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Research paper
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IMPACTS OF TRAFFIC ACCIDENT AND CRASH COSTS IN SEVERITY LEVEL ANALYSIS

Abstract: The severity level of a road interacts with factors that determine the occurrences of traffic crashes, accidents, and their crash costs. Analyzing traffic crashes, accidents, and crash costs is not sufficient to define the severity level of the road unless the combined effects are explored. The objective of this study is defining an alternative severity level based on a combined parameter approach using traffic crash, accident, and crash cost relative percentage share. The study used five years of traffic crash data from Budapest. In the study area, on average, around 45 people die annually due to traffic crashes. Based on a newly alternative severity indexing approach, the severity level of route 1 > route 2 > route 3. Route 1 was a severe segment where greater than 60% of traffic crashes were registered in the study area. In contrast, the existing severity indexing approach 2 showed that route 2 was a severe road segment of the study area. This acknowledges that having a maximum number of traffic crashes, traffic accidents, and crash costs doesn't designate the higher severity level and vice versa. In all, an alternative approach showed that the severity level route 2 was reduced while compared to the existing approach. Utilizing the relative percentage share of road traffic crashes, accidents, and crash costs, the combined effects had a significant impact in defining severity level. Based on the stated severity indexing approach, this study identified that having a higher percentage share of road traffic crashes, accidents, and crash costs designates the severity level. At the end, the study recommends that using the stated alternative severity indexing approach was potentially more comprehensive.

Keywords: combined parameter approach, determinant factors, traffic crash cost, relative percentage share, severity level indicators

1. Introduction

1.1 General Overview

This study was a continuous part of the research work published in the innovative solution infrastructure journal entitled “Road

geometry-related crash distribution, economic losses, and an alternative severity level analysis approach using combined parameters utilizing relative percentage share” (Jima & Sipos, 2025). To minimize road traffic crashes that cause huge losses of life, physical injuries, and property damage,

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identifying the severity level of road sections/networks and their indicators and determinant factors was a fundamental concern to maximizing traffic safety. For most to undertake remedial action that minimizes traffic crashes and related outcomes, identifying severity level indicators and determinant factors was important.

Even though severity level indicators and determinant factor identification have substantial impacts in minimizing traffic crashes and related outcomes, the combined effects of those parameters had significant encouragement in identifying severity level. Different researchers used different approaches to analyzing severity value. Even though they used the combined parameters of severity level indicator and determinant factor, still most empirical models and approaches had significant shortcomings. So, this study is formulated to analyze those drawbacks and bring alternative approaches.

To define the severity level of the road section, mostly the number of traffic crashes, the number of traffic accidents, and crash costs played a significant role. Those parameters had their own implication in determining the severity level. Due to some of the stated parameters not being incorporated in the existing approaches in a combined way, this study was initiated to advance the existing methods. To visualize the missing parameters in existing approaches, see table 2.

Concomitant to severity level indicators, different studies and manuals considered determinant factors as severity indexing parameters. For instance, as shown in table 2, the existing severity level analysis approach uses traffic volume, distance coverage and location, and other geometry-related issues to analyze severity value. Even though most determinant factors used to identify the causes of traffic crashes in a given road section, most researchers and manuals used determinant factors to analyze severity level.

1.2 Research Gap

Even though the existing severity level analysis approach was functional, there was still a research gap to define accurate severity value that brings a clear level of cruelty for a given road network to prioritize the road section accordingly. As a result, using an appropriate number/rate/percentage share of severity level indicators in a combined parameters approach would give a significant implication to define the severity level coherently.

Even though the existing severity level analysis approaches used determinant factors as parameters to define severity value, this study argued that determinant factors had significant implications in adopting the severity level of the road section other than defining severity value. As a parameter to define the severity level, most of the determinant factors stated above were not severity level indicators. As a result, this study argued that to characterize the severity level of the road section, defining the severity value is based on the severity level indicator parameters rather than determinant factors.

Despite the fact that this study identified that even though the severity level estimating parameter and determinant factors were used to analyze severity value in a combined way, the insight of severity level was not fully adorable to define the severity value. This is due to the missing parameters of severity indexing, like number of traffic crashes, number of traffic accidents, and crash cost in the existing severity level analysis approach. As a result, using the combined effects of traffic crashes, traffic accidents, and crash costs plays a significant role in defining the severity level.

Based on the above conceptual background, most existing severity level analysis approaches had a drawback that used to wrongly define the accuracy of severity values and the level of prioritization of the road section. As a result, this study requested

to develop an alternative approach that incorporates most severity level indicators as a parameter. Even though different determinant factors are used in existing severity level analysis approaches, basically this study considered the described severity level indicators as basic constraints. To have more information about determinant factors and severity level indicator parameters, see table 1.

Table 1. Determinant factors and Severity Level Indicators variables

Determinant factors	Severity level indicators
Traffic Volume	Number of Traffic Crashes
Distance of Road Coverage	Number of Traffic Accident
Data Review Period	Traffic Crash Cost
Location of Traffic Crash Occurrences	
Road Geometric Formation	

1.3 Study Objective

Most manuals and studies used to analyze severity index disregard one or more severity level-indicating parameters. The combined parameters approach considered the combined effects of traffic crashes, traffic accidents, and crash costs together to analyze the severity value. In addition to this, the study also considers the indicated determinant factor and supplementary parameter to characterize severity level. If some of the stated parameters are missing, the severity value was not significant because the number/rate/percentage share of traffic crashes, traffic accidents, and crash costs were not the same and interdependent except with some unexpected condition. As a result, this study tried to optimize the severity level analysis approach using an alternative technique based on the existing approach. In depth, the objective of this study was to define an alternative severity level analysis approach using combined parameters that were used to bring better insights that helped to minimize road traffic

crash occurrence through identifying the severe road section/segment/network.

1.4 Study Outline

As an outline, this paper mainly contains four sections. The first section deals with the introduction part of the study, which provides an opportunity for readers to understand the background of the study area, road traffic crashes, and related causes. In addition, it provides the research gap, the purpose, and the necessity of the study. The second section focuses on the material and method of the study and briefly describes how the research worked. Mostly emphasized are the data and their type, the approach, and their significance. The third section of the study briefly describes the results and discussion part of the study that was used to report the findings of the study about the interaction between traffic crashes, elevation differences, slope variation, and terrain formation and interpret them contextually. The last section of the study was a conclusion and recommendation that summarizes the entire effects applicability of existing and alternative approaches used to analyze severity levels.

2. Materials and Methods

2.1 Data Type, Source and Method of Collection

This study used existing severity level analysis approaches and road traffic crash data as an input to define and signify an alternative approach used to analyze the severity level of a road section. Five years of Budapest city traffic crash secondary data from 2017-2021 was used based on convenience, availability, and accuracy. In order to organize the data, MS-Excel was used. Each variable and parameter coded according to the nature of the data. Most severity level indicators and determinant factors are used as variables for further analysis. It used a combined parameter

approach as a method of analysis between variables to define the final output and relative implication. The study interpreted the outcome according to their severity value and the nature of the data. At the end, the study recommended the newly severity level analysis approach and its comparative suggestion with the existing methods.

For this study, the traffic crash data accounted for 17006. Due to the stated number of crashes, around 20884 traffic accidents were registered. From total accidents, 224, 4180, and 16480 were reported as fatalities, serious injuries, and slight injuries, respectively.

2.1.1 Some of Existing Severity Level Analysis Approaches

Table 2 below presents some of the randomly selected severity level analysis approaches stated by different researchers and manuals. Basically, it is used to analyze the severity level of the road section based on the nature of the existing data. The existing approaches used the number of traffic crashes, traffic accidents, traffic volume, crash cost, crash location, road distance coverage, respective data year, etc. as input. Even though most stated parameters are determinant factors. So, considering severity level indicators in analyzing severity level in a combined way was a better approach to solving safety problems in road transportation.

Table 2. Some of existing severity level analysis approaches

Citation	Model	Where	Missing Parameters
(US Department of Transportation, 2011)	$R = \frac{200000}{73} \frac{C}{NV}$Eq(A1)	R - crash rate expressed as - kilometers of travel, C - total number of roadway crashes V - average annual daily traffic (AADT), N - number of years of data	- Number of traffic accidents - Crash cost
(US Department of Transportation, 2011)	$R = \frac{C}{NL}$Eq(A2)	R - crashes per mile, C - total number of crashes, N - number of years of data, L - length of the roadway segment	- Number of traffic accidents - Crash cost
(Bham & Manepalli, 2009)	$R = \frac{N}{Q}$Eq(A3)	R - crash rate, N - number of crashes at a location and Q - traffic volume at the location	- Number of traffic accidents - Crash cost

2.1.2 Terminology

To have a clear understanding the traffic crashes, traffic accident and traffic crash costs were some of the word needs unblemished definition and consensus.

a. Road traffic crashes: is an collision in which at least one motor vehicle is involved for the occurrence of accident (UNDRR, 2024) . Others, traffic crash indicates that someone caused the car wreck to happen or that someone is

actually at fault (Patrick Daniel, 2024). A law firm defines a traffic crash as a collision due to the fault of one or more parties (San Francisco injury attorney, 2023).

b. Road traffic accidents: in which at least one person is injured/killed/property damaged due to traffic crashes (OECD, 2024) . It implies that a car crash happened through the fault of nobody in particular (Patrick Daniel, 2024). A law firm defines as an

unexpected happening that causes losses that is not due to the fault of a person (San Francisco injury attorney, 2023).

- c. **Traffic crash costs:** an economic cost (e.g., medical bills, lost wages) and quality-adjusted life years (QALY - commonly thought of as the cost for pain and suffering) (National Accademic Digital Library of Ethiopia, 2021).
- d. **Severity Index:** is a dimensionless value indicating the hazardousness of a spot on the road (Popli Sudershan, 2019; Li & Bai, 2008).
- e. **Determinant factor:** a factor or cause that makes something happen or leads directly to a decision (Random World, 2024; Simoes, 2016).

2.2 Method of Analysis

The study used a combined parameter approach to analyze the severity index of the road section. The study tried to visualize the existing and newly severity values that were used to define severity level. Even though the level of tolerances between existing and alternative severity level analysis approaches used severity level indicators and determinant factors. To scrutinize and discuss the result, both inferential and descriptive statistics were used. To present the findings, the study used tables. To check the significance of the data for further analysis, the study checks the amount of data and data review years. To check the outcome/result appropriateness, the study used level of severity comparative indicators and relative differences between the new and existing approaches.

2.2.1 Level of severity

In this part of the study, the severity level of the road section is characterized based on the measurements of the impacts of an accident. So, this study considers a critical accident with very high impact, a major accident with significant impact, and a minor accident with low impact. As a result, this study

considered that the severity level of a road section is characterized by the number of incidents and their severity. The impacts of the incidence are basically characterized in economic costs that define the level of severity. So, in this study, the number of traffic crashes, number of traffic accidents, and crash cost played a combined significant role in determining the severity level of the road section.

To characterize the severity level of the road section and the stated approaches functionality, the study considers the following conceptual framework. A given road section with a higher severity value would be the road section that should fulfill.

- a. When the empirical model of the severity index contains the number of traffic crashes and the number of traffic accidents, the maximum severity index/value will be registered at $S_A (\%) > S_C (\%)$. Where, $S_A (\%)$ – percentage share of accident, $S_C (\%)$ – percentage share of crashes.
- b. When the empirical model of the severity index contains the number of traffic crashes, number of traffic accidents, and crash cost in a combined way, the maximum severity level is defined based on $S_A (\%) > S_C (\%)$ and $S_{CC} (\%) > S_A (\%)$. Where, $S_A (\%)$ is the percentage share of accidents, $S_C (\%)$ is the percentage share of crashes, and $S_{CC} (\%)$ is the percentage share of crash costs.

In some cases, the share of traffic accident and crash costs is equal at road locations where the number of traffic crashes is minimum. So, at most, the share of traffic accident and crash costs ($S_A \neq S_{CC}$) is except in conditions where, for a given traffic crash, the number of traffic accidents is single (mostly property damage) in a given data review year. If the share of traffic accident and crash cost ($S_A = S_{CC}$) the existing severity level analysis approach was appropriate to define the severity value. To have a meaningful outcome and judgment, this study considers the above assumption to

characterize the severity index/value that is used to define the severity level.

Based on the availability and the nature of the data this study tried to consider equations in table 2 for further analysis and consideration to present the uncertainty and to illustrate an alternative approach. Since the existing equation is missing the number of traffic accidents and crash costs for further analysis and development of an alternative approach, this study tried to consider the following concept:

If the relative percentage share of road traffic accidents and traffic crash cost is different ($S_A(\%) \neq S_{CC}(\%)$). Like equations in table 1, in any severity level analysis approaches the stated condition below would happen.

$$\frac{\sum R_{CC}}{N_A} \neq \frac{S_{CC}(\%)}{S_A(\%)} \text{ or } \frac{N_A}{\sum R_{CC}} \neq \frac{S_A(\%)}{S_{CC}(\%)}$$

Where: N_A - number of accidents, R_{CC} – relative crash cost, $S_A(\%)$ – relative percentage share of traffic accident and $S_{CC}(\%)$ – relative percentage share of traffic crash cost.

In particular, the relative percentage share of traffic accident and crash cost was different except at condition where the traffic accident type was single and property damage only (PDO) across the data review period of the road segment.

2.2.2 Relative Difference

Relative difference was used to characterize the severity level of the road sections based on the result difference between existing and an alternative approach as shown in equation 1.

$$R_D = SI_N - SI_E \quad (1)$$

Where, R_D – relative difference, SI_N – new severity value, SI_E - existing severity value

When the relative difference becomes positive and higher in amount, the road section categorized under this section would be higher in severity level. So, not only the amount of accidents, crashes, or crash cost, but also the relative difference between

existing and newly severity value defines the severity level of the road section.

2.2.3 Combined Parameters Approach

It is a method that allows the severity index to use both severity level indicators and determinant factor variables to analyze severity value interdependently. The combined approach in this case served to improve road safety by analyzing severity value. Mostly the study emphasizes the combined effects of traffic crashes, traffic accidents, and crash costs in determining the severity level of the road section/network. Even though variables like determinant factors are used to analyze severity level in this study, it was not the main aiming factor of the study. The equation and approaches indicated in table 2 showed how the combination of severity level indicator and determinant factor parameters functioned to analyze the severity value that was used to define the severity level of the road section.

Despite the existing method, the new approach incorporated the number of traffic crashes, number of traffic accidents, and crash cost in a combined way in tolerance with all existing approaches instead of the missing parameters. To incorporate all parameters, this study multiplied all existing approaches by S_{CC}/S_A . Where S_{CC} is the share of crash cost and S_A is the share of accident that can be expressed in amount or in percentage. To have uniform impacts, the study considered relative percentage share.

$$NS_{IA} = \frac{ES_{IA} S_{CC}}{S_A} \quad (2)$$

Where, NS_{IA} – new severity indexing approach, ES_{IA} – existing severity indexing approach, S_{CC} –share of crash cost and S_A – share of traffic accident.

Relative percentage share is the percentage obtained by dividing the aggregate value of the share consideration by the aggregate consideration value (Collins, 2024; Aron, 2023) . Based on the above assumption, this

study considered relative percentage share to combine the existing approach with traffic accidents and crash costs in order to develop an alternative approach.

$$NS_{IA} = ES_{IA} \cdot \frac{S_{CC}(\%)}{S_A(\%)} \quad (3)$$

Where, NS_{IA} – new severity indexing approach, ES_{IA} – existing severity indexing approach, S_{CC} (%) – percentage share of crash cost and S_A (%) – percentage share of traffic accident.

The result of the newly severity indexing method, and the existing approach would become equal or the same, at which point the percentage share of traffic accident and crash cost for a given road section can be the same. Unless otherwise stated, the value of the new and existing severity indexing approaches remains different.

The value of $NS_{IA} =$ The value of ES_{IA} @ S_{CC} (%) = S_A (%). This implied that; $\frac{S_{CC}(\%)}{S_A(\%)} = 1$

2.2.4 Forecasting Road Traffic Accident Cost

Forecasting is a technique that uses historical data as input to make informed estimates that are predictive in determining the future direction of past trends and vice versa (Tuovila, 2024; Chambers et al., 1971). Equation 4 shown below is used to analyze the annual forecasted and backcasted accident costs. Since the study used 5-year (2017–2021) traffic accident data, Due to a lack of annual accident costs for all years, and to have precise data, this study considered the 2019 road traffic accident cost as the base year to predict the remaining years (International Transport Forum, 2021).

$$AC = AC_B \left(1 \pm \frac{1}{100} R \right)^N \quad (4)$$

Where: $AC =$ Accident cost; $AC_B =$ Accident Cost of Base Year; $R =$ Growth rate (Inflation Rate); $N =$ Number of years, $N =$

Number of years

Remark: R represents the growth rate of accident costs. Instead of the growth rate, this study used the annual inflation rate of Hungary (World Bank, 2022, 2024). The positive and negative signs of the growth rate show backcasting and forecasting of accident costs, respectively.

2.2.5 Road Traffic Crash Cost

Traffic crashes, traffic accidents, and crash costs are interdependent. Before analyzing severity level, identifying traffic crash cost was compulsory. In order to define and analyze traffic crash costs, identifying the types of traffic accidents is essential. Most road traffic accidents are categorized as death (fatal), serious injuries, slight injuries, and property damage. The cost of traffic accidents/crash costs is mostly affected by the types of accidents registered in a given road network. Even though the number of crashes and accidents had a magnificent impact to characterize severity level, mostly crash cost played a ground role. Because crash costs are related to the age of fatal traffic accidents, the age and type of traffic injuries, and the property damaged during the traffic crash occurrences and other losses expressed in monetary values that interrelate with traffic crashes. As a result, comparatively other than the number of traffic crashes and accidents, the crash cost basically plays significant roles in defining the severity level of the road network.

Road crashes result in a lot of pain and suffering, but they also have an economic cost. The economic consequences of road crashes were high (International Road Assessment Programme (iRAP), 2022; García-Altés & Pérez, 2007). Equation 5 indicated below is used to analyze crash costs (World Bank/IMF, 2023).

$$AC_a (F + SI + LI) = \frac{A(F) MCA(F) + A(SI) MCA(SI) + A(LI) MCA(LI)}{T} \quad (5)$$

Where: AC_a = Annual average accident cost; A = Number of accidents; MCA = Mean cost per accident; T = Period of time under review; F = Fatality; SI = Serious Injuries; LI = Light Injuries

2.2.6 Data quality

To analyze severity level, the available amount and quality of data were required for further investigation of reliable results. For detailed analysis of traffic crash-related severity levels of road sections, different research argued that a minimum of 3 years of data was requested. This study used 5-year traffic crash data for further analysis of the severity level of the road section. The amount of data used for the study in the specified review period was sufficient to define the severity level of the road section.

2.2.7 Data expression

In addition to the number or amount, severity value is also expressed in monetary

value or in percentage share. As a result, this study intermittently expressed traffic crash/traffic accident in number/amount/percentage share depending on the situation. Whereas the crash cost would be expressed in monetary value/amount or in percentage share.

To define the newly approached concept based on the concept of combined parameters, this study considered percentage share to define severity value and its level of indication for newly appended parameters on the existing approaches. As a result, this study tried to incorporate the share of traffic accidents and traffic crash costs in all existing severity level analysis approaches indicated in table 2.

2.3 The research framework

The general flowchart of the materials and method of the study method from idea formulation to conclusion of the study depicted in figure 1.

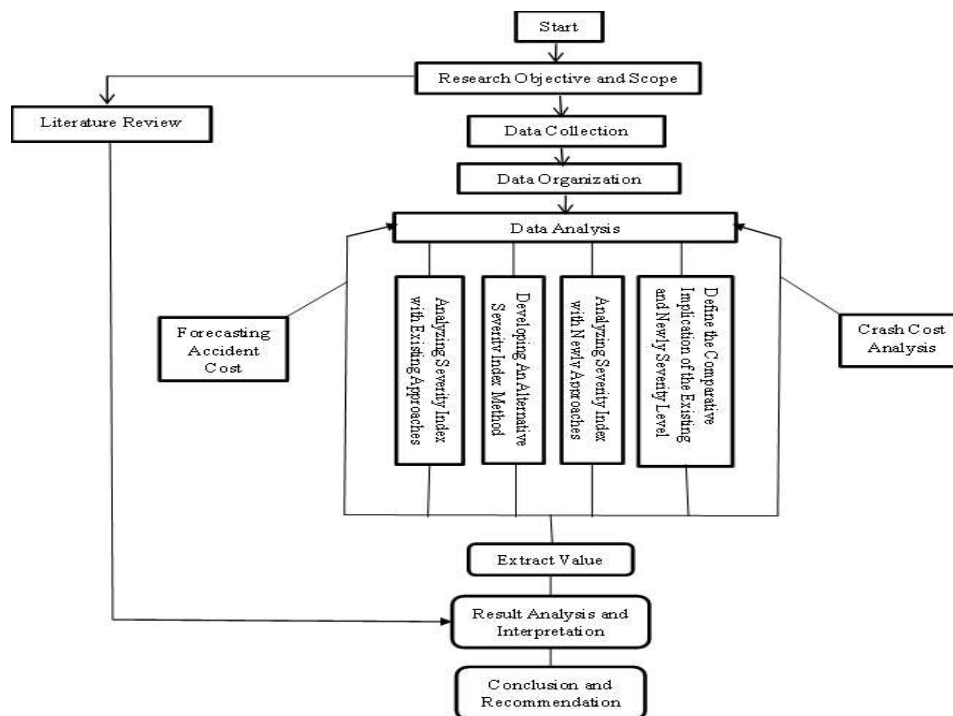


Figure 1. Idea Formulation, Data Collection, Management and Analysis Process

3. Result and Discussion

These sections attempt to explore the findings of this study and discuss the results. It contains the analyzed severity value based on the existing approach and the newly developed alternatives. To support the analysis, road traffic crash cost was analyzed. In addition, the newly developed severity index and its comparative implications with the existing approaches were explored and discussed. Overall, under this topic, the study tried to generate reliable findings and their implications that define the interactive correlation of road severity level based on traffic crashes, traffic accidents, and crash cost, and its combined effects with determinant factors to analyze severity value for specified road segments in

a given road network. The detailed analysis and discussion were prescribed in subtopics below.

3.1 Existing and An Alternative Approach to Analysis Severity Level

In order to describe and to have a detailed explanation of the severity indexing approaches indicated in table 2 the study contemplated severity index 1, 2, and 3. For more information, refer to sections 3.1.1, 3.1.2, and 3.1.3. For analysis purposes, data classification based on geometric formation can be considered as routes. As a result, straight road, crossroad, and bend road are considered route 1, route 2, and route 3, respectively.

Table 3. The Study Area Traffic Crash, Accident and Crash Cost Distribution

Geometric Formation of the Road	Routes	Number of Accident	As (%)	Number of Crash	Cs (%)	Crash Cost (bill. Euro)	Ccs (%)
Straight Road	Route 1	13006	62.3	10961	64.5	0.77	67
Cross Road	Route 2	6926	33.1	5319	31.3	0.32	28
Bend Road	Route 3	952	4.6	726	4.3	0.06	5

3.1.1 Severity Index 1

As shown in table 2, equations A1 and equation 6 the severity level of the road segment is analyzed based on the number of traffic crashes. In this equation the concept of combined parameter was missing the number of traffic accidents and crash costs to define the severity level of the road section. The severity index was expressed as a crash rate used to analyze the severity level of the road section.

$$R = \frac{200000}{73} \frac{C}{NV} \quad (6)$$

Where, R - crash rate expressed as - kilometers of travel, C - total number of roadway crashes, V - average annual daily traffic (AADT), N - number of years of data. As a result, this study proposed a new approach that defines the severity level

subjected to the existing approaches. Based on the drawbacks above, the number of traffic accidents and crash costs were incorporated in the new attempt. To have a fully labeled severity value that was analyzed by using the combined parameters of the number of traffic crashes, number of traffic accidents, and crash cost was depicted in equation 7.

$$R = \frac{200000C}{73NV} * \frac{S_{CC}(\%)}{S_A(\%)} \quad (7)$$

Where, R - crash rate expressed as - kilometers of travel, C - total number of roadway crashes, V - average annual daily traffic (AADT), N - number of years of data, $S_{CC}(\%)$ – percentage share of traffic crash cost and $S_A(\%)$ – percentage share of traffic accident.

The newly severity level analysis approach shown in equation 7 brings the number of

accidents and crash costs as an input to analyze the severity value of the road section. This model considers the percentage share of traffic accidents and crash costs to advance the severity level. In this equation, crash cost would play a significant role in defining the severity index. The percentage share of crash cost is defined in a given review period based on the severity of the accident.

Since Budapest is the capital city of Hungary and the study area of the paper, average annual daily traffic (AADT) of Budapest is expected to be around 75510 vehicles per

day. Even though the study classifies the road section based on the geometric formation for simplicity and analysis purposes, the study considers constant AADT for all road sections. As a result, 75510 vehicles per day were used for all road sections to characterize the severity level. In addition to this, the study used 5-year traffic crash data from (2017-2021). So, the number of years of the data (N) was five (5). Based on the above assumption subtopic 2.2.1 above the severity value of the road section analyzed as shown in table 4.

Table 4. Severity Value Based on Existing and Newly Approaches

Routes	Number of Accident	As (%)	Number of Crash	Cs (%)	Crash Cost (bill. Euro)	Ccs (%)	Existing Approach	Newly Approach	Relative Difference
Route 1	13006	62.3	10961	64.5	0.77	67	79.54	85.54	6
Route 2	6926	33.1	5319	31.3	0.32	28	38.6	32.65	-5.95
Route 3	952	4.6	726	4.3	0.06	5	5.27	5.73	0.46

As shown in table 4, based on the existing severity indexing approach, the severity level of route 1 > route 2 > route 3. The new approach also showed the severity level of route 1 > route 2 > route 3. Based on the nature of the existing and newly approached traffic accident and crash costs, significantly determine the severity level of the road section. Even though the existing and newly combined approaches both had significant severity level analyses based on the level of severity indicators shown in table 1, the newly combined method shown in equation 8 was more appropriate to define the severity level of road section.

To support the alternative approach's effectiveness and the significant impacts of the number of accidents, this study considered that the severity level of the road network basically depends on the impacts of accidents depicted in section 2.2.1. In accordance with the quality of the data, most severe road locations affected by major traffic accidents are characterized as higher in severity level. So, table 4 contradicted that the road section with a higher severity level

was a road section with a higher share of traffic accidents and the share of traffic crash costs relatively. This showed that other determinant factors, like average annual daily traffic (AADT), have a significant impact in determining severity level.

Comparatively, the relative difference between the existing and newly approached showed that the higher severity level was registered in route 1, in contrast to the assumption in section 2.2.1, where the share of traffic crashes was greater than the share of traffic accidents. This implied that not only the severity level indicator, but also other determinant factors play a significant role in deciding the severity level.

To identify the impact of determinant factors on road severity level, this study assumed average annual daily traffic (AADT) related to the crash frequency. So, severity value was directly proportional with the AADT. As AADT increases, the severity level of the road section decreases and vice versa. That showed the road section with the higher AADT would be registered as a lower severity level if other severity level

indicators and determinant factors remain constant. Due to data insufficiency to realize the impacts of AADT on severity level, this study considered constant AADT for all road sections of the road network.

3.1.2 Severity Index 2

As shown in table 2, equation A2, and equation 8 the severity level of the road segment is analyzed based on the number of traffic crashes and other determinant factors. In this equation the concept of a combined approach was missing the number of traffic accidents and crash costs to define the severity level of the road section.

$$R = \frac{C}{NL} \quad (8)$$

Where, R - crashes per mile for the road segment expressed as crashes per each 1 mile of roadway per year, C - total number of crashes in the study period, N - number of years of data, L - length of the roadway segment.

As a result, this study proposed a new approach that defines the severity level subjected to the existing approaches. Based on the drawbacks indicated above, the number of traffic accidents and crash costs were incorporated in the new attempt. To have a fully flagged severity value that was analyzed by using the combined parameters of the number of traffic crashes, traffic

accidents, and crash cost was depicted in equation 9.

$$R = \frac{C}{NL} * \frac{S_{CC}(\%)}{S_A(\%)} \quad (9)$$

Where, R - crashes per mile for the road segment expressed as crashes per each 1 mile of roadway per year, C - total number of crashes in the study period, N - number of years of data, L - length of the roadway segment in miles, S_{CC} (%) - percentage share of crash cost and S_A (%) - percentage share of traffic accident.

The newly severity level analysis approach shown in equation 9 brings the number of accidents and crash costs as the main input to analyze the severity value of the road section. This model considers the percentage share of traffic accidents and crash costs to advance the severity level.

To analyze severity value, defining the total length of the road section was mandatory. Since this study used Budapest city as a data source, even though there is a deficiency of real data about traffic crashes distance coverage for analysis purposes, the study randomly proposed 120 miles, 55 miles, and 36 miles for routes 1, 2, and 3, respectively. Since the study used 5 years of data, the number of years for this analysis will be five (5). Based on the assumption in subtopic 2.2.1 above the severity value of the road section analyzed as shown in table 5.

Table 5. Severity Value Based on Existing and Newly Approaches

Routes	Number of Accident	As (%)	Number of Crash	Cs (%)	Crash Cost (bill. Euro)	Ccs (%)	Existing Approach	Newly Approach	Relative Difference
Route 1	13006	62.3	10961	64.5	0.77	67	18.3	19.6	1.3
Route 2	6926	33.1	5319	31.3	0.32	28	19.3	16.4	-2.9
Route 3	952	4.6	726	4.3	0.06	5	4.1	4.5	0.4

As shown in table 5, based on the existing severity indexing approach, the severity level of route 2 > route 1 > route 3. The new approach showed that the severity level of route 1 > route 2 > route 3. Based on the nature of the existing and newly approached, the number of accidents and crashes

significantly determines the severity level of the road section. Even though the severity level indicator plays a significant role, the determinant factor, like the length of the road section, also plays a role in defining the severity level of the road section. In this part of the study, the crash rate/number of

crashes per mile defines the severity level. So, even though the existing and newly combined approaches to severity level analysis were significant based on the level of severity indicators shown in table 1, the newly combined method shown in equation 9 was more appropriate to define the severity level of a road section even though the length of the road was a determinant factor.

To support the alternative approach's effectiveness and the significant impacts of the number of accidents and crash costs, this study considered that the severity level of the road network basically depends on the impacts of accidents depicted in section 2.2.1. In accordance with the quality of the data, most severe road locations affected by major traffic accidents are characterized as higher in severity level. So, table 5 contradicted that the road section with a higher severity level was a road section with a higher share of traffic accidents and traffic crash costs relatively. This showed that other determinant factors, like the length of the road section, etc., also have a significant impact in determining severity level.

Comparatively, the relative difference between the existing and newly approached showed that the higher severity level was registered in route 1, in contrast to the assumption in section 2.2.1. The share of traffic crashes was greater than the share of traffic accidents.

To identify the impact of determinant factors on road severity level, even though this assumption was not significant and realistic, this study assumed the length of the routes based on the crash frequency. So, it was assumed that the severity value was proportional with the length of the route. Based on the above assumption and models depicted above in equations 8 and 9, as the length of the route increases, the severity level of the road section decreases and vice versa. But, in contrast, the road section with the higher length would be registered as a higher severity level. Due to data insufficiency to realize the impacts of length

on severity level, this study assumed the length of road section based on the share of traffic crashes randomly. This showed that not only are severity level indicators a determinant factor, but they also have significant implications in determining the severity level of a road section.

3.1.3 Severity Index 3

As shown in table 2, equation A3, and equation 10, the severity level of the road segment is analyzed based on the number of traffic crashes and other determinant factors. In this equation the concept of a combined approach was missing the number of traffic accidents and crash costs to define the severity level of the road section.

$$R = \frac{N}{Q} \quad (10)$$

Where, R - crash rate, N - number of crashes at a location, Q - traffic volume at the location.

As a result, this study proposed a new approach that defines the severity level to be subjected to the existing approaches. Based on the drawbacks indicated above, the number of traffic accidents and crash costs were incorporated. To have a fully flagged severity value that was analyzed by using the combined parameters of the number of traffic crashes, number of traffic accidents, and crash cost was depicted in equation 11.

$$R = \frac{N}{Q} * \frac{S_{CC}(\%)}{S_A(\%)} \quad (11)$$

Where, R - crash rate, N - number of crashes at a location, Q - traffic volume at the location, $S_{CC}(\%)$ - percentage share of crash cost and $S_A(\%)$ - percentage share of traffic accident.

The newly severity level analysis approach shown in equation 11 brings the number of accidents and crash costs as the main input to analyze the severity value of the road section. This mathematical model considers the percentage share of traffic accidents and crash costs to advance the severity level.

To analyze the severity value in this subtopic, defining the traffic volume of the road section was mandatory. Since Budapest is the capital city of Hungary, and the study used average annual daily traffic (AADT) of Budapest expected around 75510 vehicles per day for all routes as traffic volume. Even though the study classifies the road section based on the geometric formation for simplicity and analysis purposes, the study considers constant traffic volume for all road

sections. As a result, 75510 vehicles per day were used for all road sections to characterize the severity level. Even though this assumption was not significant and realistic, this study assumed traffic volume of the location was the same as average annual daily traffic volume (AADT) as indicated in subtopic 3.1.1. Based on the assumption in subtopic 2.2.1 above the severity value of the road section analyzed as shown in table 6.

Table 6. Severity Value Based on Existing and Newly Approaches

Routes	Number of	As (%)	Number of Crash	Cs (%)	Crash Cost (bill. Euro)	Ccs (%)	Existing Approach	Newly Approach	Relative Difference
Route 1	13006	62.3	10961	64.5	0.77	67	0.15	0.16	0.01
Route 2	6926	33.1	5319	31.3	0.32	28	0.07	0.06	-0.01
Route 3	952	4.6	726	4.3	0.06	5	0.01	0.01	0.00

As shown in table 6, based on the existing and newly severity indexing approach, the severity level of route 1 > route 2 > route 3. Even though the severity level of the route in both approaches was the same, route 2 showed that reduction in severity value due to traffic accident and crash cost share. Based on the nature of the data, the number of accidents and crashes significantly determines the severity level of the road section. Even though the severity level indicator plays significant roles, a determinant factor like the traffic volume of the road section plays a role in defining the severity level of the road section. In this part of the study, the crash rate/number of crashes per traffic volume defines the severity level. So, even though the existing and newly combined approaches to severity level analysis were significant based on the level of severity indicators shown in table 1, the newly combined method shown in equation 11 was more appropriate to define the severity level of road section.

To support the alternative approach's effectiveness and the significant impacts of the number of accidents and crash costs, this study considered that the severity level of the road network basically depends on the impacts of accidents as depicted in section

2.2.1. In accordance with the quality of the data, most severe road locations affected by major traffic accidents are characterized as higher in severity level. Comparatively, the relative difference between the existing and newly approached showed that the higher severity level was registered in route 1, in contrast to assumption in 2.2.1, where the share of traffic crashes was greater than the share of traffic accidents. That showed that the determinant factor also has significant implications in determining the severity level of the road section.

4. Conclusion and Recommendation

This section of the study summarizes the entire research work, dealing with the effects of the new methods to analyze severity level with respect to the relative percentage share and the combined parameters approach and recommending the applicability of the stated approach. For more information, see sections 4.1 and 4.2.

4.1 Conclusion

Severity level of road provisionally correlated with severity level indicator

variables and other determinant factors. Where traffic crashes, traffic accidents, and crash costs are severity level indicator variables, other related factors used to analyze severity levels are considered determinant factors. The main objective of this study was to define an alternative severity level analysis approach using combined parameters that are used to bring better insights that help to minimize road traffic crash occurrence through identifying the severe road section/segment/network. To address the goal as an input, the study used 5 years (2017–2021) of Budapest city road network traffic crash data, the annual inflation rate, and the GDP of Hungary. To support and analyze the severity level of a given road segment, the study used relative percentage share, severity index, average annual crash cost, and forecasting methods.

To have clarity, the study considers the alignment of the road geometry that incorporates the straight road, crossroad, and bend road as route 1, route 2, and route 3 for further analysis. In the study area, most traffic crashes, traffic accidents, and traffic crash costs were registered on route 1 of the road network. At the same time, based on existing and alternative severity level approaches, route 1 was the higher severe road segment than others.

Even though different approaches were used to analyze the severity level, the stated/existing severity level analysis approach utilizes traffic crashes as an input from severity level indicator variables and other determinant factors. As a result, this study used the relative percentage share of traffic crashes, accidents, and crash costs to analyze the severity level of a given road segment as a basic demonstrating variables in a combined way.

Based on a newly alternative severity indexing approach, the severity level of route 1 > route 2 > route 3. Route 1 was a severe segment where greater than 60% of traffic crashes were registered in the study area. In contrast, the existing severity indexing

approach 2 showed that route 2 was a severe road segment of the study area. This acknowledges that having a maximum number of traffic crashes, traffic accidents, and crash costs doesn't designate the higher severity level and vice versa. In all, an alternative approach showed that the severity level route 2 was reduced while compared to the existing approach. Utilizing the relative percentage share of road traffic crashes, accidents, and crash costs, the combined effects had a significant impact in defining severity level. Based on the stated severity indexing approach, this study identified that having a higher percentage share of road traffic crashes, accidents, and crash costs designates the severity level.

In general, based on the existing and newly developed severity level analysis approach having a higher traffic crash, traffic accident, and traffic crash cost doesn't describes the severity level of the road segment. Therefore, analyzing and considering the combined effects had significant implications for defining the severity level of the road segment. To overcome traffic crashes and related problems, investigating severe road segments and traffic crash causes and proposing remedial action was desirable to reduce loss of life and the economy.

4.2 Recommendation

Even though the number of traffic crashes, traffic accidents, and crash cost indicators of severity level have a significant effect in defining the severity level of road segments/networks. Analyzing severity level using empirical models depicted above in table 2 (existing approach) had its own drawbacks. As a result, using an alternative approach was sympathetic to defining road traffic crash/accident centers of attraction. Depending on parameters considered for analysis, the severity level having a higher number of traffic crashes/accidents/crash costs doesn't describes the severity level.

Based on overall investigation and analysis

of severity level, even though the existing approach brings important results and indicates an alternative approach using the combined parameters (traffic crash, traffic accident, and crash cost) was more

significant. As a result, this study recommended that using alternative approaches depicted above was more significant and potentially comprehensive to analyze the severity level road segments.

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