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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

An Evaluation of the Road Safety Performance of City and Zone Administrations in the Amhara Region, Ethiopia

Yetnayet Getu Worku

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Traffic Safety

SUPERVISOR :
Prof. dr. Elke HERMANS

CO-SUPERVISOR :
dr. Evelien POLDERS

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ABSTRACTS

This study evaluates the road safety performance of all city and zone administrations in the Amhara region, Ethiopia, using the analytic hierarchy process (AHP) method. Speed, priority to pedestrians, the right of way for other vehicles, safe driving distance, technical vehicle errors, illegal pedestrian behaviour, and road conditions were the road safety indicators chosen to present the current road safety situation in the study area. The criteria used to select these indicators are: policy relevance, data availability, measurability, understandability, comparability, reliability, specificity, and sensitivity. An expert survey was performed to set the relative weights of each indicator in terms of road safety. Out of fifteen experts, twelve experts' judgment was found rational and consequently considered in this research. These experts portioned the most significant weight to the speed, priority to pedestrians, and safe driving distance indicator. Linear and geometric aggregation have been applied as index methodology. The rankings of the city and zone administrations were drawn separately based on the indicators' weighted share, index score, and road safety outcome (i.e. the number of fatalities per ten thousand vehicles). There were no significant differences between the two aggregation methods in the ranking of the cities, but there were some in the zone rankings. However, the spearman's correlation results demonstrated that the two aggregation rankings were reasonable estimates of the road safety outcome ranking and that the index methods are feasible and practical. The study's findings also confirmed that behavioural indicators comprise a large proportion of the road safety index, in which speed was the most dominant indicator. Therefore, improvements in these indicators will significantly enhance the road safety performance in the region.

Key Words: Road Safety, Road Safety Indicator, Analytic Hierarchy Process, Aggregation, Road Safety Index, Comparison, Amhara Region

HIGHLIGHTS

- AHP was used as the weighting method to create a road safety performance index for the Amhara region .
- Linear and geometric aggregation indices were reasonable estimates of the final road safety outcome.
- Behavioural indicators constituted a large share of the road safety index with the speed indicator being dominant.
- Recommendations in improving road safety performance have been proposed.

1. INTRODUCTION

Nowadays, road safety is a significant issue globally. The rate of road crashes has been increasing, and the consequences are becoming more severe. According to the World Health Organization's global status report on road safety (2018), road traffic crashes claim over 1.35 million lives each year and cause up to 50 million injuries. As to the report, with an average rate of 27.5 fatalities for every 100,000 population, the risk of road death is more than three times higher in low-income nations than in high-income nations, where the average rate is 8.3 fatalities per 100,000 people. The burden of road accident causalities and damage is much higher in developing countries than in developed nations.

Ethiopia is among the developing countries where road crashes are a significant public health problem. It has one of the deadliest roads globally, showing a road crash mortality rate of at the least 114 per 10,000 vehicles per year, compared to only 10 in the UK and Ireland and 60 across 39 sub-Saharan African countries (Abdi et al., 2017). Each year, road traffic crashes cause a significant loss of human and economic resources in Ethiopia. This problem is increasing from time to time at an alarming rate, accompanying the rapid increase of population and the number of vehicles. Ethiopia has a total population of 102 million people, with a 19.9% share of the urban population increasing at a rate of 4.7% in 2016 (World Bank, 2018; cited in Teko, 2018). About 13 people die in a road traffic accident in Ethiopia each day (Yimer, 2020).

Ethiopia has a small but rising motorization rate with a fleet size of 587,400 vehicles and a motorization rate of only two vehicles per 1000 people. Therefore, the crash rate per vehicle-km is too high; 195.1 traffic accidents per 10,000 vehicles (Gebresenbet, & Aliyu, 2019). The occurrence of a traffic crash in the country increases as the exposure to this risk increases with rapid motorization (without appropriate regulation), rapid population growth, and an increment in the road network tied with a poor attitude and safety culture of road users (Redi, 2015). Thus, appropriate interventions are necessary to decrease the number of road accidents considering the high number of casualties and the corresponding suffering and costs. To develop the right strategy, insights into the real problems through scientific studies are needed.

The remaining part of this paper is organized as follows: problem statement, objectives, and research questions are presented in the remainder of this section. A literature review about road safety performance indicators, a road safety performance index and the AHP method is provided in Section 2. Section 3 describes the study area, study design, research instrument, sampling design, data source, and analysis. Weighting, aggregations, comparison, and rankings of cities and zones are described in Section 4. In Section 5, the most important results of the study will be discussed. This paper concludes with limitations and future research, conclusions, implications and recommendations and an acknowledgement.

1.1 Problem statement

Ethiopia has a few big cities and lots of small urban centres. As a result, because of the concentration of administrative and economic activities, population, and vehicles in these areas, the proportion of accidents occurring is significant (Yayeh, 2003). Following this high urbanization rate, traffic volume is getting high and is increasing. As a result, road traffic accidents have increased over the years.

They are becoming an ordinary day-to-day phenomenon of the cities resulting in loss of life, human injury, and material damage (Asaye & Mossa, 2015). In the Amhara region where this study focuses on, 1080 citizens have died while 874 and 1260 individuals were seriously and slightly injured, respectively, due to traffic accidents in 2019. (Amhara Region Road and Transport annual report, 2020).

In Ethiopia, road traffic crash data, presented in a traffic policy report, are extensively used by road authorities and local governments for road safety assessment. However, Khorasani et al. (2013) stated that simply counting crashes or injuries is often an imperfect indicator of the level of road safety. The European Transport Safety Council (2001; cited in Hermans et al., 2008) also described that counting accidents and casualties gives a preliminary indication of road accidents and casualties dependent on random variations. A count of accidents says nothing about the processes that result in accidents. Al Haji (2003; cited in Hermans et al., 2008) also expressed that frequently, accidents and injuries are merely the tips of the iceberg because they occur as the "worst-case" of unsafe operational conditions of the road traffic system safety. These crash data do not indicate which aspects of road safety an underperforming city or country should focus on to improve its road safety level. Wegman & Oppe (2010) stressed that composite indices developed by combining road safety indicators are viewed as one of the most suitable approaches in road safety assessment because of the complex nature of road crash data.

More estimable insight into the road safety situation of the destinations can be acquired by studying the existing data and comparing them to the data of other subjects (Wegman, Lynam, & Nilsson, 2002; Wegman & Oppe, 2010). Lotter (2001) stated that performance measurement is neglected in the field of road safety in developing countries, and as a result, the level of road safety is not well studied. Although studies have been conducted on the use of the composite road safety index, these have primarily focused on European countries (Al Haji, 2005; Wegman et al., 2008; Nardo et al., 2005; Hakkert et al., 2007; Hermans et al., 2008; cited in Akaateba, 2012) with none on African countries. There is a shortage of road safety index literature where regions, zones, and cities of the Ethiopian context are considered. A study by Oluwole, bin Abdul Rani, & Rohani (2006) on 'Integrating Road Safety Indicators into Performance Road Safety Index' has addressed the issue of road safety performance index for ten African countries, including Ethiopia, by using two weighting methods, i.e., simple average and based on theories using performance indicators. Past researches into road safety issues in Ethiopian regions, zones, and cities have concentrated mainly on problems, causes, extent, or type of road crashes, mostly overlooking matters related to the road safety performance index. Therefore, this study aimed to provide a more complete picture by measuring and benchmarking the road safety status of cities and zones in the Amhara region, Ethiopia, based on experts' opinions and road crash data to improve road safety and fill the knowledge gap.

1.2 Objective

1.2.1 *General objective*

The main objective of this study is to evaluate the overall road safety performance of the city and zone administrations in the Amhara region, Ethiopia using the AHP method.

1.2.2 *Specific objectives*

The specific objectives of this study are to:

1. Identify relevant road safety indicators to develop the road safety index.
2. Develop a road safety index for city and zone administrations in the region.
3. Benchmark the road safety performance of city and zonal administrations in the Amhara region.

1.3 Research Questions

The main research question for this study is: "What is the relative status of road safety in the city and zone administrations in the Amhara region using experts' opinions and road accident data?"

This study will address the following specific research questions in the study area:

1. What are the relevant road safety performance indicators in setting the road safety index of the region?
2. What is the road safety performance of the region?
3. Which city/zone administration has a better road safety performance?

2. LITERATURE REVIEW

2.1 Road Safety Indicators

Wegman et al. (2008) discussed that safety indicators are increasingly used to identify and solve the growing road safety problems. A road safety indicator is defined as a quantitative or qualitative measure derived from a series of observed facts relative to a particular collision. Al-Haji (2007) defines an indicator as a measurement that quantifies something that impacts the road safety level and can be measured using some standard terms such as a percentage, rate, or qualitative information. Davidović, Pešić, Lipovac, & Antić (2020) explained that road safety performance indicators represent one of the essential criteria for examining the state of road safety. Pakkar (2016) classified safety indicators as individual and composite indicators. Individual indicators are dimensional measures that can assess the relative positions of entities in a given area. A Composite Indicator (CI) or index is a mathematical aggregation of individual indicators into a single score. Pešić and Antić (2012 cited in Davidović et al., 2020) further elaborated that road safety performance indicators are particularly significant for monitoring the performance, defining and creating trends, foreseeing potential problems, estimating political influence, comparing, etc.

States could improve their road safety based on their experiences, systemic monitoring, and cross-country comparisons (Tešić, Hermans, Lipovac, & Pešić, 2018). Pešić (2012) emphasized that securing systemic monitoring of road safety and comparisons with other countries require selecting relevant road safety indicators representing the current road safety situation in the best possible and most accurate way. According to Davidović et al. (2020), the factors that contribute to traffic accidents, i.e., the potential road safety performance indicators (SPIs), refer to the behaviour of traffic participants, road infrastructure, and vehicles. Based on a review of safety policies in the European Union and its Member States, several road safety risk factors were designated as central to road safety activities in Europe and were selected to develop SPIs (Bao, Ruan, Shen, Hermans, & Janssens, 2012). The risk factors are alcohol and drugs, speed, protective systems, vehicle, roads, and trauma management. Moreover, each risk factor is measured by one or several performance indicators.

Vägverket (1999; cited in Lotter, 2000) revealed that most basic crash, injury, and exposure figures are either too unreliable to use or unavailable in developing nations. In Ethiopia, only basic crash data are collected by traffic police and compiled and reported by the local public transport authorities in a fragmented way. Even the available road safety data are not adequate to develop road safety indicators and analyze the road safety situation in most cases. Compared to the SPIs of Europe, there is no adequate data to measure the drivers beahiour, road condition, vehicle standard, and pedestrian behaviour indicators in Ethiopia. Besides, data about protective systems and trauma management are rarely available. Thus, adequate data about the alcohol, drugs, speed, road condition, vehicle standard, pedestrian behaviour, protective systems, and trauma management should be available in the future to estimate an accurate road safety performance index in Ethiopia in the international context.

According to Lotter, traffic law compliance rates, road user awareness of safety problems, road standards, vehicle condition, pedestrian and bicyclist visibility, emergency medical response times, and road user knowledge of first aid are some of the performance indicators that are already used in developing countries. Oluwole, bin Abdul Rani, & Rohani (2006) have also identified traffic risk, personal risk, vehicle safety, road type, road user behaviour, urban population, and GDP level as road safety performance indicators while developing a road safety performance index for ten African countries. Thus, most of the performance indicators developed for developing countries are applicable and relevant to measure road safety performance in the country.

The process of selecting relevant safety performance indicators was started by reviewing literature and identifying the essential road safety risk domains. Unfortunately, there are no such well-developed and readily available road safety performance indicators countrywide in the Ethiopian context. According to the Ethiopian Ministry of Transport (2019) report, the leading causes of road crashes are poor road design, negligence of drivers, and technical faults of vehicles. In addition, the Amhara Region Road and Transport Bureau (2020) revealed that vehicle drivers' errors, vehicle technical errors, illegal pedestrian behaviours, and road conditions are the main risk factors contributing to traffic accidents.

According to the bureau report, most road accidents (85.57%) happened in the region due to drivers' errors. Speed driving (29.5%), failure to give priority to pedestrians (18%), failure to provide a way for other vehicles (8.6%), and failure to keep a safe driving distance (7.6%) are the main drivers' errors. In addition, vehicle technical problems (3.24%), illegal pedestrian behaviour (1.08%), and unsafe road conditions (1.04%) are other main risk factors of road crashes in the region. Thus, speed, priority to pedestrians, right of way for other vehicles, safe driving distance, vehicle technical errors, pedestrian behaviour, and road conditions are identified as the region's primary road safety risk domains.

For each risk domain, indicators have been developed using eight selection criteria, i.e., policy relevance, data availability, measurability, understandability, comparability, reliability, specificity, and sensitivity. Each possible indicator for a particular risk domain has been evaluated on these criteria. Due to data unavailability, only one best available indicator was selected to represent each of the study's seven risk domains. These are:

- ✓ (RSI_1) % of accidents because of exceeding the speed limit;
- ✓ (RSI _2) % of accidents due to failure to give priority to pedestrians;
- ✓ (RSI _3) % of accidents caused by failure to yield the right of way for other vehicles;
- ✓ (RSI _4) % of accidents made by failure to keep a safe driving distance from other vehicles;
- ✓ (RSI _5) % of accidents caused by vehicle technical errors;
- ✓ (RSI _6) % of accidents induced by illegal pedestrian behaviour and
- ✓ (RSI _7) % of accidents due to poor road conditions.

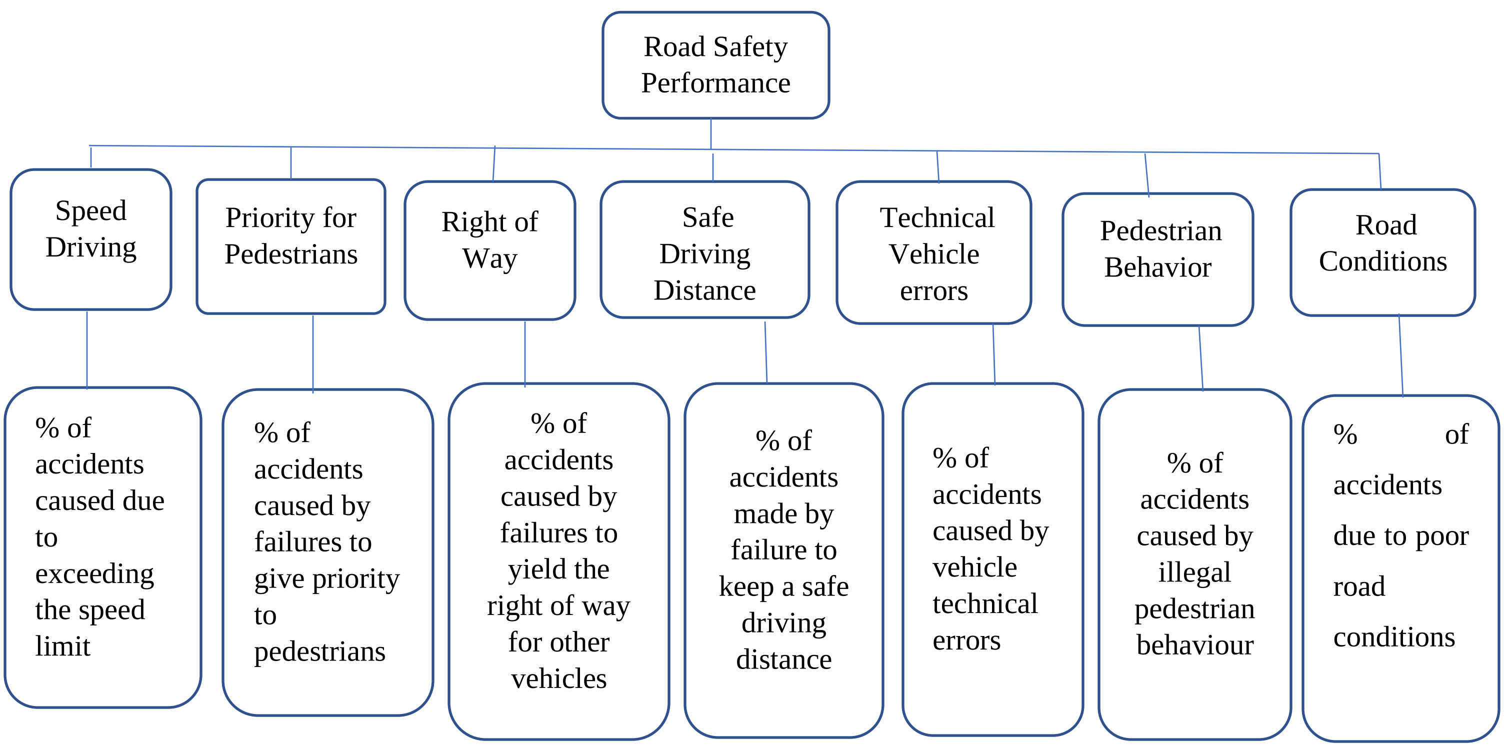

Figure 1: The hierarchical structure of the SPIs

2.2 Road Safety Index

The road safety index is a summary statistic of relevant road safety risk information. Once the index methodology has been applied, the road safety index can be used for ranking countries based on their index score (Hermans, Brijs, & Wets, 2008). Countries can be compared to each indicator individually. However, given a large number of relevant road safety performance indicators, creating an overall road safety performance index, which is a combination of road safety performance indicators, is worthful. One of the primary advantages of an index over a set of individual indicators is that the overall road safety picture is presented as the different risk factors are combined in this index (Hermans, Ruan, Brijs, Wets, & Vanhoof, 2010).

As the multidimensional road safety concept cannot be represented by one indicator, several relevant aspects are combined in an overall index. In case the methodological aggregation process is sound, transparent, and clear, the creation of an index over a set of indicators is worthwhile. Hermans et al. (2008) described that the set of individual indicators provides a tremendous amount of information. However, as the different road safety risk aspects jointly affect the frequency and severity of accidents, it is worth studying the set of indicators simultaneously and combining the information from several risk domains in one index. Moreover, based on the index scores, the countries' ranking can be set up, representing the combined performance on essential road safety risk indicators. Like the common road safety ranking based on the number of road fatalities per million inhabitants, an easy comparison across countries can be made based on one score and the country's relative position in the ranking. To contrast, the indicators of which the index consists help take appropriate action (Hermans et al., 2010).

Thus, because of the multidisciplinary nature of road safety, policymakers must consider numerous contributory factors when making decisions. A variety of such contributory factors can be combined by applying the composite index, which has been used increasingly in international cross-country comparisons (Tešić et al., 2018). As Wegman & Oppe (2010) stated, given the multitude of factors influencing road traffic collisions, it is somewhat difficult to evaluate indicators on a single basis. Thus, to ease decision-making, it is often preferable to have several indicators combined into one composite index, referred to as the Composite Safety Performance Index (CSPI). CSPIs are often employed to analyze the current safety conditions of road traffic systems and assess their performance on a continuous ground. Furthermore, they can compare and afterwards benchmark the road safety performance of various regions or countries apart from monitoring the impact of various road safety interventions (Coll, Moutari, & Marshall, 2013).

Road safety performance has usually been measured at the national level because the national authorities are assumed to have the main responsibility for managing the road safety of citizens. Assessing road safety performance at the local, provincial-level may offer novel inputs required to initiate more improvements in road safety, as it brings about higher accountability of policymakers and brings relevant issues closer to citizens. The measures and methods for such evaluation have now become broadly available, and their application may bring a difference in the current pace of road safety improvements (Eksler, 2010). Because of the migration of the population from rural to large urban areas, future trends in road transportation in megacities are of increasing interest. The ever-growing urbanization of countries worldwide results in implications for road safety due to the more complex traffic problems prevailing in cities (Yannis, Papadimitriou, Mermygka, & Engineer, 2015).

Coll, Moutari, & Marshall (2013) described that the development of the CSPI requires the choice of the road safety indicators to be combined and the selection of the method to be utilized to aggregate them. Weighting techniques, which are putting weights on each of the chosen indicators to show their importance, were commonly used to aggregate road safety indicators. In recent years, analytic hierarchy process, budget allocation, equal weighting, factor analysis, principal component analysis, data envelopment analysis, neural networks, grey Delphi method, and the fuzzy method were the main weighting methods used by many scholars in the area (Coll, Moutari, & Marshall, 2013).

3 METHODOLOGY

3.1 Study Area

This study geographically covered all city (Bahir Dar, Gondar, and Dessie; based on a relatively high rate of urbanization) and zone administrations (North Gondar, South Gondar, Central Gondar, Western Gondar, Awi, West Gojjam, East Gojjam, South Wollo, North Wollo, North Shewa, Wag Hemra, and Oromia) of the Amhara region, Ethiopia. While Bahir Dar is the region's state capital, Gondar and Dessie are the seat of Central Gondar and South Wollo zones, respectively. These cities are administered independently (of zones) because of their fast-growing urbanization and population. Zones are a second-level administrative subdivision of Ethiopia, next to regions. They are comprised of cities, rural towns, and villages. Consequently, the study area is characterized by various development and urbanization rates and unique demographic and geographic features. Thus, a comparison between the three city administrations on the one hand and the twelve zone administrations on the other will be made.

According to the Ethiopian demographic health survey (2019), Ethiopia's total population is 112,640,978, of which the Amhara region has 27% of the population (Atnafie, Muluneh, Getahun, Woredekal, & Kahaliw, 2020).

Note that the North Gondar zone has been recently divided into three different zones as Central, West, and North Gondar zones for administrative purposes. Thus, the study area map does not show the newly formed zones' boundary because the shapefiles could not be found.

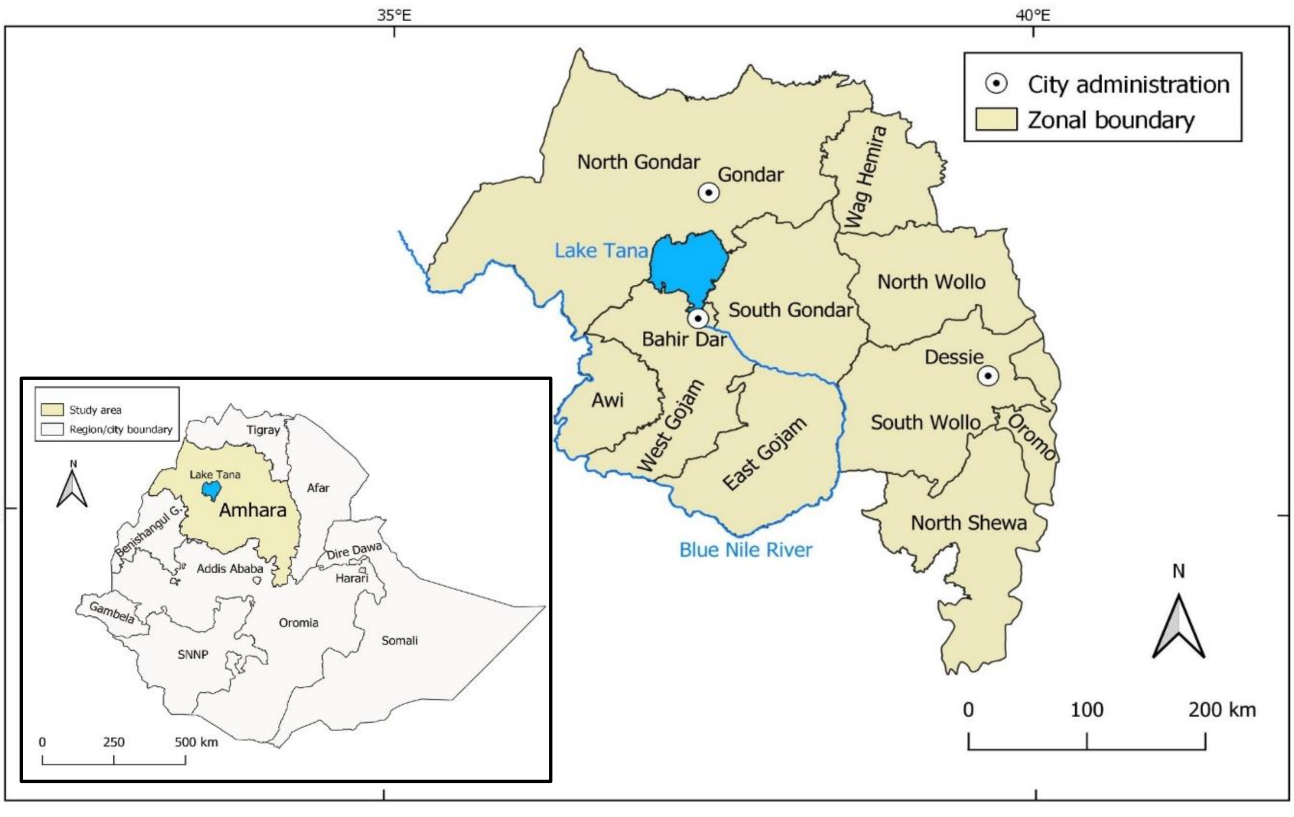

FIGURE 2: Map of the study area

3.2 Study Design

A cross-sectional study design was used to examine the Amhara region's road safety performance using a road safety index based on the aggregation of weighted road accident indicator data.

3.2.1 Weighting Method

One of the stellar steps in the procedure of the composite index calculation is "assigning the weights to each indicator." After selecting the set of indicators, the choice of a weight allocation method is the most important factor, having limited interaction effects with other input factors (Tešić et al., 2018). In this study, the weights are computed based on the AHP method.Saaty established the Analytic Hierarchy Process (AHP) in the 1970s, and over the past years, this has proven to be a very effective decision-analysis tool (Harker, 1987). AHP is a multi-criteria evaluation method used to determine the relative weights of factors using pairwise comparisons (Halmy, Gessler, Hicke, Salem, 2015; Zhang, Ban, Liu, Hu, 2011; Coll, Moutari, & Marshall, 2013; Aburas, Ho, Ramli, Ash'aari, 2017; cited in Fitawok, Derudder, Minale, Van Passel, Adgo, & Nyssen, 2020).

In road safety, experts gauge the relative weight of each indicator and similarity with other indicators (Hermans et al., 2008). First, experts should evaluate which of the two indicators is most important and the degree of variation in weights. Then, the strength of the experts' choice is described on a semantic scale of one to nine, where a value of one connotes the same importance between two indicators; on the other hand, a value of nine indicates that one indicator is exceedingly more important than the other. Once experts have determined values on each of the indicators, the pairwise comparisons then form a reciprocal square matrix (Nardo et al., 2008; cited in Coll, Moutari, & Marshall, 2013). The eigenvectors related to this matrix are employed to decide on the relative weights of the various indicators, which are utilized to average indicators' values to calculate the CSPI **(**Coll, Moutari, & Marshall, 2013).

According to Harker (1987), the basic elements which lead to the successful applications of AHP are its quality to integrate "intangibles" into the decision-making process and its simplicity to apply. Particularly, implementations of this method to group decision-making have evidenced to be most successful.

3.2.2 Data Normalization Technique

The normalization of the indicator values is needed before integrating them into RSPI. Normalization is the process of transforming data in different units into a common scale and comparable units (Vafaei, Ribeiro, & Camarinha-Matos, 2016). Max normalization technique was used to normalize the raw road safety data (see the normalized indicator values attached in appendix D) because of its ability to preserve proportionality and relationships among the original input data (Goman, & Koch, 2018; Singh & Singh, 2020). This method is a variant of min-max normalization where the data is rescaled by dividing each feature by its maximum value (Singh, & Singh, 2020).

3.2.3 Aggregation Method

The indicators are combined in an index by assigning a weight to each indicator and applying an aggregation method (Hermans, Brijs, & Wets, 2008). The researchers used both linear and geometric aggregation for developing the final index score. In the case of linear aggregation, the index consists of the sum of each of the indicator values multiplied by its weight (Hermans, 2009). Geometric aggregation results in an index score by raising each indicator value to the power of the corresponding weight and multiplying these products (Hermans, 2009).

3.3 Data Sources

Desk research was conducted to identify relevant road safety indicators. Datasets from the regional road and transport bureau, and related literature are the secondary data used in this research. A questionnaire (primary data) was developed to collect experts' opinions using the Analytic Hierarchy Process (AHP) method. Road and transportation science experts and practitioners working in Bahir Dar University and the Regional Road and Transport Bureau (three road safety supervision experts, one road safety education expert, one road safety researcher expert, two vehicle technical supervision experts, two transport planning and development experts, two road engineers, two traffic police officers, and two university instructors) were purposefully selected for the expert survey because of their nearness to the subject study. The survey was distributed in person and through email from 5th to 27th of January 2021.

The available data relating to the road safety indicators were collected and compiled from the Amhara Region Road and Transport Bureau Annual Survey Report. Data collected for each indicator belongs to the period 2019-2020.

3.4 Data Analysis

Data analysis was performed using the Statistical Package for Social Sciences (SPSS) version 26. Experts personal judgment was analysed using means and standard deviations of the indicator weights. The road safety index was computed based on linear and geometric aggregations and an independent sample t-test was performed to compare the index scores. Based on the created road safety index, the cities' and zones' road safety performance were compared. Moreover, a Spearman correlation analysis was used to benchmark the final road safety outcome with index rankings. As no data are available for all indicators over some period of time, the road safety performance index was computed for one year only.

4. RESULTS

The results found in this study have been presented in two parts. The first section shows how the road safety performance index has been developed. In this section, the results of weighting and aggregation methods are discussed. In the second section, the rankings and comparison of cities and zones based on indicators shares, index scores (based on linear and geometric aggregation), and the final road safety outcome are discussed.

4.1. Developing a Road Safety Index (RSI)

First, we discuss the computation of the indicator weights in the index. To this end, a questionnaire survey was distributed among fifteen road safety experts to gauge the relative contribution of each indicator to road safety compared to another indicator. They answered the questions ‘which one of the two is more contributing to the overall goal?’ and ‘how large is the intensity of the difference?’. Values were given on a scale of 1–9. An equal contribution results in value 1, while three implies a moderately higher, five a strongly higher, seven very strongly higher, and nine an extremely higher contribution of one indicator than the other (Saaty, 1980). Having I indicators to judge, only $I(I-1)/2$ pairs have to be considered. The expert information was presented in a reciprocal squared matrix with I rows and I columns consisting of values within the interval (1/9, 1/8, . . ., 1, 2, . . ., 9 ; the templates are attached in appendix B).

The eigenvector with the largest eigenvalue (λmax) must be found from the matrix based on expert information. The eigenvector determines the weights, and the eigenvalue is a measure for the consistency of the judgment. The consistency of a matrix reflects the soundness of judgment, whether the interdependencies of the criteria are understood, etc. (Talbert et al., 1994; cited in Hermans, Van den Bossche, & Wets, 2008). Saaty (1980) defined the consistency index as $(\lambda max - I)/(I-1)$. Using Microsoft excel, the seven indicator weights were determined out of each of the 15 matrices, and the consistency ratios were computed by dividing each consistency index by 1.32 (i.e., random index for seven indicators) (Saaty, 1980). The consistency ratio is the consistency index ratio to the average random index for a matrix of the same size (which figure is given in Saaty, 1980). As a rule of thumb, a consistency ratio smaller than 0.10 is considered an acceptable degree of consistency (less than 10%). As a result, three matrices were inconsistent (0.83, 0.91, and 0.52); thus, the average over twelve sets of weights was taken in this study. The valid response rate of the questionnaire survey was 80%. The indicator criteria weights set by twelve experts based on AHP and the combined weights based on the average are presented in TABLE 1 below.

TABLE 1: Indicator weights

Experts	Indicator Weights						
	Speed	Priority to Pedestrians	Right of way	Safe driving distance	Vehicle technical errors	Illegal Pedestrian behaviour	Road condition
1	0.35	0.21	0.1	0.14	0.08	0.06	0.05
2	0.37	0.08	0.04	0.15	0.10	0.23	0.03
3	0.48	0.04	0.11	0.05	0.10	0.04	0.18
4	0.40	0.07	0.03	0.12	0.13	0.08	0.17
5	0.53	0.1	0.05	0.05	0.17	0.07	0.03
6	0.27	0.09	0.08	0.17	0.04	0.04	0.31
7	0.47	0.11	0.07	0.17	0.03	0.11	0.03
8	0.33	0.29	0.04	0.12	0.05	0.12	0.05
9	0.44	0.18	0.05	0.12	0.03	0.14	0.05
10	0.02	0.32	0.20	0.16	0.09	0.13	0.07
11	0.21	0.07	0.09	0.13	0.12	0.08	0.30
12	0.35	0.2	0.04	0.11	0.1	0.15	0.04
Average weight	0.35	0.15	0.08	0.12	0.09	0.10	0.11

Experts gave different values for the indicator in the weighting procedure, resulting in a relatively higher or lower share of an indicator to the overall aggregated index. In this case, experts assigned the highest weight to speed, priority to pedestrians and safe driving distance which is consistent with the region's road accident report.

It was also found that there were quite some variations in the experts' judgments when we compare means and standard deviations of the indicator weights. Based on the indicators' coefficient of variation, the highest and the lowest experts' opinion difference was recorded on setting the weight of road condition (96%) and safe driving distance (32%), respectively. However, all indicators scored less than one coefficient of variation. Thus, there was no high variation of opinions among the experts (see mean, standard deviations, and coefficient of variation in appendix C).

It is necessary to decide on indicator selection, normalization, weighting, and aggregation to obtain the final road safety performance index (RSPI) scores. Indicator selection, normalization and weighting are dealt with in the previous sub-headings.

The RSPI was computed based on linear and geometric aggregation methods. As a showcase, the RSPI value of Bahir Dar was calculated using the two aggregation methods as shown below. In the case of zero normalized values, very small values close to zero were used for calculation purposes since geometric mean cannot handle zero values (Anand, 2018). In the case of linear aggregation, the index score is computed as the sum of each of the I indicator values (Xi) multiplied by its weight (Wi) using the following formula.

$$\text{RSPIJ}=\sum_{i=1}^{n} WiXi$$

Where: Wi: the weight of indicator i
Xi: normalized indicator value I
J: city or zone

RSPIJ = (speed weight*normalized speed value)+(priority to pedestrian weight* normalized priority to pedestrian value)+(right of way weight* normalized right of way value)+(safe driving weight* normalized safe driving value)+(vehicle technical error weight* normalized vehicle technical error value)+(illegal pedestrian behavior weight* normalized illegal pedestrian behavior value)+(road condition

weight* normalized road condition value)
=(0.129*0.35)+(0.089*0.15)+(0.080*0.08)+(0.103*0.12)+(0.00000000001*0.09)+(0.038*0.1)+(0.00000000001*0.11)= 0.440

In geometric aggregation, the index score is calculated by raising each indicator value (Xi) to the power of the corresponding weight (Wi) and multiplying these products.

$$\text{RSPIJ}=\prod_{i=1}^{I} xi^{wi}$$

Where: Wi: the weight of the indicator i
Xi: normalized indicator value I
J: city or zone

RSPIJ = (normalized speed value^speed weight)*(normalized priority to pedestrian value^priority to pedestrian weight)*(normalized right of way value^right of way weight)*(normalized safe driving value^safe driving weight)*(normalized vehicle technical error value^vehicle technical error weight)*(normalized illegal pedestrian behavior value^illegal pedestrian behavior weight)*(normalized road condition value^road condition weight)

=(0.129^0.35)*(0.089^0.15)*(0.080^0.08)*(0.103^0.12)*(0.00000000001*0.09)*(0.038*^0.10)*(0.00000000001^0.11)= 0.004

An independent sample t-test was performed to compare the index scores of the two aggregation methods (see appendix E). A statistically significant difference (p value=0.05; t value=2.45) was found between the scores of the two aggregation methods. However, according to Spearman's correlation result between the geometric and linear aggregation rankings (r = 0.829), the ranks of the RPSI given by the two aggregation methods were strongly correlated (see appendix H). In determining the index, those cities and zones that have many indicators close to zero normalized values have been affected by the aggregation methods. In contrast to linear aggregation, geometric aggregation is extremely sensitive for indicators with values close to zero. West Gondar and Waghemra zones are typical examples. In geometric aggregation, both zones scored the lowest index value (i.e., 0.000005 & 0.000001). But, both zones scored a higher index value in the linear aggregation (i.e., 0.0578 & 0.1537). Thus,cities and zones with indicators having close to zero raw indicator values have been penalized and scored lower index values in the case of geometric aggregation. It is shown that in geometric aggregation, the index values were lower than the results of the arithmetic aggregation (see Table 2 and 3). The ranking of West Gondar zone was not affected by the aggregation methods. However, the ranking of Waghemra zone was impacted by the index scores (i.e., 5th in the linear & 1st in geometric aggregations).

4.2. Comparison of Road Safety Performance

The rankings and comparison of cities and zones in terms of road safety levels were made based on the weighted indicator shares, the RSPI score (based on linear and geometric aggregation), and the final road safety outcome based on the number of traffic mortalities per 10,000 vehicles. The weighted indicator shares rankings were used to compare each city's and zone's performance in terms of road safety risk domains predetermined in this study for the region. RSPI rankings were also employed to evaluate each city and zone regarding the overall road safety performance in the region. Finally, the road safety outcome ranking was also utilized to benchmark the RSPI rankings, i.e., to check whether linear and geometric aggregations were reasonable estimates of the number of road fatalities per ten thousand vehicles. For the weighted indicator shares rankings, the value of indicators determined by linear aggregation have been used (for your information, the weighted indicator shares of geometric aggregation can be found in appendix F).

Cities and zones are ranked in such a way that a higher road safety index score relates to a lower rank (the lower the ranking, the worst the road safety performance). In other words, rank 1 represents the most road-safe city or zone considering the indicator values and the assigned weights. The weighted indicator shares are used to indicate the problem areas requiring urgent action. The seven weighted indicator shares of each city and zone are given a rank number, with (1) referring to the lowest indicator share and (7) to the largest one. Thus, cities and zones should not have a large indicator share to be road-safe destinations In this way, identifying ordered good performance and problem areas becomes clear and easy for each city and zone. In case of an equal indicator value, the same rank is given for both cities and zones.

4.2.1. Ranking and Comparison of the Cities' Road Safety Index Level

As shown in TABLE 2 below, based on the indicators' weighted share, all the three cities performed best concerning traffic accidents due to bad road conditions. On the other hand, Bahir Dar and Gondar performed worst for accidents due to speeding. Dessie also scored worst on accidents due to not keeping a safe following distance from the vehicles ahead.

TABLE 2: Ranking of cities based on indicators weighted share & RSPI

	Weighted share of indicators (Ranking)							RSPI Score		Rank	
City	Speed	Priority to pedestrian	Right of way	Safe driving distance	Technical vehicle error	Illegal Pedestrian behavior	Road condition	Linear	Geometric	Linear	Geometric
Bahir Dar	0.129(7)	0.089(5)	0.080 (4)	0.103 (6)	0.000(1)	0.038 (3)	0.000(1)	0.440	0.004	3	3
Gondar	0.038(7)	0.007(3)	0.024 (6)	0.020 (5)	0.000(1)	0.008 (4)	0.000(1)	0.096	0.001	1	1
Dessie	0.025 (4)	0.084(6)	0.078(5)	0.120(7)	0.014 (3)	0.000(1)	0.000(1)	0.321	0.002	2	2

Comparing the cities' road safety performance based on the weighted share of indicators, Bahir Dar was the worst performer in accidents due to speed while Dessie was the best. Regarding crashes on account of weighted share of not giving priority to pedestrians and failures to deliver right-of-way indicators, Bahir Dar was the riskiest while Gondar was the safest. Concerning the weighted share of accidents because of the failure to keep a safe driving distance, Dessie was the worst, and Gondar was the best. Dessie was also the weakest performer in weighted share of accidents due to technical vehicle errors. But Bahir Dar and Gondar were equivalently most effective performers in weighted share of accidents because of technical vehicle errors. In terms of weighted share of pedestrians' illegal behaviour, Dessie was the most adept, while Bahir Dar was the most defective.

Comparing the three cities' road safety levels based on the index score of both linear and geometric aggregation, Gondar was the safest while Bahir Dar was the most insecure. There was no difference in the rankings of the cities using the two aggregation methods. Based on the weighted share of indicators, the behavioural indicators – speed, priority to pedestrians, right of way, and safe driving distance – have a significant share in the overall RSPI of Bahir Dar and Dessie. Gondar also has the same experience except for the priority to pedestrian indicator. From the behavioural indicators, speed was the most influential in the index development of the cities because of its relatively high weight and normalized values.

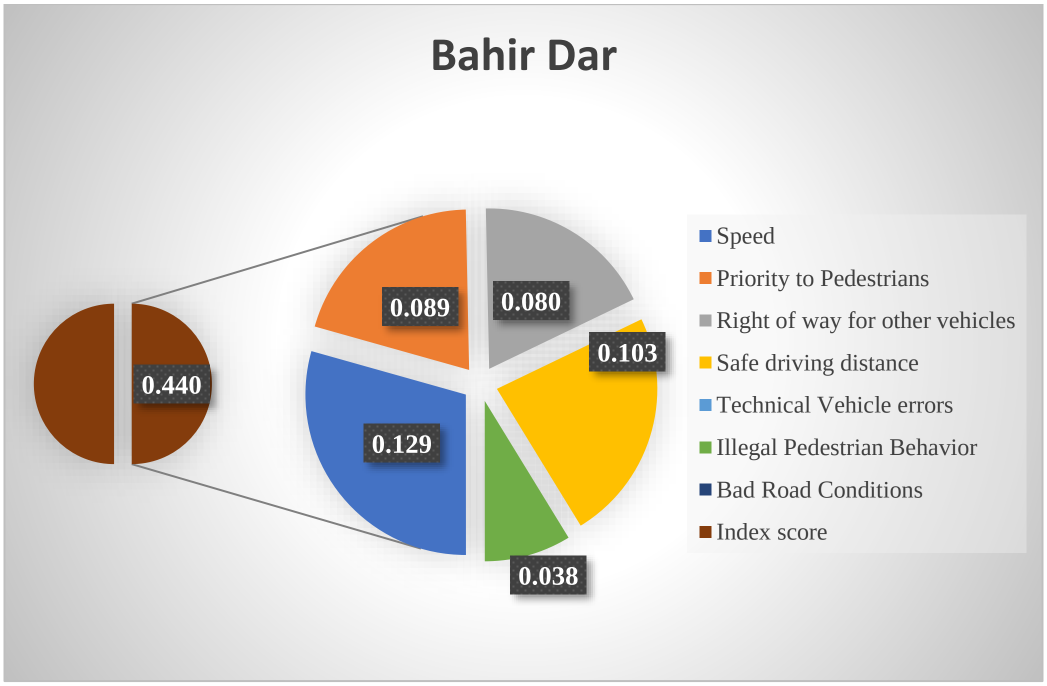

FIGURE 3:Visualization of RSPI & its component (using linear aggregation) for Bahir Dar City

4.2.2. Ranking and Comparisons of the Zone Administrations' Road Safety Index Level

All zonal administrations, except North Gondar, North Wollo, Waghemra, and North Shewa, performed worst regarding accidents due to speeding from all road safety performance indicators (Table no. 3). Similarly, North Gondar, North Wollo, and North Shewa performed weakest in accidents because of failures to prioritize pedestrians, while Waghemra was poorest in accidents on account of technical vehicle errors.

Based on the weighted share of indicators, West Gondar performed best in road accidents because of technical vehicle errors. Awi, North Gondar, and West Gondar performed most adept in traffic accidents due to illegal pedestrian behaviours. North Shewa performed worst in crashes because of safe driving distance and illegal pedestrian behaviour. East Gojjam was the poorest performer in accidents on account of bad road conditions. West Gojjam, Awi, North, Central, and West Gondar zones performed best in traffic accidents owing to bad road conditions.

TABLE 3: Ranking of Zones based on indicators weighted share & RSPI

	Indicators Index (Ranking)							RSPI Score		Rank	
Zone	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle error	Illegal Pedestrian behavior	Road condition	Linear	Geometric	Linear	Geometric
W. Gojjam	0.154(7)	0.043(6)	0.014(3)	0.042(5)	0.012(2)	0.038(4)	0.000(1)	0.303	0.022	9	6
E. Gojjam	0.154(7)	0.055(3)	0.024(2)	0.073(4)	0.012(1)	0.100(6)	0.092(5)	0.510	0.452	11	11
Awi	0.075(7)	0.029(5)	0.000(3)	0.037(6)	0.004(4)	0.000(3)	0.000(3)	0.144	0.000[a]	4	3
S. Gondar	0.350(7)	0.020(6)	0.012(4)	0.012(4)	0.008(1)	0.015(5)	0.009(2)	0.426	0.244	10	10
N. Gondar	0.017(6)	0.021(7)	0.002(3)	0.005(5)	0.004(4)	0.000(2)	0.000(2)	0.049	0.000[a]	1	4
C. Gondar	0.046(7)	0.038(6)	0.000(2)	0.007(4)	0.004(3)	0.008(5)	0.000(2)	0.102	0.001	3	5
W. Gondar	0.050(7)	0.002(5)	0.006(6)	0.000(4)	0.000(4)	0.000(4)	0.000(4)	0.058	0.000[a]	2	2
N. Wollo	0.038(6)	0.052(7)	0.002(1)	0.029(5)	0.012(3)	0.023(4)	0.009(2)	0.165	0.134	6	8
S. Wollo	0.104(7)	0.066(6)	0.000(1)	0.022(3)	0.012(2)	0.023(4)	0.037(5)	0.264	0.040	7	7
Waghemra	0.000(3)	0.000(3)	0.012(5)	0.007(4)	0.090(7)	0.008(4)	0.037(6)	0.154	0.000[a]	5	1
N. Shewa	0.100(5)	0.150(7)	0.040(2)	0.110(6)	0.020(1)	0.077(3)	0.083(4)	0.579	0.497	12	12
Oromiya	0.163(7)	0.054(6)	0.004(1)	0.039(5)	0.008(2)	0.015(4)	0.009(3)	0.292	0.228	8	9

[a] Not actually zero index values (approximated to three decimals and converted to zero)

Comparing the road safety level of zones in terms of weighted indicator shares, South Gondar was the worst performer in traffic accidents due to speeding while Waghemra was the most effective. Based on the weighted share of traffic accidents due to failure to provide pedestrian priority, South Wollo was the riskiest while Waghemra was the safest. Related to the safe driving distance weighted share, North Shewa was the poorest when West Gondar was the best performer. Waghemra was the worst in terms of weighted share of traffic accidents due to technical vehicle errors, but West Gondar scored best on this weighted indicator. East Gojjam was the worst of all zones on the weighted share of traffic accidents due to bad road conditions, while Awi, North, Central, and West Gondar were the most proficient.

Overall, there were some differences between the rankings of zones based on linear and geometric aggregations. North Gondar and Waghmera were the most affected zones by the aggregation method. In the linear aggregation ranking method, North Gondar was labelled as the safest. But in the geometric aggregation method, it was placed as the fourth safest zone. The reverse was true for the Waghemra zone. It was considered the safest in geometric aggregation ranking while ranked fifth in the linear aggregation ranking. This result confirmed that linear aggregation compensates while geometric aggregation punishes indicators with values close to zero. However, the two aggregation rankings indicated that North Shewa was the unsafest among all zones.

The weighted share of indicators, the behavioural indicators–speed, priority to pedestrians, and safe driving distance– have a significant share in all zones' overall RSPI. From the behavioural indicators, except for North Shewa, speed was the most critical indicator in the road safety index of zone administrations due to its relatively high weight and normalized value.

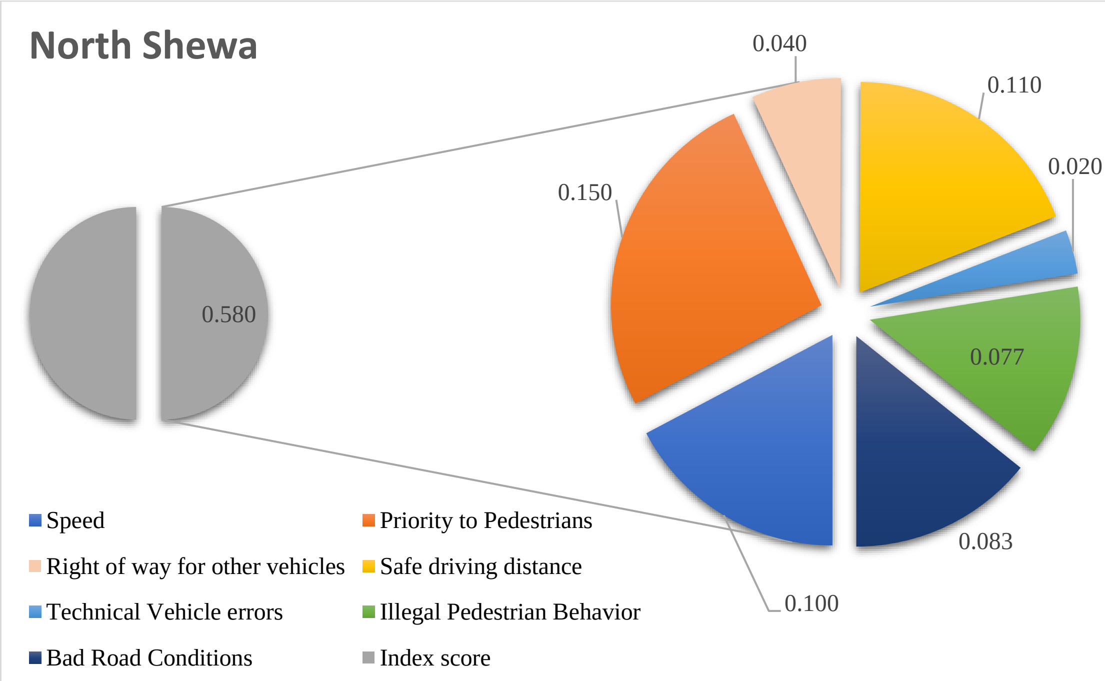

FIGURE 4: Visualization of RSPI & its component (using linear aggregation) for North Shewa Zone

4.3. Comparison of Road Safety Outcome and Index Rankings

The researchers employed both linear and geometric aggregation to compute the final index score for the studied cities and zones. To ascertain whether the index scores developed by the two aggregation methods were reasonable estimates of the number of road deaths per ten thousand vehicles, a Spearman correlation analysis between the values of the linear and geometric aggregation rankings and the road safety outcome ranking was performed (see appendix G). In the case of linear aggregation, the correlation coefficient was 0.986. Geometric aggregation resulted in a correlation coefficient of 0.855. Thus, these results assured that rankings based on the linear and geometric aggregations were reasonable approximations of the final road safety outcome ranking. Besides, based on their correlation coefficients, the degree of agreement with the final road safety outcome in linear aggregation appeared to be higher than in case of geometric aggregation. Therefore, the linear aggregation ranking was a better estimate of the road safety outcome ranking.

TABLE 4: Rankings based on linear & geometric aggregation & final road safety outcome

Area	Linear Aggregation Ranking	Geometric Aggregation Ranking	Final Outcome Ranking	Area	Linear Aggregation Ranking	Geometric Aggregation Ranking	Final Outcome Ranking
Bahir Dar	3	3	3	C. Gondar	3	5	3
Gondar	1	1	1	W. Gondar	2	2	1
Dessie	2	2	2	N. Wollo	6	8	6
W. Gojjam	9	6	9	S. Wollo	7	7	7
E. Gojjam	11	11	11	Waghemra	5	1	5
Awi	4	3	4	N. Shewa	12	12	12
S. Gondar	10	10	10	Oromiya	8	9	8
N. Gondar	1	4	2				

5. DISCUSSION

In this section, a brief discussion of indicators, normalization, weighting, and aggregation methods of the study results are presented. The main objective of this study was to evaluate the road safety levels of cities and zone administrations in the Amhara region. It aimed to measure, compare and benchmark road safety performances of cities and zones for improving road safety in the region. The benchmarking of road safety performance in this study was relative, so it was limited by the set of cities/zones considered and road safety indicators selected. Thus, careful considering of the units to benchmark as well as the set of indicators to use is required.

Most road safety index studies are conducted at a cross-boundary level to benchmark countries' road safety levels. But researches have also been conducted to measure and compare cities' and provinces' road safety performance within a country. For example, Castro-Nuño & Arévalo-Quijada (2018) have studied assessing urban road safety by applying multi-criteria decision-making analysis to compare the Spanish provinces. Seyedalizadeh & Rassafi (2019) have also measured the road safety performance of Iranian provinces using a double-frontier data envelopment analysis model and evidential reasoning approach. On the other hand, Yilmaz & Gürsoy (2020) have also researched a developing composite road traffic safety performance index of Turkish metropolitan cities to measure and compare the road traffic safety performance using principal components analysis. Thus, though methodologically different, this study was not unique in measuring and evaluating cities' and provinces' road safety performance within a nation. But, the application of this study in developing countries such as Ethiopia is innovative.

The analytic hierarchy process is a comprehensible and common technique that can be used for very complex decisions implying numerous levels of criteria and sub-criteria (Hermans, Van den Bossche, & Wets, 2008). Furthermore, the weights derived from the analytic hierarchy process are less sensitive to errors of judgments; thus, the resulting weights are defensible and justifiable in front of the public (Nardo et al., 2005; Greco, Ishizaka, Tasiou, & Torrisi, 2019). In this study, the analytic hierarchy process was the only weighting method used to set weights of indicators. Some researchers (e.g. Khorasani et al., 2013; Abu-shaweesh; Yadav, & Jayswal, 2013) used AHP as a sole weighting method in their research while others (e.g. Hermans, Van den Bossche, & Wets, 2008; Al Haji, 2005) combined it with other weighting techniques.

It is discovered that the experts' judgment about the leading road safety performance indicators was consistent with the regions' actual road crash report. Expert selection is vital and should be well considered in the AHP method since subjectivity is its characteristic (Saaty, 1980). Results can become biased if an expert assigns a high weight to a dimension on which only his/her district performs well (Hermans, Van den Bossche, & Wets, 2008). In this study, experts with a broad spectrum of knowledge and experience were carefully selected; thus, the weight values represented the regions' current road safety issues.

The Max normalization method was employed to normalize the raw road safety indicator data in this study. This normalization technique is useful for preserving the relationships among the original input data, unlike normalization methods which are based on a mean and standard deviation of the data, which vary with time (Singh, & Singh, 2020). Furthermore, rescaling with the maximum value preserves proportionality (Goman, & Koch, 2018). Vafaei, Ribeiro, & Camarinha-Matos (2016) conducted a study on normalization techniques for multi-criteria decision-making with the analytical hierarchy process method to identify the best-suited normalization technique. They found that max normalization is the best normalization technique for the analytical hierarchy process.

This study applied both the linear and geometric aggregation method. It is common to use the two methods in combination. Researchers (e.g. Al Haji, 2005; Nardo et al., 2005; Hermans, 2009; Mazziotta & Pareto, 2013) applied both aggregation methods in their study. However, some scholars strongly discourage using linear aggregation. They advocate geometric as the most appropriate method for aggregating indicators (Aczél & Saaty 1983; Ossadnik, 2016; Krejčí & Stoklasa, 2018). They argue that linear aggregation does not preserve the reciprocity condition when applied to the aggregation of the ratios of local priorities and may cause a rank reversal. Krej & Stoklasa (2018) also described that the results of linear aggregation to decision problems might depend on the choice of the normalization technique. Nardo et al. (2005) further elaborated that full compensability is an undesirable characteristic of linear aggregations; adequately high values of other indicators can compensate for poor performance in some indicators. On the other hand, Tešić, Hermans, Lipovac & Pešić (2018) mention that linear aggregation can give a meaningful result. They argued, that based on pre-defined criteria, linear aggregation scored the best result (based on the test made by Nardo et al., 2005 & Pešić, 2012).

In this paper, a correlation analysis between the values of the linear and geometric aggregation rankings and final road safety outcome ranking was conducted to show the appropriateness of the aggregation method. The results indicated that both aggregation methods are good estimates of the final road safety outcome. This result is consistent with Hermans (2009), who studied developing a composite road safety performance index method for cross-country benchmarking. She did a spearman's correlation test between linear and geometric aggregation rankings and the final road safety outcome ranking,and found that both aggregation methods are reasonable estimates of the final road safety outcome. Hermans, Van den Bossche, & Wets, have emphasized that a weighted sum of indicators should be a good approximation of the number of road fatalities per million inhabitants. Thus, they performed a correlation analysis between weighting method rankings and road safety outcome ranking to decide the best-fit weighting method.

Knowledge of performance indicators is valuable in understanding the processes that contribute to accidents and finding the main risk factors, determining the agreeing interventions, and monitoring the effectiveness of the safety actions taken (Bao et al., 2012). Our study showed that behavioural indicators have the most significant contribution to the index score of cities and zones, where speed has the most significant impact. A similar study by Cheng, Chen, & Li (2011) confirmed that human factors represent a large percentage of road accidents, in which speeding was the most contributing factor. Hermans, Van den Bossche, & Wets (2008) also agreed that behavioural indicators have a significant share in the overall road safety index. They further explained that an enhancement in these aspects would significantly heighten road safety performance. Thus, more efforts should be exerted towards these factors to bring meaningful change in the region's road safety status. The road safety interventions of the region should focus on and target behavioural indicators, mainly speed.

6. LIMITATIONS AND FUTURE RESEARCH

The scope of the study is limited to only the road safety performance evaluations of city and zone administrations in the Amhara region. Therefore, generalization of results across all geographical regions of the country may not be possible. So, further similar studies to other parts of the country can be conducted. Subjectivity is the main limitation of the AHP method; thus, the study's findings might not apply to cities and zones in other regions. Hence, the researcher suggests further study using other weighting methods separately or in combination in the same or other sections of the country to complement this study's results. Further similar researches are also recommended at country and across country levels.

Besides a spatial boundary, the data set used in this study is limited in time. As no data are available for all indicators over time, the road safety performance index was computed for one year only (the most recent one for which all needed data was available). In addition, only one best available indicator was used to represent each of the seven risk domains. As selected final outcome indicator the traffic risk (i.e. the number of fatalities per ten thousand vehicles) was used in the study. Consequently, the seven road safety indicators were not developed based on intermediate outcomes but related to the final outcome layer. So, these indicators might not be enough to illustrate the underlying conditions, but are the best available indicators to combine in a road safety index. Hence, the national and regional road and transport authorities should conduct further research on collecting road safety performance data based on the risk domains and core dimensions of road safety indicators.

7. CONCLUSIONS

In this study, the road safety index of all zone and three city administrations in Amhara region was developed and their road safety performances were benchmarked. Speed, priority to pedestrians, the right of way for other vehicles, safe driving distance, technical vehicle errors, illegal pedestrian behaviour, and road conditions were the best available road safety indicators used to demonstrate the road safety situation of the region. AHP was the sole weighting method applied. Based on the judgment of experts, the average weight of the indicators was determined. There was no significant difference in opinions amongst experts in deciding on the relative weight of the indicators. It is also observed that the experts assigned the largest weight to speed, priority to pedestrians and safe driving distance which was consistent with the region's actual accident report.

The road safety data sourced from Amhara Region Road and Transport Bureau were rescaled using the max normalization method for this research purpose. The cities' and zones' one-year road safety index was developed employing both linear and geometric aggregation methods.

The rankings of cities' and zones' road safety levels were constituted based on the indicators' weighted share, index score, and final road safety outcome. In terms of the indicators' weighted share ranking, all cities performed best in accidents due to bad road conditions. Except for Dessie, all performed worst in accidents because of speed. Dessie scored worst in accidents on account of failure to keep a safe following distance from vehicles in front. In the indicators' weighted share rankings of zones, all zone administrations, except North Gondar, North Wollo, Waghemra, and North Shewa, performed worst in accidents due to speeding. In traffic accidents due to failure to provide pedestrian priority, South Wollo was the worst while Waghemra was the safest. In accidents because of the failure to keep a safe driving distance, North Shewa was the poorest when West Gondar was the best performer. Waghemra was the worst in traffic accidents due to technical vehicle errors, while West Gondar scored best. East Gojjam was the worst of all zones in traffic accidents due to bad road conditions, but Awi, North, Central, and West Gondar were the best performers.

Based on the linear and geometric aggregation (RSPI) ranking, compared to the three cities' road safety levels, Gondar was the safest while Bahir Dar was the most insecure. The city ranking was not affected by the two aggregation methods used in the study. However, there were some differences between the rankings of zones based on linear and geometric aggregations. In the linear aggregation ranking, North Gondar was the safest of all zones. But in the case of geometric aggregation ranking, Waghemra was the safest. However, the two aggregation rankings confirmed that the North Shewa zone was the unsafest among all zones. It is learned that North Gondar and Waghmera were the most impacted zones by the aggregation methods.

Based on the weighted share of indicators, the behavioural indicators–speed, priority to pedestrians, right of way, and safe driving distance**-** have a significant share in the overall RSPI of the city of Bahir Dar and Dessie. The same is true for Gondar except for the priority to pedestrian indicator. Similarly, the behavioural indicators–speed, priority to pedestrians, and safe driving distance**-** have a significant share in all zones' overall RSPI. From the behavioural indicators, speed was the most vital indicator in the composite index of cities and zones due to its relatively high weight and normalized value.

The final road safety outcome ranking was used to benchmark the index rankings. A spearman's correlation analysis was done to determine the aggregation methods' fitness to the study. It is confirmed that the results of both aggregation methods were a close estimate of the final road safety outcome. In addition, it is also concluded that linear aggregation was the better approximate of the final road safety outcome.

8. IMPLICATIONS AND RECOMMENDATIONS

8.1 Implications

This study is essential for policymakers, practitioners, and researchers. It will create awareness to transportation policymakers at the national and regional level about the concepts of road safety index (but also risk domain, indicators, weighting, aggregation, ranking and benchmarking). It will guide them to design appropriate policies and strategies based on the actual road safety issues. Given most indicator data are gathered on a standard basis, this index research could be repeated in the future as well in order to become a valuable tool in future knowledge and data-driven policymaking in the region and the country at large.

From this study, developing countries could learn that this weighting method gives the chance to substantiate the poor(er) road safety data with the qualitative assessment of respective experts about the actual road safety situation and gain insights.

The findings of this research will also be helpful to concerned government bodies and practitioners to take appropriate interventions at the operational level by overcoming the drawbacks of the traditional analytical measures. By developing a road safety index at the city and zonal level, the study also brings the road safety issue closer to implementers, practitioners, and citizens.

This study further fills the gap in the existing literature concerning the road safety index. This paper introduced the concept of benchmarking road safety performance at regional and city levels in Ethiopia's road safety literature. Thus, it will serve as a stepping-stone for further research ventures regarding the road safety index in Ethiopia and other African countries.

8.2 Recommendations for a meaningful road safety performance Index

Given the implications of RSPI for road safety improvement, the following recommendations are suggested to the national, regional, and city-level transport authorities for meaningful road safety index development in the Amhara region, Ethiopia, and other developing countries:

- ✓ Based on the international and national context, risk domains and core dimensions of road safety indicators should be identified at the country level.
- ✓ Detailed road safety data that represent the risk domains and indicators' dimensions must be collected.
- ✓ Training for road safety data collectors and researchers about road safety performance indicators and road safety index must be provided.

8.3 Recommendations for improvement of road safety performance

Based on this study's results, behavioural indicators have the highest impact on the overall road safety index values. Thus, a betterment in this indicator will significantly improve cities' and zones' road safety performance in the region. Considering the indicators' impact on the index value, the following recommendations are put forward for the Federal, Regional, and City Administration Transport Authority to improve the road safety situation in the Amhara region in particular and Ethiopia in general:

With respect to accidents due to behavioural indicators (speed, failure to prioritize pedestrians, failure to keep a safe driving distance, and failure to yield right of way to other vehicles), it is recommended ed to consider and further investigate the following possible measures:

- ✓ Give more emphasis to safe driving behaviour in the drivers' training curriculum.
- ✓ Revise the speed limit and adjust according to the function of the roads.
- ✓ Formulate regulations that make it mandatory for (all/specific) cars to be fitted with a speed limiter.
- ✓ Consistent and highly visible law enforcement operations through a mix of visible patrols, speed monitoring radars, fixed cameras, and traffic calming measures (such as speed bumps and rumble strips, signages) in selected high-risk networks.
- ✓ Improve the penalty system for drivers with a/multiple traffic violations.

For accidents because of illegal pedestrian behaviour:

- ✓ Awareness creation campaigns to improve the level of awareness of the pedestrians on traffic rules, symbols, and regulations.
- ✓ Incorporate related road safety education in the formal education curriculum.

For accidents on account of bad road conditions:

- ✓ Follow up and maintain roads which are damaged.
- ✓ Expanding self explaining roads and roadside infrastructures.

For accidents due to technical vehicle errors:

- ✓ Educate drivers on the benefits of regular vehicle inspection, maintenance, and repair.
- ✓ Improve the vehicle standard legislation and its enforcement.

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APPENDICES

Appendix A: Expert Survey Questionnaire

Hasselt University Transportation Research Institute

Expert Survey Questionnaire

Dear Sir/Madam,

Thank you for agreeing to take this survey. My name is Yetnayet Getu. I am studying my Master thesis at Hasselt University in Belgium on the Road Safety Index in Amhara Region, Ethiopia. The objective of this questionnaire is to **determine the weight (importance level) of indicators in terms of their relative contributions in road unsafety or road crashes** that are ultimately used in measuring road safety performance in the Amhara region. The study area, the Amhara region, includes city administrations (Bahir Dar, Dessie, and Gondar) and all zonal administrations. Please note this when you complete the questionnaire. Your participation in this survey is extremely important as the results of the study contribute to enhance road safety performance in the study area that benefits all road users.

There are seven indicators to be compared pairwise, resulting in 21 combinations for which you should indicate a score of 1/3/5/7/9. A one-page description about the indicators is attached at the end of the questionnaire; please refer while completing the questions. This survey will take a maximum of 20 minutes to complete. You do not need to write your name, and all of the answers you provide in this survey will be kept confidential and will be used for academic purposes only.

Email address: yetnayetgetu.worku@student.uhasselt.be

Please circle the fitting weight for the below indicators. Here you can find what each of the numbers represents:

<u>A paired comparison of the relative contribution of the indicators in terms of road unsafety or road crashes</u>

1=equally important 3=moderately more important 5=strongly more important 7=very more strongly important

9= extremely more important 2, 4, 6, and 8 are intermediate importance values

Extremely important ← **Equally important** ⇓ **Extremely important** →

1.	Speed driving	9		7		5		3		1		3		5		7		9	Priority to pedestrians
2.	Speed driving	9		7		5		3		1		3		5		7		9	Right of way for other vehicles
3.	Speed driving	9		7		5		3		1		3		5		7		9	Safe driving distance
4.	Speed driving	9		7		5		3		1		3		5		7		9	Vehicle standard
5.	Speed driving	9		7		5		3		1		3		5		7		9	Pedestrian behavior
6.	Speed driving	9		7		5		3		1		3		5		7		9	Road designs & condition
7.	Priority to pedestrians	9		7		5		3		1		3		5		7		9	Right of way for other vehicles
8.	Priority to pedestrians	9		7		5		3		1		3		5		7		9	Safe driving distance
9.	Priority to pedestrians	9		7		5		3		1		3		5		7		9	Vehicle standard
10.	Priority to pedestrians	9		7		5		3		1		3		5		7		9	Pedestrian behavior
11.	Priority to pedestrians	9		7		5		3		1		3		5		7		9	Road designs & condition
12.	Right of way for other vehicles	9		7		5		3		1		3		5		7		9	Safe driving distance

13.

Right of way for other vehicles	9		7		5		3		1		3		5		7		9	Vehicle standard

14.

Right of way for other vehicles	9		7		5		3		1		3		5		7		9	Pedestrian behavior

15.

Right of way for other vehicles	9		7		5		3		1		3		5		7		9	Road designs & condition

16.

Safe driving distance	9		7		5		3		1		3		5		7		9	Vehicle standard

17.

Safe driving distance	9		7		5		3		1		3		5		7		9	Pedestrian behavior

18.

Safe driving distance	9		7		5		3		1		3		5		7		9	Road designs & condition

19.

Vehicle standard	9		7		5		3		1		3		5		7		9	Pedestrian behavior

20.

Vehicle standard	9		7		5		3		1		3		5		7		9	Road designs & condition

21.

Pedestrian behavior	9		7		5		3		1		3		5		7		9	Road designs & condition

Background of the respondents

Educational Level: ___________________

Field of study (specialization): _____________________

Work experience in the transport sector (in years): ______________________

Email address: ______________________

Thank you for your time!!!

Appendix B: Templates of Reciprocal Matrix

7x7 AHP Matrix 1 (consistency ratio: 0.097)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	3	5	5	3	3	5
Priority to pedestrians	0.333	1	3	3	5	3	3
Right of way	0.2	0.333	1	0.333	3	3	1
Safe driving distance	0.2	0.333	3	1	3	3	3
Technical vehicle errors	0.2	0.2	0.333	0.333	1	3	3
Pedestrian behavior	0.333	0.2	0.2	0.2	0.2	1	3
Road condition	0.2	0.333	1	0.333	0.2	0.2	1
Sum	2.466	5.399	13.533	10.199	15.4	16.2	19

7x7 AHP Matrix 2 (consistency ratio: 0.827)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	1	5	0.333	7	1	5
Priority to pedestrians	1	1	3	0.143	1	0.111	9
Right of way	0.2	0.333	1	0.2	3	9	0.2
Safe driving distance	3	7	5	1	5	1	3
Technical vehicle errors	0.143	1	0.333	0.2	1	1	1
Pedestrian behavior	1	9	0.111	1	1	1	1
Road condition	5	0.111	5	0.333	1	1	1
Sum	11.343	19.444	19.444	3.209	19	14.111	20.2

7x7 AHP Matrix 3 (consistency ratio: 0.096)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	5	7	5	3	3	7
Priority to pedestrians	0.2	1	3	0.333	0.333	0.333	5
Right of way	0.143	0.333	1	0.2	0.333	0.2	3
Safe driving distance	0.2	3	5	1	3	0.333	5
Technical vehicle errors	0.333	3	3	0.333	1	0.2	3
Pedestrian behavior	0.333	3	5	3	5	1	7
Road condition	0.143	0.2	0.333	0.2	0.333	0.143	1
Sum	2.352	15.533	24.333	10.066	12.999	5.209	31

7x7 AHP Matrix 4 (consistency ratio: 0.906)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	9	5	5	9	3	1
Priority to pedestrians	0.111	1	9	0.111	0.111	0.143	9
Right of way	0.2	0.111	1	0.111	0.111	0.111	0.111
Safe driving distance	0.2	9	9	1	1	1	1
Technical vehicle errors	0.111	9	9	1	1	1	0.143
Pedestrian behavior	0.333	7	9	1	1	1	0.143
Road condition	1	0.111	9	1	7	7	1
Sum	2.955	35.222	51	9.222	19.222	13.254	12.397

7x7 AHP Matrix 5 (consistency ratio: 0.086)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	9	7	7	7	7	7
Priority to pedestrians	0.111	1	0.333	1	0.2	1	0.2
Right of way	0.143	3	1	5	1	3	0.333
Safe driving distance	0.143	1	0.2	1	0.333	3	0.2
Technical vehicle errors	0.143	5	1	3	1	3	0.333
Pedestrian behavior	0.143	1	0.333	0.333	0.333	1	0.2
Road condition	0.143	5	3	5	3	5	1
Sum	1.826	25	12.866	22.333	12.866	23	9.266

7x7 AHP Matrix 6 (consistency ratio: 0.056)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	5	7	5	5	5	3
Priority to pedestrians	0.2	1	3	0.333	0.333	1	0.333
Right of way	0.143	0.2	1	0.333	0.2	0.333	0.333
Safe driving distance	0.2	3	3	1	1	1	1
Technical vehicle errors	0.2	3	5	1	1	3	0.333
Pedestrian behavior	0.2	1	3	1	0.333	1	0.333
Road condition	0.333	3	3	1	3	3	1
Sum	2.276	16.2	25	9.666	10.866	14.333	6.332

7x7 AHP Matrix 7 (consistency ratio: 0.093)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	9	9	9	9	9	9
Priority to pedestrians	0.111	1	5	3	0.333	1	3
Right of way	0.111	0.2	1	1	0.2	0.333	3
Safe driving distance	0.111	0.333	1	1	0.2	1	3
Technical vehicle errors	0.111	3	5	5	1	3	5
Pedestrian behavior	0.111	1	3	1	0.333	1	3
Road condition	0.111	0.33	0.333	0.333	0.2	0.333	1
Sum	1.666	14.863	24.333	20.333	11.266	15.666	27

7x7 AHP Matrix 8 (consistency ratio: 0.524)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	9	9	9	9	9	9
Priority to pedestrians	0.111	1	0.2	0.143	0.111	0.143	0.333
Right of way	0.111	5	1	3	3	0.143	5
Safe driving distance	0.111	7	0.333	1	0.143	0.143	0.2
Technical vehicle errors	0.111	9	0.333	7	1	0.143	0.143
Pedestrian behavior	0.111	7	7	7	7	1	0.143
Road condition	0.111	3	0.2	5	7	7	1
Sum	1.666	41	18.066	32.143	27.254	17.572	15.819

7x7 AHP Matrix 9 (consistency ratio: 0.055)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	7	5	1	5	5	1
Priority to pedestrians	0.143	1	1	1	3	3	0.2
Right of way	0.2	1	1	0.333	3	3	0.2
Safe driving distance	1	1	3	1	5	5	0.333
Technical vehicle errors	0.2	0.333	0.333	0.2	1	1	0.143
Pedestrian behavior	0.2	0.333	0.333	0.2	1	1	0.2
Road condition	1	5	5	3	7	5	1
Sum	3.743	15.666	15.666	6.733	25	23	3.076

7x7 AHP Matrix 10 (consistency ratio: 0.097)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	5	9	7	9	5	9
Priority to pedestrians	0.2	1	3	0.333	5	0.333	5
Right of way	0.111	0.333	1	0.333	5	0.333	3
Safe driving distance	0.143	3	3	1	5	3	5
Technical vehicle errors	0.111	0.2	0.2	0.2	1	0.333	1
Pedestrian behavior	0.111	3	3	0.333	3	1	3
Road condition	0.111	0.2	0.333	0.2	1	0.333	1
Sum	1.787	12.733	19.533	9.399	29	10.332	27

7x7 AHP Matrix 11 (consistency ratio: 0.021)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	1	7	5	5	3	7
Priority to pedestrians	1	1	7	3	5	3	5
Right of way	0.143	0.143	1	0.333	1	0.333	1
Safe driving distance	0.333	0.333	3	1	3	1	3
Technical vehicle errors	0.2	0.2	1	0.333	1	0.333	1
Pedestrian behavior	0.333	0.333	3	1	3	1	3
Road condition	0.143	0.2	1	0.333	1	0.333	1
Sum	3.152	3.209	23	10.999	19	8.999	21

7x7 AHP Matrix 12 (consistency ratio: 0.083)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	5	5	5	7	7	9
Priority to pedestrians	0.2	1	0.2	3	5	5	5
Right of way	0.2	0.2	1	0.333	3	0.333	0.2
Safe driving distance	0.2	0.333	3	1	5	0.2	5
Technical vehicle errors	0.143	0.2	0.333	0.2	1	0.2	0.2
Pedestrian behavior	0.143	0.2	5	1	5	1	5
Road	0.111	0.2	0.333	0.2	5	0.2	1
Sum	1.997	7.133	14.866	10.733	31	13.933	25.4

7x7 AHP Matrix 13 (consistency ratio: 0.060)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	0.111	0.111	0.111	0.143	0.2	0.333
Priority to pedestrians	9	1	3	3	3	3	3
Right of way	9	0.333	1	3	3	1	3
Safe driving distance	9	0.333	0.333	1	3	1	3
Technical vehicle errors	7	0.333	0.333	0.333	1	1	1
Pedestrian behavior	5	0.333	1	1	1	1	3
Road condition	3	0.333	0.333	0.333	1	0.333	1
Sum	43	2.776	6.11	8.777	12.143	7.533	14.333

7x7 AHP Matrix 14 (consistency ratio: 0.098)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	5	3	3	1	3	0.2
Priority to pedestrians	0.2	1	1	0.333	1	1	0.333
Right of way	0.333	1	1	1	1	1	0.333
Safe driving distance	0.333	3	1	1	1	1	1
Technical vehicle errors	1	1	1	1	1	3	0.333
Pedestrians behavior	0.333	1	1	1	0.333	1	0.333
Road condition	5	3	3	1	3	3	1
Sum	8.199	15	11	8.333	8.333	13	3.532

7x7 AHP Matrix 15 (consistency ratio: 0.039)

	Speed	Priority to pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Speed	1	3	5	3	3	3	7
Priority to pedestrians	0.333	1	5	3	3	1	3
Right of way	0.2	0.2	1	0.333	0.333	0.333	1
Safe driving distance	0.333	0.333	3	1	1	1	3
Technical vehicle errors	0.333	0.333	3	1	1	0.333	3
Pedestrians behavior	0.333	1	3	1	3	1	3
Road condition	0.143	0.333	1	0.333	0.333	0.333	1
Sum	2.675	6.199	21	9.666	11.666	6.999	21

Appendix C: Indicator weights' Mean Score, Standard deviation, and Coefficient of Variation

	N	Mean	Std. Deviation	coefficient of variation
Speed	12	.3517	.13816	.39
Priority to pedestrians	12	.1467	.09188	.63
Right of way for other cars	12	.0750	.04739	.63
Safe driving distance	12	.1242	.04010	.32
Vehicle technical errors	12	.0867	.04313	.50
Illegal pedestrian behavior	12	.1042	.05452	.52
Bad road condition	12	.1092	.10492	.96
Valid N (listwise)	12			

Appendix D: Normalized Indicator Data

Area	Speed	Priority to Pedestrians	Right of way	Safe driving distance	Technical Vehicle errors	Pedestrian behavior	Road condition
Bahir Dar	0.369	0.595	1.000	0.857	0.000	0.385	0.000
Gondar	0.107	0.048	0.300	0.163	0.000	0.077	0.000
Dessie	0.071	0.560	0.975	1.000	0.152	0.000	0.000
West Gojjam	0.440	0.286	0.175	0.347	0.130	0.385	1.000
East Gojjam	0.440	0.369	0.300	0.612	0.130	1.000	0.833
Awi Zone	0.214	0.190	0.000	0.306	0.043	0.000	0.000
South Gondar	1.000	0.131	0.150	0.102	0.087	0.154	0.083
North Gondar	0.048	0.143	0.025	0.041	0.043	0.000	0.000
Central Gondar	0.131	0.250	0.000	0.061	0.043	0.077	0.000
West Gondar	0.143	0.012	0.075	0.000	0.000	0.000	0.000
North Wollo	0.107	0.345	0.025	0.245	0.130	0.231	0.083
South Wollo	0.298	0.440	0.000	0.184	0.130	0.231	0.333
Waghemra	0.000	0.000	0.150	0.061	1.000	0.077	0.333
North Shewa	0.286	1.000	0.500	0.918	0.217	0.769	0.750
Oromiya	0.464	0.357	0.050	0.327	0.087	0.154	0.083

Appendix E: Independent Sample T-test result

			Index Score	
			Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		0.025	
t-test for Equality of Means	Sig.		0.875	
	t		2.446	2.446
	df		28	27.999
	Sig. (2-tailed)		0.021	0.021
	Mean Difference		0.15181	0.15181
	Std. Error Difference		0.062053	0.062053
	95% Confidence Interval of the Difference	Lower	0.024701	0.024701318
		Upper	0.278919	0.278919

Appendix F: the weighted share of indicators based on geometric aggregation

	Weighted Share of indicators						
	Speed	Priority to Pedestrians	Right of way	Safe driving distance	Vehicle	Pedestrians	Road
Bahir Dar	0.705	0.925	1.000	0.982	0.102	0.909	0.062
Gondar	0.458	0.633	0.908	0.805	0.102	0.774	0.062
Dessie	0.397	0.917	0.998	1.000	0.844	0.079	0.062
West Gojjam	0.751	0.829	0.870	0.881	0.833	0.909	0.062
East Gojjam	0.751	0.861	0.908	0.943	0.833	1.000	0.980
Awi Zone	0.583	0.780	0.132	0.868	0.754	0.079	0.062
South Gondar	1.000	0.737	0.859	0.760	0.803	0.829	0.761
North Gondar	0.345	0.747	0.744	0.681	0.754	0.079	0.062
Central Gondar	0.491	0.812	0.132	0.715	0.754	0.774	0.062
West Gondar	0.506	0.514	0.813	0.048	0.102	0.079	0.062
North Wollo	0.458	0.853	0.744	0.845	0.833	0.864	0.761
South Wollo	0.654	0.884	0.132	0.816	0.833	0.864	0.886
Waghemra	0.000	0.022	0.859	0.715	1.000	0.774	0.886
North Shewa	0.645	1.000	0.946	0.990	0.872	0.974	0.969
Oromiya	0.764	0.857	0.787	0.874	0.803	0.829	0.761

Appendix G: Spearman’s Correlation Coefficient between index rankings and final outcome ranking

1. Correlation between geometric and linear rankings

			Geometric Ranking	Linear Ranking
Spearman's rho	Geometric Ranking	Correlation Coefficient	1.000	.829**
		Sig. (2-tailed)	.	.000
		N	15	15
	Linear Ranking	Correlation Coefficient	.829**	1.000
		Sig. (2-tailed)	.000	.
		N	15	15
**. Correlation is significant at the 0.01 level (2-tailed).				

2. Correlation between linear aggregation and road safety outcome rankings

	Linear Ranking	Outcome Ranking		
Spearman's rho	Linear Ranking	Correlation Coefficient	1.000	.986**
		Sig. (2-tailed)	.	.000
		N	15	15
	Outcome Ranking	Correlation Coefficient	.986**	1.000
		Sig. (2-tailed)	.000	.
		N	15	15
**. Correlation is significant at the 0.01 level (2-tailed).				

3. Correlation between geometric aggregation and road safety outcome rankings

	Geometric Ranking	Outcome Ranking		
Spearman's rho	Geometric Ranking	Correlation Coefficient	1.000	.855**
		Sig. (2-tailed)	.	.000
		N	15	15
	Outcome Ranking	Correlation Coefficient	.855**	1.000
		Sig. (2-tailed)	.000	.
		N	15	15
**. Correlation is significant at the 0.01 level (2-tailed).				