Road Safety Development Evaluation by Entropy–PROMETHEE for the ASEAN Region

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Abstract

With the rapid growth of motor vehicles, road safety has become a significant concern. This underscores the importance of evaluating road safety at a regional level. Applying an appropriate evaluation method is crucial to visualize fluctuations in outcomes. This study develops a hybrid Entropy–PROMETHEE model to assess road safety development for the ASEAN countries. Comparisons of the empirical results verify the robustness of the proposed model, indicating its reliability and validity. Overall, the proposed methodology provides a scientific foundation for future policymaking and resource allocation regarding road safety in Southeast Asia.

Keywords

Road safety development, policymaking, ASEAN, Entropy, PROMETHEE.

1. Introduction

As traffic accidents garner increasing global attention, governments worldwide are closely monitoring the annual impact of traffic accidents on their countries. Each year, approximately 1.19 million people die, which is caused by traffic. Moreover, traffic crashes impose 3% of gross domestic product on most countries. Among all those damages, 92% of world fatalities occur in low-middle income countries (UNESCAP, 2020). The situation is particularly severe in the Southeast Asia region. Almost 28% of total fatalities happen here. In terms of absolute numbers, 330,222 deaths were reported in 2023 (WHO, 2023). Therefore, evaluating road safety development for Southeast Asian countries is important to support the subsequent action plan and resource utilization.

Under these circumstances, employing scientific and systematic evaluation methodology is of paramount importance. However, selecting an appropriate evaluation method can be challenging. To ensure the reliability of the evaluation, conducting robustness testing is one of the most straightforward and effective ways to assess the validity of the chosen method.

For this purpose, this study conducts a base evaluation method, i.e., Entropy–PROMETHEE–K-means, to measure the road safety progress for Southeast Asia countries. Specifically, it uses Entropy to calculate the weight of original data, PROMETHEE to construct the composite index, and k-means to group the countries. This study also introduces two other rigorous methods, “Entropy–TOPSIS” and “Entropy–RSR,” to determine the usability of the base method by comparing three outcomes with a robustness test. After all, the outcome rank and correlation within the group of evolution are analyzed to indicate the validity of “Entropy–PROMETHEE” and further ensure the assistance for the upcoming development of road safety in Southeast Asia.

2. Data

2.1. Safety Performance Indicators

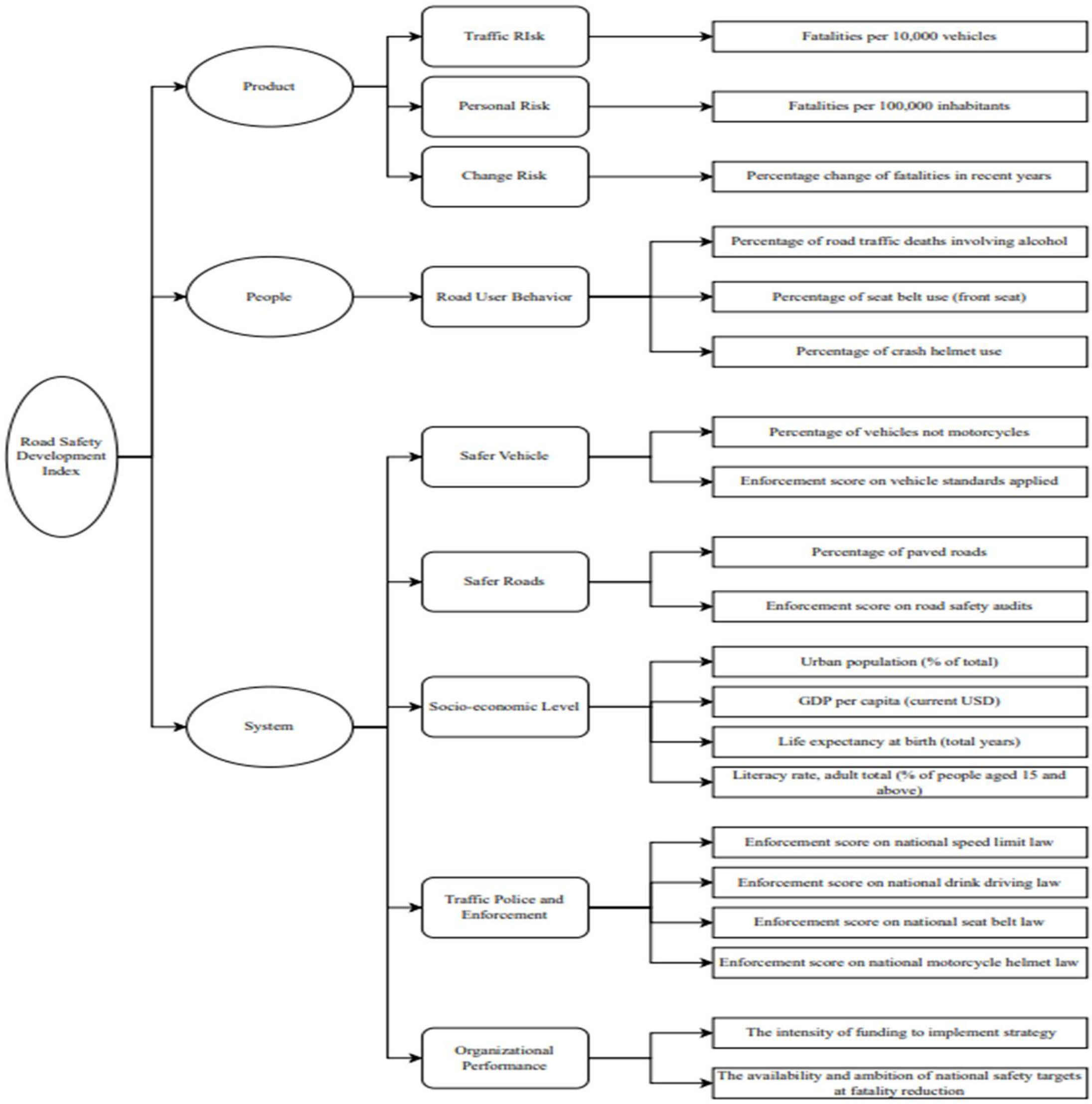

Fig. 1 Road safety development Index.

To start the modeling process, suitable data was required to be collected. The expected outcome rank can be affected by multiple aspects, including factors that are humanly intervenable and statistically measurable, as well as unpredictable environmental factors (Chen et al., 2020; Haghani et al., 2022). Willing to construct a stable model to determine good predictors is significant. After an extensive article review (Aarts & Houwing, 2015; Bax et al., 2012; Chen et al., 2022; Cui et al., 2023) and discussions between scholars, we developed a road safety development index based on the framework proposed by Al-Haji (Al-Haji, 2005, 2007), by adding more indicators, for example, Traffic Police and Enforcement and Organizational Performance to increase the accuracy of the evaluation. This "Product-People-System" index comprises a set of evaluation indicators that can reflect the development of road safety, as shown in Fig. 1.

2.2. Data Collection

After identifying the necessary indicators, explicitly collecting indicator data from official databases is indispensable. These official databases include international, regional, and national sources. This research gathers four years of index data (2009, 2012, 2015, 2018) for eleven Southeast Asian countries. To ensure correctness and authenticity, this study avoids using reported data directly from individual country databases. Instead, international databases, including those of the OECD, UNESCAP, UNESCO, World Bank, WHO, and WTO, are used for data collection. Regional databases are used as substitutes for any data unavailable in these sources, including Eurostat, ASEANstats, and AJTP. These data are applied for further Entropy–PROMETHEE modeling to produce the expected evaluation results.

3. Methodology

Step 1. Data normalization by min-max method

The first step is to normalize the collected data. Data are not comparable across different dimensions. Moreover, directly operating these data can not reflect the function of outcomes due to the indicators moving in the opposite direction. For example, a smaller number of fatalities implies better road safety development, whereas a larger area of paved road reflects better development. The purpose of normalization is to ensure all indicators are in the same direction and break the boundary of dimensions so they can fit into models. In this study, the min-max approach is used. While data consists of number m evaluation targets (11 countries in this case study) and number n indicators (20 indicators in this case study), a matrix $R = (r_{ij})_{m\times n}$ can be formed. Two formulas for different direction indicators are calculated as:

$$Y_{ij} = \frac{r_{ij} - r_{j\max}}{r_{j\max} - r_{j\min}} \tag{1}$$

$$Y_{ij} = \frac{r_{j\max} - r_{ij}}{r_{j\max} - r_{j\min}} \tag{2}$$

where X_{ij} represents each value of the indicator in collected data. r_{jmax} and r_{jmin} donates the maximum and minimum value for data in the given j column. The final normalized data can construct a new $m \times n$ matrix, donating as Y_{ij}. The positive direction indicator will use equation, and the negative direction indicator will use equation (2).

Step 2. Weight calculation by Entropy approach

Normalized indicator data is still insufficient for the evaluation model. The importance of indicators does not contribute evenly to the model. Bias caused by possibly overlapping proportions and misjudgement of index intensity can affect the result. To eliminate the bias, determining the appropriate weight for each indicator is necessary. This study conducts Entropy method for objective weight calculation. The probability of each value in indicators is denoted as P_{ij}, which is calculated as:

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{m} Y_{ij}} \tag{3}$$

The Entropy of each state represents:

$$e_j = -k\sum_{i=1}^{m}(p_{ij} \ln p_{ij}), k = \frac{1}{\ln m} \tag{4}$$

A smaller entropy value of an indicator implies a greater variation within the group. Thus, the indicator can provide more information and play a more significant role in evaluation. The weight of this indicator should, meanwhile, be higher. In application, operating entropy values e_j based on their variation can output objective weights. The operation is shown as:

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} \tag{5}$$

With the weight of each indicator, the study will reveal the PROMETHEE model approach for evaluation.

Step 3. PROMETHEE modeling for ranking countries

PROMETHEE is also called Preference Ranking Organization Method for Enrichment Evaluations. This method is an approach that focuses on evaluating multiple targets based on preference relations. To apply this approach, this study decides to use the Max function $O_j(A, B)$ as preference function for evaluation.

$$O_j(a,b) = \max(0, Y_{Aj} - Y_{Bj}), where\ A \neq B \tag{6}$$

Where Y_{Aj} and Y_{Bj} represent the value of a fixed column (indicator) for rows (country) a and b. To determine more precise preference value of each indictor for countries, weights are used. The operation generates the comprehensive preference value $\pi(A, B)$ as:

$$\pi(A,B) = \sum_{j=1}^{m}\left(w_j \times O_j(A,B)\right) \tag{7}$$

Where $\pi(A, B)$ is used to represent the superiority of country A relative to country B in terms of road safety. By performing pairwise comparisons of all targets, we can obtain the comprehensive preference value of each target relative to all other targets. These values will form the "flow" of each target. A "flow" can be divided into the positive flow $\emptyset^+$ and negative flow $\emptyset^-$. Meanwhile, n represents the total number of pairs that a fixed country A has relative to all other countries. Positive flows indicate the extent to which a target is better than other targets, while negative flow indicates the extent to which a target is worse than others. Finally, adding these two flows will output the net flow $\emptyset$, representing the overall score for each target.

$$
\begin{aligned}
\phi^{+} &= \frac{1}{n-1}\sum_{B \neq A}\pi(A,B) \\
\phi^{-} &= \frac{1}{n-1}\sum_{B \neq A}\pi(B,A) \\
\phi &= \phi^{+} + \phi^{-}
\end{aligned} \tag{8}
$$

4. Result

After applying Entropy–PROMETHEE, this study can obtain the road development score for Southeast Asia countries. By comparing all scores, the road safety development evaluation ranks can be presented for further analysis. Table 1 shows the overall score and ranks of four years overall score and ranks for eleven Southeast Asian countries.

Table 1. Overall score and ranks of the ASEAN countries by the proposed model.

Country	2018		2015		2012		2009	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Brunei	2.1657	3	4.1004	1	3.4760	2	1.1753	3
Indonesia	1.0581	4	0.0178	4	-0.2084	6	-0.544	7
Cambodia	-2.35	9	-2.1803	9	-1.5299	8	-3.5286	11
Laos	-2.5074	11	-1.7732	8	-1.5328	9	-1.372	9
Myanmar	-1.9045	8	-2.4135	11	-1.6409	10	-0.1166	6
Malaysia	2.3047	2	2.9123	3	0.3972	3	2.9219	2
Philippines	-0.4558	7	-0.4855	6	0.2306	4	0.0999	5
Singapore	3.7040	1	3.0676	2	3.9438	1	4.0138	1
Thailand	0.0447	6	-0.9036	7	-0.4769	7	-0.7473	8
Timor-Leste	-2.3998	10	-2.2597	10	-2.6834	11	-2.5782	10
Vietnam	0.3402	5	-0.0823	5	0.0245	5	0.6756	4

Table 1 reflects the ranking trend of road safety development for each country. Singapore, Malaysia, and Brunei consistently performed exceptionally. They share the top three places for all the interested years, especially Singapore, which ranks first in 2018, 2012, and 2009. Its worst ranking was still second place, which occurred in 2015. Vietnam, the Philippines, Indonesia, and Thailand generally occupy the middle positions, covering 4th to 8th place. Among them, Indonesia and the Philippines show significant variation in their rankings. Indonesia, which ranked 7th in 2009, rose to 4th place in both 2018 and 2015. In contrast, the Philippines showed a declining trend in road safety, ranking 5th in 2009 but dropping to 7th by 2018. Cambodia, Laos, Timor-Leste, and Myanmar typically ranked in the lower positions. Notably, Timor-Leste consistently remained in the bottom two. Laos ranked last in 2018, while Myanmar, after experiencing its worst rankings in 2012 and 2015, showed signs of a positive trend and finally settled at 8th place in 2018.

5. Discussion

To verify the reliability and validity of this Entropy–PROMETHEE approach, this study also obtains the ranking by two different approaches "Entropy–TOPSIS" and "Entropy–RSR". A robustness analysis is conducted by comparing the final rankings from three methods. To visualize the results, the study plotted the line charts as presented in **Fig. 2**.

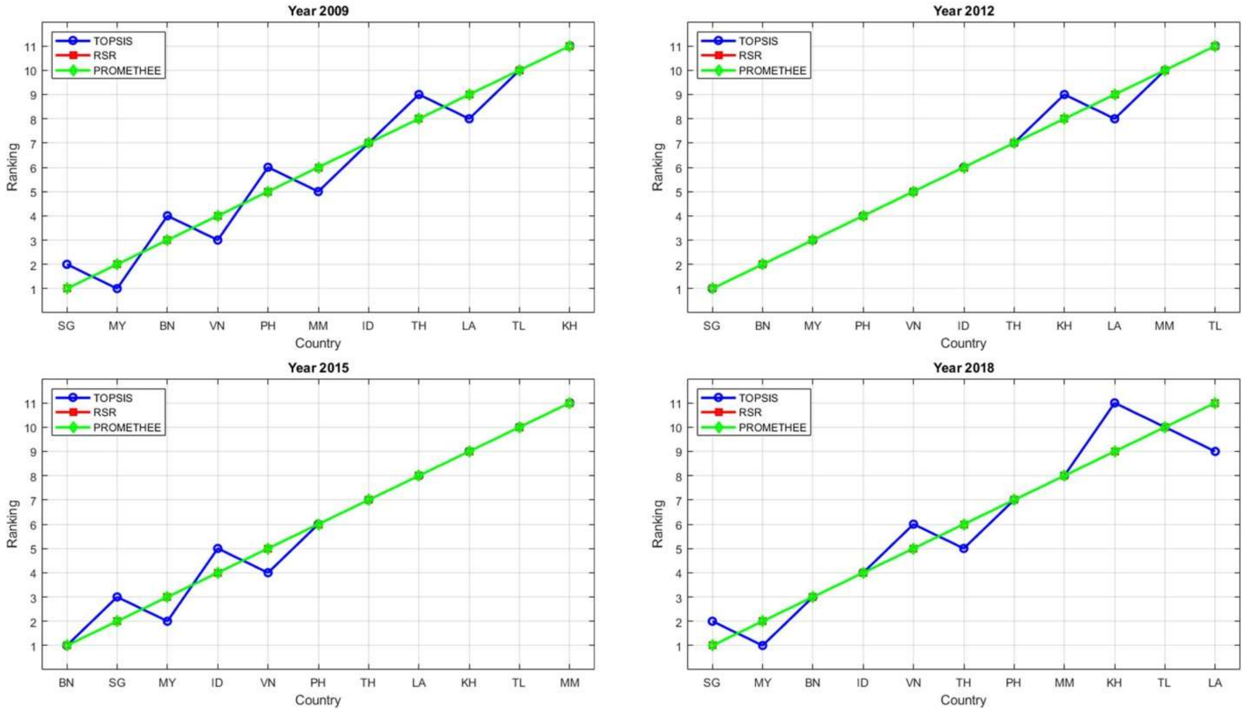

Fig. 2 Ranking comparisons based on different aggregating methods.

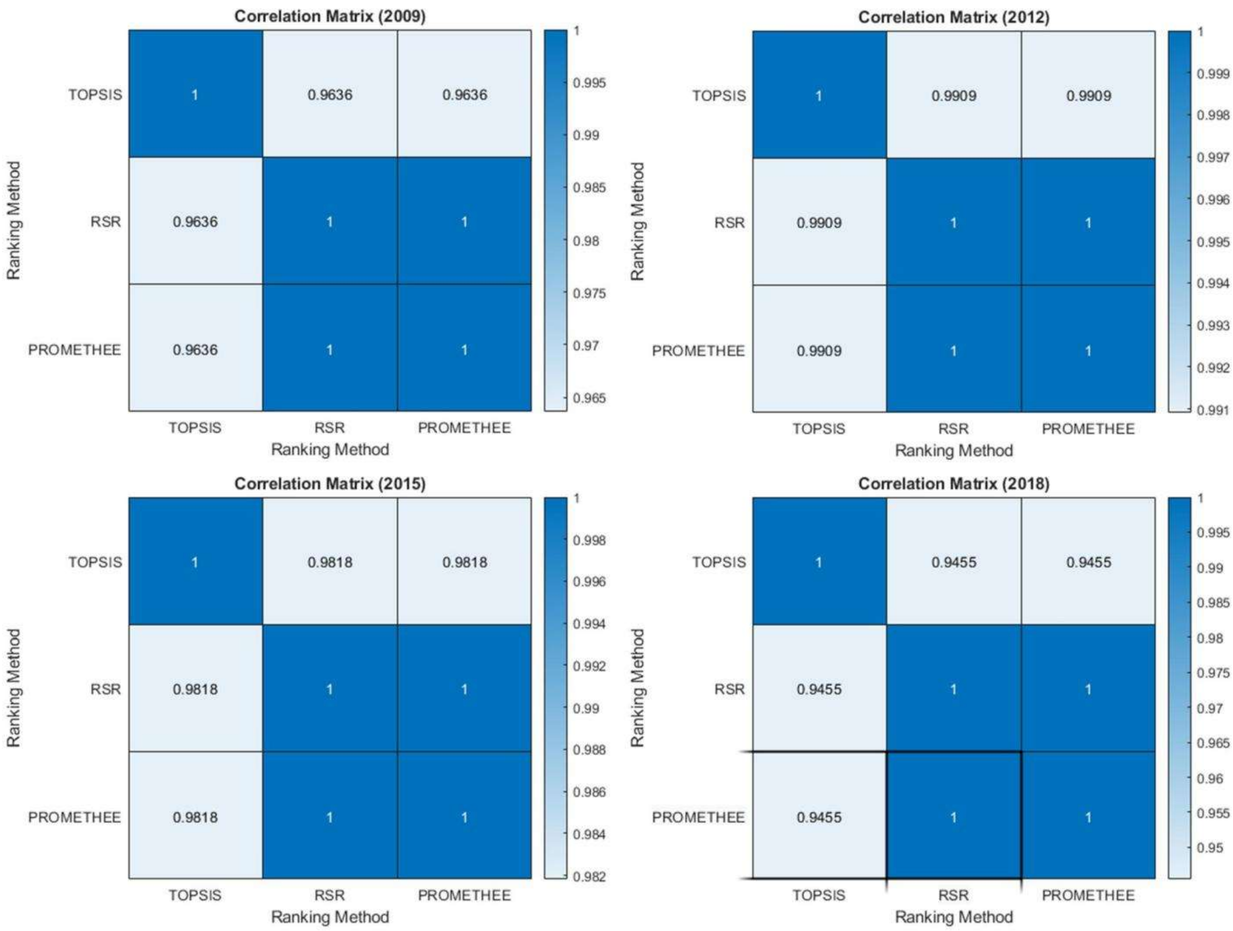

Fig. 3 Correlation coefficients among the rankings based on different aggregating methods

As shown in **Fig. 2**, over the four years, the rankings obtained from the PROMETHEE are completely consistent with those from the TOPSIS and RSR approaches. Although there are slight differences in some places with TOPSIS, the overall ranking trend is very consistent.

The study also introduces the rankings obtained from the three methods and conducts a correlation coefficient analysis. The correlation coefficients between the three methods over four years are shown in **Fig. 3**.

As shown in **Fig. 3**, the correlation coefficient between RSR and PROMETHEE is one, indicating that the two methods yield the same results. The correlation coefficients between TOPSIS and the other two methods are 0.95, 0.98, 0.99, 0.96, very close to one, suggesting that the method we tested is highly reliable.

6. Conclusion

To reduce the impact of traffic accidents on both the socioeconomic system and personal safety each year, this study introduces the Entropy–PROMETHEE approach for evaluation in the ASEAN region, based on the road safety development index. Through careful calculation and analysis, the proposed method can provide a scientific foundation for future policymaking and resource allocation for Southeast Asia.

By robustness test, comparing the Entropy–PROMETHEE approach with two different methods (TOPSIS and RSR), the approach is proved to be valid. Correlation coefficient analysis additionally reflects that the method is rigorous. As a result, Entropy–PROMETHEE can be used as a modeling tool for further road safety evaluation in the ASEAN region. More importantly, the road safety development ranking that is conducted in this study serves as a guiding role. Southeast Asian countries can observe their ranking changes from 2009 to 2018 and reflect on the policy adjustments made during that period, providing valuable reference for future policymaking.

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