1,1,1,0.5,0,0) \in [0.25;0.5] \Leftrightarrow 0.25 < w_1 + w_2 + w_3 + w_4 + 0.5w_5 < 0.5$

$$\Leftrightarrow 0.25 < (\frac{4}{7})^\alpha + 0.5(\frac{5}{7})^\alpha - 0.5(\frac{4}{7})^\alpha < 0.5 \Leftrightarrow 1.580 < \alpha < 3.235. \qquad (5)$$

Based on Eqs. (4) and (5), we can conclude that α should be in the interval [2.477;3.235] to obtain an aggregation which is acceptable for experts. Hence, for α equal to 2.5;2.6;2.7;2.8;2.9;3.0;3.1;3.2 we get the weights using Eq. (3). The weights are then multiplied with the indicator values to compute the index scores. The strongest relationship with the number of road fatalities per million inhabitants is found for an α of 2.5, i.e., -0.699 (orness = 0.25).

4. Discussions

Each α is associated with a weighting vector and results in road safety index scores. In the end, we want to obtain a road safety index constructed by means of a correct methodology. In order to select out of several alternatives one value for α, the results were compared to the number of road fatalities per million inhabitants. The aggregation of the most essential risk factors should have a desirable level of predictive power for the level of road safety. Of course, this should not be a mathematical exercise. It is essential to obtain sound results. The inclusion of experts' opinions is therefore valuable. As it is relatively easy to roughly state what the score of a country should be in case e.g., all indicator scores are below-average, useful constraints for the parameters can be obtained.

The degree of complexity is another issue. Other studies dealing with constructing a composite indicator, often select the simplest methods (e.g., equal weighting, linear aggregation). This study shows that considering the maximum or minimum operator – and restricting the road safety index to one indicator only – is not justifiable based on numeric (correlation) results; even more importantly is the belief that all indicators are selected as relevant and essential part of the combined index. The same applies for the average operator. Although this operator is very straightforward, one should always ask oneself if it is acceptable that a good score completely counterbalances a bad one. This way of aggregation can only be used in case no synergies or conflicts exist between the indicators. To summarize, the basic operators do not fulfill the methodological needs required for constructing a sound road safety index.

5. Conclusions

In general, indicators are useful policy tools. Representing large amounts of information in a concise way, they can identify trends, prioritize actions and assess the relative performance of countries. The current development of an

aggregated road safety index – taking into account seven important risk domains – will provide new insights in road safety policy making. In the road safety context, the use of aggregation operators is new.

It is important to first limit the extensive set of possible OWA parameter values. Reflecting experts' and decision makers' attitudes is very useful in this respect. Translating their verbal preferences with respect to compensational behavior with a few computations into a smaller number of α's increases the reliability of the final road safety index. For the given data set, the ordered values (starting with the best performance) receive the following weights: 0.01; 0.03; 0.08; 0.13: 0.18; 0.25; 0.32. In other words, all indicator values are used to some extent (compared to the max and min operator), compensation is only partly allowed (contrary to the average operator) and the three worst performances account for 75% of the overall index score.

Though the class of OWA operators proved to be useful in the road safety context, other aggregation techniques should be evaluated too: fuzzy integrals, non-compensatory multi-criteria decision making, fuzzy preference relations, etc.

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