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CAIO ASSUNÇÃO TORRES

BENCHMARKING METHODOLOGY FOR ROAD SAFETY POLICIES ANALYSIS IN BRAZILIAN CITIES BASED ON THE SAFE SYSTEM APPROACH

FORTALEZA
2023

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Approved in: 05/26/2023.

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To my parents, who never stopped believing in me; to my partner, with whom I am lucky to share the life; and to my true friends.
I DEDICATE.

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“As a road safety engineer, you will probably
save more lives than a doctor. The difference
is that you will never meet the people whose
lives you save”.
Sofia Braun.

ABSTRACT

The road traffic injuries are considered an actual and urgent issue of global public health. This complex epidemiological phenomenon requires a multisectoral and vertically coordination approach across multiple levels of governments. The current road safety paradigm, called Safe System, recognizes that road safety policies (RSP) should be properly defined in order to consider the fallibility and vulnerability of the human body. In this approach, the road safety outcomes consider the interaction between the dimensions of the complex and dynamic system that influences the way people travel and behave on the roads. The most relevant Safe System dimensions, defined by WHO, are: (i) Road Safety Management; (ii) Safer Driving Environment; (iii) Safer Vehicles; (iv) Safer Road Users and (v) Post-crash Response. In a scenario of economic recession, mainly for low- and middle-income regions, understanding the impact of these dimensions should be useful for designing more efficient RSP. In addition, comparative analysis between regions, based on the benchmarking approach, could generate opportunities for the regions to rethink their RSP based on best practices from other similar regions. In this sense, this thesis proposes a road safety policies benchmarking methodology for Brazilian cities, considering a framework able to quantify the structural relationships of the main Safe System dimensions and the road traffic fatality (RTF) rate. In an effort to apply the proposed method, this framework was evaluated for a global level. After, a Brazilian road safety indicators database was consolidated based on a structured questionnaire. A multivariate modeling was performed to evaluate the complex relationships between the Safe System dimensions and its respective road safety indicators. The modeling outcomes are used to build a RSP performance index applied in the benchmarking analysis. The indices analysis allowed a quantitative evaluation of the Safe System dimension relevance. RSP aims to promote Safer Driving Environment and Safer Road Users have the highest and direct effect in reducing RTF. Road Safety Management and Post-crash Response policies present an indirect effect. Finally, these RSP performance indexes are used to compare cities within clusters, considering its socioeconomic indicators. The results of the comparative benchmarking analysis could bring valuable contribution to support the definition of strategic planning scenarios, identifying opportunities to objectively improve the Brazilian cities' road safety policies efforts.

Keywords: Road safety policies; Safe system approach; Benchmarking; PNATRANS.

RESUMO

As lesões causadas pelo trânsito são consideradas uma questão atual e urgente de saúde pública mundial. Este fenômeno epidemiológico complexo requer uma abordagem multissetorial e de coordenação vertical em vários níveis de governo. O atual paradigma de segurança viária, denominado Sistema Seguro, reconhece que as políticas de segurança viária (PSV) devem ser devidamente definidas de forma a considerar a falibilidade e vulnerabilidade do corpo humano. Nesta abordagem, os resultados da segurança viária consideram a interação entre várias dimensões que formam um sistema dinâmico que influencia a forma como as pessoas trafegam e se comportam nas vias. As dimensões mais relevantes do Sistema Seguro, definidas pela OMS, são: (i) Gestão da Segurança Viária; (ii) Ambiente de Condução Seguro; (iii) Veículos Seguros; (iv) Usuários Seguros e (v) Atendimento às vítimas. Em um cenário de recessão econômica, a compreensão do impacto dessas dimensões deve ser útil para o desenho de PSV mais eficientes. Além disso, a análise comparativa entre regiões, baseada em benchmarking, gera oportunidades para que as regiões repensassem suas PSV com base nas melhores práticas de regiões semelhantes. Nesse sentido, esta tese propõe uma metodologia de benchmarking de PSV em cidades brasileiras, considerando uma estrutura capaz de quantificar as relações estruturais das principais dimensões do Sistema Seguro e a taxa de letalidade no trânsito. No esforço de aplicação do método proposto, esta abordagem foi avaliada a nível global. Em seguida, foi consolidado um banco de dados de indicadores de segurança no trânsito brasileiro com base em um questionário estruturado. Uma modelagem multivariada foi realizada para avaliar as relações entre as dimensões do Sistema Seguro e seus respectivos indicadores de segurança viária. Os resultados da modelagem foram usados para construir um índice de desempenho das PSV aplicado na análise de benchmarking. A análise dos índices permitiu uma avaliação quantitativa da relevância das dimensões do Sistema Seguro. As políticas destinadas a promover um ambiente de direção e usuários mais seguros têm efeito direto na redução da letalidade. As políticas de gestão de segurança viária e atendimento às vítimas apresentam efeito indireto. Os índices de desempenho das PSV são utilizados para comparar cidades dentro de clusters, considerando indicadores socioeconômicos. Por fim, os resultados do benchmarking trazem contribuições para apoiar a definição de cenários de planejamento estratégico, identificando oportunidades para melhorar os esforços das PSV nas cidades brasileiras.

Palavras-chave: Políticas de segurança viária; Abordagem do sistema seguro; Benchmarking; PNATRANS.

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LIST OF ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
CFI	Comparative Fit Index
DARS	Decade of Action for Road Safety
GDP	Gross Domestic Product
HDI	Human Development Index
IPEA	Instituto de Pesquisa Econômica Aplicada
LAI	Law Access Information
LMIC	Low- and Middle-Income Countries
ML	Maximum Likelihood
MSA	Multivariate Statistical Analysis
PCR	Post-Crash Response
RMSE	Root Mean Square Error
RSM	Road Safety Management
RSP	Road Safety Policy
RSPP	Road Safety Policy Performance
RTF	Road Traffic Fatalities
RTI	Road Traffic Injuries
SDE	Safer Driving Environment
SDG	Sustainable Development Goals
SEM	Structural Equation Modeling
SPF	Safety Performance Functions
SRU	Safer Road User
SS	Safe System
UN	United Nations
WHO	World Health Organization

SUMÁRIO

1 INTRODUCTION

1.1 Background

According to The World Health Organization (WHO, 2022), road crashes cause nearly 1.35 million preventable deaths and an estimated 50 million injuries each year. The social and financial impacts of both fatalities and injuries are substantial and aggravated for low-income populations. For some households, the loss or injury of a family member in a road traffic crash can be the difference between financial stability and poverty (WELLE et al., 2018). In total, the WHO (2018) estimates the annual economic cost of road traffic fatalities and injuries to be around 3% of global gross domestic product (GDP).

Currently, considered an urgent issue of global public health, the road traffic injuries (RTI) problem is far from uniform at the geographical distribution. 90% occur in low- and middle-income countries (LMIC), and most are among poorer working-age males (WHO, 2022). This group tends to use vulnerable modes of transport such as walking, cycling, and motorcycling. The road traffic fatalities (RTF) are also the leading cause of death among children and young adults globally.

To draw the attention of society and government to this serious and urgent issue, The Commission for Global Road Safety issued a call for a Decade of Action for Road Safety (DARS) in its 2009 report (WHO, 2011). The first Decade started in 2011 providing a timeframe for action to encourage political and resource commitments at regional, national, and local level to promote road safety policies and halve road traffic deaths until 2020.

In this context, the United Nations (UN) Road Safety Collaboration has developed a Global Plan for the Decade of Action for Road Safety 2011-2020 with input from many partners through an extensive consultation process (WHO, 2011). The Global Plan provides an overall framework for activities which may take place in the context of the DARS and adopts a systemic and comprehensive approach to tackle the road safety problem. This approach is based on a concept from the Vision Zero Program (TINGVALL, 1998a; WEGMAN; AARTS; BAX, 2008) known as Safe System (SS). Based on the principle that humans are fallible, and errors are to be expected, the document suggests a multisectoral and vertically coordinated approach across multiple levels of government.

The SS approach recognizes road safety as the outcome of the interaction between many dimensions that form a dynamic system that influences the way people travel and behave on the roads and thus their level of exposure to the road crash risks. The Global Plan highlighted the main important SS dimensions for actions, that must be related to: (i) increase road safety management capacity; (ii) improve the safety of road infrastructure and broader transport networks; (iii) further develop the safety of vehicles; (vi) enhance the behavior of road users; and (v) improve post-crash response. Governments, international agencies, civil society organizations, the private sector and other stakeholders were invited to make use of the Global Plan and its recommendations as a guiding document for development of policies and activities as part to support the DARS (WHO, 2011).

A significant achievement of the DARS was the inclusion of road safety among the Sustainable Development Goals (SDGs). Integrating a road safety target into SDG 3.6 and 11.2 was a remarkable accomplishment with far-reaching potential and reinforced the DARS target, giving more strength to the promotion of road safety policies proposed in the Global Plan.

With the establishment, road safety was explicitly included for the first time as part of the global development agenda, and this heightened recognition provided a new and unique opportunity to accelerate progress. This recognition puts road traffic safety on the same level of global criticality as climate, health, and equity issues and means that road safety can no longer be traded off in order to promote other needs (TINGVALL et al., 2022).

Welle et al. (2018) points out that the current paradigm of road safety is based on a complex understanding of the underlying RTI causes, the human fallibility and vulnerability and the responsibility of governments to protect their citizens. The five road safety dimensions highlighted in the Global Plan 2011–2020 include a set of evidence-based interventions that can measurably improve the safety of road traffic, especially if they are applied with the SS current paradigm.

However, the implementation of policies from the SS perspective in some environments can face strong barriers. Competing priorities, lack of resources, the capacity of local governments to act, and differences in geographic, geopolitical, and geodemographic situations or scales can present serious challenges to implementing changes necessary to promote road safety. These challenges have likely been an obstacle to RTI reductions in many regions, mainly in LMIC (WHO, 2019).

A regular global assessment is essential to measure and compare the road safety performance of regions. Several techniques have been developed to support road safety policy (RSP) makers in developing possible safety measures or actions. Procedures for such complex safety comparisons have been developed and tested in several so-called road safety Benchmarking studies (WEGMAN; OPPE, 2010). This approach has been applied in the road safety area with the aim of comparing and reducing the RTI in the regions where it is applied (AL-HAJI, 2007; WEGMAN; AARTS; BAX, 2008).

Due to the complexity of the multidimensional relationships of road safety policies, the indicators and model technique need to be properly defined. The decision and importance of choosing these parameters to represent the RTI problem becomes even more complex with the diversity of existing indicators and the difficulty of access to many of them. For a better understanding of this complex relationship embedded in road safety evaluation, the indicators that make it possible to measure the effect of SS approach dimensions on the RTI should be investigated (TORRES; XAVIER; CUNTO, 2020).

A widely used tool for investigating road safety are statistical models applied to safety performance functions (SPF), such as generalized linear models (Poisson or Negative Binomials), categorical models (ordered and hierarchical), random parameter models, zero inflated models and spatial models, among others (GOMES; CUNTO; SILVA, 2017; LORD; PERSAUD, 2004; MANNERING; BHAT, 2014).

Despite its recognized contribution, most road safety performance studies involving statistical modeling are focused on a more disaggregated level and a specific dimension, such as vehicle, road users or road environment (AASHTO, 2014; BARBOSA et al., 2014). Within this approach, the predictive models still predominate, where, on several occasions, the modeling strategy results are poorly informative about the complex relationship between the contributing factors and the RTI (HAUER, 2015a; HAUER; BOARD, 2004a; HOLLÓ; EKSLER; ZUKOWSKA, 2010). According to Nikolaou et al. (2019), when it comes to RSP assessment this predictive modeling paradigm seems to be inadequate to provide objective inferences between the key SS approach dimensions.

Multivariate Statistical Analysis (MSA) technique have been used successfully in the social sciences, economics and, in recent years, have gained strength in their application in road safety studies (AL-MAHAMEED et al., 2019; CHEN; CHEN, 2011a; LEE; CHUNG; SON, 2008). This approach provides a more adequate framework objectively incorporating constructs and variables more compatible with the analysis of this complex and multidimensional phenomenon at the policy level (SCHUMACKER; LOMAX, 2004). According to the OECD (NARDO et al., 2005), the MSA offers the opportunity to compare the statistically determined structure of the dataset to the theoretical framework and discuss possible differences and to identify groups of indicators or groups of entities that are statistically similar and provide an interpretation of the results.

The Structural Equation Modeling (SEM), a MSA model used to analyze structural relationships, allow to evaluate the significance and strength of a particular relationship in the context of the complete model and provide a good platform for considering multicollinearity and eliminating measurement error by using latent variable (constructs), a type of unmeasured variable (LITTLE et al., 2012). Road safety studies have incorporated this technique to modeling these complex relationships based on several constructs, inferred through a structural model from observable variable (CHEN; CHEN, 2011; ROSLI et al., 2016; ZHOU; ROMERO; QIN, 2016).

According to Estiri et al. (2021), the factor loadings, SEM main output, indicate the strength of structural relationships and can be used to formulate integrated indexes perceived within a holistic context of road safety performance. This type of index is compatible with the application of an integrated benchmarking (AL-HAJI, 2007) that makes it possible to compare and improve road safety policies by incorporating the SS approach dimensions.

1.2 Research questions

Near the end of the first DARS, the WHO published the periodic Global Plan monitoring report (WHO, 2018) that provides open data access for country specific RTI estimate statistics and road safety indicators from the main SS approach dimensions. The publication presented that little progress has been made, highlighting the urgent need to expand road safety policies and investment based on data driven evidence. Between 2013 and 2016, the number of deaths increased in 104 of 175 countries monitored by WHO, all of them LMIC.

In this context, the Stockholm Declaration on Road Safety (UN, 2020) has postponed the DARS by another decade. In 2021, the second DARS calls for a new global target to reduce road traffic deaths and injuries by 50% by 2030. This new time frame provides an opportunity for harnessing the successes and lessons of previous years and building upon them to save more lives based on expanded application of SS approach and integration of road safety among the SDG.

The five SS approach dimensions identified in the first DARS, and reinforced in the second, include a set of evidence-based policies that have significantly promote road safety. Monitoring the performance of these strategies and ensuring proper linkage to outcomes can be helpful in guiding policy decisions in other regions, from the application of the benchmarking principles. These dimensions include tools to improve road safety management and increase the safety of roads and mobility, vehicles, road users and emergency response. From these findings and the need to contribute scientifically to the mitigation of this still urgent global issue, comes the first research question:

i. How appropriate is the use of the SS approach dimensions as Latent Constructs that supports the effort to analyze road safety policies at global level based on data driven evidence?

As at the national level, the engagement of its administrative subdivisions is also fundamental for promote road safety policies. The new Global Plan for the Second DARS highlighted the importance of local (city-level) government commitment in efforts to reduce RTI (WHO, 2022). Nations that register the highest numbers of road traffic deaths have continental dimensions, such as Brazil, a middle-income country in South America with more than 5,500 cities. According to WHO (WHO, 2019), the number of road traffic deaths estimated in Brazil is 41.007 and the social cost generated by the road traffic injuries estimated at approximately 50 billion reais per year (INSTITUTO DE PESQUISA ECONÔMICA APLICADA, 2015). Thus, another research question of this thesis is defined:

ii. What is the status of road safety policies in Brazilian cities with more than 100k inhabitants considering the SS approach dimensions?

According to the department of the Brazilian Unified Health System (CARVALHO, 2016), on a national scale, it is possible to observe positive and negative road safety performances during the DARS in Brazilian cities. This fact may be the result of the different levels of political interest and the unequal allocation of resources for road safety promotion, especially in small and low-income cities.

A recent study carried out by the Mapfre Foundation (2022) highlighted that the analyzed Brazilian cities that adopted actions inspired by the SS approach had lower exposure to traffic deaths than those that did not adopt them. Thus, it is likely that the SS approach dimensions have correlations with the RTI in different magnitudes when policies in different administrative and geographic aggregations are analyzed. In light of this, the last two research questions emerge:

iii. How to compare city-level road safety policies incorporating a framework able to measures the SS approach dimensions structural relationships with the RSP indicators and RTF rate?

iv. Given the different situation among the different Brazilian cities, which is the most adequate comparative analysis for conducting a benchmarking exercise to objectively improve the road safety policies efforts based on best practices evidence from socioeconomic similar cities?

1.3 Objectives

Based on the research questions presented, this thesis aims to propose a methodology for perform a benchmarking analysis of Brazilian cities road safety policies. This study considers a framework able to quantify the structural relationships of the core Safe System approach dimensions, its road safety policy performance indicators, and the road traffic fatality rate of the Brazilian cities. The potential outcome of this benchmarking analysis allows the construction of strategic planning scenarios at the cities level, objectively improving their road safety policies efforts. The methodological structure of the thesis consists of four specific objectives stated as follows:

a) To propose a quantitative modeling structure that allows the representation of the SS approach dimensions as constructs and their potential correlations, with focus on RTF at the nation level;
b) To structure a database of road safety performance indicators for the characterization of the road safety policy status for Brazilian cities with more than 100,000 inhabitants based on the SS approach dimensions;
c) To develop a RSP index based on a multivariate modeling analysis which represents the potential correlations of safe system approach dimensions, with focus on RTF rate at cities level;
d) To perform a comparative analysis of Brazilian cities based on the RSP index, that objectively considers the SS approach dimensions and socioeconomic clusters of the cities.

1.4 Thesis structure

To achieve the proposed objectives, this thesis was subdivided into five chapters. The first one presented the background, research questions and objectives for this academic work. The second chapter, review of literature, present the concepts of the safe system approach paradigm and its global implications as a core of Decade of Action for Road Safety. The main dimensions of this approach, recommended by the WHO to be main role in policies to promote road safety globally, are presented in the subsections of this chapter.

Still in chapter 2, a literature review on multivariate statistical models is presented. This knowledge supports the methodological development for implement the framework able to consider the SS approach and road safety policies quantitatively. The last part of this chapter brings a review effort on the RSP indicators and benchmarking analysis tool for evaluate different regions. Whenever possible and available, the review effort presented in this chapter features applications with focus in the road safety area.

In the third chapter, a methodological proposal for a benchmarking analysis based on a MSA framework able to quantify the structural relationships of the SS approach dimensions is presented. The chapter four discuss the result of the methodological modeling applications at nations- and Brazilian cities-level. For the city-level, a database consolidation process for characterizing the status of road safety policies for 110 Brazilian cities is performed and present is this chapter. In the last part of this section a clustering process based on socioeconomic indicators and analyzes of the integrated benchmarking outputs are presented

Finally, the fifth chapter presents the conclusions of the thesis. In this section, road safety policies improvements are suggested based on best performance cities for SS approach dimensions, considering the municipalities socioeconomic cluster. The methodological and phenomenological contributions of this research, the scientific and technical recommendations and the next steps are highlighted in the final considerations of this chapter. Whenever possible, discussions are presented from graphical elements that facilitate understanding of the aspect discussed.

2 REVIEW OF LITERATURE

When the basic assumptions used in defining a problem and evaluating solutions change, it can be said that this process is undergoing a paradigm shift (LITMAN, 2015). From a road safety perspective, the traffic safety has traditionally focused on promoting adherence to the rules of the road through education, training, regulation, and enforcement. Although such initiatives are worthy, they leave out a whole set of design, infrastructure, and systemic issues that affect the ability of people to conduct themselves safely on the road. After observing the impact from education and enforcement diminish over time, many governments in high-income countries have adopted a broader and more systemic approach (WHO, 2015).

Initially, this chapter aims to present the origins, core principles of the safe system approach paradigm and its global implications in the formulation of the Road Safety Action Plan. Next, the main safe system dimensions, recommended by the WHO as key elements in policies to promote road safety, are presented. The second part of this chapter, presents a review of multivariate modeling techniques, using safety performance indicators, for evaluating and monitoring road safety policies considering the safe system approach and the complex road traffic injury problem. Finally, fundamental concepts and applications of the benchmarking process as a tool for road safety policy assessment are presented in the last subsection.

2.1 The Safe System approach

The concept of the safe system (SS) began to be structured in the 1990s through programs such as Vision Zero in Sweden and Sustainable Security in the Netherlands (TINGVALL, 1998; WEGMAN; AARTS; BAX, 2008). During the next years that Vision Zero has been a part of the systematic road safety work in Sweden it shows examples of measures that have had effect on traffic safety and how the numbers of road traffic fatalities have been reduced.

The positive results found emphasize the importance of spreading the knowledge and experience in Sweden and Netherlands to the rest of the world. Australia and New Zealand, as well as the US states of Minnesota and Washington and US cities such as New York and San Francisco, adopted similar practices over the following decades (OECD/ITF, 2016a; WEGMAN; AARTS, 2005). Many nations around the world have been successful in adopting this approach. Nowadays, there is a global consensus that the SS is the most appropriate framework to mitigate the complex RTI problem (WHO, 2021).

The SS approach recognizes that road transport is a complex system and that humans, vehicles, and the road infrastructure must interact in a way that ensures a high level of safety. This fundamental principle addresses problems closer to their root cause and on a broader scale than conventional methods (TINGVALL et al., 2022). This road safety risk come from a combination of the physical vulnerability of the human body and the levels of kinetic energy in crashes (a combination of speed and mass). Therefore, for an efficient SS approach, all parts of the system must be strengthened to multiply their effects, so that if one part fails, road users are still protected.

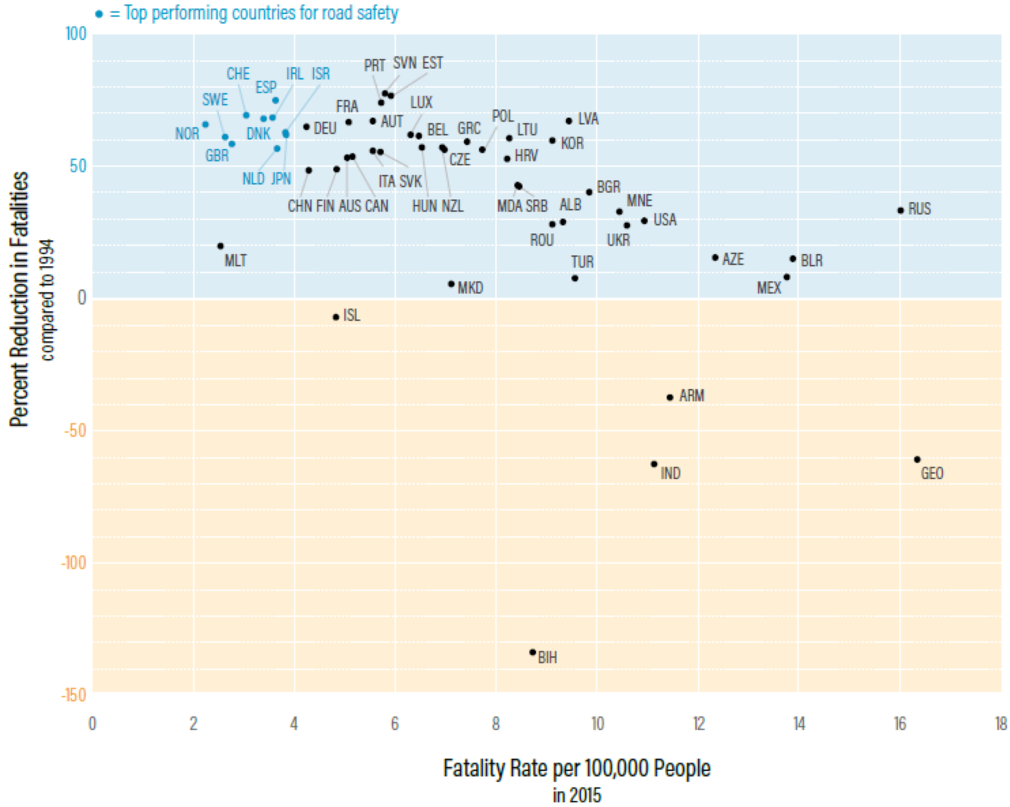
Another core SS principle is the shared responsibility. All road users and system designers are responsible to create a safe mobility system and to encourage safe behaviors (BELIN; TILLGREN; VEDUNG, 2012). Governmental decision-makers are often referred to as transport system designers, a term that encompasses not only design professionals, but everyone involved in contributing to the development and operation of the transport system, from engineers and planners to police to lawmakers and rule-makers, health professionals, and others (OECD/ITF, 2016b).

According to the International Road Traffic and Accident Database (IRTAD), the number of road traffic deaths fell by an average of 42% between 2000 and 2013 in 32 countries that applied the principles of the SS approach (OECD/ITF, 2016b). IRTAD concludes that this overall performance reflects the implementation of systematic road safety strategies and programs that address educational and enforcement issues; improve technical standards for road infrastructure and vehicles; improve health and emergency care.

The World Resources Institute (WELLE et al., 2018) conducted an additional analysis of traffic deaths in 53 countries between 1994 and 2015. The analysis revealed that countries that have adopted a SS approach have both the lowest rates of fatalities per 100,000 inhabitants and the fastest rate of change in fatality levels (Figure 1). The most significant advance has been observed in the countries that pioneered the approach: Sweden and the Netherlands. Only 3 out of 100,000 Swedes die in traffic each year, and the death rate dropped 55% between 1994 and 2015. The Netherlands has less than 4 deaths per 100,000 residents, and the rate has fallen by more than 50% in the same period (WEIJERMARS; WEGMAN, 2011).

More recently, cities from middle-income countries, including Bogota, São Paulo, and Mexico City, have begun to redirect their road safety strategies to a systemic approach (WELLE et al., 2018). Brazil adopted the Vision Zero in the revision of its National Plan for the Reduction of Deaths and Injuries in Traffic (PNATRANS) with the forecast of halving the road traffic mortality rate by 2028 (BRASIL, 2018). In 2023, Fortaleza was the first Brazilian city to institutionalize the SS approach based on the municipal law that enacts its Municipal Road Safety Plan (FORTALEZA, 2022).

Figure 1 - Reduction in Fatalities between 1994 and 2015 in 53 Countries



COUNTRY CODES:

ALB = Albania
ARM = Armenia
AUS = Australia
AUT = Austria
AZE = Azerbaijan
BEL = Belgium
BGR = Bulgaria
BIH = Bosnia and Herzegovina
BLR = Belarus
CAN = Canada
CHN = China
CRO = Croatia
CZE = Czech Republic
DEU = Germany
DNK = Denmark
ESP = Spain
EST = Estonia
FIN = Finland
FRA = France
GBR = Great Britain
GEO = Georgia
GRC = Greece
HUN = Hungary
IND = India
IRL = Ireland
ISL = Iceland
ISR = Israel
ITA = Italy
JPN = Japan
KOR = South Korea
LTU = Lithuania
LUX = Luxembourg
LVA = Latvia
MDA = Moldova
MEX = Mexico
MKD = Macedonia
MLT = Malta
MNE = Montenegro
NLD = Netherlands
NOR = Norway
NZL = New Zealand
POL = Poland
PRT = Portugal
ROU = Romania
RUS = Russia
SRB = Serbia
SVK = Slovakia
SVN = Slovenia
SWE = Sweden
SWZ = Switzerland
TUR = Turkey
UKR = Ukraine
US = United States

Source: WELLE et al., 2018b (based on data from OECD/ITF, 2017).

2.2 The first Decade of Action for Road Safety

As a result of its successful implementation in various regions and scales of government, the SS approach has attracted global attention. The United Nations Road Safety Collaboration (UNRSC) was established as a follow up to General Assembly resolution 58/289 of April 2004, recognizing the need for the United Nations system to support efforts to address the global road safety crisis (HYDER et al., 2017).

The goal of the UNRSC is to facilitate international cooperation and to strengthen global and regional coordination among UN agencies and other international partners to implement Resolution 58/289 and the recommendations to support country programs (UN GENERAL ASSEMBLY, 2004). In 2010, the UNRSC issued a call for a Decade of Action for Road Safety (DARS) between 2011 and 2020. The overarching goal of the DARS is to stabilize and subsequently reduce the forecasted number of global road traffic deaths by providing a timeframe for action to support political and resource commitments both globally and nationally.

The WHO, in cooperation with the UNRSC and other stakeholders, prepared a Plan of Action for the DARS, which was officially launched on May 11, 2011 (Bliss & Breen, 2012; WHO, 2011). The Plan is a guiding document for facilitates management of actions towards the achievement of the goal of the DARS. It is also a tool to support the development of national and local plans of action, while simultaneously providing a framework to allow coordinated activities at regional and global levels (WHO, 2011).

The principles underlying the DARS Plan of Action are those included in the SS approach (UN GENERAL ASSEMBLY, 2010). Based on the shared responsibility principle, The Plan suggests that activities should be implemented at the most appropriate level and the involvement of a variety of sectors (transport, health, police, justice, urban planning, etc.). Within the legal constructs of national and local governments, countries are encouraged to implement activities and policies to improve road safety taking a holistic approach, such as with the SS principles and its five main dimension (Figure *2*) and actions points (Figure *3*) (BLISS; BREEN, 2012; WHO, 2011). Effective road safety management and coordination is crucial for effective implementation of road safety policies, to ensure the design of and investments in safer roads, safer vehicles, post-crash response and to promote sustainable and safe mobility.

Figure 2 - The main Safe System dimensions

Source: UNITED NATIONS ROAD SAFETY TRUST FUND, 2018.

Figure 3 - The core Safe System dimensions and action points

PILLARS	12 ACTION PLAN POINTS
1. Road Safety Management	Establish a Road Safety policy addressing all pillars
	Establish governance mechanism
	Improve data collection and analysis
	Review Funding
2. Safer Fleets	Encourage investment in Fleet management
	Encourage the acquisition and use of safer vehicles
3. Safer Road Users	Develop standar training and awareness-raising methods and materials
	Develop driver-authorization standards
	Develop enforcement mechanism
4. Post-crash Response	Increase responsiveness to post-crash emergencies
5. Safer Driving Environment	Promote safe operation, maintenance and improvement of roads in local communities
	Improve driving conditions in areas under the control of the UN

Source: UNITED NATIONS ROAD SAFETY TRUST FUND, 2018.

According to the United Nations Road Safety Trust Fund (UNRSTF, 2018), within these pillars, there is a strong need to support national and local governments and authorities to ensure capacity building and the effective development and implementation of national road safety plans, strategies, and legislation. These five dimensions are considered equally important to achieving roads safety. However, regions may prioritize policies in the dimension in which acting at the start would bring about the highest short-term road safety impact. These five SS dimensions are detailed in the following subsections.

2.2.1 Road Safety Management

In the road safety management dimension, policies should focus on target setting, vertical and horizontal management as well as monitoring, based on data evidence. While the work across the dimensions and areas will be done by specific bodies, coordination of their work through road safety management may be enhanced by setting up a lead agency for road safety or designating a department to coordinate road safety, or it may be ensured by the governments (UNRSTF, 2018).

While governing is a purposeful act to steer, guide and control behavior, governance is a mode of social coordination focused on outcomes. Governance structures are optimized to organize negotiation processes, determine objectives, influence motivations, set standards, resolve disputes as well as performing allocation functions and ensuring compliance. They effectively exercise power through managing networks of interconnected actors, in which all actors contribute to a mutually desired outcome through knowledge, resources, money and rights granted to them under the governance arrangements.

According to ITF, (2016), leading practice in the management of road safety for ambitious results includes:

a. The political will and leadership to adopt a paradigm shift towards zero deaths and serious injuries, while setting and achieving ambitious interim targets on this journey.
b. The implementation of systematic and coordinated interventions based on evidence for the achievement of improved results.
c. Ensuring the required management functions are in place and operating optimally to provide the "production line" that will generate the necessary interventions.

According to Bliss and Breen (2012), data and targets have proved effective in focusing attention on road safety at the highest decision-making levels and, as a consequence, in securing resources for road safety interventions to progress implementation of a SS. They help achieve transparency, accountability, and deliverability and - when they include the operational dimension - drive concrete results.

As part of the first evaluation round in 2011, the Institute for Road Safety Research (WEIJERMARS; WEGMAN, 2011) provided forecasts for the number of fatalities and serious injuries in 2020. From these, it was concluded that the injury target most probably would not be met without additional policy measures. The analysis showed that cyclists and older people required extra attention, as the number of seriously injured road users from these groups was growing. It also showed that achieving the fatality target will depend on investments in infrastructure road safety measures and on the general development of mobility patterns.

2.2.2 Safer Vehicles

The vehicles are much safer today than ever before, as the result of a combined effort to use mandatory standards and consumer information to advance the safety performance of motor vehicles. Safer vehicles policies encourage universal deployment of improved vehicle safety technologies for both passive and active safety through a combination of harmonization of relevant global standards, consumer information schemes and incentives to accelerate the uptake of new technologies (WHO, 2015).

In the United States an estimating that between 1960 and 2012 more than 600.00 lives were saved by automotive safety technologies required by Federal Motor Vehicle Safety Standards (KAHANE, 2015). Similar progress has been achieved in the EU, where between 2001 and 2012 there was a 55% reduction in car occupant fatalities (ADMINAITE; ALLSOP; JOST, 2015). An analysis of vehicle-based crash rates in the Australian state of New South Wales estimates that occupant fatality risk of cars built in 2010 are 75% lower than for ones built in 1995 (RYB et al., 2011).

A review of the effectiveness of casualty reduction measures in the United Kingdom between 1980 and 1996 found that the greatest contribution to casualty reduction was vehicle crash protection (BEGG et al., 2009). The SUNFlower study on road safety in Sweden, United Kingdom and the Netherlands attributed 20% reduction of fatalities from 1980-2000 (i.e. about 1% per year) to vehicle safety improvements (KOORNSTRA et al., 2002).

The resolution A/RES/70/260 (UN GENERAL ASSEMBLY, 2016) includes strong commitments on vehicle safety. In recommendation number nine, the resolution invites Member States that have not already done so to consider adopting policies and measures to implement UN vehicle safety regulations or equivalent national standards to ensure that all new motor vehicles, meet applicable minimum regulations for occupant and other road user protections, with seat belts, air bags and active safety systems fitted as standard. The resolution is an unprecedented call for standard fitment of vehicle safety technologies and is consistent with the vehicle safety actions proposed in the Global Plan for Road Safety.

Occupant restraint is the single most important safety feature in the car and most crash protective design is based on the premise that a seat belt will be used. A study developed by Elvik and Vaa (2009) involved conducting a meta-analysis on 29 published studies looking into the effects of seatbelts on safety and concluded that seatbelts reduce fatalities by: 50% for drivers, 45% for front seat passengers and 25% for rear seat passengers. Very similar results were reported for serious injury reduction. For children aged 1-7 using an adequate child seat instead of a seat belt would lead to a 71% reduction in severe injuries.

Airbags do not offer protection in all types of impact and do not reduce the risk of ejection. Airbags are no substitutes for seat belts but are designed to work with them. Estimates of the general effectiveness of frontal air bags in reducing the risk of fatal injury by 68% when combined with seat-belt use (CUMMINGS, 2002). A study developed by Kahane (2015) showed an 8% reduction in fatality with a torso only and a 31% reduction with a torso/head bag combination. There are some significant indications of side airbags causing injuries (YOGANANDAN et al., 2005).

One of the earliest crash avoidance technologies is the antilock braking system (ABS) and it has been followed more recently by electronic stability control (ESC) which prevents loss-of-control skidding incidents. Seventeen different studies undertaken between 2001 and 2007 have shown ESC to be highly effective, reducing single-vehicle crashes by approximately 30% as well as reducing the risk of opposing-traffic crashes and roll-over crashes, especially for Sport Utility Vehicles (DE ROME et al., 2011).

The follow-on technology from ESC is autonomous emergency braking (AEB). A 2016 study by the Insurance Institute for Highway Safety (2016), shows that automatic braking reduced rear-end crashes by about 40% on average. It estimates that if all vehicles had been equipped with autobrakes that worked as well as the systems studied, there would have been at least 700 000 rear-end crashes in the US in 2013.

ABS in motorbikes is another priority as studies of fatal crashes, insurance claims, and test track performance all confirm the system's importance for powered two wheelers. In the United States, the rate of fatal crashes has been estimated to be 37% lower for motorcycles equipped with optional ABS than for those same models without ABS (TEOH, 2011). Supporting this evidence of effectiveness are collision insurance claims for motorcycles with ABS which are filed 23% less frequently than for motorcycles without it.

2.2.3 Safer Road Users

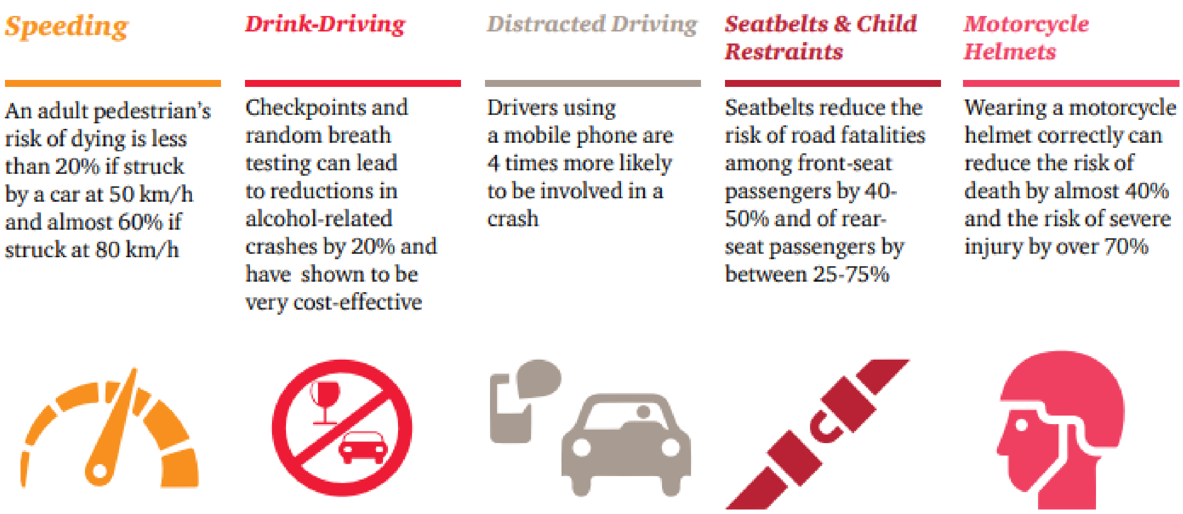
Humans have always been the weak link in the safety of road transport safety, as in other complex socio-technical systems. The large and persistent variability in the performance of humans in traffic makes them a critical safety problem, while the other technical components can be designed to minimize variability. It has long been considered that road users may not have enough knowledge and information in specific situations to be able to make rational (and correct) decisions (OECD/ITF, 2016b). The technology, the social and organizational context, group affiliation, productivity requirements, time pressure, legislation, monitoring, the risk of discovery, consequences, the individual's level of knowledge, etc. are all examples of environmental factors which influence human behavior (LEVESON, 2011).

As previously discussed, the SS approach considers the nature of human errors and goes even further in acknowledging human fragility by making its very premise that human beings cannot always cope with the complex demands either physical, cognitive or psychological - that the road transport system confronts them with. The SS holds that, for this reason, there is a need to understand the human capabilities in relation to the system and how to adapt their properties (OECD/ITF, 2016b).

The core idea of this dimension has been to provide road users with sufficient information and knowledge, to ensure they have the right mind-set and follow rules and procedures to encourage compliance behavior (READ; SALMON; LENNÉ, 2013). This requires thorough analyses to understand the complex mechanisms behind human errors or non-compliance in different situations; otherwise, the countermeasures might well turn out to be ineffective.

These countermeasures include infrastructure design that invites safe use, speed limits and road design that encourages safe speeds, road laws and traffic regulations for safety compliance, traffic safety education, training (and re-training), and assessment and, ultimately, licensing for safe road use. Both general and targeted enforcement are required to limit the incidence of the critical errors most commonly leading to serious injury. Enacting and enforcing legislation on key risk factors, including speeding, drinking and distracted driving, motorcycle helmet use, seatbelt, and child restraint use. Figure 4 present some evidence based about this risk factor policies (FARIED et al., 2017; VECINO-ORTIZ et al., 2014; VORKO-JOVIĆ; KERN; BILOGLAV, 2006).

Figure 4 - Risk factors evidence based



Source: Vorko-Jovic; Kern; Biloglav (2006).

According to (WHO, 2019), a traffic law that does not incorporate these key best practices will not be able to achieve the desired reduction in road traffic fatalities and positive change in behavior. The excessive speed is perhaps the main element of risk in the entire road transport system. Speed management measures should be consistent with the global SS approach to road safety: road designers, builders and managers must take into account the known limits of the human body. A credible speed limit is defined as one that matches drivers' expectations as evoked by their experience driving in a road. Roads that are "self-explaining" include such specific design elements which drivers will take as a signal for a certain road type requiring a certain driving style. In this way, they act as built-in controls on driver behavior (WEIJERMARS; WEGMAN, 2011).

Brazil's first drink-driving law based on blood alcohol concentration (BCA) was enacted in 1998 marking it an offense to drive with a BCA more than 0.06g/dl. A study conducted by Andreuccetti et al. (2019) , in São Paulo city, found that 39% of people killed in road traffic crashes had BCA levels greater than 0.01 g/dl and 42 of drivers presented had BCA levels greater than 0.06 g/dl. In order to tackle this public health threat, the Brazilian government enacted the new "Lei Seca" (Zero BCA) law in June 2008, which reduced the legal BCA limit from 0.06 g/dl to 0.02 g/dl. A monitoring in the Sao Paulo state and city between 2001 to 2010 indicated that the new law resulted in significant reductions in injuries and fatalities. According to the authors, the effect was stronger for fatalities (a decrease of 7.2% and 16% in the monthly rate in the State and capital, respectively) than for injuries (1.8% and 2.3%).

2.2.4 Post-crash response

In many countries and cities road injuries can account for a significant proportion of trauma patients in hospitals and other treatment centers (WHO, 2011). Appropriate management of road casualties following the crash is a critical determinant of both the chance of survival and, on survival, the quality of life. The post-crash response policies intend to increase responsiveness to post-crash emergencies and improve the ability of health and other systems to provide appropriate emergency treatment and longer-term victims rehabilitation.

A national evaluation study carried out in the United States found that the adjusted risk of death in trauma centers was significantly lower than in non-trauma centers (MACKENZIE et al., 2006). Hakkert, Gitelman and Vis (2007) concluded that 35-50% of cases could be considered as treatable, i.e. occurring during treatment facilities and follow-up phases, and therefore, can be influenced (and reduced) by an improved trauma management system.

Thoughtful legislation can do a lot to improve the post-crash response, and in a variety of ways. According to (ITF, 2016), many countries make it a statutory duty for emergency services' intervention to save lives and to play a role in prevention. Other helpful supporting legislation may include recognition of a protection for those who offer help (Good Samaritan Laws) and duty to assist the injured; first aid training and equipment requirements for drivers or vehicles; protocols outlining minimum standards of pre-hospital and facility-based care; and financing mechanisms to ensure universal access to free emergency care.

Jayaraman and Sethi (2009) evaluated a first aid training program delivered to police, taxi drivers and community leaders in Kampala, Uganda, where there is no formal prehospital system. The low-cost program trained participants to deliver basic life-saving measures at the roadside and provided each participant with a first aid kit comprised of locally available materials. On follow up, providers had maintained their skills over time, and many injured patients had received potentially lifesaving attention.

Research is another lever that can be effectively employed to improve post-crash response. The collection of post-crash data and their scientific analysis is critical for improving various aspects of how the post-crash phase is handled. Injury surveillance systems, trauma registries and quality improvement programs all contribute to an increasing body of knowledge about injury and patient care can be used to optimize post-crash services and inform injury prevention strategies (WHO, 2016).

Advances in surgical technique, trauma management and technology, all informed by research, are also improving hospital care of road and other trauma victims; panel reviews indicate an average reduction of 50% in medically preventable deaths and trauma registry studies show around a 15-20% reduction (ITF, 2008). A project developed by Vietnam Administration of Preventive Medicine in Hanoi dispatched emergency care providers by motorcycle to road traffic crashes. The average response time was 5.18 ± 4.5 minutes, compared to an average ambulance response time of 11.16 ± 6.2 minutes (TAKASHIMA et al., 2017).

Run by the *Associação das Pioneiras Sociais*, an independent institution created under Brazilian Federal Law, rehabilitation within the SARAH program is not restricted to the hospital environment. Placing the focus on patient strengths, specialists work with patients and their families to customize individual rehabilitation programs with facility and home-based components. Unfortunately, despite an increasing need for multidisciplinary rehabilitation services, these services are non-existent or extremely limited in many parts of the world (WHO, 2019).

2.2.5 Safer Driving Environment

The driving environment refers to the conditions and surroundings that road users are exposed to while on the road. This includes factors such as infrastructure, road conditions, traffic operation, signage, and other environmental factors that can influence the ability to safely traveling the road.

Stigson, Krafft and Tingvall (2008) reviewed fatal crashes in Sweden based on in-depth crash investigation, with crashes categorized based on factors that contributed to the crash outcome. The study found that were strong interactions between system components, but that road-related factors were most strongly linked to a fatal crash outcome. Put another way, in the crash event, regardless of how that crash occurred, infrastructure always have an impact on the severity of the outcome.

All road users need to be considered when designing or upgrading road infrastructure. The design of road infrastructure and the broader street environment should start with the needs of the most vulnerable users and then progress towards the safety needs of the least vulnerable. Many useful infrastructure interventions can be found in various guides (ELVIK; VAA, 2009) and in on-line tools such as the Road Safety Toolkit created by the International Road Assessment Program (iRAP).

The International Traffic Safety Data and Analysis Group (IRTAD) report on Road Infrastructure Safety Management (OECD/ITF, 2015) identifies and evaluates 10 procedures being used. These procedures are aimed at enhancing road safety at different stages of a road infrastructure life cycle from planning and design through construction, operation, maintenance, improvement and major upgrading and renewal. While there are overlaps and similarities between some of these, there are also important differences. In general, the choice of which procedure to use is linked to the data, budget available and the stage in the project life cycle.

A framework for assessing how infrastructure rates in terms of a SS has recently been developed by the association of Australasian Road transport and traffic agencies known as Austroads (2015). Based on a review of literature on SS infrastructure and existing risk assessment frameworks, the framework considers typical crash types resulting in fatal and serious injury outcomes, and the risks of these crashes (exposure, likelihood and severity). While the scoring is to some extent subjective, guidance is provided in an attempt to make it as consistent and objective as possible.

So, the safer roads and mobility policies intend to raise the inherent safety and protective quality of road networks for the benefit of all road users, especially the most vulnerable (e.g. pedestrians, bicyclists and motorcyclists). This will be achieved through the implementation of various road infrastructure agreements, road infrastructure assessment and improved safety-conscious planning, design, construction, and operation of roads. A lack of basic facilities, such as footpaths, cycle paths, motorcycle lanes and safe speed-controlled crossing points on many roads, increases the level of risk for all road users.

In general, safe infrastructure tends to be expensive and therefore not always applicable in countries in middle and low-income regions. However, in the urban environment, several low-cost interventions have proven to be very positive. Among these, tactical urbanism stands out. Tactical urbanism refers to the use of low-cost, temporary interventions to make streets and public spaces safer and more accessible. While there is limited research specifically on the relationship between tactical urbanism and road traffic injuries, there is evidence that these types of interventions can have a positive impact on safety. there is evidence to suggest that these types of interventions can be an effective strategy for improving safety in urban areas (WELLE et al., 2018).

2.3 The second Decade of Action for Road Safety

The findings of the last published Global status report on road safety 2018 (WHO, 2019) highlighted the rate of death relative to the size of the world's population has remained constant. It also indicates that progress to realize Sustainable Development Goal (SDG) and DARS target – which calls for a 50% reduction in the number of road traffic deaths by 2020 – remains far from sufficient.

The report also showed that the Progress is uniform. There has also been more progress in reducing the number of road traffic deaths among middle- and high-income countries than low-income countries. Between 2013 and 2016, no reductions in the number of road traffic deaths were observed in any low-income country, while some reductions were observed in 48 middle- and high-income countries. Overall, the number of deaths increased in 104 countries during this period.

Recognize that road safety is still an urgent development priority and in continuation of global efforts to address this grave public health and development problem, the Resolution A/RES/74/299 (UN GENERAL ASSEMBLY, 2020) proclaimed a second Decade of Action for Road Safety (2021–2030) following the end of the first such decade (2011–2020).

A Global Plan for the new decade was developed by WHO, United Nations Commissions and partners reaffirming the commitment to the SS approach and integrating road safety in relevant policy agendas.

This new Global Plan calls on governments and stakeholders to take a new path – one that prioritizes and implements an integrated SS approach – a core feature of the Decade of Action – that squarely positions road safety as a key driver of sustainable development. It also calls for actions that help the world hit the target of a 50% reduction in the number of road traffic deaths and serious injuries by 2030.

The document present recommendations (what to do) draw from proven and effective interventions and best practices for preventing road trauma and provide a comprehensive overview of actions to implement and strengthen the keys SS dimensions (Figure 5). The Global Plan also presents the requirements for implementation (how to do it?) and who must be contribute (who to do it?), based on a Shared responsibility principle (WHO, 2021).

Figure 5 - Infographic of the Decade of Action for Road Safety 2021-2030

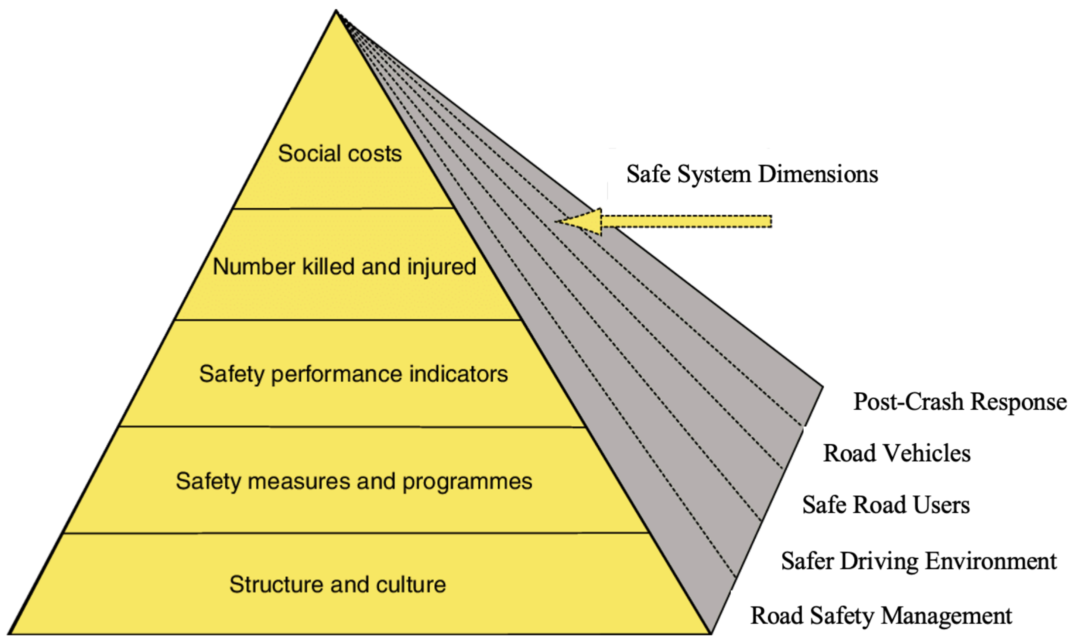
Source: WHO, 2021.

2.4 Monitoring and Evaluation of the Road Safety Policies

Monitoring of progress is vital in achieving the ultimate goal of the Decades, reducing the forecasted number of road traffic deaths and injuries globally (HYDER et al., 2017). Road safety is produced within a complex multi-sectoral context and across several levels of governance - global, national, and city level. Many factors directly and indirectly contribute to the road safety performance of a region. Quantitative assessment of the road safety policies is complex, requiring in depth review of a variety of inputs (ELVIK; VAA, 2009; HAUER, 2015; WEGMAN, 2017).

The traffic fatality rates are very useful for a primary diagnosis and global view on the situation but does not provide any suggestion on how to tackle the situation and improve road safety (GOLOB; RECKER; ALVAREZ, 2004). In this context, the use of Safety Performance Indicators (SPIs) in road safety research is continuously growing to complement and provide extra information in addition to the traditional outcome-based diagnosis using traffic fatalities or injuries (SHEN et al., 2012). Figure 6, based on representation from Koornstra et al. (2002), present the pyramid framework that symbolizes the variety of elements that contribute to the road safety situation, SPIs act as intermediate outcomes, one layer below the final outcomes (expressed by the social costs of killed and injured people).

Figure 6 - Target pyramid: target hierarchy for road safety at a disaggregate level



Source: Autor adapted from Koornstra et al 2002.

According to Bastos (2014), SPI serves as an assisting tool in assessing the current safety conditions, monitoring the evolution, measuring impacts of various safety interventions, making comparisons, and other purposes (e.g. HAKKERT; GITELMAN; VIS, 2007; VIS et al., 2005). Some examples of SPIs are the seatbelt wearing rate, the average speed on a particular road, the percentage of drivers who drink and drive and how often they do that, the average rescue time after a collision, etc.

Specific SPIs for each dimension as well as broader outcome measures serve as the main tool for observing how regions are implementing good practice interventions. Progress on implementation of the interventions and related performance under each of the five dimensions also needs to be monitored systematically in order to understand what needs to be done to achieve the goal of road safety policies (HYDER et al., 2017).

However, many SPI data sources, especially in LMICs, are typically limited, sometimes fragmented, and often incomplete or unavailable (WHO, 2011). Another gap is related of knowledge provides the rationale for the research to explore ways to improve road safety with the intent of enabling policy makers around the world to assess and improve their performance based on good practice models that consider all SS dimensions that impact RTI.

Most studies involving statistical modeling are focused on a more disaggregated level and a specific dimension, such as vehicle, road users or road environment (AASHTO, 2014; BARBOSA et al., 2014). Within this approach, the predictive models predominate that, on several occasions, the modeling strategy results are poorly informative about the complex relationship between the contributing factors and the RTI (HAUER, 2015; HAUER; BOARD, 2004; HOLLÓ; EKSLER; ZUKOWSKA, 2010).

Furthermore, when it comes to road safety policy assessment this predictive modeling paradigm seems to be inadequate to provide objective inferences between the SS approach dimensions. (NIKOLAOU; DIMITRIOU; ANTONIOU, 2019). Studies highlight the need for a more robust approach capable to demonstrate cause and effect, especially through the multisectoral SPI that influence RTI and may be correlated (HUGHES et al., 2015; VASCONCELLOS; SIVAK, 2009; WEIJERMARS; WEGMAN, 2011).

Multivariate Statistical Analysis (MSA) technique have been used successfully in the social sciences, economics and, in recent years, have gained strength in their application in road safety studies (AL-MAHAMEED et al., 2019; CHEN; CHEN, 2011; LEE; CHUNG; SON, 2008). This technical approach that is based on the integrated modeling tools with a process integration structure and design optimization has been used to model complex systems (KIM et al., 2013).

2.5 Multivariate modeling techniques on road safety

The modeling facilitates the development and testing of our understanding, while in the context of decision-making, models provide a mean for applying our understanding to solve real world problems (KIKER et al., 2005). They represent a mean for expressing the interdependent influences and behaviors of multiple science-based components (models, data, and assessment methods) that together form the basis for constructing an appropriate modeling system (LANIAK et al., 2013).

According to EPA (2008), integrated modeling reflects more a conceptual approach than a single, well-defined collection of components. Thus, the actual science components necessary to address individual problems may vary in number and type. The following implementation characteristics of science-based modeling are important in all applications and take on additional meaning and importance in the context of modern integrated modeling.

Among the multivariate statistical analysis technique, one that stands out is the Structural Equation Modeling (SEM) used to analyze structural relationships. This technique is useful to researchers as a multivariate technique combining regression, factor analysis and analysis of variance in order to estimate interrelated dependence relationships simultaneously. SEM was applied in several fields of research and generalized by Joreskog and Werts (1973).

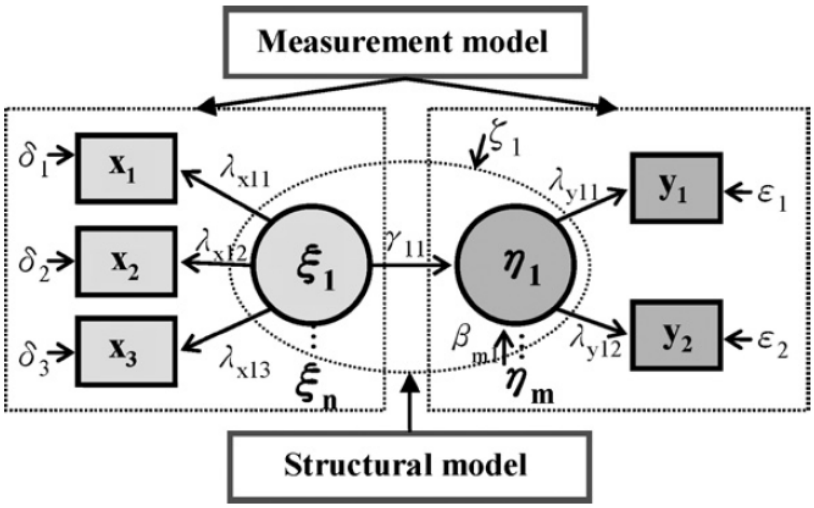
2.5.1 Structural equation modeling

The SEM has been used since the 1950s by economists and social scientists seeking a formal framework to allow for more appropriate causal analysis (PEARL, 2009). These models allow to evaluate the significance and strength of a particular relationship in the context of the complete model and provide a good platform for considering multicollinearity and eliminating measurement error by using latent (unmeasured) constructs (LITTLE et al., 2012). The SEM approach allows the execution of regressions, simultaneous equations, path analysis and variations of factor analysis and canonical correlations (GOLOB, 2003).

Hair et al. (2006) claim that analysis employing SEM have assumptions similar to multivariate data analysis techniques, ie.: i) independence of observations, ii) random samples and iii) linearity of latent constructs. SEM has two main components, the measurement models, and the structural model. Measurement models, which may have exogenous (external to a model and are not influenced by it) or endogenous (influenced by other variables within a model) variables, represent directly observed variables for which measurement errors (covariance) are predicted. The structural model, in turn, consolidates the link between exogenous variables and endogenous variables through underlying constructs that cannot be directly measured, known as latent variables. The latent variables are variables that are not directly observable but are inferred from other observable variables.

In Figure 7, δ and ε represent the measurement errors of the exogenous and endogenous variables, respectively. Latent variables are often represented by circles or ellipses (ξ and η), λ and γ are the respective coefficients of the models, while ζ represents the error on estimating relationship between the latent variables of the structural model. Rectangles or squares represent observed variables. A directional arrow (or path) usually indicates a statistical dependence, in which the variable at the tail of the arrow causes the variable at the point. A double-headed arrow is an indication of correlation between variables (AL-MAHAMEED et al., 2019; SCHUMACKER; LOMAX, 2004).

Figure 7 - An example of structural equation model



Source: Lee et al., 2008b.

In the general path structure shown in Figure 7, the measurement models assume the structures presented in Equations 1 and 2.

$$Y = \Lambda_Y \eta + \varepsilon \tag{1}$$

$$X = \Lambda_X + \delta \tag{2}$$

Where Y and X are the column vector of observed endogenous and exogenous variables, respectively. δ and ε represent their respective measurement errors. Λ_y and Λ_x are the coefficient matrices of endogenous and exogenous variables with their respective latent indicators. In terms of the structural model, all these variables are collected in a vector η which is expressed by Equation 3.

$$\eta = \beta\eta + \gamma\xi + \varepsilon \tag{3}$$

Where β and γ are estimated vectors of regression coefficients for the dependent and independent variables, respectively, ε is a vector of regression errors and ξ is a vector containing the collected independent variables. The basic premise of structural equation models is to assume that the variance-covariance matrix of the observed variables is a function of the model parameters, so if the model is well specified, this variance-covariance matrix is equivalent to the same population matrix (SCHUMACKER; LOMAX, 2004).

From the premises regarding the distributions of the observed variables, it is possible, for example, to apply the Maximum Likelihood methods and the Least Squares method for continuous variables and with a multivariate normal distribution respectively (NACHTIGALL et al., 2003). For variables in which it is not possible to assume normality, so-called asymptotic distribution-free methods (Asymptotically Distribution-Free - ADF) can be used as the Weighted Least Squares Method (WLS) (SCHUMACKER; LOMAX, 2004).

The SEM is quite flexible as it allows one to use combinations of various types of data, such as dichotomous, ordered categorical, and continuous. Because ordered categorical and dichotomous data may not come from a normal distribution, the commonly used approach of maximum likelihood is not applied. Instead, the WLS method is used for parameter estimation (YANUAR; IBRAHIM; JEMAIN, 2010). Among the applications and computational routines most used for SEM development, LISREL and R stand out through their washing routine.

Schumaker and Lomax (2004) present three initial criteria to assess the statistical significance and the substantive meaning of a given theoretical model:

i. Assess global criteria such as the non-significance of the chi-square statistic and the root mean square error of approximation (RMSEA). The non-significance of chi-square can be interpreted as an approximation between the covariance matrix and model. Values of RMSEA less than 0.05 are considered acceptable;
ii. The statistical significance of the estimated coefficients for the path specified in the model (t-test) and;

iii. The magnitude and direction (signal) of the loading factors between the variables. As in traditional modeling, it is a step that depends on an analysis based on prior knowledge between the variables, being subject to a certain degree of subjectivity.

Regarding the model adjustment criteria, Margon (2016) reports the existence of several indicators, which can be used for different model structure assumptions. Thus, they emphasize that the choice of a single (or more appropriate) criterion requires a more careful analysis.

The SEM ability to calculate the weight of assessment measures in the decision-making models has been investigated by some researchers (PUNNIYAMOORTY; MATHIYALAGAN; LAKSHMI, 2012; RAVIKUMAR et al., 2016; TORRES; XAVIER; CUNTO, 2020). To this end, studies used SEM to calculate the weights of the assessment measures. From the significant factors, the relative weightage for the measures is calculated using high-order factor loadings of these measures to formulate indices (ESTIRI et al., 2021; GBONGLI et al., 2020)

Boniface and Tefft (1997) used the structural equation modeling approach to identify the relationship between an unobservable factor (latent variables), i.e., lifestyle, and observed variables, such as cigarette smoking, physical activity, and alcohol intake. Yanuar, Ibrahim and Jemain (2010) demonstrate the value of structural equation modeling for the construction of an index to describe the health status of an individual living in the district of Hulu Langat, Malaysia. The findings show that Socio-demography and mental health condition were found to have a direct effect on the health index. However, lifestyle had an indirect effect on the health index, as mediated by the mental health.

2.5.2 SEM studies on Road Safety

The most frequent use of SEM in road safety studies concerns the validation of psychological constructs in the influence of behavioral aspects such as high-speed, risky crossings and proper helmet use. These studies frequently apply questionnaires as a way to obtain exogenous variables, which, in turn, are used to define the constructs such as sensation-seeking and experience, instrumental attitude, descriptive norm and perceived risk (CHEN; CHEN, 2011; ROSLI et al., 2016; ZHOU; ROMERO; QIN, 2016).

These constructs are defined by a social psychological theory, known as Theory of Planned Behavior (TPB). According to the TPB, an individual's behavior is influenced by three main factors: their attitudes toward the behavior, subjective norms, and perceived behavioral control. Attitudes toward the behavior refer to an individual's positive or negative evaluation of the behavior. Subjective norms refer to the individual's perception of social pressure or influence to engage in the behavior, which may come from their friends, family, or other influential people. Perceived behavioral control refers to the individual's perception of their ability to perform the behavior successfully, considering factors such as skills, resources, and environmental factors (ROSLI et al., 2016).

The main findings from these studies show that SEM allowed to improve the basic theory of planned behavior (TPB) framework as well as to act as a platform to link different theories such as the TPB and the flow theory. Chen and Chen (2011) explored the behavior, at high speed, of Taiwanese motorcyclists from the TPB, including psychological variables, using the SEM technique. The results reveal that TPB variables have a greater predictive power in explaining speeding behavior than the TPB variables and that the group differences in relation to the search for sensations and the experience of high-speed behavior are evident.

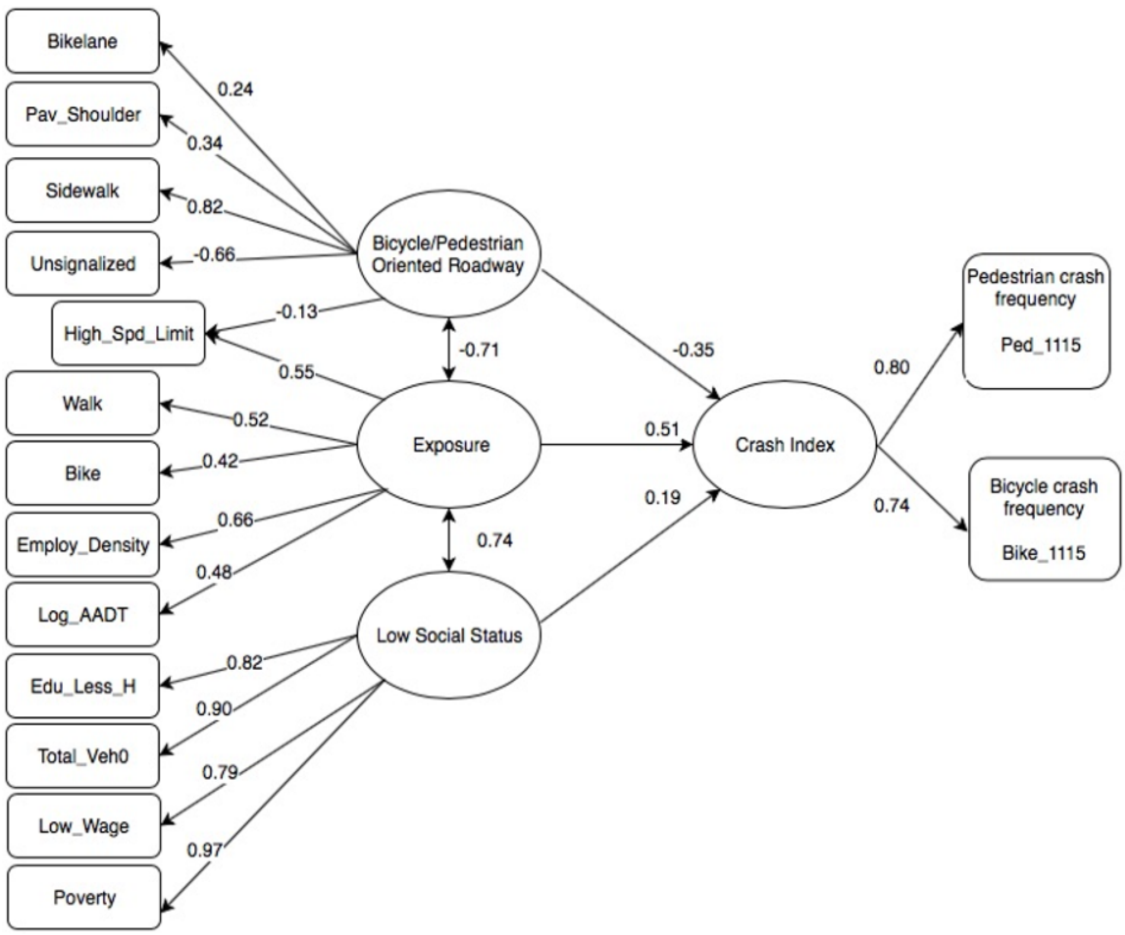
Zhou, Romero and Qin (2016) assessed the pedestrian crossing behavior using 260 questionnaires collected in the city center of Dalian, China. The data was used to test four SEM models. The best model presented the instrumental attitude, the descriptive norm and the tendency of conformity as significant predictors of behavioral intention. The perceived risk was not significant, indicating that pedestrians were probably unaware of the danger of this behavior.

Rosli et al. (2016) applied questionnaires using theories of behavioral sciences to understand the behavioral intention in relation to the proper use of the helmet among motorcyclists in Malaysia, based on the perception of a conceptual system called the Helmet Wear Reminder. The authors used SEM to test the relationship between exogenous (intention) and endogenous (behavior) variables and identified that ease of use, perceived utility and social norm are significant in relation to the behavioral intention to use the Helmet Wear Reminder.

Al-Mahameed et al. (2019) evaluated the use of SEM to assess the road safety performance of pedestrians and cyclists in a sample of 200 one-mile road corridors in urbanized areas of Wisconsin (USA). Due to the lack of data, the exposure of pedestrians and cyclists was estimated as a latent variable based on the percentage of workers walking to work, population density and job density. The final model of structural equations also had a latent endogenous variable (crash index) which was defined according to three other latent variables (Figure 8). The findings indicated a strong and negative correlation between the design of roads directed to the vulnerable users and the crash index, also defining a very informative causal structure between the various exogenous variables and the proposed latent variables. Exposure and low social status were positively related to the vulnerable users' crashes.

Suteja et al. (2018) analyzed the factors that influence the intentions of Denpasar (Bali) motorcyclists in relation to traffic violations and speeding through a cross-sectional survey. SEM were built to examine the causal relationship between behavioral characteristics, perceptions, and intentions. The findings identified that the search for risky driving is significantly influenced by the intentions of motorcyclists, sensations, and attitudes towards the violation of traffic rules and speeding. In addition, men and young motorcyclists were more likely to commit traffic violations.

Figure 8 - Vulnerable users' crashes SEM model

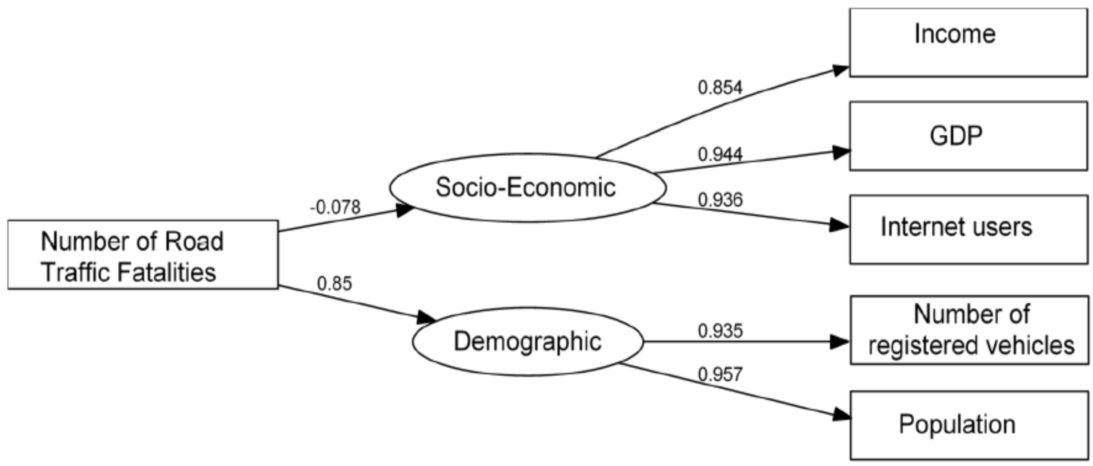


Source: Al-Mahameed et al. (2019).

Nikolaou et al. (2019) analyzed the socioeconomic and demographic factors of 121 countries in order to expose possible explanatory relationships with road traffic deaths. The authors assumed the existence of latent information for understanding the phenomenon, validating this hypothesis through SEM. The findings suggested that a significant relationship exists between road traffic fatalities and demographic conditions. In the SEM model only two observed variables remained for measuring the demographic latent variable.

Figure 9 present that a SEM model estimated a higher coefficient (0.935) for the number of registered vehicles.

Figure 9 - SEM diagram for Global number of road traffic fatalities



Source: Nikolaou et al., (2019).

Recently, Xavier et al (2020) evaluated the influence of quantitative exposure and trip quality on crashes from the perception of cyclists. Structural equation models were used to analyze the associations between twelve indicators, three reflective latent variables and the number of crashes with cyclists in Fortaleza, Brazil. The results indicated that the poor quality of the trip has the greatest influence on the increase in reported crashes, followed by the quantitative exposure of the cyclist.

2.6 Benchmarking studies

Benchmarking can be defined as a systematic comparison of a given process and performance of one production entity against other entities, which could be countries, organizations, firms, industries, divisions, projects, or individuals. Moreover, the essence of benchmarking is the process of identifying the highest standard of excellence for products, services, or processes, and then making the improvements necessary to reach those standards − commonly known as best practice (BHUTTA; HUQ, 1999). In addition, benchmarking does not represent the end of the process, but is an ongoing diagnostic management tool focused on learning, collaboration, and leadership to achieve continuous improvement in the organization over time (GARLICK; PRYOR G., 2004).

Since the first successful application implemented by Xerox Corporation in the late 1970s, benchmarking quickly became one of the fastest growing techniques for quality and performance improvement and has been receiving significant attention in a multitude of entities engaged in a variety of performance evaluation, quality management, and continuous improvement activities (CAMP, 1993; LAI; HUANG; WANG, 2011; LAU; NG, 2006; MURRAY et al., 2015; SINGH et al., 2002; SPENDOLINI, 1992; TINSLEY GOODEN; MCCREARY, 2001).

According to Al-Haji (2007), the benchmarking models in general are mostly based on two dimensions. The first is to develop of performance indicators that measure the entities performance from different aspects; and the second is the composite indices that combine many performance indicators into a single value.

Business, in general, has recognized the importance of having a multi-dimensional index for managing, assessing, controlling and sustaining the performance of the company/organization (AHMED; RAFIQ, 1998). This has led to the development of quality benchmarking and excellence models, which are today quite popular and are widely accepted and used in modern economic and business benchmarking research at national and international levels. Such examples are Total Quality Management and the European Foundation for Quality Management.

Since the beginning of the last decade, some developed countries have adopted the benchmarking approach to create the preconditions for a rethink of road safety policies based on RSP of similar countries. Regular global assessment of road safety is needed not only to measure progress, but also to enable to compare road safety performance (RSP) between regions (WHO, 2019).

2.6.1 Benchmarking applied on road safety

According to the Wegman and Oppe (2010), benchmarking the road safety performance as a basis for learning and speeding up positive developments can be considered a promising step in improving road safety. When benchmarking comes to be seen as the basis for learning from each other, the interest is not only in the final score/index/rating, but also in the antecedents of those scores, the components that contribute to the scores, and the potential for developing policies and programs which are aimed at increasing performance of regions.

A number of benchmarking studies in road safety has already been developed and they range from relatively simple to highly complex models depending on the number of indicators involved, details of data and complexity of methods used in calculations and analysis. (SANTOS et al., 2022; BASTOS et al., 2015; INTERNATIONAL TRANSPORT FORUM, 2016a; WEGMAN; AARTS, 2005). These benchmarking studies in road safety can be classified into four broad categories as follows (AL-HAJI; ASP, 2006):

1. Product Benchmarking is used to compare road safety final outcomes, such as RTF;
2. Practices Benchmarking is used to compare activities related road safety performance, such as drink driving, seat belt wearing, vehicle and road safety ratings, and corresponding policy action. It also has been given more attention in current road safety studies since they are causally related to crashes or injuries and can provide a better understanding of the process that leads to crashes;
3. Strategic and organizational Benchmarking is used to compare Road Safety strategies, resources, management, and the organizational framework. However, due to the lack of appropriate indicators characterizing their features, only some initial attempts have been carried out at this moment, such as Al-Haji (2007) and Eksler et al. (2009).
4. Integrated Benchmarking is used to compare regions in terms of the three previous types of benchmarking altogether. Road safety performance is seen and perceived within a holistic context, which combines performance indicators/indexes developed in the above separate benchmarking aspects into one overall index (AL-HAJI, 2007; WEGMAN; AARTS; BAX, 2008).

There is a considerable number of studies (beyond road safety sector) that has highlighted the importance and usefulness of having composite indices as a tool for making integrated benchmarking (AL-HAJI, 2007; BEITZ; WIECZOREK, 2000; SAISANA; TARANTOLA, 2002). Many composite indices have been developed internationally and used in different aspects of life to indicate progress or achievements between countries. Such examples are: Human Development Index (HDI), which was developed by the United Nations and the Overall Health System Index by the World Health Organization (WHO, 2022).

According to Shen et al. (2015), when a number of indicators are considered for a particular benchmarking aspect, simple comparisons per indicator with the purpose of examining the gaps in performance may only show a small piece of the road safety picture and can be misleading since different countries may operate in different circumstances with different focal points. Consequently, a composite road safety indicator (or index), which combines individual indicator values into scores, is often computed for the sake of meaningful benchmarking. Several studies have been undertaken aiming at the development of a composite road safety index which enabled meaningful national or subnational comparison and monitoring of road safety performance (AL-HAJI, 2007; HERMANS; VAN DEN BOSSCHE; WETS, 2008; SHEN et al., 2012; WEGMAN; AARTS; BAX, 2008; YANNIS et al., 2013).

Hermans et al. (2008) explored a methodological framework for developing a composite road safety performance index for cross-country comparison. To illustrate the use of this framework, six risk factors were investigated to combine the separate indicators into one overall index for 21 European countries. The study concluded that comparing the performance of countries in terms of road safety by means of an index at the intermediate outcome level enabled earlier and goal-oriented action.

Shen et al. (2012) carried out research regarding the combination of risk indicators on the one hand and a hierarchy of safety performance indicators on the other hand for the sake of meaningful road safety benchmarking of 28 European countries. A comprehensive set of hierarchically structured safety performance indicators was developed to capture the road safety performance of a country. The constructed road safety performance index showed a high correlation with the overall road safety risk from the view of the final outcome level, and useful insight in the areas of underperformance in each country was gained.

Bastos et al. (2015) presented research on indicators and indexes with the objective of delivering both overall and disaggregated evidence about the road safety performance and targets in fatality reduction in Brazil at the state level, including a hierarchy of 27 safety performance indicators related on the main road safety domains. The findings provided a road safety diagnosis per state as well as traffic fatality targets according to different perspectives: the entire group of road users (motorized and nonmotorized ones), motor vehicle occupants, and finally a disaggregated performance evaluation.

Most attempts in past research have focused on improving and implementing SPIs in road safety (i.e. ETSC, 2003). Standard safety indicators have been used and developed by a number of international institutions and databases such International Road Federation (IRF) and International Road Traffic and Accidents Database (IRTAD) (OECD/ITF, 2008; OECD/ITF, 2015). To date, no similar SS dimensions (composite) index has been developed and used for benchmarking road safety issues.

2.6.2 Road safety benchmarking process

Based on benchmarking cycle (ANDERSEN, 1999), Shen et al. (2015) established the benchmarking cycle for road safety adapted from Wegman et al. (2008), with five core activities (Figure 10). Each of the activities are vital elements for a successful road safety benchmarking practice, and need to be carefully planned, designed, and implemented.

Figure 10 - The road safety benchmarking cycle

Source: Shen et al. (2015), Wegman et al. (2008).

Initially, to compare the road safety performance among entities, one should always determine the key components for the benchmarking framework. Four aspects of the road safety management and improvement process have been identified to the benchmarking category (see section 2.6.1). The next step is to identify the benchmarking entities, i.e., with whom to compare. According to Al-Haji (2007), in order to achieve adequate and meaningful results during comparisons, road safety benchmarking studies usually have to be carried out between similar countries or regions at as much as possible the same level of development, motorization and with a similar type of transport system. Some large-scale benchmarking studies applied clustering techniques to perform analysis (WEGMAN; AARTS; BAX, 2008).

The third step for implementing benchmarking of road safety cycle is to develop a set of relevant indicators for the selected benchmarking framework (see section 2.4). The appropriate road safety indicators for a specific benchmarking study is the basis of a successful benchmarking practice (SHEN et al., 2015). The next step is to identify the gaps in road safety performance among the entities under study and to understand the root causes for these gaps. Statistical techniques, such as multiple regression, are widely applied to assess comparative performance of different entities, which utilizes a weighted scoring method in the analysis of various indicators. In addition, it measures a correlation or central tendency rather than best practice (WEGMAN; AARTS; BAX, 2008).

In the last step, the target-setting for those underperforming entities in terms of different road safety aspects is performed. The process findings allow to determinate what needs to be done to match the best practice and to fill the identified gaps. Moreover, from the road safety policy point of view, this step does not represent the end of the benchmarking process but is an ongoing diagnostic management tool requiring effective strategies, sufficient allocation of resources, successful implementation, and persistent monitoring and evaluation in order to achieve continuous improvement over time (SHEN et al., 2015).

A useful example of a road safety benchmarking cycle is the SUNflower study of Koornstra et al. (2002). Within this study, road safety strategies and developments were compared for Sweden, the United Kingdom (UK) and the Netherlands (abbreviated as “SUN”). The study aimed to determine the underlying elements in road safety policy that make these countries successful and thereby identify policy improvements most likely to produce casualty reductions. The two main finding were that the policy areas targeted were similar and all three countries have achieved similar levels of road safety, through continuous improvements. The study provided recommendations for both SUN countries, others European Union member countries and the European Commission.

Wegman (2017) applied this approach to assess road safety performances in ten Latin American countries and benchmark their performance against a set of indicators and best practices leading to a set of recommendations for individual countries and for other stakeholders to further improve road safety. The findings identified in order for Latin American countries to learn from each other and to assess their weaknesses and strengths identifying areas deserving policy attention and where the experience of other countries may be usefully applied.

More recently, Santos et al. (2022), proposed the application of a benchmarking process to Brazilian municipalities in order to suggest targets for reducing traffic deaths in Brazilian municipalities. The authors used 12 secondary indicators for the clustering of 5,570

Brazilian municipalities, divided into three groups: indicators of final results, intermediate results, and socioeconomic conditions. As a result, targets for the reduction of traffic deaths were obtained for each Brazilian municipality, which resulted in an accumulated national reduction target of 56%.

2.7 Final Considerations

Monitoring public policies is essential to assess the road safety performance of a region. Due to the complexity of the multidimensional relationships of road safety policies, the SPIs and type of modeling need to be properly defined. The decision and importance of choosing indicators to represent the RTI problem becomes even more complex with the diversity of existing indicators and the difficulty of access to many of them, especially in LMIC.

Despite its recognized contribution, most of monitoring road safety studies involving statistical modeling, are focused on a more disaggregate level, in which specific aspects of the road, vehicle or road users. This framework seems not appropriate for the policy level as the modeling results are poorly informative about the interrelationship between the policy-related dimensions and the road safety outcomes. The difficulty in establishing this association is in part attributed to the multidimensional nature of the road safety problem, which is influenced in different intensity levels by all SS dimensions.

In this perspective, the application of multivariate modeling emerges, which allows the definition of variables as constructs and complex relationships between independent variables and response variables. From the understanding of the structural relationship of the indicators, dimensions and RTI, it is understood that it is possible to create a composite road safety index for road safety benchmarking purposes. Through this process, the literature review shows that is possible to determine the underlying dimensions in road safety policies that make successful and thereby identify policy design or improvements most likely to produce RTI reductions, at national and city level.

Benchmarking the road safety performance is a process in which countries or sub-national jurisdictions (regions and states), evaluate various aspects of their performance in relation to other policies practices, among those with the best performances. In this context, the clustering techniques are commonly required in order to achieve adequate and meaningful results during comparisons. Road safety benchmarking studies usually have to be carried out between similar regions at as much as possible the same level of development.

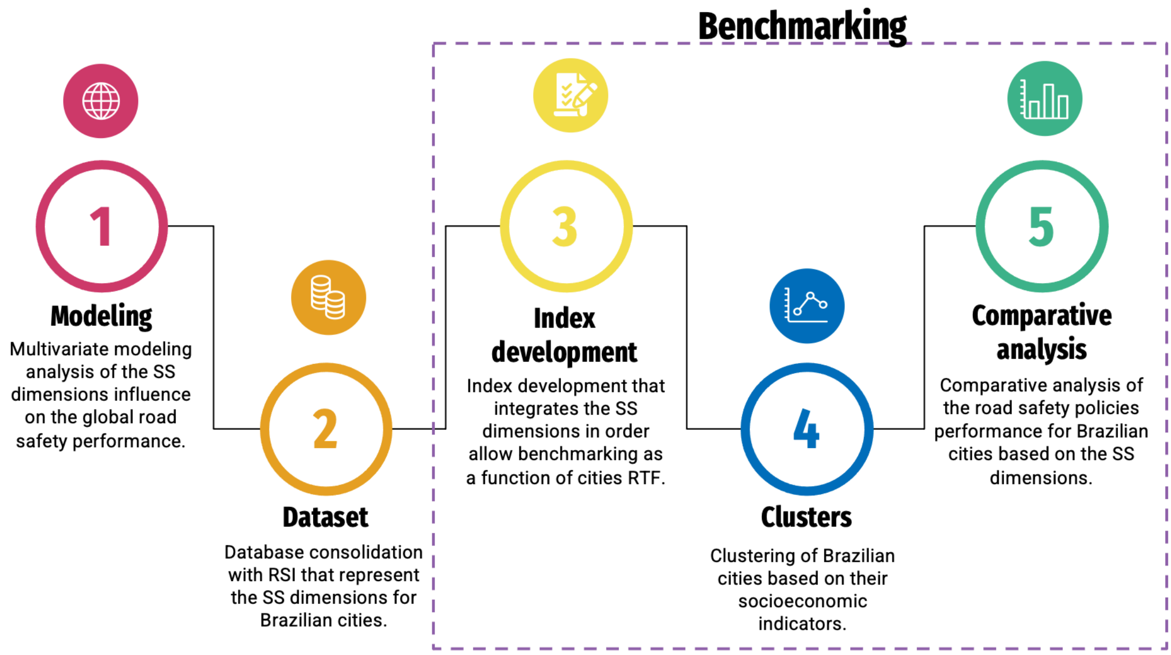
The benchmarking results enable countries or jurisdictions to learn from others as a basis for developing measures and programs which are aimed at increasing their own performance. This approach is considered a basis for learning and accelerating positive developments can be considered a promising step in improving road safety.

With the aim of advancing this knowledge, chapter 3 presents a method that allows the application of this knowledge to the development of integrated benchmarking for Brazilian municipalities with more than 100,000 inhabitants.

3 METHODOLOGY

The proposed method (Figure 11) consists of five macro steps: (i) A Multivariate modeling analysis of the SS dimensions influence on the global road safety performance; (ii) Database consolidation with RSI that represent the SS dimensions for Brazilian cities; (iii) Index development that integrates the SS dimensions in order allow benchmarking analysis as a function of the RTF rate at the city level; (iv) Clustering of Brazilian cities based on their socioeconomic indicators; (v) Comparative analysis of the road safety policies performance for Brazilian cities based on the SS dimensions. The last three macro steps represent the Benchmarking activities developed in this research.

Figure 11 - Proposed method



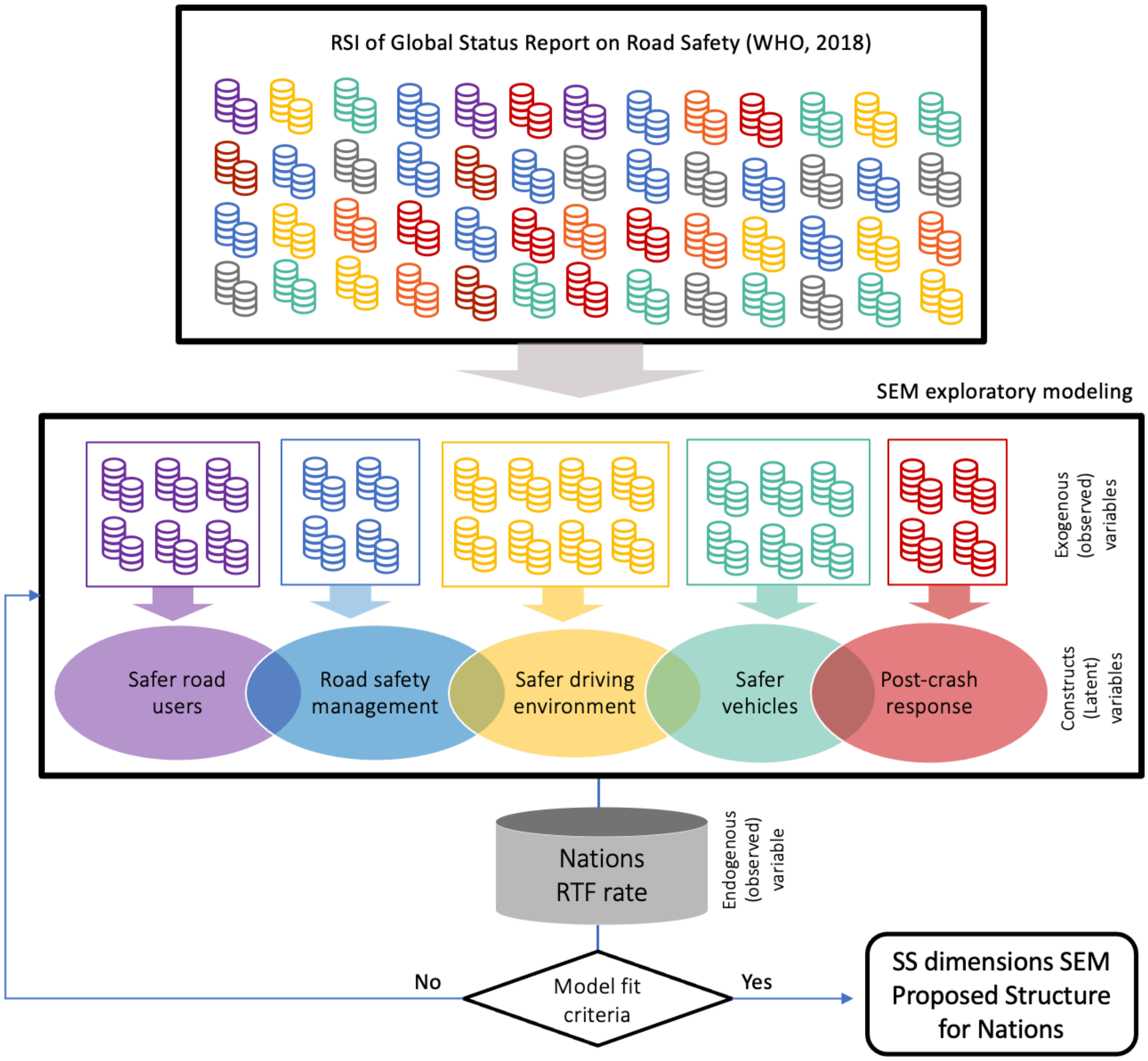
Source: The author.

3.1 Multivariate analysis of the SS dimensions

Understanding the relationships between SS dimensions and the road safety performance of a region is crucial for defining public policies and effective strategies for reducing RTI. These dimensions represent the main road safety policies core pillars and can be treated as constructs, inferred from related RSI.

The first stage of the method aims to propose a quantitative modeling structure that allows the representation of the SS approach dimensions as constructs and their potential correlations, with focus on RTF at the nation level. Based on SEM approach, the central points of this stage consist of: i) to evaluate the influence of the various RSI available in the WHO Global Road Safety Status Report on the constructs variables proposed to SS dimensions; ii) to define the relationship type and intensity between the latent variables (constructs) representing the SS dimensions and; iii) to estimate the relative importance of SS dimensions in the mortality rate of WHO Member States (endogenous variable). Figure 12 presents the scheme for defining the structural model of SS dimensions at national level.

Figure 12 - Method to estimate a structural model of SS dimensions at national level



Source: The author.

After organizing the RSI available in the WHO report in its respective dimensions, an initial exploratory model was estimated considering all observed (exogenous) variables directly related to their respective latent constructs, also considering a structure of mutual influence among all latent variables (covariance). The exploratory model was used to propose several confirmatory models in which different structure configurations were tested until all criteria for model fit were met.

Initially, as part of the model development, endogenous observed variables were removed, and latent variables dependency structure was adjusted according to the statistical significance criteria (p-value<0.05) of the loading factors and their respective p-values. Subsequently, variables with weak loading factors (<0.4) or with high correlation with another variable associated with the same latent were also removed. Based on review of existing literature, this process sought to simplify the model structure and improve its goodness-of-fit metrics.

The estimation of the model parameters was obtained from the optimization of a function that relates the S-matrix (observed variance-covariance) with Σ(θ) (variance-covariance matrix of the model), constructed from the assumptions regarding the observed variable distributions and the proposed structure for the measurement models (NACHTIGALL et al., 2003). All models were estimated using the *lavaan* library of the R software statistical application through the maximum likelihood (ML) method. The routine also allowed the use of Lagrange multiplier tests (*modindices()* function) which allow changes in structure to achieve an improved model fit.

Regarding the model fit criteria as well as in the comparison between models, the following metrics were considered: (i) the root mean square error (RMSE) that is related to the difference in the sample data and what would be expected if the model were considered correct (Equation 4), (ii) the comparative fit index (CFI) which is the ratio between the fit of proposed model and a baseline model, typically a null model where all variables are uncorrelated, (Equation 5) and, (iii) the ratio between chi-square (χ^2) and degrees of freedom (df).

$$RMSE = \frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{n} \tag{4}$$

$$CFI = 1 - \frac{\chi_m^2 - df_m}{\chi_b^2 - df_b} \tag{5}$$

Where, $\hat{y_i}$ is the estimated response variable for element i and y_i is the observed response variable for element i $(i = 1, 2, \dots, n)$. The subscript indicates whether the statistics are of the model of interest (m) or the baseline model (b).

According to Hair (2006), CFI values equal to or above 0.9 and RMSE equal to or below 0.05 indicate a good fit between the model and the data. Schumacker and Lomax (2004) suggests observing the relationship between chi-square and degrees of freedom (χ^2/df), as the χ^2 it is highly sensitive to sample size. If the null hypothesis of the fit test χ^2 is true, the expected value of the degrees of freedom is equal to the expected value of the test statistic. A model that properly represents the sample will have the relationship χ^2/df =1.

3.2 Database consolidation for Brazilian cities.

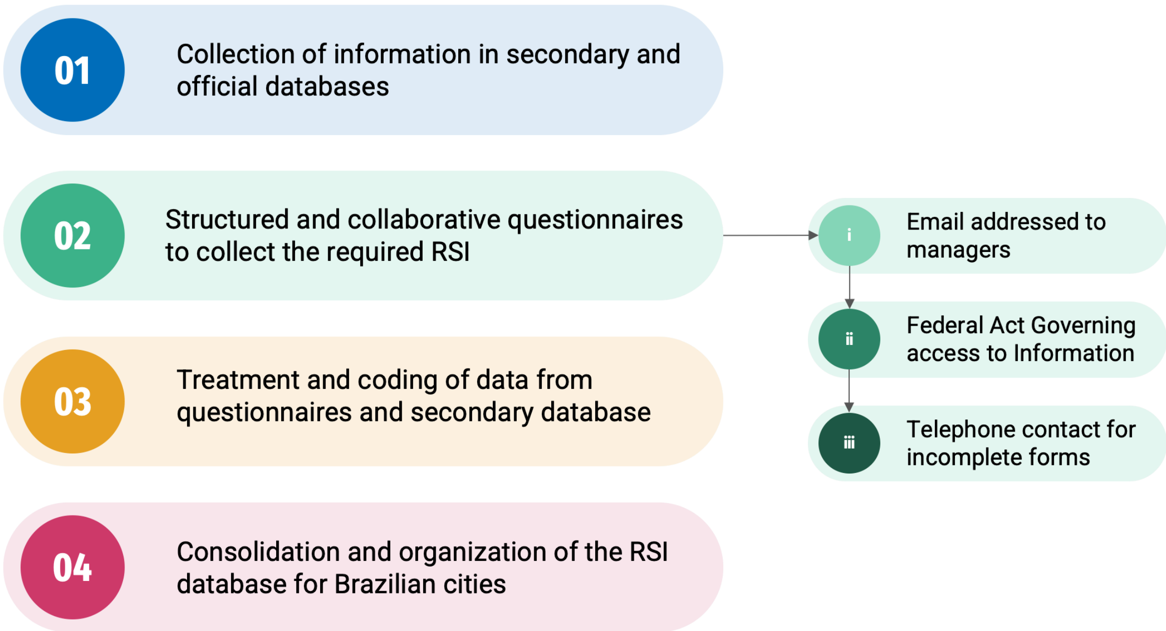
The data collection effort was defined based on the structure of the SS dimensions SEM for the Nations. In an attempt to find RSI compatible with those available at the national level, secondary and official databases were consulted, and considerations were made regarding the differences between the national and municipal levels. For indicators related to the presence of legislation (i.e. seat-belt, drink-driving law), which have a national (an theoretical) homogeneous coverage in all cities, municipal level RSIs were searched by their capacity to measure the municipality's potential to supervise the application of the respective laws.

Given the limitations found in the official database, such as the lack of standardization in the collection, level of data aggregation and unavailability of data necessary for this study, an effort to collect data from questionnaires was also developed. The definition of the structure and questions were guided by the definition of the targeted RSI for the representation of the SS dimensions, based on the National RSI. The questionnaires were addressed to managers of mobility, traffic, or transport departments in Brazilian cities with more than 100,000 inhabitants.

The steps to get the questionnaires data were: (i) Contact by e-mail available on the City Hall websites; (ii) Formal request based on the Law on Access to Information (LAI - Law No. 12,527 of November 18, 2011) through the Citizen Information Service of cities; and (iii) Telephone contact, only for managers who partially completed the form. If the contact e-mail was not available on the website, the request was made only by LAI (step 2). Figure 13 summarizes the activities of this step.

The questionnaire (available in Appendix A) was divided into four main sections, which totaled 25 questions. An online spreadsheet application was used that allows creating and formatting forms in collaboration. Each municipality had its own online form, which had the option of autosaving, allowing it to be answered in stages and collaboratively. In this way, managers did not have to fill in all the information at the same time, considering that some of it could need an effort of research or internal consultation.

Figure 13 - Data collection steps



Source: The author.

The first questionnaire section addressed the characterization of the road safety management dimension. The section included questions about the existence of a mobility plan, goals for reducing RTF/RTI and the existence of a road crash database, as well as the practice of using these data for the road traffic management (engineering, inspection, education, and communication).

In the second section, issues related to safe roads, mobility and safe vehicles were addressed. Information was requested on vehicle inspection procedures, design standards for vulnerable users, existence, and operational capacity of the traffic engineering department, as well as policies or actions that encourage the use of transit and active transport. To compose the RSI for the dimension of safe vehicles, secondary and official data, made available by the National Traffic Secretariat (SENATRAN), were included regarding the composition and age of the vehicle fleet of the cities.

In the third section, the questions were directed to address the SS dimensions of safer road users and post-crash response. It was composed of questions related to the cities operational capacity to carry out road safety campaigns and to perform enforcement to reduce traffic violations related to the main risk factors (speeding; drinking and drive; and helmet, seatbelt and cell phone use). Regarding the post-crash response dimension, information related to the type of Mobile Emergency Care Service (SAMU in Portuguese) operation was requested. To compose this dimension, secondary and official data related to the operational capacity to care for victims (ICU beds, SAMU and Emergency Room units) were included. This information is made available to all Brazilian cities by the Department of Informatics of the Unified Health System (DATASUS), associated to the Brazilian Ministry of Health.

Systematic follow-up was applied to monitor form completions. The forms in which unfilled information was identified received an additional step of data collection by telephone contact. After completing this step, the forms of the cities sample that filled its out in full followed on to the stage of processing and encoding the information. The answers provided were transformed into ordinal categorical variables. The higher the variable value, the better the city performance for that respective RSI. Values equal to zero indicate that the city does not have strategies related to RSI. Finally, all data were consolidated into a single database to carry out the next macro step, the index development. The consolidation of this database made it possible to characterize the sample of cities in relation to road safety policy status, based on the SS dimensions.

3.3 SS dimensions Index development

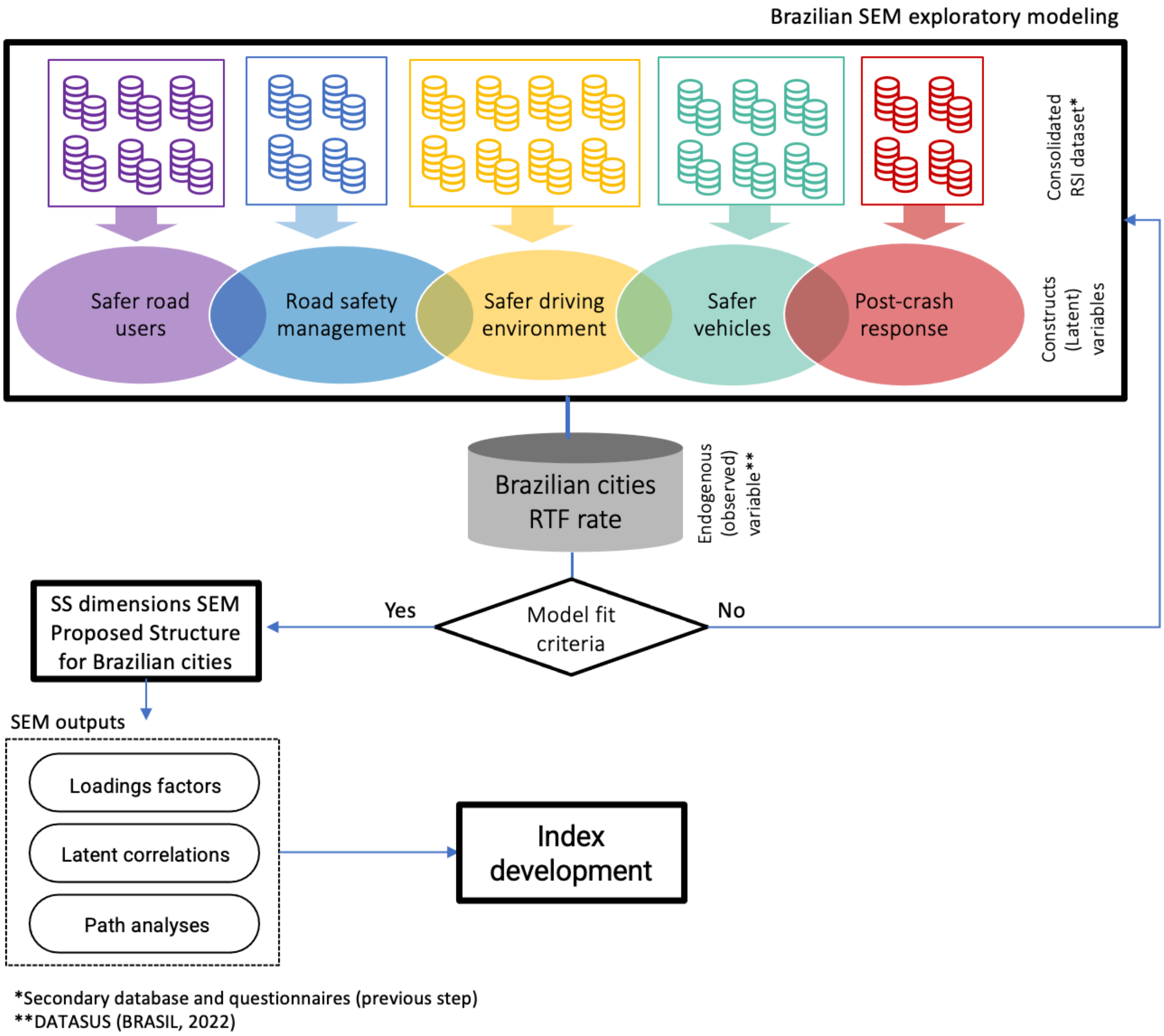
The first step of this research showed that the SEM approach is promising to quantitatively represent the complex relationship between the road safety policies and the road safety regions performance based on the SS approach. The SEM output provides indicators that allow estimating weights of the assessment measures. From the significant factors, the relative weightage for the measures is calculated using high-order factor loadings of these measures to formulate indices (ESTIRI et al., 2021; GBONGLI et al., 2020).

Therefore, to estimate the weight of assessment measures for SS dimensions policies, it was necessary to estimate the Brazilian cities SEM. The estimation process was similar to that developed in the first step (Figure 12). The same model fit criteria were used. All models were estimated using the *lavaan* library of the R software statistical application through the nonlinear optimization method using diagonally weighted least squares estimation.

The SEM outputs, considering the direct and indirect relationships, were used to build the indices for each SS dimension. The SEM ability to calculate the weight of assessment measures in the decision-making models has been used by some researchers (PUNNIYAMOORTY; MATHIYALAGAN; LAKSHMI, 2012; RAVIKUMAR et al., 2016).

The index definition considered three SEM outputs: the loading factors, the latent correlations, and the path analysis. These outputs make it possible to estimate the strength of the SS dimension relationships on road safety performance. The estimation of these indices was a fundamental input for the benchmarking developed in this research. Figure 14 summarizes the activities of this step.

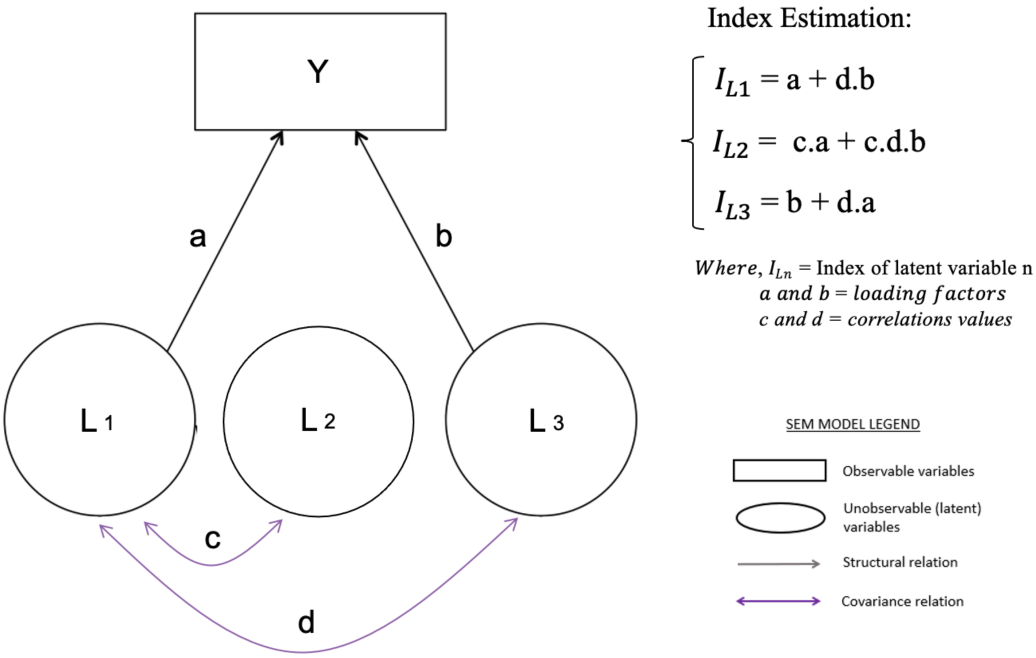
Figure 14 - Method for the index development based on SEM outputs



Source: The author.

Figure 15 presents a hypothetical and simplified example to demonstrate how the indices of the SS dimensions were estimated. The loading factor (a and b) represents the direct effect, while the correlations (c and d) represent the indirect effects of SS dimension on road safety performance. The path analysis indicated the effects composition for the index development. In this research, effects up to the 3rd order were considered. The estimated indices significance was evaluated using a hypothesis test. In this study, a predetermined significance level of 95% was assumed (p-value < 0.05).

Figure 15 - Hypothetical measurement part of a model and index estimation



Source: The author.

In the example present in Figure 15, the indices of latent variables 1 and 3 (L_1 and L_3) have 1st and 2nd order effects. Both have a direct relationship with the observed variable (Y) as well as a correlation with another latent that also has a direct relationship with the observed variable (Y). On the other hand, the index of the latent variable 2 (L_2) has only indirect effects of 2nd and 3rd order. Its relationship with the observed variable (Y) occurred through their correlations with other latent variables (L_1, 2nd order and L_3, 3rd order) that have a direct effect with the observed variable (Y).

3.4 Clustering of Brazilian cities

Brazil can be considered a country with continental dimensions and very contrasting backgrounds in the different regions. These contrasts refer to many aspects, from which the most obvious concern socioeconomic issues. In addition to the large geographical distance between some Brazilian cities, strong disparity levels concerning the mentioned background aspects may make the transference of good experiences from best to underperforming cities difficult or, at least, result in the reduction of the possibility of success on this transference. It would probably not be so realistic to suggest that the worst-performing sampling city should adopt the best-performing sampling city as a benchmark.

The advantage of clustering within the road safety framework is to gain insight in rather homogeneous or similar stats and next, to offer a more feasible basis for the transference of good experiences from best to underperforming city. From a practical point of view, it is to be expected that cities can learn more easily from similar cities. This suggests that forming classes of more or less similar and comparable cities does make sense to perform a benchmarking. Consequently, in this study the clustering procedure is centered on the premise that efficacious policies to improve road safety in a certain city are more likely to generate desirable results in cities with a similar background.

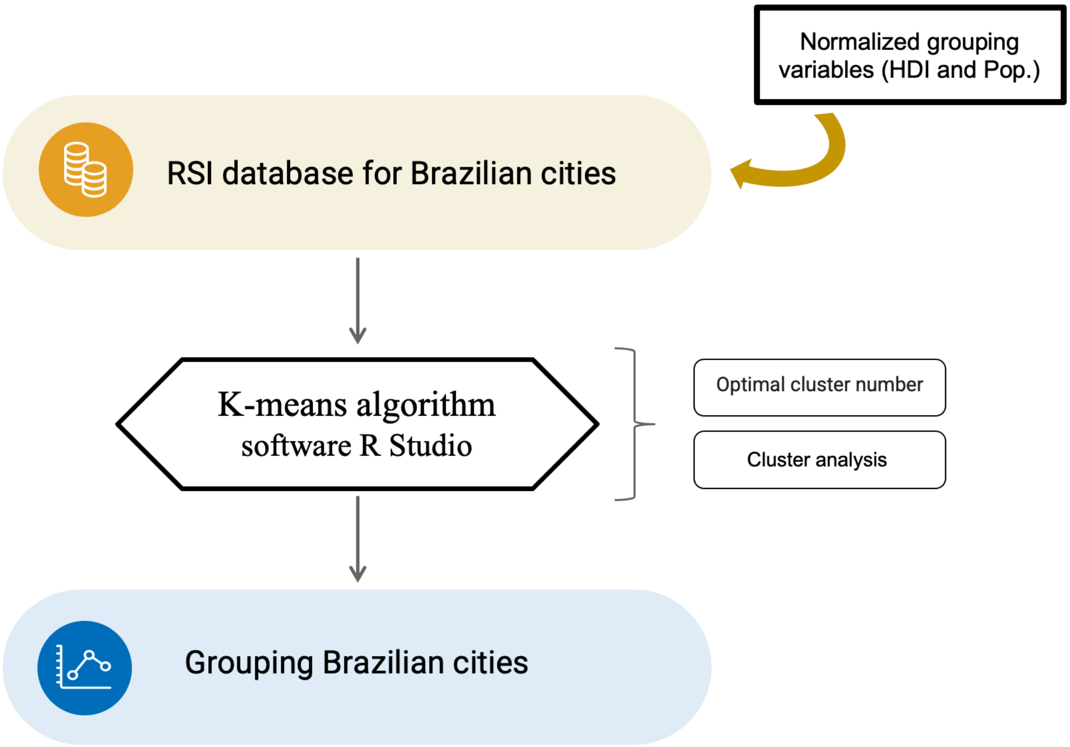
The gap throughout the set of Brazilian states in terms of road safety performance is substantially related to the socioeconomic background. In this context, national measures towards road safety are applied in distinct environments, each one offering a specific background for implementation. A successful measure implemented at a place, when reproduced at another place due to its successful prognostic, might deliver frustrating results if the background for application is very dissimilar and was not considered during this experience and expertise transference process (BASTOS, 2014).

The parameters used for clustering the cities must present a relationship with the investigation and must substantially influence the road safety situation of a place. Moreover, it is desirable that the chosen parameters are available for every Brazilian city. In light of the foregoing, this research used the population and the Human Development Index (HDI) of the sampling cities for the clustering process.

The data clustering technique used in this research was the K-means algorithm (MACQUEEN, 1967). This technique aims to partition the sample of N elements into K clusters based on the multidimensional distances (normalized or not) between the variables. The algorithm initially randomly defines values for the K centroids that, during the iterative process, are changed seeking the combination that results in the smallest sum between the distances between clusters and their elements. The procedure requires that the number K of clusters be informed in advance, a definition that is based on the reduction of the sum of the distances between elements and centroids with the increase of K. Figure 16 summarizes the activities of this step.

The RSI database for Brazilian cities developed in the macro step two was incremented. The variables used for grouping (HDI and population) was included in normalized format to render them in the same direction. The software RStudio (RSTUDIO TEAM, 2021) function for k-means clustering, *kmeans()* package, was applied to establish the optimal number of groups through the principle of maximizing the likelihood based on the Euclidean distance (EVERITT, 2011).

Figure 16 - Method for the grouping Brazilian cities into socioeconomic clusters



Source: The author.

The K-means algorithm starts with the first object in the first cluster. Euclidean distances of all objects to all clusters are calculated. If an object is detected whose distance to the center of gravity of its own cluster is greater than the distance to the center of gravity (centroid) of another cluster, this object is shifted to the other cluster. Finally, the centroids of the two changed clusters are calculated again since the compositions have changed here. These steps are repeated until each object is located in a cluster with the smallest distance to its centroid (center of the cluster).

The optimal number of clusters (K) was determined based on a graphical technique called the Elbow Method. The method involves plotting the sum of squares for different numbers of clusters and identifying the point of inflection (the elbow) in the plot. The optimal number of clusters is the point just before the point of inflection, where the reduction in sum of squares begins to level off.

Clustering is an important phase in benchmarking as it makes it possible to achieve adequate and meaningful results during comparative analysis (final step of this research). Al-Haji (2007) recommends that road safety benchmarking studies should generally be carried out between similar regions, as much as possible with the same level of development.

3.5 Comparative analysis of the road safety policies performance

Road Safety Benchmarking is a process in which jurisdictions evaluate various aspects of their RSP in relation to others in order to improve the policies and strategies to promote road safety in their jurisdictions. After the clustering process, a comparative analysis was performed based on the Road Safety Policy Performance (RSPP) of each city and their respective SS dimensions. The indices (I_D) developed in step 3 and the loading factors (between the constructs and their exogenous variables) of the Brazilian cities SEM were used to estimate the RSPP. Equation 6 present the estimation of cities' RSPP for their SS dimension ($RSPP_{D\gamma i}$).

$$RSPP_{D\gamma i} = \frac{\sum_n^\gamma (\beta_{n\gamma} * x_{n\gamma}) * I_{D\gamma}}{\sum_n^\gamma \beta_{n\gamma}} \tag{6}$$

Where, $\beta_{\gamma n}$ is the loading factor between the construct that represents the SS dimension γ and the endogenous variable x_γ related to it; x_n is the weighted value of the exogenous variables (*n*), obtained from the ratio of the value collected for a respective city (*i*) and the maximum value of this variable; and $I_{D\gamma}$ is the index value of the SS dimension γ.

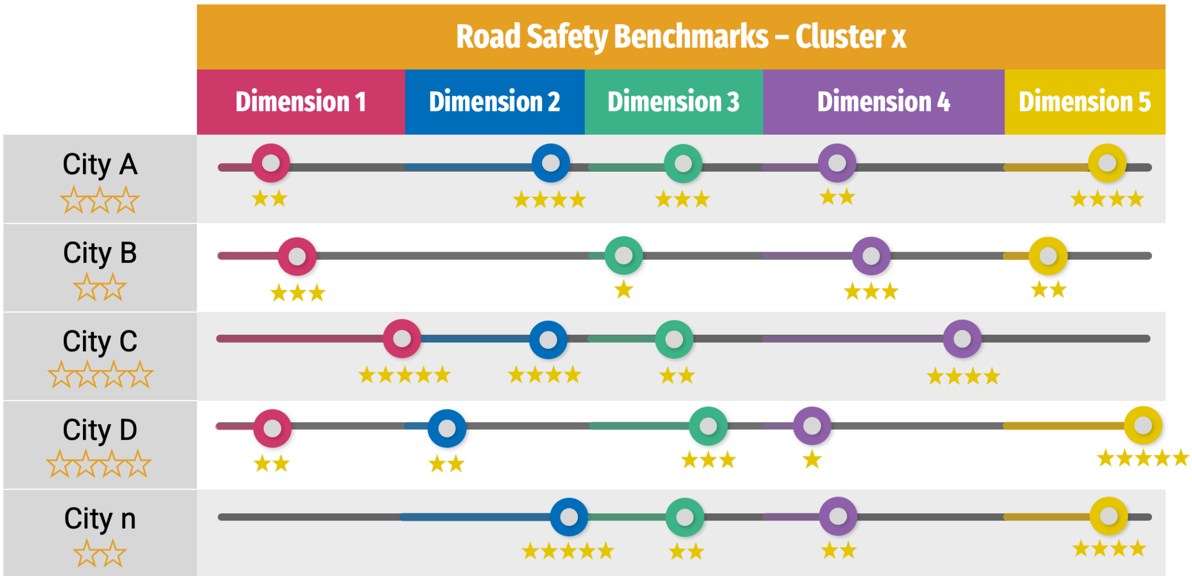
The maximum values of the performance of a city (*i*) for each of the SS dimensions ($D\gamma$), measured by the indicator $RSPP_{D\gamma i}$, is the index value of the respective dimension ($I_{D\gamma}$). The overall performance of each city is calculated by the sum of its $RSPP_{D\gamma i}$, as shown by Equation 7.

$$RSPP_{i=} \sum_\gamma^i RSPP_{D\gamma i} \tag{7}$$

To support results interpretations, a star rating analysis criterion, commonly used in other road safety studies (e.g. 5-Star Safety Ratings Program for vehicle and for roads, the NCap and IRap) was defined. The index values of each SS dimension and the overall value (sum of all indexes) were partitioned into five intervals. Each of these intervals represents one star-rating. The stars sum indicates the city's performance (rating) for overall road safety policies and for each SS dimension.

The first comparative analysis was carried out between the clusters, evaluating the RSP average of the cities that compose it. This analysis considered the overall performance ($RSPP_i$) of the cities and their respective Star Safety Ratings. The second comparative analysis was carried out between the cities of each cluster. At this stage of the analysis, the performance of each city was compared for each SS dimension ($RSPP_{D\gamma i}$) and their respective Star Safety Ratings. Figure 17 exemplifies this evaluation and comparison process, based on the SS approach.

Figure 17 - Proposed scheme for comparative analysis between cities



Source: The author.

This approach means comparing the performance of city policies or strategies with those of other cities, with the best-in-class (the cities with the best $RSPP_{D\gamma i}$). That one may identify opportunities for improvement and indicate the cities' priorities; the performance of their SS dimensions was compared with the average performance value of the SS dimensions in the respective cluster. Equation 8 demonstrates the formula for determining the SS dimensions average performance γ for each cluster *x*.

$$D_{\gamma x} = \frac{\sum_{n}^{\gamma}(RSPP_{D\gamma i})}{n} \quad (8)$$

Where, $D_{\gamma x}$ represents the SS dimensions average performance γ for each cluster *x* e is the number of cities in the cluster *x*. If a city has one or more $RSPP_{D\gamma i}$ lower than its cluster average $(D_{\gamma x})$, the domains for action, in the respective SS dimensions, are highlighted. This opportunities for improvement are ranked considering the highest difference in relation to the average value $(D_{\gamma x})$. Cities with the highest $RSPP_{D\gamma i}$ are highlighted as best-in-class and should be use as a benchmark for cities where opportunities for RSP improvement are identified.

In the hypothetical example shown in Figure 17, city D would be the best-in-class for SS Dimension 5, as it had the best performance among the other cities in its cluster. On the other hand, cities B and C underperformed the average cluster performance for this dimension. In this situation, these cities would be highlighted (policy act opportunity) because opportunities for improvement were identified in this SS dimension

The implementation of the proposed methodological approach provided relevant insights for RSP knowledge and useful implications for policy makers as well as for public awareness purposes. In Appendix A, there are RSPP cities where the best-in-class bets in class of all the clusters and the priority domains (SS dimensions) for action in each city are underlined.

Finally, in this macro step, best-in-class cities (highest RSPP) are investigated in depth. The main best practices (based on their RSI), considered as benchmark, are highlighted. Likewise, the cities with the lowest RSPP are also investigated. The main RSP limitations and priority SS dimensions for action are highlighted.

4 RESULTS AND DISCUSSIONS

Following the steps proposed in the method, this section presents the results achieved and its discussion. The chapter structure is similar to the methodological proposal and is subdivided into 5 parts. In the first (section 4.1), the results and discussions of the modeling structure that allows the representation of the SS approach dimensions as constructs and their relationship with the RTF at the nation level are presented.

In section 4.2, the effort to collect and consolidate the RSI database for Brazilian cities, made it possible to perform a diagnosis of the situation of its road safety policies based on the SS dimensions. The result of the development of the index based on the database and the structural modeling focus for the Brazilian cities is presented in section 4.3. The cities' clustering process is presented in section 4.4. These last two sections present the initial results related to the benchmarking performed in this study.

The last stage of the benchmarking is presented in section 4.5 and consists of a comparative analysis between clusters and between cities in the same cluster. This comparative analysis allows identifying the cities with the highest and lowest RSPP for each SS dimension. The main findings are opportunities for RSP improvement of cities based on best practices performed by other cities in a same cluster. The results and discussions in this section could support the definition of strategic planning scenarios at the cities level, objectively improving their road safety policies efforts.

4.1 Global multivariate analysis of the Safe System dimensions

This research used the database of one hundred seventy-fifth countries available in the Global Status Report on Road Safety (WHO, 2018). Details of the procedure for collecting and standardizing the data collected by WHO are available in this report. Forty-nine RSI related to the SS dimensions were treated and converted into ordinal or binary categorical variables. The higher the value of these variables, the better the national performance for that specific RSI. These indicators (exogenous variables) were organized and associated with their specific dimension (latent variables). Tables 1 to 9 presents the data set used in this statistical modeling.

The RTF rate is the only endogenous variable used in this modeling step. To minimize the variance within the class and maximize the differences between the classes of the variable that defines the RTF rates, stratification techniques of natural breaks into 5 classes were used. Table 10 presents the classes based on the RTF modeled values (WHO, 2018).

Table 1 - Global RSI for Road Safety Management dimension

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
lead_ag	Lead agency (LA)	(1)No (2)Yes and not funded (3)Yes and funded	2.66	0.62
ag_func	Lead agency functions	(1)Don't have LA (2)Coordination (3)Coordination and legislation (4)Coordination and legislation and monitoring & evaluation	4.50	1.16
strateg	Road safety strategies	(1)No (2)Yes and not funded (3)Yes and partially funded (4)Yes and funded	2.71	0.95
target	Road safety targets	(1)No (2)Yes, non-fatal only (3)Yes, fatal only (4)Sim, non-fatal and fatal	2.65	1.33

Source: The author, based on WHO (2018).

Table 2 - Global RSI for Safer Vehicles dimension

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
seatbelt	Seat-belts	(1)No (2)Yes, seat-belt anchorages only (3)Yes, seat-belt and child seats anchorages	1.55	0.88
protec	Protections	(1)No (2)Frontal impact (3)Frontal/lateral impact (4)Pedestrian protection and frontal/lateral impact	1.79	1.28
stab_cont	Electronic stability control	(1)No (2)Yes	1.26	0.44
abs_motor	Motorcycle anti-lock bracking system	(1)No (2)Yes	1.20	0.40

Source: The author, based on WHO (2018).

Table 3 - Global RSI for Safer Driving Environment dimension

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
audits	Audits or star rating required for new road	(1)No (2)Partial (3)Yes	2.32	0.74
inspec	Inspections / star rating of existing roads	(1)No (2)Yes	1.65	0.48
des_stand	Design standards for the safety of pedestrians / cyclists	(1)No (2)Partial (3)Yes	2.29	0.65
upgrade	Investments to upgrade high risk locations	(1)No (2)Yes	1.66	0.47
public_transp	Policies & investment in urban public transport	(1)No (2)Yes	1.73	0.44
walk_cyc	Policies promoting walking and cycling	(1)No (2)Partial (3)Yes	1.99	0.92
audits	Audits or star rating required for new road	(1)No (2)Partial (3)Yes	2.32	0.74

Source: The author, based on WHO (2018).

Table 4 - Global RSI for Post-crash Response dimension

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
uni_number	Universal access telephone number	(1)No (2)Partial coverage (3)National, multiple numbers (4)National, single number	3.35	0.95
trauma_reg	Trauma registry	(1)No (2)Subnational or some facilities (3)National	2.06	0.79
emer_care	National assessment of emergency care system	(1)No (2)Yes	1.23	0.42
spec_doct	Specialist doctors*	(1)No (2)Emergency medicine or trauma surgery only (3)Emergency medicine and trauma surgery only	2.29	0.86
post_grad	Post graduate courses in emergency and trauma care*	(1)No (2)Yes	1.58	0.50
form_cert	Formal certification pathway*	(1)No (2)Yes	1.55	0.50

* The values of these variables were collected from questionnaires applied by WHO.
Source: The author, based on WHO (2018).

Table 5 - Global RSI for Safer Road Users related to speed

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
speed_law	National speed limit law	(1)No (2)Yes	1.97	0.18
mod_allow	Speed limit modifications allowed	(1)No (2)Yes	1.48	0.50
urban_max	Urban maximum default speed limits	(1)No or >79kmh (2)between 79 and 51km/h (3)<51km/h	2.34	0.79
rural_max	Rural maximum default speed limits	(1)No or >99kmh (2)between 99 and 61km/h (3)<61km/h	1.71	0.60
mway_max	Urban maximum default speed limits	(1)No or >119kmh (2)between 119 and 81km/h (3)<81km/h	2.11	0.83
speed_enf	Level of enforcement	Scale* (0)not effective to (10)highly effective	5.35	2.38
type_enf	Predominant type of enforcement	(1)Don't have (2)Manual (3)Automated (4)Both	2.48	0.94

* The values of these variables were collected from questionnaires applied by WHO.
Source: The author, based on WHO (2018).

Table 6 - Global RSI for Safer Road Users related to mobile phone use

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
mob_phonelaw	National mobile phone law	(1)No (2)Hand-held phone use (3)Hand-held phone use and applies to hands-free phone use	2.06	0.59
mob_phonedata	Any data on use of mobile phone while driving	(1)No (2)Yes	1.49	0.50

Source: The author, based on WHO (2018).

Table 7 - Global RSI for Safer Road Users related to helmet use

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
helm_law	Motorcycle helmet law	(1)No (2)Just drivers (3)All occupants	2.87	0.45
helm_applroad	Applies to all roads	(1)No (2)Yes	1.93	0.25
helm_appleng	Applies to all engines	(1)No (2)Yes	1.87	0.34
helm_fast	Helmet fastening required	(1)No (2)Yes	1.47	0.50
helm_stand	Standard referred and / or specified	(1)No (2)Yes	1.53	0.50
child_ pass	Children passengers on motorcycles	(1)No (2)<10 years (3)<15 years (4)Inadequate stature	1.56	0.82
helm_enf	Level of enforcement	Scale* (0)Not effective to (10)Highly effective	5.79	2.90

* The values of these variables were collected from questionnaires applied by WHO.
Source: The author, based on WHO (2018).

Table 8 - Global RSI for Safer Road Users related to drink and driving

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
dd_law	National drink driving law	(1)No (2)Yes (3)Yes, based on BAC / BrAC	1.78	0.41
dd_level	National maximum legal BAC levels (g/dl)	(1)No (2)>0.05 for all (3)<=0,05 for all (4)Zero for some groups (5)Zero for all	2.98	1.48
rand_test	Random breath testing carried out	(1)No (2)Yes	1.79	0.41
fat_test	Testing carried out in case of fatal crash	(1)No (2)Some drivers (3)All drivers	2.13	0.83
dd_enf	Level of enforcement	Scale* (0)Not effective to (10)Highly effective	5.39	2.63
drug_law	National drug driving law	(1)No (2)Yes	1.89	0.31
alcoh_prohi	Alcohol prohibited	(1)No (2)Yes	1.10	0.30

* The values of these variables were collected from questionnaires applied by WHO.
Source: The author, based on WHO (2018).

Table 9 - Global RSI for Safer Road Users related to seatbelt use

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
seatb_law	National seat belt law	(1)No (2)Just drivers (3)Front occupants (4)All occupants	3.37	0.95
seatb_enf	Level of enforcement	Scale* (0)Not effective to (10)Highly effective	5.51	2.66
child_restrlaw	Child restraint systems law	(1)No (2)< 6 years (3)< 13 years	1.85	0.96
child_ front	Children seated in front seat	(1)No (2)< 8 years (3)< 13 years (4)Forbidden	2.30	1.23
child_restrenf	Level of enforcement	Scale* (0)Not effective to (10)Highly effective	2.57	3.26

* The values of these variables were collected from questionnaires applied by WHO.
Source: The author, based on WHO (2018).

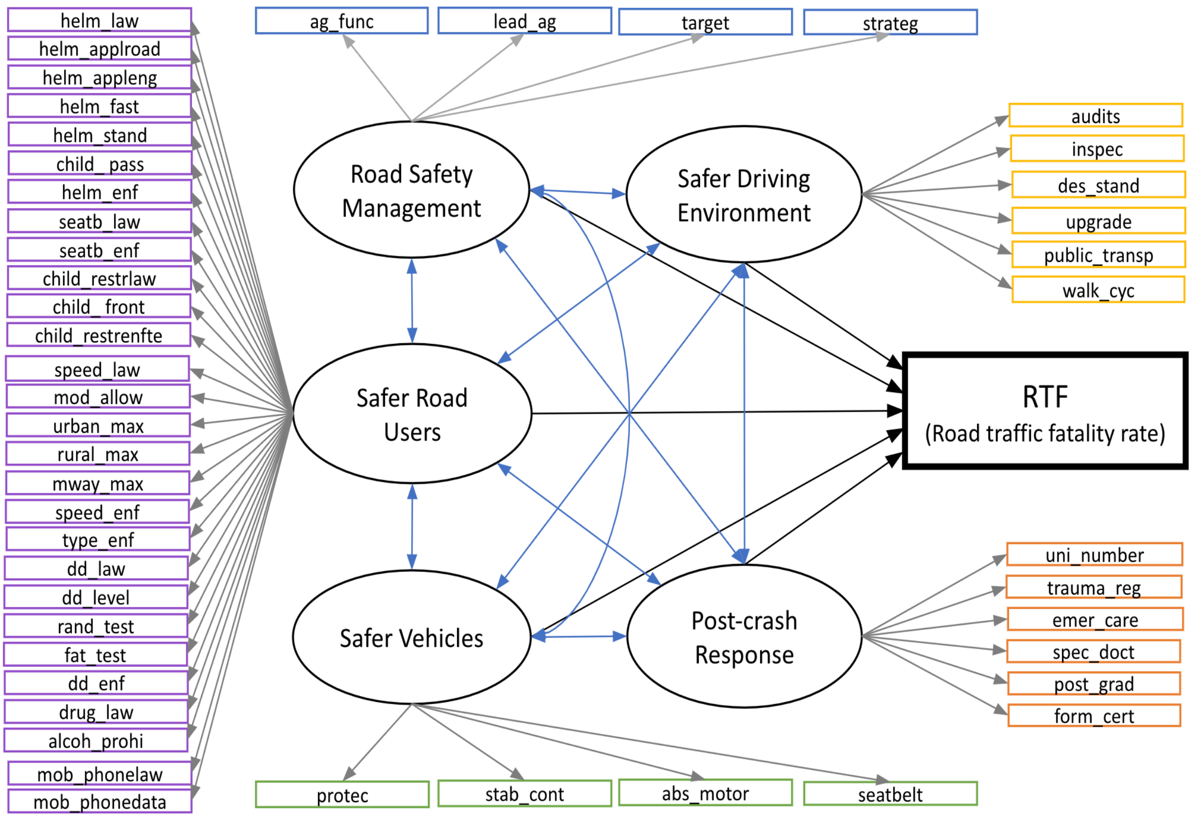
Table 10 - Global RTF modeled rate

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
RTF (rate)	Road traffic deaths per 100k inhabitants WHO estimated value*	(1)<7.19 (2) 7.19 to 14.36 (3)14.37 to 21.54 (4)21.55 to 28.72 (5)>28.72	2.82	1.31

* Modeled values following WHO methodology available in global road safety status report (WHO, 2018).
Source: The author, based on WHO (2018).

A measurement model was initially developed with all observed exogenous variables with statistical dependence on their respective latent constructs (SS dimensions) and these on the endogenous variable deaths (RTF rate). In this first exploratory model, all possible covariances between the latent constructs were considered in the structure. Figure 18 presents the proposed structure of the exploratory model.

Figure 18 - Exploratory structural equation model



Source: The author,

The model in Figure 17 converged with 143 interactions and presented chi-square $(\chi^2) = 2590.8$ and degrees of freedom = 1113 $(\chi^2/gl = 2.33)$. The *p-value* statistics indicate rejection of the SEM fit test (*p-value* < 0.05). The other goodness-of-fit metrics also did not indicate a good SEM fit (CFI = 0.65 and RMSE = 0.087).

In this first exploratory model, many loading factors between the RSI (exogenous variables) and their respective SS dimensions (latent variables) were not statistically significant. The same happened with some loading factors between the SS dimensions and the RTF rate (endogenous variable). The *Road safety management* and *Safer driving environment* dimensions did not present a direct relationship with the RTF rate (*p-value* > 0.05). The *Safer vehicles* dimension presented the highest loading factor (-0.34), followed by *Post-crash response* (-0.11) and *Safer road users* (-0.08). The signs of the coefficients indicate agreement between the hypothesized relationships, the higher the investment in these SS policy dimensions, the lower the RTF rates.

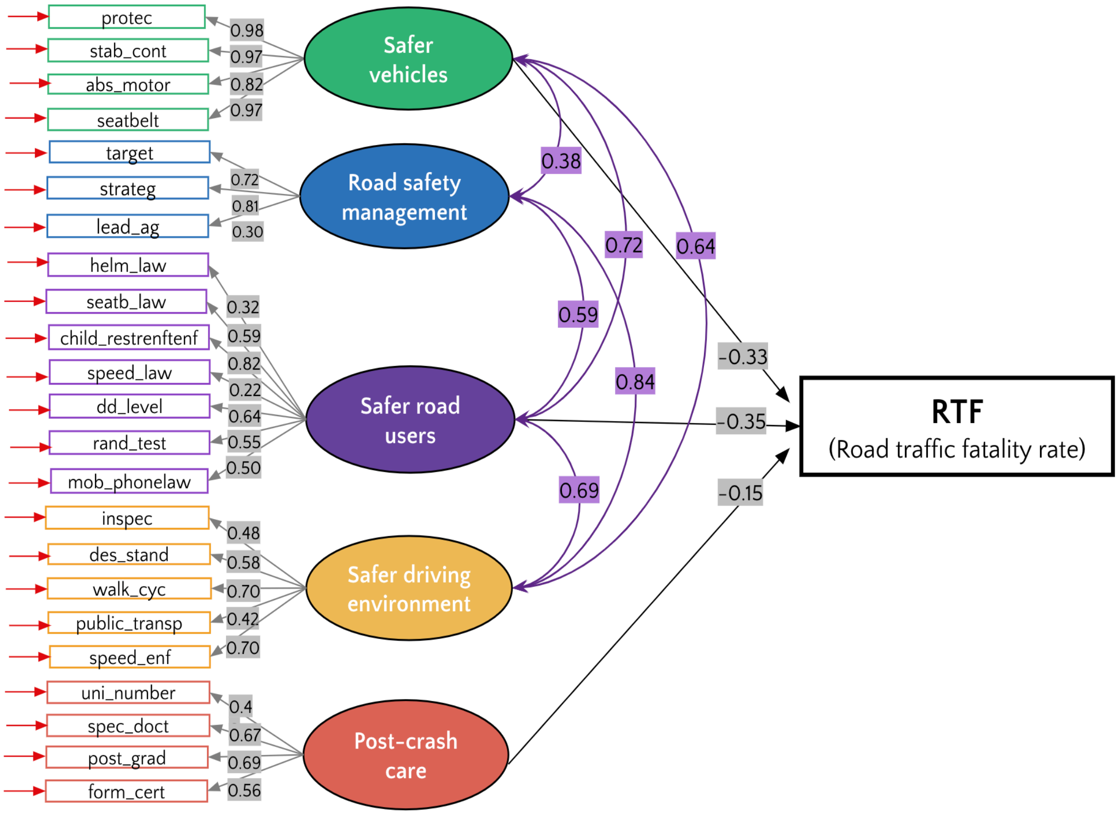
After the initial exploratory model, the parameters of new SEM configurations were evaluated, eliminating loading factors and variables without statistical significance, and following the methodology defined in this research for SEM exploratory analysis. It is noteworthy that, in none of the SEM analyzed in the exploratory stage, the structure with direct influence (loading factor in unidirectional arrow) of *road safety management* and *safer driving environment* to RTF provided appropriate goodness-of-fit metrics.

In the final configuration of the proposed SEM, only the significant loading factors and covariances above the values defined in the methodology were considered. After analyzing the Lagrange modification indices, some coherent changes in the model structure were made, specifically, the RSI speed enforcement level was reallocated to the safer driving environment dimension and some covariance between the observed variables were added. These changes improved the goodness-of-fit metrics of the final proposed SEM framework.

The SEM shown in Figure 19 presented a better fit than the other exploratory models and converged with 96 interactions. The value of the relationship between chi-square and degrees of freedom was close to the perfect fit of 1 ($\chi^2/gl = 1.37$). The CFI and RMSE indicators showed a good adjustment with values of 0.96 and 0.046, respectively.

The *Safer vehicles* (-0.33), *Post-crash response* (-0.15) and *Safer road users* (-0.35) dimensions have had a significant direct negative effect on the RTF rate. The road safety policies performance SEM for Nations indicated that the *Road safety management* and *Safer driving environment* dimensions had an indirect effect on the mortality rate. The effects analysis presented in Table 11 allows the comparison of the relationship intensity between the SS dimensions and the RFT rate, considering the combination of direct and indirect effects and its statistical significance. Policies for *Safer road users* dimension were the ones that present the highest influence in RTF rate reduction, followed by the *Safer vehicles, Road safety management, Safer driving environment* and *Post-crash response* dimensions, respectively.

Figure 19 - Road Safety Policies performance SEM for Nations.



Source: The author.

Table 11 - Effects of global SS dimensions on RTF rate

Safe System dimensions (Latent Variables)	Effects			p-value
	Direct	Indirect	Total	
Safer road users	-0.35	-0.63	-0.98	0.004
Safer vehicles	-0.33	-0.49	-0.82	0.009
Road safety management	n.a.	-0.68	-0.68	0.032
Safer driving environment	n.a.	-0.37	-0.37	0.025
Post-crash response	-0.15	n.a.	-0.15	0.032

Source: The author.
Note: n.a. = not applicable (non-significant loading factors).

The SEM road safety policies performance for Nations indicates that for the *Road safety management* dimension, the existence of targets, strategies and a leading road safety agency are the most important RSI. As expected, this SS dimension has a strategic role on global road safety policies, having an indirect influence on reducing the RTF rate through *Safe vehicles*, *Safer road users* and *Safer driving environment* dimensions.

Establishing a safe vehicle legislative policy has contributed significantly to reducing the RTF rate (-0.33). The *Safe vehicles* dimension should be geared towards encouraging the presence of active and passive vehicle occupant protection devices such as seatbelts, anchorages systems, airbags (frontal and lateral), electronic stability control and motorcycle anti-lock braking systems. It is remarkable that many of these devices are not mandatory items in new vehicles in several of the WHO Member States (WHO, 2018).

The stricter legislation promoting safe user behavior was the SS dimension with the higher direct impact on reducing the RTF rate (-0.35). Among the 28 exogenous variables collated, those that significantly and incisively influenced the *Safer road users* dimension are: the seatbelt use enforcement level, the allowed alcohol limits, randomization of breath tests and the existence of laws for speed limit, seatbelt use, helmet and cellphone use while driving.

Policies that promote *Safer driving environment* dimension indirectly influence the RTF rate reduction through *Safer road users*, *Road safety management* and *Safe vehicles* dimensions. Among the most important RSI for this dimension are the promotion of active mobility (walking and cycling), the existence of road design standards for vulnerable road users and the speed limits enforcement level.

Improvement in *Post-crash response* dimension is best achieved when focusing on enhancements post-graduate courses in emergency and trauma care, formal government-ratified certification pathway for prehospital providers, certified specialization/ sub-specialization programs for doctors on emergency medicine and trauma surgery, and a universal access telephone number. Policies aimed at improving the quality of crash response also directly influence the RTF rate reduction (-0.15).

Comparatively, the results indicated that the promotion of *Safe vehicles* and *Safer road users* have a higher impact in reducing mortality when compared to *Post-crash response*. Thus, there is an indication that despite the importance of *Post-crash response* dimension, preventive policies should be even more effective in reducing global RTF.

Finally, the SEM approach proved to be an adequate tool to evaluate different possible relationships between SS dimensions, including correlations between exogenous variables in an effort to investigate RSP. With the results presented in this section, the first specific objective of this thesis was achieved. These results made it possible to produce the first paper of this study. It was presented at the Transportation Research Board (TRB) 98th Annual Meeting and is published in the Transportation Research Record (TRR) Journal (TORRES; XAVIER; CUNTO, 2020).

However, due to the different territorial socio-political context between the regions, it is expected that at city level the SEM outputs may present different values and structure. Therefore, following up the proposed method, to perform this structural modeling for Brazilian cities, it was necessary to perform a massive data collection effort, presented in the following section.

4.2 Road Safety Indicators Database for Brazilian cities

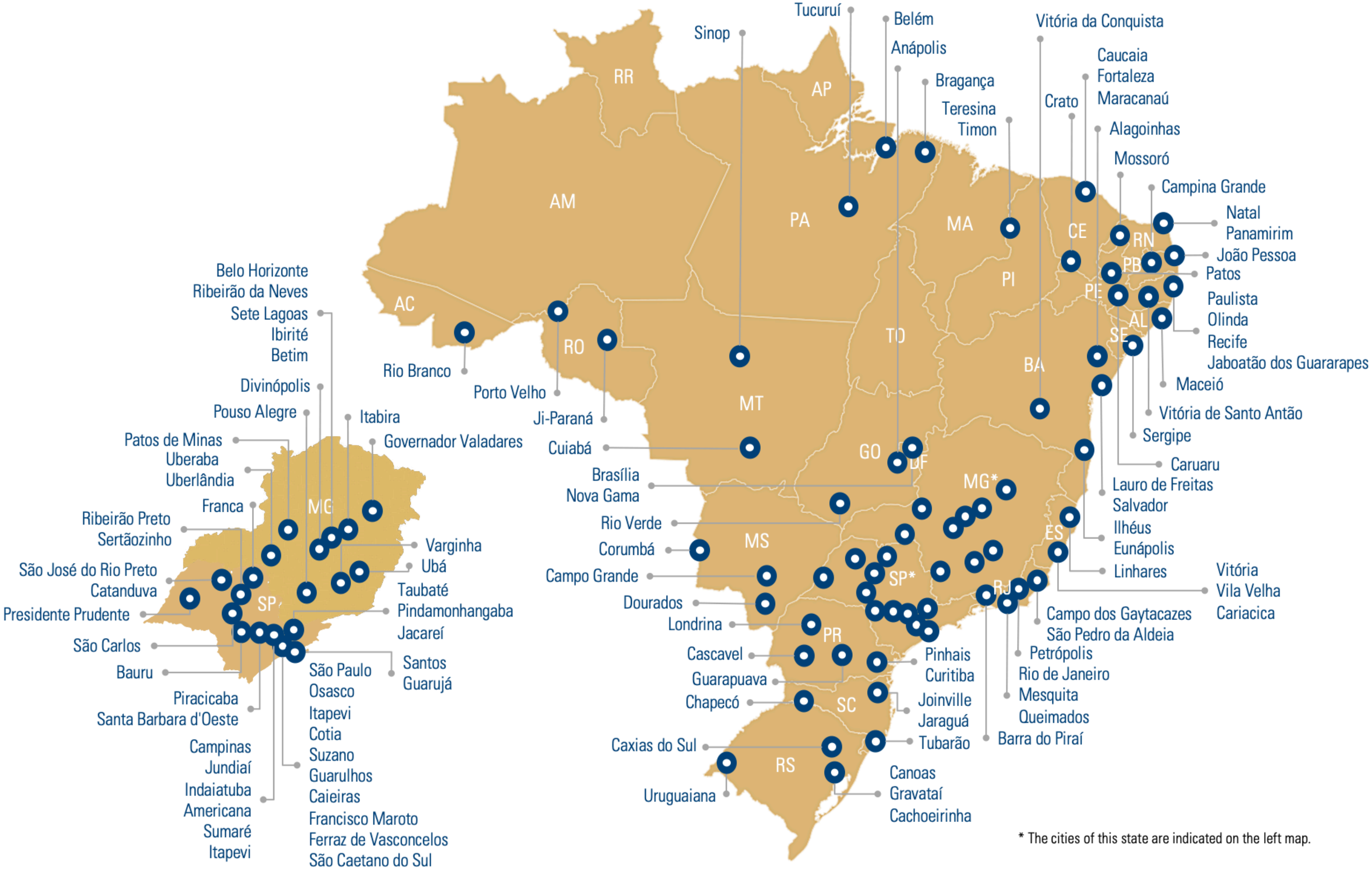
Based on the previous step and the RSI that represent the SS dimensions for nations, this step tracked RSI at the city level that would match, within the possibilities, with those available for Brazilian cities. Therefore, the search for such correspondences defined the data collection process. This effort consisted of a first step of consulting secondary and official databases that measure indicators homogeneously for all Brazilian cities. The national bases that provided data for the consolidation of the database of this research were from the Department of Informatics of the Unified Health System (DATASUS), National Department of Transit (DENATRAN) and the Brazil Ministry of Regional Development.

Due to factors related to the lack of standardization in the Brazil National databases, level of disaggregation and unavailability of data, the official databases were not sufficient to meet the needs of this study. Therefore, a data collection stage with the Brazilian cities was performed. This activity was structured as described in the methodology section, using a collaborative online tool.

First, attempts were made to establish contact, via e-mail, with the managers responsible for the municipal traffic, transport, or mobility departments. The e-mails were searched on the official city halls websites of all Brazilian cities with more than 100k inhabitants, between August 2020 and January 2021. Only 33 cities answered their structured questionnaires, available in Appendix A. The return rate was much lower than expected, which may be related to the COVID-19 pandemic period and difficulty in accessing managers in the home office reality required by global health agencies. It is important to highlight that although the research took place between the period of the COVID-19 pandemic, the questionnaire made it clear that the reference year for the answers was 2019 (pre-pandemic).

The second effort to answer the questionnaires began in February 2021. Formal and electronic requests were made from the Electronic Citizen Information System (e-SIC) portals. Thus, the requests were supported as determined by the Law on Access to Information (BRASIL, 2011). Due to the bureaucratic process of this activity, it lasted until the end of 2021. Finally, 118 of 314 cities answered their structured questionnaires, however, 15% of these were partially answered. In January 2022, telephone contacts were made to these cities to request the missing information. At the end of this activity, eight cities were excluded because the information provided was not sufficient to include it in the database built in this study. Thus, the study city sample consisted of 110 cities. Figure 20 presents the map of Brazil highlighting the cities that were investigated.

Figure 20 - Sample Brazilian cities map



Source: The author.

In the final activity of this step, a variable coding process was carried out for the replies provided in the questionnaires. The dictionary of adopted codes is present in Tables 12 to 17. The answers provided were transformed into ordinal categorical variables. The higher the variable value, the better the city performance for that respective RSI. Values equal to zero indicate that the city does not have strategies related to RSI. Finally, all data were consolidated into RSI Brazilian cities database (Tables 12 to 16).

Table 17 presents the classes based on the average RTF value for the years 2017 to 2019 based on data consolidated by DATASUS for Brazilian cities (BRASIL, 2021). Regarding minimize the variance within the class and maximize the differences between the classes of the variable that defines the RTF rates, stratification techniques of natural breaks into 6 classes were applied.

Table 12 - Brazilian cities RSI for Road Safety Management

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
mobility_plan*	Local Mobility Plan*	(0)No (1)In development (2)Yes	1.35	0.74
dept_rs	Road safety department	(0)No (1)Yes, without funding sources (2)Yes, with funding sources	0.85	0.86
crash_database	Crash database use	(0)No (1)Yes, not unified (2)Yes, unified and applied for diagnosis only (3)Yes, unified and applied for diagnosis and strategies evaluation	1.47	1.14
target	Road safety target	(0)No (1)Yes, fatality crashes only (2)Yes, injury crashes (3)Yes, all crashes severity	1.05	0.94

Source: The author.
* Brazil Ministry of Regional Development (BRASIL, 2021)

Table 13 - Brazilian cities RSI for Safer Vehicles

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
fleet_2wheel	% of 2-wheel vehicles in the fleet*	(0)73-58% (1)57-42% (2)41-26% (3)25-10%	2.30	0.94
fleet_age	Fleet age*	(0)+35% fleet over 15 years old (1)34-25% fleet over 15 years old (2)+50% fleet over 10 years old (3)-50% fleet over 10 years old	2.35	1.47
vehicular_inspe	Vehicular inspection	(0)Don't perform (1)Yes, cargo trucks only (2)Yes, cargo trucks and urban private transport	1.02	0.65

Source: The author.
* National Secretariat of Traffic (SENATRAN, 2021)

Table 14 - Brazilian cities RSI for Safer Driving Environment

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
engineering_dept	Engineering department	(0)No (1)0,3-6 employees/100k hab (2)7-12 employees/100k hab (3)13-18 employees/100k hab	1.09	0.57
stard_cic	Standard road design for cyclists	(0)No (1)Yes, local guidelines (2)Yes, incorporating best practice manuals	0.86	0.66
stard_ped	Standard road design for pedestrians	(0)No (1)Yes, local guidelines (2)Yes, incorporating best practice manuals	0.97	0.68
active_mobility	Active mobility strategies	(0)No (1)Yes, one action (2)Yes, betwen two and four actions (3)Yes, more than four actions	1.33	0.87
transit_str	Transit strategies	(0)No (1)Yes, until two actions (2)Yes, more than two actions	1.31	0.52
auto_enforcem	Electronic enforcement techniques	(0)No (1)Yes, fixe type (2)Yes, static type (3)Both	1.01	01.03
video_enforcem	Video electronic enforcement	(0)No (1)Yes	0.37	0.49
arter_speeds	Arterial roads speed limits	(0)more than 60km/h (1)60 km/h (2)equal to or less than 50km/h	1.10	0.31
inter_tfoper	Traffic light intersections operation	(0)No (1)Yes, with manual programming (2)Yes, with more than 30% in smart programming (3)Yes, with more than 50% in smart programming	1.37	0.50

Source: The author.

Table 15 - Brazilian cities RSI for Post-Crash Response

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
ambulance_type	Ambulance	(0)State (1)Municipal (2)Municipal decentralized.	0.51	0.79
ambulance_rate	Ambulance/ 100k inh*	(0)No (1)0-9 vehicles/100k inh (2)10-19 vehicles/100k inh (3)20+ vehicles/100k inh	1.64	0.63
firstaid_rate	First Aid Units/ 100k inh*	(0)No (1)0-19 unit/100k inh (2)20-79 unit/100k inh (3)80+ unit/100k inh	0.61	1.02
ICU_rate	Intensive care units/ 100k inh*	(0)4-10 unit/100k inh (1)11-20 unit/100k inh (2)21-30 unit/100k inh (3)31+ unit/100k inh	2.15	0.99

Source: The author.
* Department of Informatics of the Unified Health System (DATASUS, 2021)

Table 16 - Brazilian cities RSI for Safer Road Users

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
education_dept	Traffic education department	(0)No (1)Yes	0.87	0.33
traffic_agents	Traffic agents	(0)until 10 agt/100k inh (1)between 10 e 20 agt/100k inh (2)between 20 e 30 agt/100k inh (3)more than 30 agt/100k inh	1.51	1.11
checkpoints	Checkpoint operations	(0)No (1)At least once a month (2)At least once a week (3)More than 3 times a week (4)More than 5 times a week (5)Every day	2.12	1.65
dd_ enforcement	Drink and Drive enforcement	(0)Never (1)Rarely (2)Partially (3) Often (4) Always	1.51	1.11
cel_ enforcement	Cell phone use enforcement	(0)No (1)Yes	0.83	0.37
speedlimit_law	Arterial roads speed limits according to National legislation (SENATRAN)	(0)No, higher than SENATRAN (1)Yes, similar to SENATRAN (2)No, lower than SENATRAN	1.11	0.31
campaigns	Educational campaigns	(0)No (1)State or National campaign (2) Campaign from the municipality itself	1.14	0.70
media_use	Type of media used	(0)No (1)Owned media (2)Paid media	1.42	0.79

Source: The author.

Table 17 - Brazilian cities RTF rates

Variable Abbreviation	Variable Definition	Description and coding of variable values	Average	Standard deviation
RTF_rate	Road Traffic Fatality/ 100k inh* (natural breaks)	(1)<8,2 deaths/100k inh (2) 8,2 a 11,4 deaths/100k inh (3)11,4 a 14,5 deaths/100k inh (4)14,5 a 18,5 deaths/100k inh (5)18,5 a 23,6 deaths/100k inh (6)> 23,6 deaths/100k inh	3.1**	1.34

Source: The author.
* Department of Informatics of the Unified Health System (DATASUS, 2021)
** Average and standard deviation considering the variable codes

The consolidation of this database made it possible to characterize the road safety policy status for Brazilians based on the collected RSPI related to the SS dimensions. Thus, the results of this step represent another specific thesis objective achieved. These results were presented in Associação de Pesquisa e Ensino em Transportes (ANPET) 35th Annual Meeting (TORRES; CUNTO, 2021).

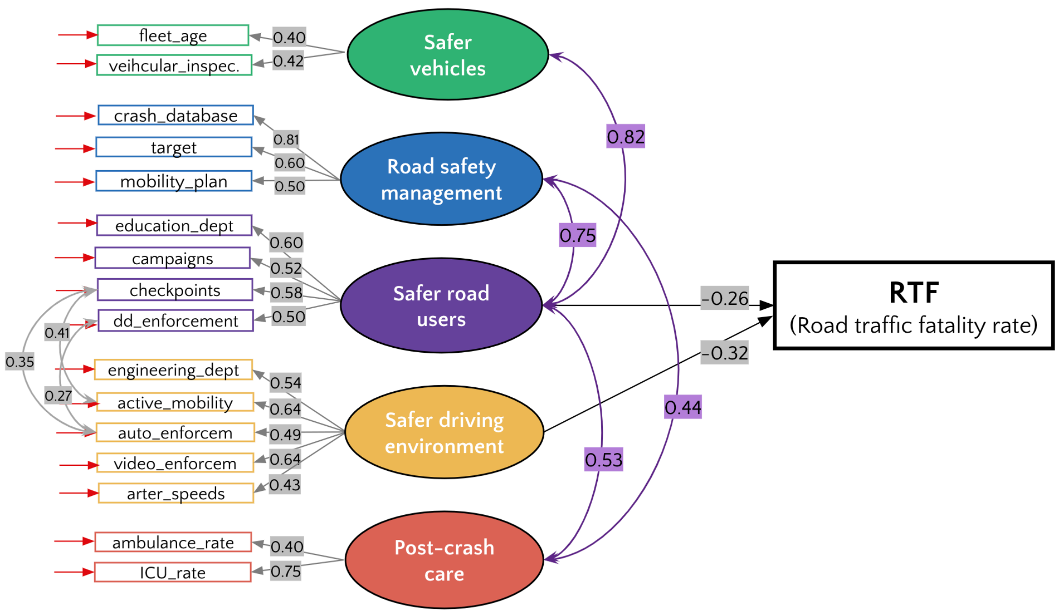
4.3 Safe System dimensions Index for Brazilian cities

The procedure for identifying the Brazilian cities SEM structure followed the same steps as the SEM modeling effort for nations. An initial exploratory model was developed with all 28 RSI, consolidated in the previous step. These exogenous variables were statistically related with their respective latent constructs (SS dimensions). All covariance between the dimensions and their relationship with the RTF rate (endogenous variable) were considered. This exploratory strategy was similar to that performed in activity one with global RSI.

Despite this first SEM configuration has not converged, it was possible to propose other configurations with different dependency configurations among the latent variables and between the latent variables and the endogenous variable. For each new structure, the evaluation parameters defined in the methodology were analyzed, verifying the loading factors magnitude and significance of the direct and mutual influence.

The nonlinear optimization analysis indicated the inclusion of some correlations between RSI that represent strategies in the *Safer road users* and *Safer driving environment* dimension. These changes improved the RSPP adjustment measurements of the SEM for Brazilian cities. The proposed model (Figure 21) converged with 26 interactions and the ratio between chi-square and degrees of freedom was close to the perfect fit of 1 ($\chi^2/gl = 1.25$). The goodness-of-fit metrics, CFI and RMS, presented values of 0.91 and 0.047, respectively. According to Hair (2006), this metrics indicate a good fit between the model and the data.

Figure 21 - Road Safety Policies performance SEM for Brazilian cities.



Source: The author.

The Brazilian cities SEM (Figure 21) script and RStudio outputs are available in Appendix D. From this modeling process, the SS index for each dimension were estimated. The *Safer road users* and *Safer driving environment* are the only dimensions that presented a significant direct effect on the RTF rate. The negative loading factors indicate agreement between the hypothesized relationships, i.e, the more investments to promote safer driving environments or road users, the lower the fatality rates.

The *Road safety management*, *Safer vehicles* and *Post-crash response* dimensions present an indirect effect on the RTF rate. This indirect effect was estimated from the composition of covariances with other constructs and its respective direct effect with RTF rate. Finally, the total effect is a combination between the loading factors that represent the relationship intensities, and the covariances that exist between the dimensions. Table 18 presents these effects, up to the third order, and their statistical significance (p-value). The total effect represents the SS index for each dimension. Considering the relationships up to the 3rd order, the SS index value of the *Safer road users* and *Safer driving environment* dimensions considered only the direct effect (load factor). On the other hand, the other dimensions considered indirect effects only (correlations with dimensions with direct effect).

Table 18 - Effects of Brazilian cities SS dimensions on RTF rate

Safe System dimensions (Latent Variables)	**Effects**			**p-value**
	Direct	**Indirect**	**Total (SS index)**	
Safer Driving Environment	-0.322	n.a.	-0.322	0.003
Safer Road Users	-0.256	n.a.	-0.256	0.009
Road Safety Management	n.a.	-0.253	-0.253	0.022
Post-crash Response	n.a.	-0.221	-0.221	0.045
Safer Vehicles	n.a.	-0.213	-0.213	0.071*

Note: *p-value > 0,05
na = not applicable (non-significant loading factors).
Source: The author.

Considering the Brazilian cities investigated, municipal investments in policies that promote safer driving environments have the higher SS index. Among the RSI that measure this dimension are the strategies to promote active mobility, the existence of technological tools for monitoring roads (e.g. enforcement and monitoring cameras), the existence (and capacity) of engineering department and the speed limit legislation aligned with best practices recommendations (equal to or less than 50km/h in urban areas).

Policies to promote safe user behavior also present direct influence on the RTF reduction. This dimension presents the second highest SS index. Among the eight RSI tested for this dimension, those that influenced significantly are: the existence of a department/sector that coordinates education strategies and the capability to perform enforcement checkpoints (systematically), drink and driving enforcement and road safety campaigns.

Improvement in *Post-crash response* policies is better achieved when focusing on supply of ambulances and intensive care units (ICU). This dimension presents only indirect effects, through their covariance with the *Safer road users* dimension. There is an indication that despite the importance of the *Post-crash response* dimension, prevention initiatives can be even more effective in RTF reduction. This finding matches with the road safety policies performance SEM for Nations (objective one).

The *Road safety management* dimension, as expected, has a strategic role in the road safety policies. This dimension presents only indirect effects on reducing the RTF rate through their covariances with *Safer road users* and *Post-crash response* dimensions. This result also corroborates with the road safety policies performance SEM for Nations. The RSI that measures this dimension is the existence of institutionalized goals for road safety outcomes, the unified database, and the city mobility plan existence.

The *Safer vehicles* dimension does not present significant direct and indirect effects (p-value = 0.07) for the dataset analyzed. The hypothesis for this finding consists of the argument that strategies focused on safer vehicles are usually taken at the national level (e.g. anti-lock braking systems and airbags in new vehicles), therefore, covering somewhat uniformly all cities in each country. For road safety policies performance SEM for Nations, safe vehicles showed direct and significant influence in reducing road traffic fatalities. This finding indicates that the efforts of these dimensions should be coordinated by the National Traffic Agencies. However, this result should also be viewed with caution. In the first place, this action pillar would be significant for a higher level of p-value (e.g. 0.10). In other words, the loading factor variability was relatively high as a function of its expected value. Thus, a larger sample of cities or RSI that could better represent this dimension at the city level, for example, could help to consolidate its influence on RTF.

The effort to define the SS indices represent the first stage of the benchmarking proposed in this research. The results presented in this section achieved another specific objective and allowed the production of the third paper presented at the Transportation Research Board 102nd Annual Meeting (TORRES; CUNTO, 2023).

Brazilian cities' diversity of socio-economic and geopolitical contexts reinforces the importance of cooperation to establish policies for the challenge to promote RSP. Therefore, for a successful benchmark, it is necessary to group the cities of this study before the comparative analysis and proposition of RSP improvements.

4.4 Brazilian cities clustering

The literature review section shows that road safety benchmarking studies usually must be carried out between similar regions at a similar level of development. Therefore, clustering is an important phase in benchmarking as it makes it possible to achieve adequate and meaningful results during comparative analysis.

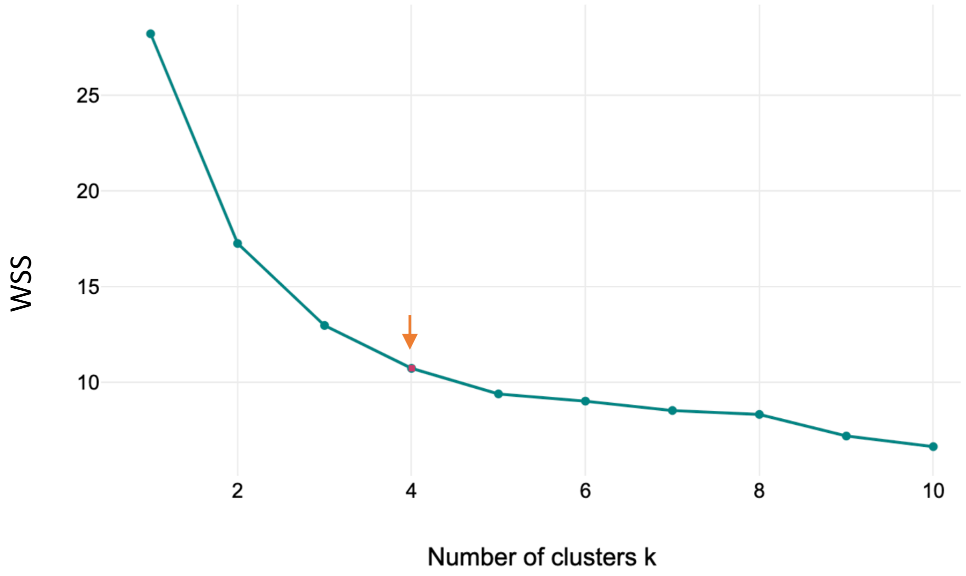
Clustering techniques can generate results in several dimensions, defined by the number of variables inserted in the process. The variables that represent the demographic and socioeconomic cities development were chosen. The hypothesis assumed here is that the population and HDI could represent mobilization potential of cities to develop RSP. Larger and wealthier cities may face fewer challenges in implementing policies related to promoting road safety. On the other hand, less wealthy cities may never be able to perform certain policies due to limited resources. Since the objective of this research is to perform a benchmark, it would not make sense to group cities with different mobilization potential in the same cluster.

The K-means algorithm, from R Studio *k-means clustering package*, presented the best conformation of the groups based on the sum of squares (WSS) errors between groups. This technique measures the sum of the distance between each element and the centroid of its cluster (K). The increase in the K number brings reductions in the SSEC, making the indicator to be applied in the identification of until when these retractions in the errors are significant.

Applied the Elbow Method, it is verified that the bend of the curve is close to K= 4 (Figure 22). This bend indicates that additional clusters beyond the fourth have little value in the WSS consecutive differences. Therefore, the estimation of optimal number of clusters indicated should be 4 clusters.

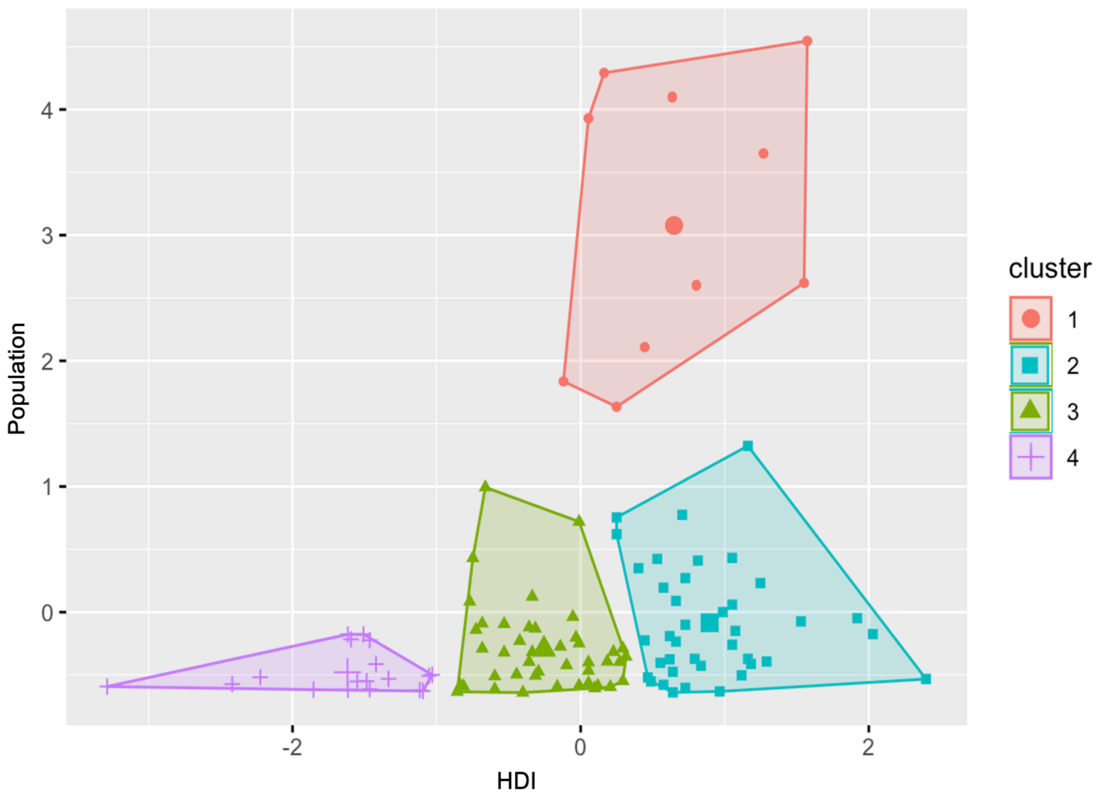
After indicating the optimal number of clusters, the K-means algorithm performed the grouping process. Figure 23 shows the four clusters and their respective centroids and wrappers. The first cluster groups the eleven most populous cities in the sample study. The other cities were grouped based on the HDI indicator (low, medium, and high) and population. The formatting of the grouping proposed by the algorithm proved to be concise, allowing the formation of groups of smaller amplitudes, being the most adequate for the continuation of the benchmarking process.

Figure 22 - Definition of the optimal number of clusters (Elbow Method)



Source: The author.

Figure 23 - Selected grouping settings: parameterized population and HDI



Source: The author.

Cluster one has the 11 most populous cities. The cluster with low HDI has 18 cities, most of them in the northeast region of Brazil. The cluster with a medium HDI is the largest, comprising 43 cities. Finally, the cluster with the highest HDI has 38 cities, most of them in the southeastern region of Brazil. Table 19 presents the list and number of cities (N) and the average and standard deviation of HDI and population for each cluster (K).

Table 19 - Brazilian cities clustering

K	**Cities/State**	**N**	**HDI** Average (Standard Deviation)	**Population** Average (Standard Deviation)
1	Belém/PA; Belo Horizonte/MG; Brasília/DF; Campinas/SP; Curitiba/PR; Fortaleza/CE; Guarulhos/SP; Recife/PE; Rio de Janeiro/RJ; Salvador/BA; São Paulo/SP	11	0.79 (0.03)	3,426,799 (3,299,802)
2	Americana/SP; Aracaju/SE; Bauru/SP; Caieiras/SP; Campo Grande/MS; Cascavel/PR; Catanduva/SP; Caxias do Sul/RS; Chapeco/SC; Cotia/SP; Cuiabá/MT; Franca/SP; Indaiatuba/SP; Jacareí/SP; Jaraguá do Sul/SC; Joao Pessoa/PB; Joinville/SC; Jundiai/SP; Londrina/PR; Natal/RN; Osasco/SP; Pindamonhangaba/SP; Piracicaba/SP; Pouso Alegre/MG; Presidente Prudente/SP; Ribeirão Preto/SP; Santa Barbara d'Oeste/SP; Santos/SP; São Caetano do Sul/SP; São Carlos/SP; São Jose do Rio Preto/SP; Taubaté/SP; Tubarão/SC; Uberaba/MG; Uberlândia/MG; Varginha/MG; Vila Velha/ES; Vitória/ES	38	0.79 (0.02)	391,950 (226,860)
3	Anápolis/GO; Barra do Pirai/RJ; Betim/MG; Cachoeirinha/RS; Campina Grande/PB; Campos dos Goytacazes/RJ; Canoas/RS; Cariacica/ES; Crato/CE; Divinópolis/MG; Dourados/MS; Ferraz de Vasconcelos/SP; Governador Valadares/MG; Gravataí/RS; Guarapuava/PR; Guarujá/SP; Itabira/MG; Itapevi/SP; Jaboatão dos Guararapes/PE; Ji-Paraná/RO; Lauro de Freitas/BA; Linhares/ES; Maceió/AL; Mesquita/RJ; Mossoró/RN; Olinda/PE; Parnamirim/RN; Patos de Minas/MG; Paulista/PE; Petrópolis/RJ; Pinhais/PR; Porto Velho/RO; Rio Branco/AC; Rio Verde/GO; São Pedro da Aldeia/RJ; Sertãozinho/SP; Sete Lagoas/MG; Sinop/MT; Sumaré/SP; Suzano/SP; Teresina/PI; Ubá/MG; Uruguaiana/RS	43	0.73 (0.02)	294,324 (196,269)
4	Alagoinhas/BA; Bragança/PA; Caruaru/PE; Caucaia/CE; Corumbá/MS. Eunápolis/BA; Francisco Morato/SP; Ibirité/MG; Ilhéus/BA; Maracanaú/CE; Novo Gama/GO; Patos/PB; Queimados/RJ; Ribeirão das Neves/MG; Timon/MA; Tucuruí/PA; Vitória da Conquista/BA; Vitória de Santo Antão/PE	18	0.68 (0.02)	191,187 (92,143)

Source: The author.

From a practical point of view, it is to be expected that cities can learn more easily from similar countries. This suggests that forming groups of more or less similar and comparable cities does make sense for the next step of this benchmarking exercise, the comparative analyses, presented in the next section.

4.5 Comparative analysis of Brazilian cities based on the Safe System Approach

All 110 cities shown in Table 20 were included in this benchmarking study. Individual SS dimension performance as well as the overall Road Safety Policy Performance (RSPP) were estimated for each city according to Equations 6 and 7 respectively.

For the composition of the overall RSPP, the *Safe vehicles* dimension was not considered because it did not present the index with statistical significance (p-value>0.05). Thus, the maximum value for overall RSPP is 1.05 (the sum of the other SS dimensions indices). Based on the overall RSPP values, a five-star rating analysis criterion was performed for the cities. The classification considered equal RSPP intervals as shown in Figure 24.

Figure 24 - RSPP five-star rating interval values

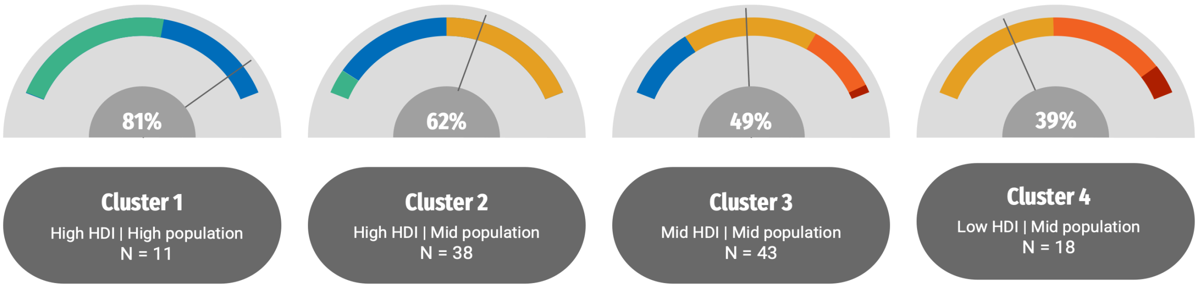
Source: The author.

First, a comparative analysis between different clusters was performed using the cluster's RSPP average (percentage values in relation to the maximum RSSP value). Figure 25 presents this group comparative analysis and the cities star rating representation in each cluster. The overall RSPP maximum value (1.05) represents 100% of performance.

This comparative analysis shows that HDI and number of inhabitants of cities may be related to the performance of its policies and strategies for promoting RSP. All municipalities in Cluster 1 were classified with 4 or 5-stars rating, reaching a cluster average RSPP of 81%. On the other hand, cities in Cluster 4 were classified with 3-stars rating or less. The cluster average RSPP is 39%. Cluster 2 and 3 presented an RSPP average of 62% and 49% respectively.

The results highlight the importance and coherence of the proposed grouping. Since the HDI and size of cities reflect their economic capacity and mobilization potential, it would not be fair to compare RSP without considering this dimension. This could produce suggestions for improvements outside cities' political reality. For example, cities in cluster 4 could find budget difficulties in implementing policies and strategies similar to cities in cluster 1.

Figure 25 - Clusters comparative analysis of RSPP



Source: The author.

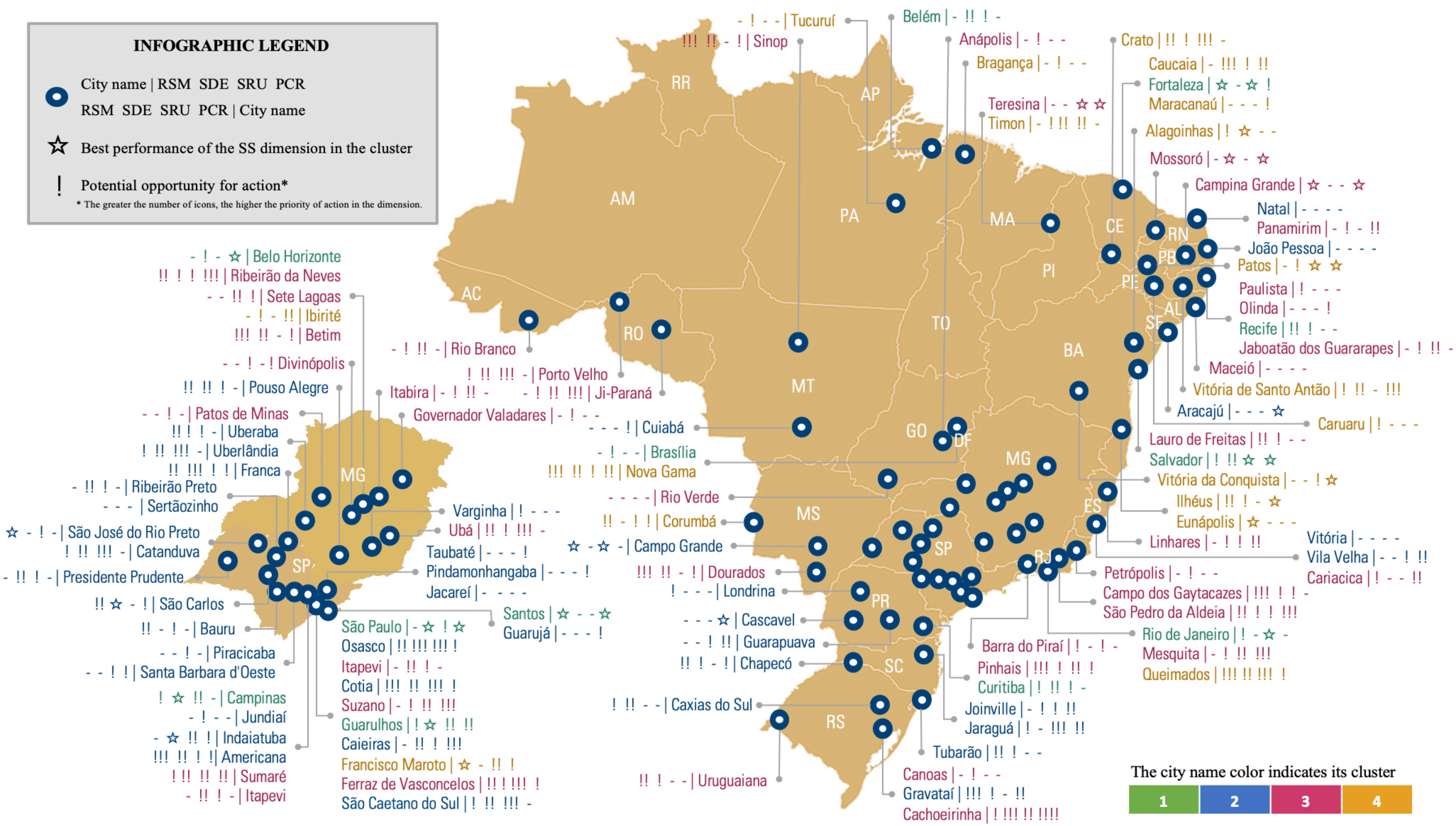
Finally, as a final step to achieve the general objective of this thesis, a second comparative analysis between the cities of the same cluster was performed. This effort produced findings that provide analytical support for cities to improve SS dimensions policies based on the best practices of cities in their cluster.

The estimated RSPP for each of the SS dimensions was used as the main quantitative measure to compare the performance of cities in the same cluster. Analogously to what was done in the first comparative analysis of this step, the SS dimensions performance were classified based on the five-star rating analysis criterion. The maximum performance of each SS dimension is the value of its index (Table 19) and its RSPP was measured from the policies related to that dimension (Equation 6).

The cities' profile was defined by comparing the performance of its dimensions with the respective clusters average value (Equation 8). From these findings, the best-in-class cities (higher RSPP) and the opportunities for improvement (RSSP below the cluster average) were identified. Figure *26* presents an infographic that summarizes the results of applying the benchmarking methodology develop to evaluate traffic safety policies in Brazilian cities.

The color of the city name indicates its cluster. Next to the city names, the result is expressed in icons for the dimensions: *Road safety management, Safer driving environment*, *Safer road users* and *Post-crash response*, respectively. The icons on the infographic indicate whether the cities present the best performance in its cluster (☆) or whether they present potential opportunities for action (!). When there is none of this information (-), it means that the city's performance is higher than the average of its cluster, however, it is not the best-in-class city.

Figure 26 - Infographic with the results of the benchmarking of Brazilian cities



Source: The author.

The results presented in this section reached the general objective of this research, which was to propose a benchmarking analysis of road safety policies of Brazilian cities, considering the SS approach. Appendix B graphically presents the profiles of the general and SS dimensions RSPP for each city.

The following subsections bring a more in-depth investigation into the RSSP of the cities with the highest and worst performances in each cluster. Some of the main best practices are presented, as well as the main limitations and opportunities for improvement in those cities with lower RSSP. This effort represents the last specific objective of the thesis, the performance of a comparative analysis of Brazilian cities based on the RSP index.

4.5.1 Cluster 1 comparative analysis

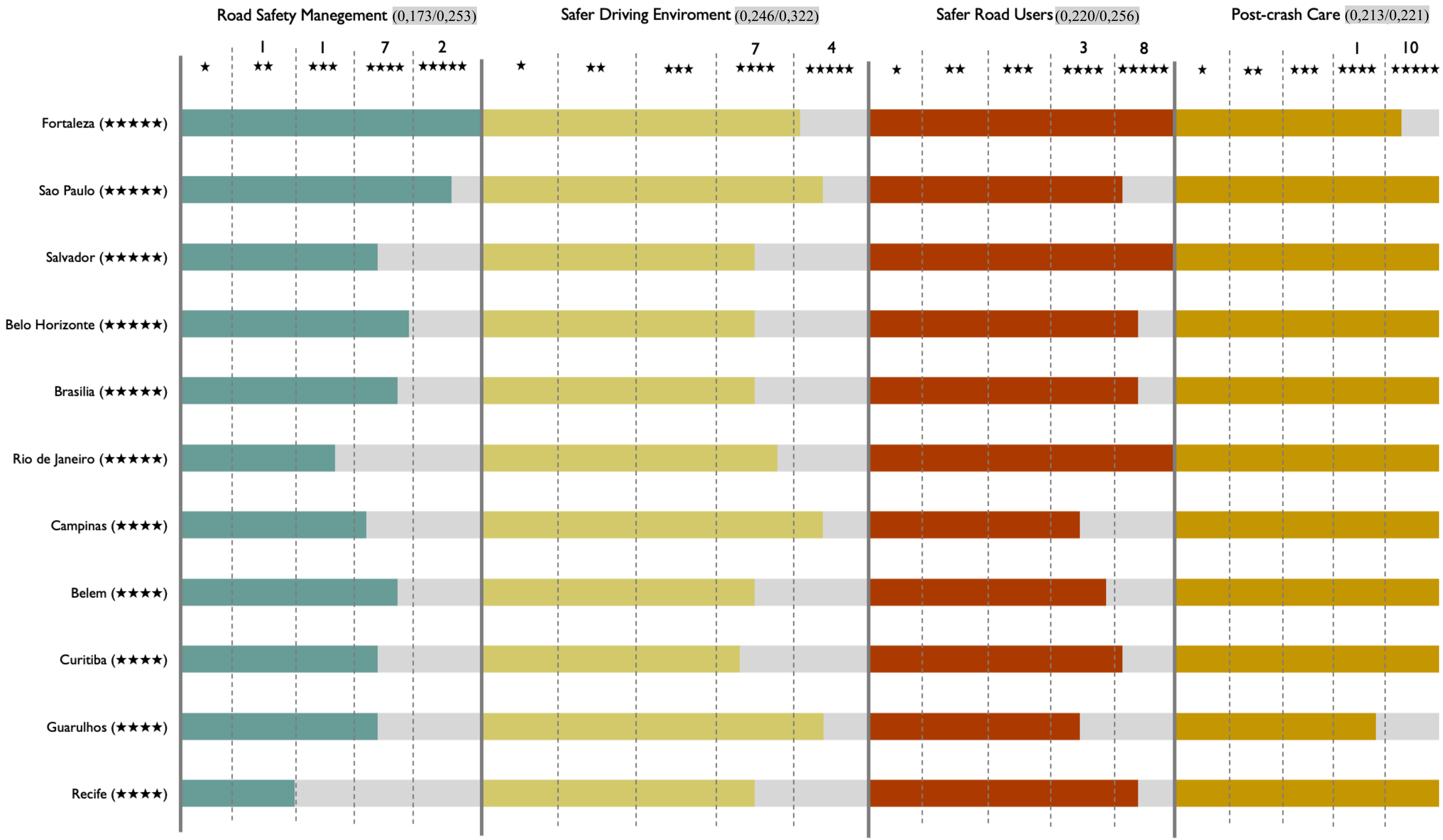
Cluster 1 has 11 cities only and is the most populous in the sample with an average HDI of 0.79. Most of these cities are capitals and the others are from São Paulo state (cities of Campinas and Guarulhos). This cluster presented an average RSPP of 0.85 (81%).

Figure 27 presents a graph with the performance quantitative values of the SS dimensions, and their classification based on the five-star rating analysis criterion, for all cities in cluster 1. The stars in parentheses next to the name of the cities indicates its overall star rating value. The information in parentheses next to the name of the SS dimensions indicates its average and maximum values, respectively. The values below these names indicate the number of cities within star rating values. Cities are ranked by their overall RSPP performance. That is, in cluster 1, the city of Fortaleza had the best overall performance of its RSPP. The city of Recife is the one with the lowest RSPP performance.

The dimension with the high difference between city performances is *Road safety management*. The cities of Recife and Rio de Janeiro present a 2-star and 3-star rating, respectively. On the other hand, Fortaleza and São Paulo are the only two cities that performed in this dimension with a 5-star rating. The policies and strategies related to this dimension are the existence of a mobility plan and a road safety sector/department, the maintenance of a road crash database and the routine of establishing road safety targets.

The low performance observed for the city of Recife is related to the fact that it is the only city without a municipal mobility plan. In the reference year of the collected data (2019), the plan was in the elaboration phase. In addition, the city's road crash database does not integrate other actors involved in a crash response service. Therefore, the data available to characterize road safety situations are only those collected by the road traffic agents.

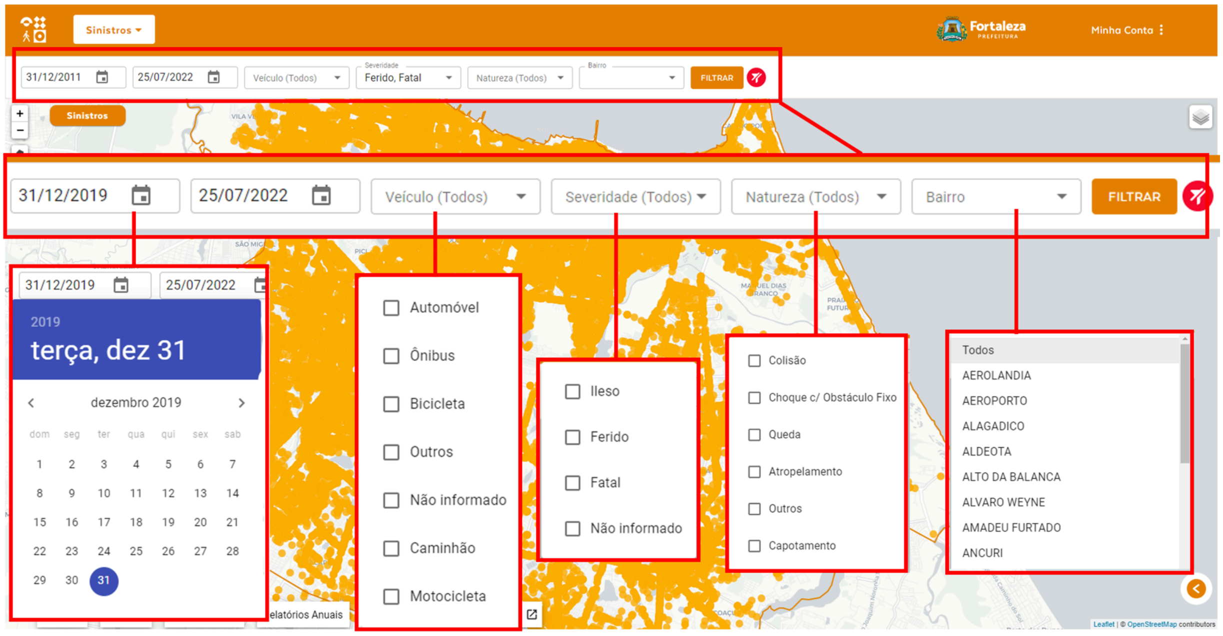
Figure 27 - Clusters 1 cities comparative analysis



Source: The author.

Underreporting of RTI makes it difficult to monitor road safety and set targets. This same limitation was identified in the cities of Rio de Janeiro and Campinas. These cities can learn from the best practices of the city that performed best for this dimension. Fortaleza is the best-in-class for *Road safety management* dimension. The city had a mobility plan since 2015 and, in 2019, it was in the review process, incorporating new strategies for sustainable and safe trips. In addition, the city uses an innovative web-based system (Figure 28) for capturing, integrating, consolidating, processing and visualizing road cash data (TORRES; SOUSA; AQUINO, 2022).

Figure 28 - Fortaleza Road Cash database web-based platform



Source: TORRES; SOUSA; AQUINO (2022).

The effort to manage RTI indicators allows the city to be able to diagnose and monitor road safety and to establish robust targets for road traffic fatalities and injuries. Fortaleza was the first Brazilian capital to institutionalize a Municipal Road Safety Plan with the goal of halving RTF by 2031 (TORRES et al., 2022). This plan is based on the SS approach and is in line with the guidelines of the PNATRANS and the Global Plan for the Second Decade of Action, as shown in Figure 29.

Figure 29 - Fortaleza Road Safety Plan Framework

Source: TORRES et al. (2022).

For the other dimensions of this cluster, all cities achieved a performance of 4-star or 5-star rating. In the *Safer Driving Environment* dimension, which has the greatest influence on the overall RSPP, the cities in the state of São Paulo (Campinas, Guarulhos, and São Paulo) are the ones that presented the best performances. These cities performed well for having an expressive team of employees/100k inhabitants in their traffic engineering departments/sector. Guarulhos had the highest rate (8.8 employees/100k inhabitants). In addition, these have electronic enforcement using fixed cameras installed in strategic sites. In Guarulhos, static cameras are also used to increase their enforcement capacity. In the arterial corridors of these cities, speeds limits equal or below than 50km/h prevail, following WHO recommendations.

In the cities of Campinas and São Paulo, there are strategies that aim to guarantee the safety of all vulnerable users (pedestrians, cyclists, and motorcycles), as shown by examples of best practices in Figure 30. Figure 30a presents the Frente Segura Project in São Paulo (LUCHESI; MEYER, 2021) and Figure 30b presents Complete Streets Project in Campinas (SANTOS; SAMIOS; BATISTA, 2021). In addition, the city of Sao Paulo has its own Road Design Manual (SÃO PAULO, 2022), a national reference guide filled with instructions to order the road environment and ensure safe mobility far all road users. Figure 31 brings an example of a manual recommendation for the bicycle infrastructure project in São Paulo city.

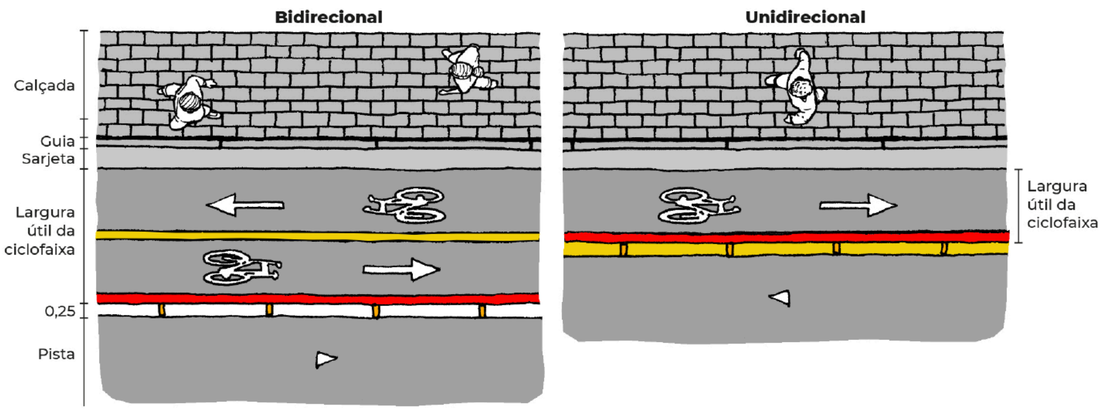
The combination of such *Safer Driving Environment* policies adopted by these best-in-class cities may be a suggestion of policies that cities such as Curitiba, Belém, Brasília, Salvador, Belo Horizonte and Recife should adopt to improve their performance in this dimension. The common finding for these cities is the prevalence of arterial roads with a speed equal to or greater than 60km/h and the electronic enforcement conducted only by fixed cameras. Curitiba, lowest city performance for this dimension, also had the lowest rate of employees in its traffic engineering sector. This finding limits the city's capacity to implement more interventions that could guarantee a *Safer Driving Environment.*

Figure 30 - Safer Driving Environment policies in São Paulo (a) and Campinas (b)

(a) Frente Segura Program (b) Complete Streets Program

Source: (a) LUCHESI; MEYER (2021); (b) (SANTOS; SAMIOS; BATISTA, 2021).

Figure 31 - São Paulo Road Design Manual: recommendations for bike lane infrastructure



Tráfego horário (bicicletas por hora/sentido)	Largura útil unidirecional (m)			Largura útil bidirecional (m)		
	Desejável	Mínima	Excepcional	Desejável	Mínima	Excepcional
Menos de 1.000*	1,5	1,0	0,8	2,5	1,8	1,6
De 1.000 a 2.500	2,0	1,5		3,0	2,5	
De 2.500 a 5.000	3,0	2,0		4,0	3,0	
Mais de 5.000	4,0	3,0		6,0	4,0	

Source: SÃO PAULO (2022).

Most of the cities in this cluster achieved a performance of 5-star rating for the *Safer road users* dimension. Fortaleza, Salvador and Rio de Janeiro presented the maximum performances for all RSI related to this dimension. These three capitals conduct checkpoints every day in different shifts and sites in all city's regions. In 2016, Fortaleza published its Operational Procedure Checkpoints Manual. According to Matos (2018), the new operational framework is based on the principles of predictive enforcement, using the intelligence of crash database from the perspective of road safety management The framework has directed the enforcement effort in order to increase the dissuasive effect, contributing to consecutives reduction in the RFT in Fortaleza city.

These best-in-class cities perform checkpoints focused on drinking and driving in at least 2/3 of enforcement operations. One of the most emblematic is Operation *Lei Seca* in Rio de Janeiro, which has been conducted in the same format since 2009, coordinated by the government of the state of Rio de Janeiro. Their checkpoints, called "*Abordagem Cidadã*", are structured around two pillars: enforcement and education. Not only punitive, but mainly educational, the traffic agents involved in the checkpoints are not only responsible for the legal procedures, but also transmit knowledge of the legislation. Operations are usually quite robust with the use of vans, panels, awnings, and big balloons that bring a dissuasive character to these commands, as shown in Figure 32.

Figure 32 - Lei Seca Checkpoint in Rio de Janeiro

Source: JOMAR; ABREU; LAUS (2013).

Jomar, Abreu and Laus (2013) conducted a random study with a non-probabilistic sample of 362 drivers who answered a questionnaire with sociodemographic information and opinion on the Operation *Lei Seca* in Rio de Janeiro. In addition, the drivers were submitted to the breathalyzer test. The vast majority (90%) of the drivers in the sample were satisfied with the checkpoints and they believe that the Operation *Lei Seca* contributes to road safety. 3.1% of those submitted to the breathalyzer test had a positive result.

As well as enforcement efforts, educational campaigns have an important role in changing road users' behavior. The three best-in-class cities for this dimension have a team that produces the city campaigns based on local reality and road safety evidence. In Fortaleza, these campaigns get to be aligned with the checkpoint focus in order to enhance road safety message for change behaviors. An exploratory analysis conducted by Torres et al. (2019) showed an increase in the road safety devices use (seatbelt and helmet) after the city adopted this approach, indicating positive impacts of educational campaigns in line with enforcement actions.

Another RSI of relevance for this dimension is the existence of a Traffic Education department. In this cluster, all municipalities have it. One that is a national reference is that of Salvador (BA). The city reports its major educational actions in schools and on the roads on its blog. In addition, Salvador's road education department has demonstrated that competitions are worth mentioning to encourage discussion of the agenda in different educational areas.

The two cities with the lowest performance in the *Safer road users* dimension were Campinas and Guarulhos, the only ones in the cluster that are not capital cities. This performance was due to the fact that these cities have a low frequency of checkpoints (once a week) and drinking and driving enforcement rarely happens. This finding indicates that the perception of low enforcement in the cities may be related to a more unsafe users' behavior.

In the *Post-crash response* dimension, all cities achieved a performance 5-star rating, except Guarulhos. This city had the lowest ICU rate per inhabitant. Most of the serious road crash victims in the city are treated in the ICU of the neighboring city (São Paulo). According to WHO (2022), the travel time for injuries treatment is a crucial factor for the survival of these road crash victims.

In Table 20, the main cities opportunities for RSPP improvements are indicated considering the average performance value of the SS dimensions (average score). The table present the five cities that performed below the cluster average score. In addition, Appendix B, which provides the cities' profile, all opportunities for action were indicated (based on the same criteria). The profiles findings recommend which SS dimensions cities should prioritize and indicates the best-in-class cities of each dimension, based on the best practices presented.

Table 20 - Cluster 1 cities priority SS dimensions for action.

SS Dimension (average score)		**Road Safety Management** (0.173)	**Safer Driving Environment** (0.246)	**Safer Road Users** (0.220)	**Post-crash Response** (0.213)
Rank of priority dimensions for action (cities with a score below the cluster average)	1º	Recife/PE (0.09)	Curitiba/PR (0.21)	Guarulhos/SP (0.18)	Guarulhos/SP (0.17)
	2º	Rio de Janeiro/RJ (0.13)	Recife/PE (0.23)	Campinas/SP (0.18)	Fortaleza/CE (0.19)
	3º	Campinas/SP (0.16)	Belém/PA (0.23)	Belém/PA (0.2)	*
	4º	Guarulhos/SP (0.16)	Brasília/DF (0.23)	Curitiba/PR (0.21)	
	5º	Curitiba/PR (0.16)	Belo Horizonte/MG (0.23)	São Paulo/SP (0.21)	

* Only two cities performed below the SS dimension mean score in cluster 1.

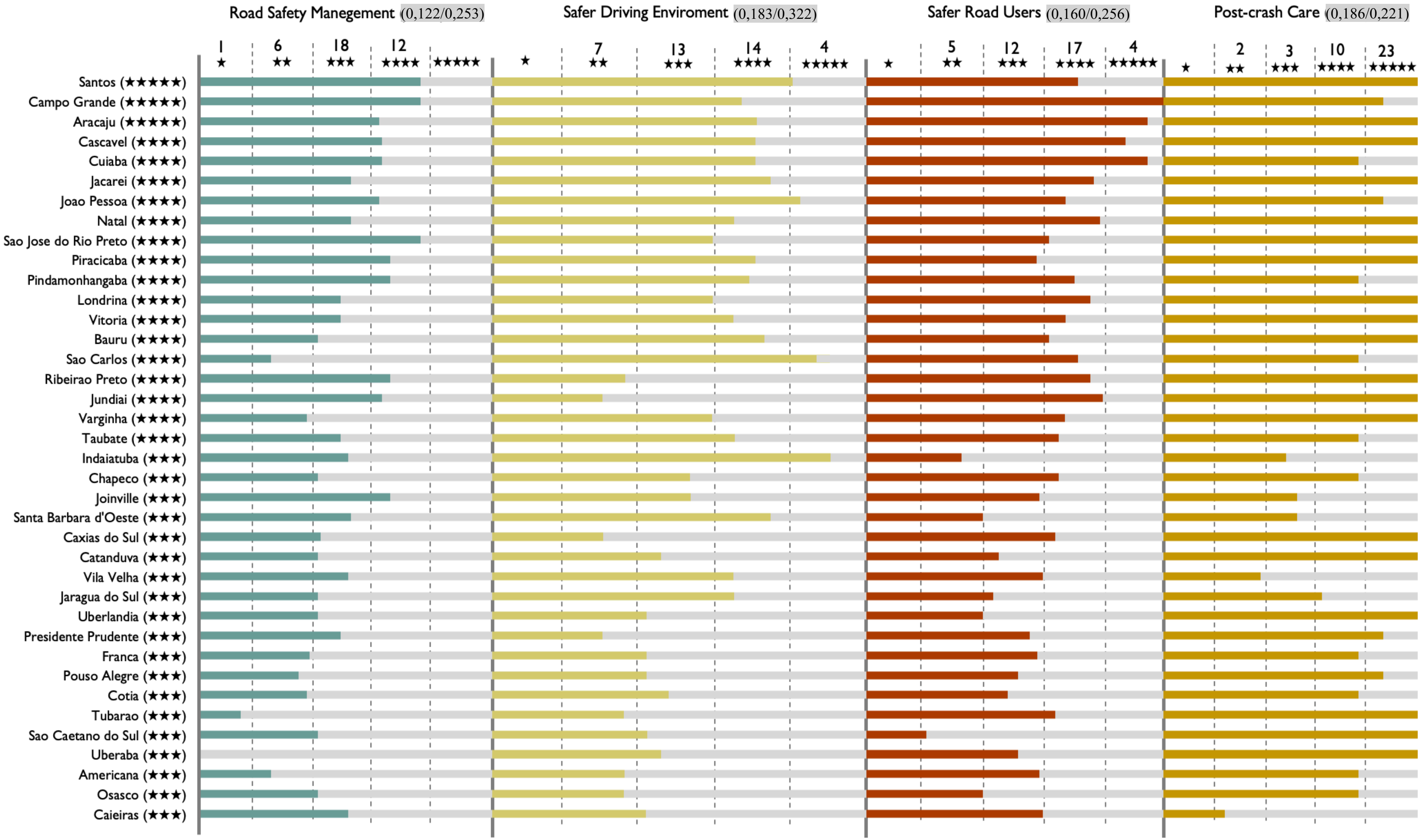
Source: The author.

4.5.2 Cluster 2 comparative analysis

Cluster 2 has 38 cities. The average HDI and population are 0.79 and 392 thousand inhabitants, respectively. This cluster presented an average RSPP of 0.65 (62%). Figure 33 presents a graph with the performance quantitative values of the cities SS dimensions, and their classification based on the five-star rating analysis criterion. The information in parentheses next to the name of the SS dimensions indicates its average and maximum values, respectively. The values below these names indicate the number of cities within star rating values.

The cities are ranked by their overall RSPP performance. The city of Santos/SP had the highest overall performance, while the city of Caieiras/SP presented the lowest. Different from observed in cluster 1, in the other clusters there is a wide variation in the city's performance for the SS dimensions. For the *Road safety management* dimension, the highest performance was achieved by 12 cities (4-stars rating). On the other hand, the city with the lowest performance did not reach any star (zero performance in all RSI of this dimension). This is the case of the Uberaba in the state of Minas Gerais. This finding indicates a strong recommendation for the city to develop road safety management policies. The cities of Tubarão and São Carlos also had the lowest performance in the cluster.

Figure 33 - Clusters 2 cities comparative analysis



Source: The author.

Of the 12 best performing cities for this dimension, Campo Grande/MS, Santos/SP and São José do Rio Preto/SP are highlights. These best-in-class cities have a mobility plan and a crash database that integrates records from different sources. Another prominent strategy among the cities was the strategy for setting targets for road safety outcomes.

The city of Campo Grande (MS) was the first to join the *Vida no Trânsito* Project (PVT), under the national coordination of the Ministry of Health and the Pan American Health Organization. The PVT goal is to guarantee the qualification of RTI data for the development of action plans and its intersectoral implementation. A best practice developed by the city was the constitution of local intersectoral commissions formed by representatives of the sectors of health, policies, traffic, transport infrastructure, education, and communication.

For the *Safer driving environment* dimension, four cities performed with a 5-star rating. Indaiatuba is the best-in-class. The city provides a safety road environment through the presence of electronic enforcement techniques and video electronic enforcement. Indaiatuba reported the highest rates of employees per inhabitants in its traffic department. In addition, this city promotes some best practices to encourage the active mobility. One of them is the Ecobike Project, which provides free ecological bikes. This bike sharing system already has more than 15,000 registered users and more than 90,000 trips have been registered.

The three cities with the lowest performances for the *Safer driving environment* dimension were Presidente Prudente, Jundiaí and Caxias do Sul. None of them indicated the use of video electronic enforcement. In Presidente Prudente and Jundiaí there are also no electronic enforcement techniques on the city's roads, which can produce more unsafety to the road environment. In addition, these cities reported a low rate of employees in their traffic departments (1.3 and 3.8 employees/100k inhabitants, respectively).

The city of Campo Grande is also highlighted in the *Safer User* dimension. Every day, the city performs checkpoints in partnership with the Military in order to prevent road traffic infractions and other criminal practices. On the other hand, in the city of São Caetano do Sul, the lowest performance was observed for this dimension. The city performs checkpoints with low frequency compared to the other cities in the cluster and does not have a road traffic education department structured. These findings may limit São Caetano do Sul city's potential to change the driver’s behavior. Strategies to improve these RSI, based on best-in-class cities, could bring improvements to the RSP of the city.

Half of the cities in this cluster registered maximum performance in the *Post-crash response* dimension. Caieiras and Vila Velha are the two cities with the lowest performances. Both are cities in the metropolitan regions of São Paulo and Vitória, respectively. Similar to what was observed in cluster 1, with Guarulhos, the cities have few ICU and ambulances due to their proximity to capitals. However, this should increase the travel time for injuries treatment, influencing the victims' survival chances.

In Table 21, the main cities opportunities for RSPP improvements are indicated considering the average performance value of the SS dimensions (average score). The table present the five cities that performed below the cluster average score. In addition, Appendix B, which provides the cities' profile, all opportunities for action were indicated (based on the same criteria). The profiles findings recommend which SS dimensions cities should prioritize and indicates the best-in-class cities of each dimension, based on the best practices presented.

Table 21 - Cluster 2 cities priority SS dimensions for action.

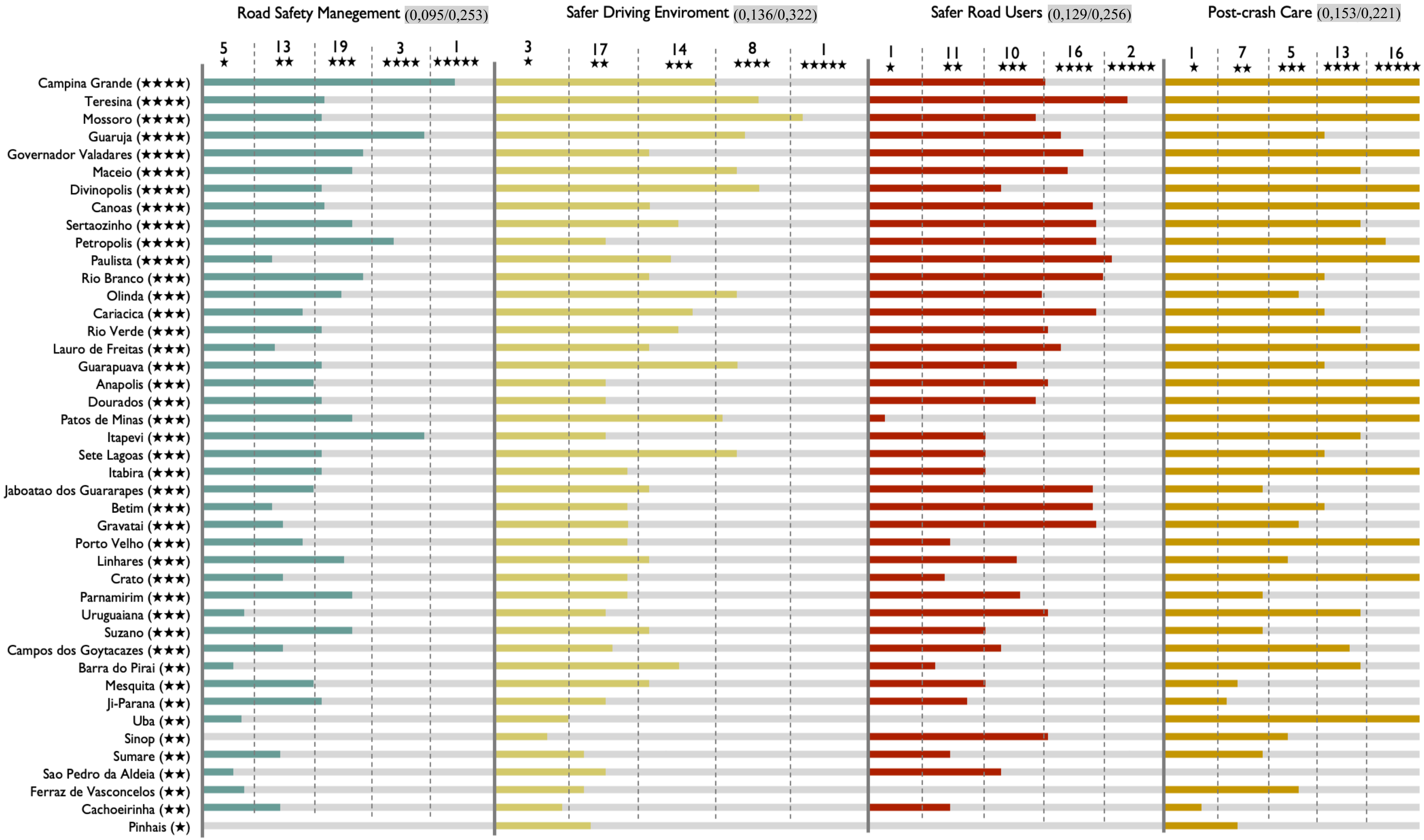
SS Dimension (average score)		**Road Safety Management** (0.122)	**Safer Driving Environment** (0.183)	**Safer Road Users** (0.160)	**Post-crash Response** (0.186)
Rank of priority dimensions for action (cities with a score below the cluster average)	1º	Uberaba/MG (0)	Presidente Prudente/SP (0.09)	São Caetano Sul/SP (0.05)	Caieiras/SP (0.05)
	2º	Tubarão/SC (0.03)	Caxias do Sul/RS (0.09)	Indaiatuba/SP (0.08)	Vila Velha/ES (0.08)
	3º	Americana/SP (0.06)	Jundiaí/SP (0.09)	Osasco/SP (0.1)	Indaiatuba/SP (0.11)
	4º	São Carlos/SP (0.06)	Osasco/SP (0.11)	Uberlândia/MG (0.1)	Santa Barbara/SP (0.12)
	5º	Pouso Alegre/MG (0.87)	Americana/SP (0.11)	Santa Barbara /SP (0.1)	Joinville/SC (0.12)

Source: The author.

4.5.3 Cluster 3 comparative analysis

The Cluster 3 is the largest with 43 cities. The average HDI and population are 0.73 and 294 thousand inhabitants, respectively. This cluster presented an average RSPP of 0.51 (49%). Figure 34 presents a graph with the performance quantitative values of the cities SS dimensions, and their classification based on the five-star rating analysis criterion. The information in parentheses next to the name of the SS dimensions indicates its average and maximum values, respectively. The values below these names indicate the number of cities within star rating values.

Figure 34 - Clusters 3 cities comparative analysis



Source: The author.

The cities are ranked by their overall RSPP performance. No cities in this cluster achieved the 5-star rating. The city of Campina Grande/PB had the highest overall performance, while the city of Pinhais/PR presented the lowest (1-star rating only).

Campina Grande was the only city that achieved a 5-star performance rating for the *Road safety management* dimension. Best practices in crash data management practices are the highlight. The city provides a system that consolidates information in partnership with Ambulance services, Military Policy, Fire Department, Federal Road Policy, and Trauma Hospitals (CAMPINA GRANDE, 2022). This information is made available in a BI (Business Intelligence platform) public and easy to handle with the main indicators of road crashes, as shown in Figure 35. The system is used by managers and technicians and provides a technical-scientific basis to perform strategies more effectively in all SS dimensions.

Figure 35 - BI for road crash database in Campina Grande

Source: Campina Grande (2022).

In this same SS dimension, two cities did not reach any star (zero performance in all RSI). The cities of Sinop and Pinhais do not have a mobility plan and do not have a road crash database. This finding indicates a strong recommendation for the cities to develop *Road safety management* policies and start to establish targets for their RSI.

For the *Safer driving environment* dimension, Mossoró is the best-in-class city. The city is the only one to achieve a 5-star rating in this dimension. The good practices that build the city's road environment safer are the presence of electronic enforcement techniques (fixed and static) and video cameras that support traffic enforcement activities. In addition, Mossoró indicated some policies to promote active mobility (e.g. strategies for roads closed for car and open for leisure activities such as walking and cycling).

The cities of Sinop, Ubá and Cachoeirinha register the lowest performance for *Safer driving environment* dimension. None of these cities apply cameras or radar for electronic enforcement, except for Sinop which has some fixed electronic enforcement at some points on federal roads that cross the urban areas. In addition, Ubá and Sinop do not have a road traffic engineering department or sector in the structure of their traffic authority. This finding should be a barrier in the development of policies that encourage active mobility in these cities.

In Teresina, capital of Piaui, the best performance in the *Safer user* dimension is registered. The city has a traffic education department, responsible for producing awareness campaigns, based on the local context. The outdoor campaigns, shown in Figure 36, highlight the vulnerable road users and the risk factors related to RTI in Teresina. The campaigns were publicized in July (motorcycle riders' month), August (Father's month) and September (Brazil independence month) alluding to drinking and driving behavior (pointed out as a priority risk factor in Teresina).

Figure 36 - Road safety campaigns in Teresina

Source: STRANS (2017).

Another policy that Teresina invests in with a potential impact on behavior change is the performance of checkpoints more than five times a week. Most of these focus on monitoring drinking and driving. On the other hand, Pinhais, Ferraz de Vasconcelos and Ubá do not perform checkpoints and road safety campaigns. These cities had the lowest performance for the *Safer road users* dimension and did not reach any star (zero performance in all RSI).

In the *Post-crash response* dimension, most cities achieved a 5-star and 4-star rating. In the reference year for data collection (2019), the cities of São Pedro da Aldeia and Cachoeirinha did not have ICU beds. In these cities, the rescue of the crash victims is performed by firefighters. Therefore, these were the cities with the lowest performances in this dimension.

In Table 22, the main cities opportunities for RSPP improvements are indicated considering the average performance value of the SS dimensions (average score). The table present the five cities that performed below the cluster average score. In addition, Appendix B, which provides the cities' profile, all opportunities for action were indicated (based on the same criteria). The profiles findings recommend which SS dimensions cities should prioritize and indicates the best-in-class cities of each dimension, based on the best practices presented.

Table 22 - Cluster 3 cities priority SS dimensions for action.

SS Dimension (average score)		**Road Safety Management** (0.095)	**Safer Driving Environment** (0.136)	**Safer Road Users** (0.129)	**Post-crash Response** (0.153)
Rank of priority dimensions for action (cities with a score below the cluster average)	1º	Pinhais/PR (0)	Sinop/MT (0.04)	Pinhais/PR (0)	São Pedro da Aldeia/RJ (0)
	2º	Sinop/MT (0)	Cachoeirinha/RS (0.06)	Ferraz de Vasconcelos/SP (0)	Cachoeirinha/RS (0.03)
	3º	São Pedro da Aldeia/RJ (0.03)	Ubá/MG (0.06)	Ubá/MG (0)	Ji-Paraná/RO (0.05)
	4º	Barra do Pirai/RJ (0.03)	Ferraz de Vasconcelos/SP (0.08)	Patos de Minas/MG (0.01)	Pinhais/PR (0.06)
	5º	Ubá/MG (0.03)	Sumaré/SP (0.08)	Barra do Pirai/RJ (0.06)	Mesquita/RJ (0.06)

Source: The author.

4.5.4 Cluster 4 comparative analysis

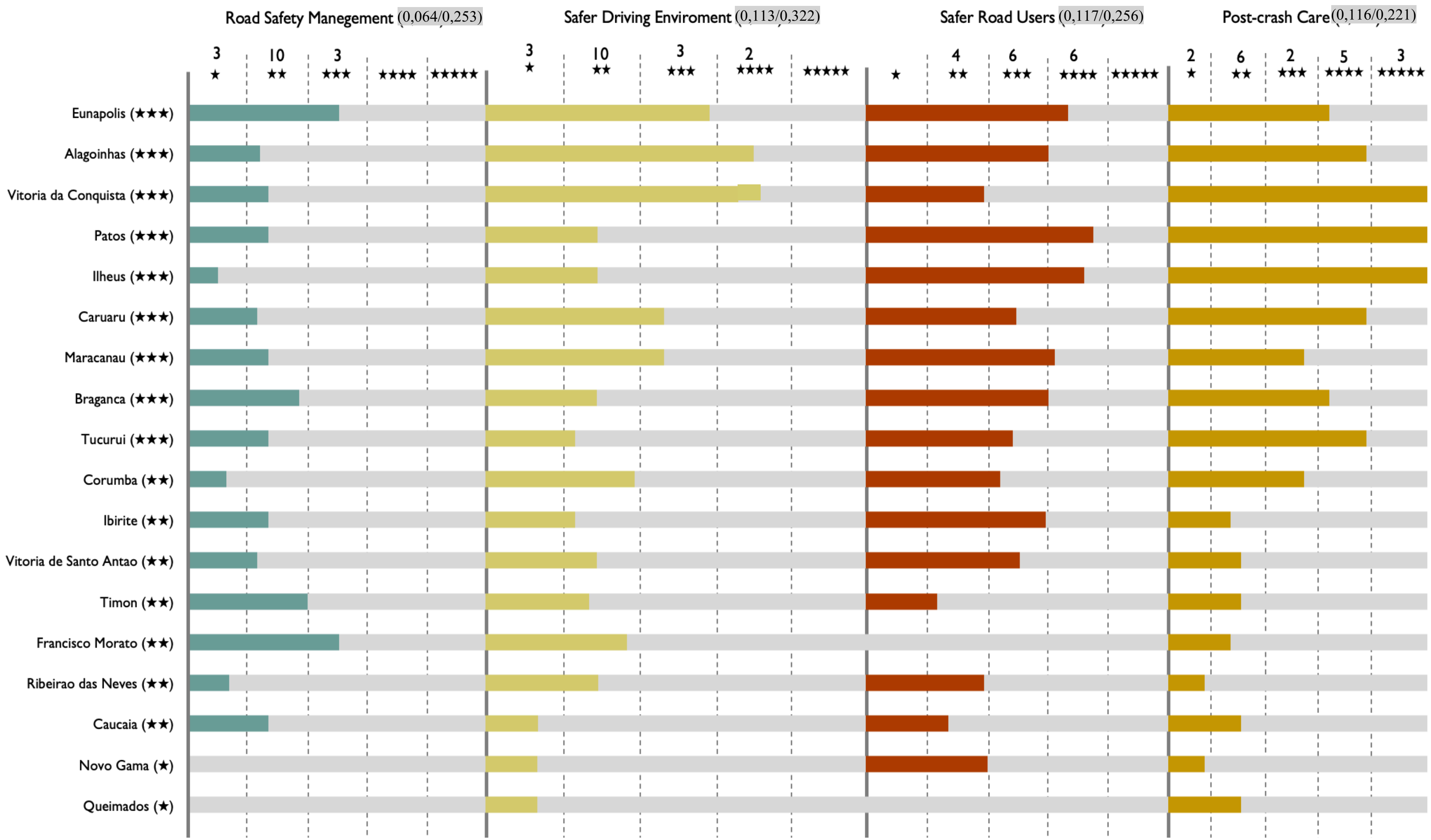
Cluster 4 has 18 cities. The average HDI and population are 0.68 and 191 thousand inhabitants, respectively. This cluster presented an average RSPP of 0.41 (39%), the lowest among the others. The highest overall RSPP of cities in this cluster is 3-star rating. Figure 37 presents the quantitative values of the cities SS dimensions performance, and its classification based on the five-star rating analysis criterion. The information in parentheses next to the name of the SS dimensions indicates its average and maximum values, respectively. The values below these names indicate the number of cities within star rating values.

The cities are ranked by their overall RSPP performance. The city of Eunápolis/BA had the highest overall RSPP, while the city of Queimados/RJ presented the lowest. The best performance (3-star rating) cities in the *Road safety management* dimension are the only ones that have a mobility plan. They are Eunápolis, Francisco Morato and Timon. These cities report having a road crash database, however they do not perform integration with other actors involved in a crash response service. The cities of Queimados and Nova Gama do not perform policies related to the RSI of this SS dimension, so they are the cities with the lowest performances. It is strongly recommended that these cities allocate efforts to develop policies for improving road safety management.

The city of Vitória da Conquista registers the best RSPP for the *Safer driving environment* dimension. The prevailing speed limits on arterial city roads are equal to or less than 50km/h (recommended for urban areas by WHO). In addition, fixed electronic enforcement are used to increase the safety of the road environment. The three cities with the lowest performances in this dimension are Caucaia, Nova Gama and Queimados. They do not have a traffic engineering department or sector and do not use any electronic enforcement tools on their arterial roads, which predominantly have speed limits of 60km/h.

In the *Safer user* dimension, the best-in-class performance city is Patos. The city performs checkpoints more than three times a week and, partially, it focuses on drinking and driving enforcement. Aligned with enforcement strategies, Patos produces its own road safety campaigns. A low-cost and best practice is communication in social medias (Facebook and Instagram), as shown in Figure 38. This strategy allows the city's transit authority to reach a younger population, which are the more susceptible to dangerous behavior on roads. Queimados and Francisco Morato did not register any star (zero performance in all RSI) in this SS dimension. This finding indicates a strong recommendation for the cities to develop policies to promote safer user behaviors on roads.

Figure 37 - Clusters 4 cities comparative analysis



Source: The author.

Figure 38 - Road safety campaigns in Instagram of Patos/PB

Source: The author.

The three cities that achieved the best and maximum RSPP in *Post-crash response* dimension are host to important regional hospitals in their states. The general hospital in Vitória da Conquista (BA), the Regional Hospital in Patos (PB) and the Regional Hospital in Costa do Cacau, in Ilhéus (BA). The high supply of ICU beds and the agility of access to injury treatment could considerably reduce the RTI severity.

On the other hand, Ribeirão das Neves and Nova Gama reported a low rate of ICU beds and ambulances per 100,000 inhabitants. The low performance in these RSI resulted in these cities being classified only with a 1-star rating for RTI response. This finding indicates a strong recommendation for the cities to develop policies on the *Post-crash response* dimension.

In considering the average performance value of the SS dimensions (average score). The table present the five cities that performed below the cluster average score. In addition, Appendix B, which provides the cities' profile, all opportunities for action were indicated (based on the same criteria). The profiles findings recommend which SS dimensions cities should prioritize and indicates the best-in-class cities of each dimension, based on the best practices presented.

Table 23, the main cities opportunities for RSPP improvements are indicated considering the average performance value of the SS dimensions (average score). The table present the five cities that performed below the cluster average score. In addition, Appendix B, which provides the cities' profile, all opportunities for action were indicated (based on the same criteria). The profiles findings recommend which SS dimensions cities should prioritize and indicates the best-in-class cities of each dimension, based on the best practices presented.

Table 23 - Cluster 4 cities priority SS dimensions for action.

SS Dimension (average score)		**Road Safety Management** (0.064)	**Safer Driving Environment** (0.113)	**Safer Road Users** (0.117)	**Post-crash Response** (0.116)
Rank of priority dimensions for action (cities with a score below the cluster average)	1º	Queimados/RJ (0)	Queimados/RJ (0.04)	Queimados/RJ (0)	Nova Gama/GO (0.03)
	2º	Nova Gama/GO (0)	Nova Gama/GO (0.04)	Francisco Morato/SP (0)	Ribeirão da Neves/MG (0.03)
	3º	Ilhéus/BA (0.03)	Caucaia/CE (0.04)	Timon/MA (0.06)	Francisco Morato/SP (0.05)
	4º	Corumbá/MS (0.03)	Ibirité/MG (0.08)	Caucaia/CE (0.07)	Ibirité/MG (0.05)
	5º	Ribeirão da Neves/MG (0.04)	Tucuruí/PA (0.08)	Ribeirão da Neves/MG (0.1)	Queimados/RJ (0.06)

Source: The author.

5 FINAL REMARKS

For a better organization of these final remarks, the chapter was structured in conclusions and limitations, future work, and opportunities. The first part emphasizes the research topic relevance and the methodological and practical contributions that can be learned from this study. The second part indicates the main limitations, opportunities for applying the results in other cities and regions as well as possibilities for future research in the road safety policy field.

5.1 Conclusions

The way in which society and technicians interpret the RTI problem has evolved over time. The road safety has traditionally focused on promoting respect for road rules through education, training, regulation, and enforcement. While these initiatives are valid, they leave out a whole range of systemic issues that affect the ability of people to move safely on the roads. The most advanced countries in tackling the problem have already realized that this traditional approach is not enough to mitigate RTI. In this context, it has been observed a paradigm shift towards considering the road user and its vulnerable nature as the center of a complex roadway system, known as the safe system approach.

The SS paradigm recognizes road safety as a result of a complex interrelation of several components that form the mobility system. The basic premise of this approach is that human error is inevitable and that the human body is vulnerable to RTI. This concept was incorporated as a fundamental element of the Global Plan for the Decades of Action for Road Safety, an instrument for nations to implement road safety policies at national and local levels. This polices should prioritize the five main SS dimensions: Road Safety Management, Safer Vehicles, Safer Road Users, Post-crash Response and Safer Driving Environment.

Road safety priorities differ from one city to another according to their socio-economic development and local context. Therefore, cities should take different approaches to solving their own RTI issues. Understanding weaknesses in one or more SS dimensions provides a useful basis for local policy makers to address the road safety problem. The policy adopted by a city (best-in-class) could potentially be an alternative to improve the RSP in another city with similar economic development and local context. This approach, already adopted by developed nations and regions, is known as road safety benchmarking.

In the effort to apply this technique with a focus on RSP, incorporating the SS approach, it is important to highlight that there is latent information that can have a significant effect on the complex and multisectoral RTI phenomenon. In this context, quantifying these effects is an important step in estimating indices to perform the road safety benchmarking process.

The findings related to the first thesis specific objective revealed that SEM is an appropriate quantitative modeling technique to incorporate the SS approach, in policy analysis perspective. This technique application used national RSI to represent the SS dimensions, considered as SEM constructs. The proposed SEM for Nations allowed estimations of the influence of the RSP, represented by the SS dimension, on countries' RFT rates. In addition, this modeling technique enabled to incorporate the correlation that should exist between these dimensions. The results showed that the dimensions *Safer Road Users, Safer Vehicles* and *Post-crash Response* had direct effect on the RTF reduction. The other SS dimensions present indirect effects from their correlations with the other dimensions.

Since this structure proved to be promising for modeling the interactions between SS dimensions, RTF rate and the RSI that represent road safety policies at the national level, an effort was made to estimate these effects at the city level to perform a road safety benchmarking process in Brazil. This country, one of the largest LMIC, has been facing a huge challenge in the process of implementing its National Plan for the Reduction of Deaths and Injuries in Traffic (PNATRANS). The continental extension, differences in local and financial contexts, lack of data and resource limitations are the main challenges.

In this sense, the Brazil benchmarking could provide a strategic contribution that can support local governments to allocate resources in more efficient RSP to reduce RTF. To proceed with the study, city's data would be essential. In specific objective two, an extensive data collection was performed to collect RSI capable of representing the Brazilian cities' SS dimensions. The RSI database consolidated was based on secondary data and the application of structured questionnaires with essential information for the SEM development at Brazilian cities level. From results of this step, it was possible to characterize the 110 cities that completed the questionnaires forms.

The same quantitative modeling technique for objective one was performed in the cities 'database consolidated. As expected, differences in the modeling structure and SS dimensions effects on RTF rate were identified when comparing the proposed SEM for nations and cities. At the municipal level, the Safer Vehicle dimension was not statistically significant. The hypothesis for this finding consists of the argument that strategies focused on safer vehicles are usually taken at the national level, therefore, covering somewhat uniformly all cities in a given country. Policies in this dimension should be coordinated by the National Road Safety Agencies or Departments.

The results related to the third thesis specific objective revealed that Brazilian cities' investments in strategies that promote *Safer driving environment* and *Safer road users* dimension present the highest influence on the RTF reduction. *Road safety management* and *Post-crash response* policies also present influence, however, indirectly through their correlations with the other dimensions. The proposed Brazilian cities SEM outputs (loading factors, latent correlations, and path analysis) were used to estimate the SS dimension indices for Brazilian cities. This effort and the clustering of 110 cities, based on their socioeconomic indicators, represented the initial stages of the benchmarking developed in this research.

The SS dimension indices were used as inputs to estimate the Brazilian cities road safety policy performance (in general and for SS dimensions). These results are related to the fourth specific objective of the thesis, the comparative cities analysis. This last stage of the benchmarking revealed that there is a positive correlation between the overall RSSP and the cities' socioeconomic indicators. More populous cities and with higher HDI presented higher performances in their RSPP. Thus, confirming the importance to perform this comparative analysis between cities in the same cluster. From a practical point of view, it is to be expected that cities can learn more easily from similar cities, offering an offer a more feasible basis for the transference of good experiences from best to underperforming city.

The strategy adopted to generate insights from the benchmarking developed enable to identify the best-in-class Brazilian cities for each SS dimension and cluster. The policies adopted by these cities should be used as benchmark for those cities that presented lower RSP performances. The thesis results also enable to identify the ranking priority SS dimensions for action for those cities with the RSP lower than the mean value of their cluster. These findings are useful for cities to learn from others and accelerate the positive Brazilian RSP development.

The benchmarking, general objective, performed in this thesis creates transparency and exposes problems, but at the same time points to potential solutions by highlighting which RSP is most appropriate in Brazilian cities 'context. This tool provides governments with valuable information on best practices that can assist in decision making (policy formulation, program development and definition of goals and strategies) to improve the RSP performance in their cities. This research can be considered a promising step towards improving road safety and creating the preconditions for rethinking the RSP, at city level, based on SS approach.

Finally, it is possible that other Brazilian cities, in addition to those in this study, use the findings to identify their opportunities for RSP improvement. However, it is necessary that it has data available in the pattern determined by this study. This opportunity can be very valuable for government officials to allocate available resources to meet the main limitations of Brazilian cities and promote appropriate RSP for each local context. In Appendix C of this research, a tutorial is available for new cities to estimate the RSP (in general and for SS dimensions) and compare it with the average value of their cluster. This procedure will enable the city to identify the possible priority SS dimensions for action and the best-practices adopted by cities similar cities. This approach will provide valuable insight and offer data-driven evidence for the transference of good experiences from best to underperforming city.

5.2 Limitations, future work, and opportunities

This research is one of the first benchmarking applications of road safety policies for cities that incorporates the safe system approach. It is recommended to apply this methodological framework to different sets of data, especially considering a larger number of cities from other countries to confirm the assumptions, regional particularities and underlying results obtained from the effort of this research.

However, due to the complexity of the multidimensional road traffic injuries phenomenon, the road safety indicators need to be properly defined. The decision and importance of choosing indicators to represent the RTI problem becomes even more complex with the diversity of existing indicators and the difficulty of access to many of them, especially in LMIC, as in Brazil. I. e., the traffic exposure is an important measure to estimate the road casualty rates. However, this information is unavailable in several Brazilian cities. For this reason, it was not used as a variable in this research.

A more data-driven than subjectively (or political) based policy decisions are vital to address the issue of road safety in Brazilian cities. The lack of standardized data to measure the RSI was the determining factor for the number of cities that compose this study. The creation and consolidation of a solid data-driven road safety policies system is essential for enabling future investigations, elaborating adequate strategic planning, and establishing priority RSP.

Despite the breadth and relevance of the study findings, especially with regard to the RSP definition and evaluation, it is considered important to evaluate the stability of the proposed model in other temporal aggregation intervals (another years). In addition, the multivariate modeling allows cities' RSP effects to be assessed using multiple simultaneous outcomes, such as non-fatal injuries and property damage only, as well as RTI categorized by user or vehicle type. The understanding of the possible effect of SS dimensions on such variables can significantly broaden the RSP definition or adjustment.

Another methodological challenge is the fact that the best performing cities, considered as a benchmark, presented few or no suggestions for action. However, it is also true that these cities labeled as best-performing do not exhibit the best-in-class in all SS dimensions. For these cities, these dimensions should be considered as priority for action. On the other hand, the suggestion of less ambitious benchmarks would probably be helpful for making the opportunities for RSP improvements even more realistic. In other words, if a city is not able to reach the best performing level, it could learn from the performance of other cities on clusters that present a better performance – and not necessarily the best one.

Finally, it is important to highlight that the study was performed using the year 2019 as a reference. Since then, some cities may have already adopted policies, thus modifying their RSI (e.g., In 2021, Recife concluded its mobility plan). Future works is recommended in estimating the social and economic effect of adopting specifics RSP on the cities' RTF, since this aspect was not considered in this research. Also, is important to investigate the possibility of temporal transfer of the benchmarking indices to evaluate the cities' RSP over the years.

5.3 Thesis publications

i. TORRES, C. A.; XAVIER, V. J. M.; CUNTO, F. J. C. Relação entre os pilares da segurança viária e a taxa de mortalidade dos países membros da Organização Mundial da Saúde: um estudo utilizando modelos de equações estruturais. In: 33rd CONGRESSO DE PESQUISA E ENSINO EM TRANSPORTES (ANPET), 2019, Balneário Camboriú, SC. **Proceedings** [...]. Balneário Camboriú, SC: ANPET, 2019. (Best Paper Award – ANPET 2019).

ii. TORRES, C. A.; XAVIER, V. J. M.; CUNTO, F. J. C. Analyzing the relationship between road safety pillars and the World Health Organization member states' mortality rate using a structural equation modeling approach. Transportation **Research Record: Journal of the Transportation Research Board**, v. 2674, n. 4, p. 1–10, 2020.

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APPENDIX A - DATA COLLECTION INSTRUMENT

BRAZILIAN CITIES' QUESTIONNAIRE

UNIVERSIDADE FEDERAL DO CEARÁ

GTTEMA

petran
Programa de pós-graduação em Engenharia de Transportes

Research: Road Safety Policies Benchmarking in Brazilian cities

Dear, thank you for your visit.
Completing this questionnaire will help us to obtain indicators to evaluate road safety policies in Brazil.
Thanks for your collaboration.

ID: [IPEA Code]

City: [City name]

Population (IBGE): [Inhab. in 2019]

Email [email of the transit/transport agency]

Fleet (DENATRAN): [Vehicles in 2019]

Research Motivation

This research is performed by the Transport Engineering Program at the Federal University of Ceará (UFC). Its objective is to evaluate road safety policy indicators in Brazilian cities. The methodology used is based on a systematic approach based on five dimensions of actions to promote road safety. These dimensions were defined by the World Health Organization (WHO) as the main targets of policies and strategies to reduce road traffic deaths and injuries. The data will be explored only for academic purposes for the development of a UFC doctoral research.
Responsible researchers: Caio Assunção Torres, Msc & Prof. Flávio José Craveiro Cunto, PhD.

Filling Instructions

The framework of the five dimensions was used to structure the following questionnaire. There will be three blocks of questions that can be answered by more than one person holding the requested information. The questionnaire can be answered in stages, if you do not have the information for a particular question, it can be completed or edited later. Filled data will be saved automatically (as long as you are online).
Any questions send an email to: caio@det.ufc.br or flaviocunto@det.ufc.br

Part I: Road Safety Management

ROAD SAFETY MANAGEMENT	SAFER DRIVING ENVIRONMENT	SAFER VEIHCLES	SAFER ROAD USER	POST-CRASH RESPONSE

1. Does the city have a mobility plan?

- ☐ No
- ☐ In elaboration
- ☐ Yes

2. If yes, what year was it completed?

A:

3. Is there any department or sector that EXCLUSIVELY coordinates road safety actions?

- ☐ No
- ☐ Yes, but there is no own funding source(s)
- ☐ Yes, and it has its own funding source

4. Is there a unified road crash database? Is it used?
(Consolidates information from police and health agencies)

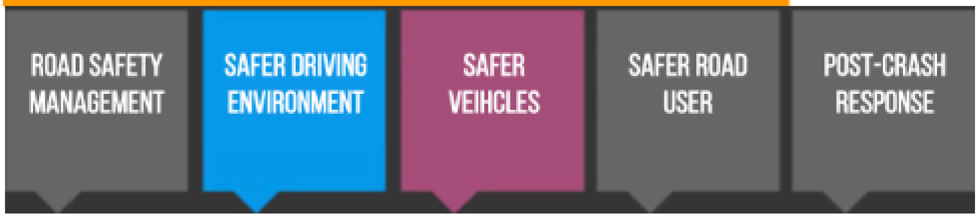
- ☐ Does not have database
- ☐ It has a database, but not unified
- ☐ Yes, unified and applied for diagnosis only
- ☐ Yes, unified and applied for diagnosis and strategies evaluation

5. Does the city have a target to reduce road traffic deaths and injuries?

*Selecionar uma ou mais respostas

- ☐ No
- ☐ Yes, fatality crashes only
- ☐ Yes, fatality and injury crashes
- ☐ Yes, all crashes severity

Part II: Safer Driving Environment and Safer Veihcles



6. Are there vehicle inspection protocols for vehicles in the city?

*Select one or more answers

- ☐ Don't realize
- ☐ Yes, cargo trucks only
- ☐ Yes, cargo trucks and urban private transport
- ☐ Outhers...

...if you select other, specify here:

7. If yes, how often (in months)?

A:

8. Does the city have a department or sector of engineering/traffic signaling?

- ☐ No
- ☐ Yes

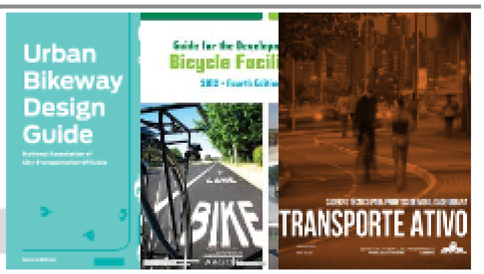
9. If yes, how many employees?

A:

10. Are there safe design standards for vulnerable users (cyclists) or do you follow a good practice manual?

- ☐ No
- ☐ Yes, local guidelines
- ☐ Yes, incorporating best practice manuals
- ☐ Outhers...

...if you select other, specify here:



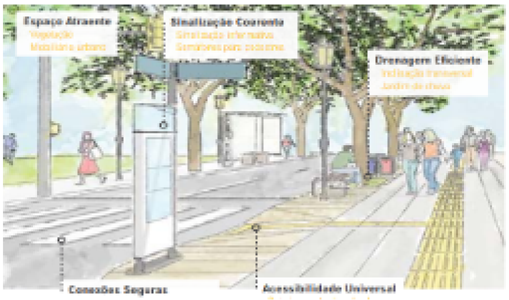
11. Are there safe design standards for vulnerable users (pedestrians) or do you follow a good practice manual?

- [ ] No
- [ ] Yes, local guidelines
- [ ] Yes, incorporating best practice manuals
- [ ] Outhers...

...if you select other, specify here:

12. Does the city have incentive policies for active mobility?

*Select one or more answers.



- [ ] No
- [ ] Cycling infrastructure
- [ ] Complete and active streets
- [ ] Sidewalks with greater or equal free movement range
- [ ] Public bicycle system
- [ ] Sidewalk widening (physical or painting)
- [ ] Others

...if you select other, specify here:

13. Does the city have incentive policies for transit use?

*Select one or more answers.

- [ ] There is no transit
- [ ] There are no incentive policies
- [ ] Dedicated lanes for buses
- [ ] Social tariff
- [ ] Presence of public terminals
- [ ] Integration of lines outside the terminals
- [ ] Integration of modes (train, bus, metro, bike)
- [ ] Others

...if you select other, specify here:

14. Does the city have enforcement equipment on roads?

- [ ] No
- [ ] Yes, fixe type
- [ ] Yes, static type
- [ ] Yes, both

15. If known, inform the number of fines recorded by this equipment

Reference year 2019

A:

16. Has the city peformes image enforcement (video enforcement) in the last year?

- [ ] Doesn't have the system
- [ ] No
- [ ] Yes

17. If known, inform the number of fines recorded by this equipment

Reference year 2019

A:

18. What is the regulated speed of the city's arterial roads (predominantly)?

☐ 60 km/h or more
☐ 50 km/h
☐ Below 50km/h

19. Does the city have intersections controlled by traffic lights (traffic park)?

☐ No
☐ Yes, with manual programming
☐ Yes, with more than 30% in smart programming
☐ Yes, with more than 50% in smart programming

Part III: Safe Road Users and Post-crash Response

20. What is the number of active transit agents in the city?

Reference year 2019

A:

21. How often has the city performed checkpoint in the past year?

☐ Did not perform
☐ At least once a month
☐ At least once a week
☐ More than three times a week
☐ More than five times a week
☐ All day

22. Do the checkpoint have an exclusive focus on the DRINKING AND DRIVING?

☐ Never
☐ Rarely
☐ Partially
☐ Often
☐ Ever

23. Has the city enforced cell phone use while driving in the last year?

☐ No
☐ Yes

24. Does the city have its own legislation on speed limits in the urban area?

☐ Yes, higher than DENATRAN
☐ No, similar to DENATRAN
☐ Yes, lower than DENATRAN

25. Does the city have a traffic education department/sector?

☐ No
☐ Yes

26. If yes, how many educators?

A:

27. Does the city produce its own road safety campaigns?

☐ No
☐ No, use State or National campaign
☐ Yes

28. What are the levels and scale of coverage of road safety media campaigns?

*Select one or more answers.

☐ Don't have
☐ Owned media
☐ Paid media
☐ Others

...if you select other, specify here:

29. Is the Ambulances (Mobile Emergency Care) from the city or state?

☐ Don't have
☐ City
☐ State

30. Are you interested in joining a collaborative network for disseminating good practices for promoting road safety in Brazilian cities?

☐ No
☐ Yes, WhatsApp (Open group for discussions)
☐ Yes, WhatsApp (Group only for promoting good practices)

Please share your contact (DDD) + Cell phone : ( )+

Please provide an email address to contact if you have questions about the answers provided.

A:

THE END! THANKS FOR YOUR COLLABORATION.

APPENDIX B – ROAD SAFETY POLICES PERFORMANCE PROFILE FOR BRAZILIAN CITIES

This appendix presents the profile of all cities in the study based on performance of their Road Safety Policy (RSP) and respective SS dimensions. Best-in-class cities are highlighted (with the highest SS dimension performances in their cluster, in case of equal values, both are highlighted). Cities with RSP priority SS dimensions for action are also highlighted (with the SS dimension performance lower than the respective average performance of their cluster, see Equations 6 and 8).

LIST OF ACRONYMS

RSPP	Road Safety Policy Performance
RSM	Road Safety Management
SDE	Safer Driving Environment
SRU	Safer Road User
PCR	Post-crash Response

LEGENDS OF ICONS

City site

Best-in-class city

Potential opportunity for RSP improvement*

* The size of the icon represents the RSP improvement priorities indicated by the analysis.

Table colors indicate city cluster.

1	2	3	4

Alagoinhas – BA

POP: 151,596
HDI: 0.683
Cluster: 4

Star-rating: ★★★

RSPP	0.612 (2º)
RSM	0.062
SDE	0.227
SRU	0.155
PCR	0.168

Americana - SP

POP: 239,597
HDI: 0.811
Cluster: 2

Star-rating: ★★★

RSPP	0.493 (36º)
RSM	0.062
SDE	0.114
SRU	0.149
PCR	0.168

Anápolis – GO

POP: 386,923
HDI: 0.737
Cluster: 3

Star-rating: ★★★

RSPP	0.566 (18º)
RSM	0.095
SDE	0.095
SRU	0.155
PCR	0.221

Barra do Pirai – RJ

POP: 100,374
HDI: 0.733
Cluster: 3

Star-rating: ★★

RSPP	0.41 (34º)
RSM	0.026
SDE	0.158
SRU	0.057
PCR	0.168

Aracaju – SE

POP: 657,013
HDI: 0.770
Cluster: 2

Star-rating: ★★★★★

RSPP	0.846 (3º)
RSM	0.155
SDE	0.227
SRU	0.242
PCR	0.221

Bauru – SP

POP: 239,597
HDI: 0.811
Cluster: 2

Star-rating: ★★★★

RSPP	0.716 (14º)
RSM	0.102
SDE	0.234
SRU	0.158
PCR	0.221

Belém - PA

POP: 1,492,745
HDI: 0.746
Cluster: 1

Star-rating: ★★★★

RSPP	0.566 (18º)
RSM	0.155
SDE	0.095
SRU	0.155
PCR	0.221

Betim – MG

POP: 439,340
HDI: 0.749
Cluster: 3

Star-rating: ★★★

RSPP	0.503 (25º)
RSM	0.060
SDE	0.114
SRU	0.193
PCR	0.137

Belo Horizonte – MG

POP: 2,51,070
HDI: 0.810
Cluster: 1

Star-rating: ★★★★★

RSPP	0.864 (4º)
RSM	0.191
SDE	0.227
SRU	0.226
PCR	0.221

Braganca – PA

POP: 127,868
HDI: 0.600
Cluster: 4

Star-rating: ★★★

RSPP	0.482 (8º)
RSM	0.095
SDE	0.095
SRU	0.155
PCR	0.137

Brasília – DF

POP: 3,015,268
HDI: 0.824
Cluster: 1

Star-rating: ★★★★★

RSPP	0.855 (5º)
RSM	0.182
SDE	0.227
SRU	0.226
PCR	0.221

Caieiras – SP

POP: 101,470
HDI: 0.781
Cluster: 2

Star-rating: ★★★

RSPP	0.466 (38º)
RSM	0.129
SDE	0.132
SRU	0.152
PCR	0.053

Cachoeirinha – RS

POP: 130,293
HDI: 0.757
Cluster: 3

Star-rating: ★★

RSPP	0.225 (42º)
RSM	0.067
SDE	0.057
SRU	0.07
PCR	0.031

Campina Grande – PB

POP: 409,731
HDI: 0.720
Cluster: 3

Star-rating: ★★★★

RSPP	0.78 (1º)
RSM	0.217
SDE	0.189
SRU	0.152
PCR	0.221

Campinas – SP

POP: 1,204,073
HDI: 0.805
Cluster: 1

Star-rating: ★★★★

RSPP	0.837 (7º)
RSM	0.155
SDE	0.284
SRU	0.177
PCR	0.221

Campos dos Goytacazes – RJ

POP: 507,548
HDI: 0.716
Cluster: 3

Star-rating: ★★★

RSPP	0.442 (33º)
RSM	0.114
SDE	0.100
SRU	0.114
PCR	0.159

Campo Grande – MS

POP: 895,982
HDI: 0.784
Cluster: 2

Star-rating: ★★★★★

RSPP	0.851 (2º)
RSM	0.191
SDE	0.215
SRU	0.256
PCR	0.19

Canoas – RS

POP: 346,616
HDI: 0.750
Cluster: 3

Star-rating: ★★★★

RSPP	0.652 (8º)
RSM	0.193
SDE	0.133
SRU	0.193
PCR	0.221

Cariacica – ES

POP: 381,285
HDI: 0.718
Cluster: 3

Star-rating: ★★★

RSPP	0.589 (14º)
RSM	0.086
SDE	0.17
SRU	0.196
PCR	0.137

Cascavel – PR

POP: 338,454
HDI: 0.782
Cluster: 2

Star-rating: ★★★★

RSPP	0.829 (4º)
RSM	0.158
SDE	0.227
SRU	0.223
PCR	0.221

Caruaru – PE

POP: 361,118
HDI: 0.677
Cluster: 4

Star-rating: ★★★

RSPP	0.507 (6º)
RSM	0.060
SDE	0.151
SRU	0.128
PCR	0.168

Catanduva – SP

POP: 121,862
HDI: 0.785
Cluster: 2

Star-rating: ★★★

RSPP	0.583 (25º)
RSM	0.102
SDE	0.145
SRU	0.114
PCR	0.221

Caucaia – CE

POP: 361,400
HDI: 0.682
Cluster: 4

Star-rating: ★★

RSPP	0.246 (16º)
RSM	0.069
SDE	0.044
SRU	0.070
PCR	0.062

Chapeco – SC

POP: 220,367
HDI: 0.790
Cluster: 2

Star-rating: ★★★

RSPP	0.607 (21º)
RSM	0.102
SDE	0.17
SRU	0.166
PCR	0.168

Caxias do Sul – RS

POP: 510,906
HDI: 0.782
Cluster: 2

Star-rating: ★★★

RSPP	0.584 (24º)
RSM	0.105
SDE	0.095
SRU	0.163
PCR	0.221

Corumbá – MS

POP: 111,435
HDI: 0.700
Cluster: 4

Star-rating: ★★

RSPP	0.389 (10º)
RSM	0.033
SDE	0.126
SRU	0.114
PCR	0.115

Cotia – SP

POP: 249,210
HDI: 0.780
Cluster: 2

Star-rating: ★★★

RSPP	0.535 (32º)
RSM	0.093
SDE	0.152
SRU	0.122
PCR	0.168

Cuiabá – MT

POP: 612,547
HDI: 0.785
Cluster: 2

Star-rating: ★★★★

RSPP	0.795 (5º)
RSM	0.158
SDE	0.227
SRU	0.242
PCR	0.168

Crato – CE

POP: 132,123
HDI: 0.713
Cluster: 3

Star-rating: ★★★

RSPP	0.469 (29º)
RSM	0.069
SDE	0.113
SRU	0.065
PCR	0.221

Curitiba – PR

POP: 1,993,105
HDI: 0.823
Cluster: 1

Star-rating: ★★★★

RSPP	0.812 (9º)
RSM	0.165
SDE	0.215
SRU	0.212
PCR	0.221

Divinópolis – MG

POP: 283,230
HDI: 0.764
Cluster: 3

Star-rating: ★★★★

RSPP	0.665 (7º)
RSM	0.102
SDE	0.227
SRU	0.114
PCR	0.221

Eunápolis – BA

POP: 113,380
HDI: 0.677
Cluster: 4

Star-rating: ★★★

RSPP	0.627 (1º)
RSM	0.129
SDE	0.19
SRU	0.171
PCR	0.137

Dourados – MS

POP: 222,949
HDI: 0.747
Cluster: 3

Star-rating: ★★★

RSPP	0.562 (19º)
RSM	0.102
SDE	0.095
SRU	0.144
PCR	0.221

Ferraz de Vasconcelos – SP

POP: 194,276
HDI: 0.738
Cluster: 3

Star-rating: ★★

RSPP	0.227 (41º)
RSM	0.036
SDE	0.076
SRU	0
PCR	0.115

Fortaleza – CE

POP: 2.669,342
HDI: 0.754
Cluster: 1

Star-rating: ★★★★★

RSPP	0.964 (1º)
RSM	0.253
SDE	0.265
SRU	0.256
PCR	0.190

Francisco Morato – SP

POP: 175,844
HDI: 0.703
Cluster: 4

Star-rating: ★★

RSPP	0.301 (14º)
RSM	0.129
SDE	0.12
SRU	0
PCR	0.053

Franca – SP

POP: 353,187
HDI: 0.780
Cluster: 2

Star-rating: ★★★

RSPP	0.544 (30º)
RSM	0.095
SDE	0.133
SRU	0.147
PCR	0.168

Governador Valadares - MG

POP: 279,885
HDI: 0.727
Cluster: 3

Star-rating: ★★★★

RSPP	0.676 (5º)
RSM	0.138
SDE	0.132
SRU	0.185
PCR	0.221

Gravataí – RS

POP: 281,519
HDI: 0.736
Cluster: 3

Star-rating: ★★★

RSPP	0.494 (26º)
RSM	0.069
SDE	0.114
SRU	0.196
PCR	0.115

Guarujá – SP

POP: 320,459
HDI: 0.751
Cluster: 3

Star-rating: ★★★★

RSPP	0.709 (4º)
RSM	0.191
SDE	0.215
SRU	0.166
PCR	0.137

Guarapuava – PR

POP: 181,504
HDI: 0.731
Cluster: 3

Star-rating: ★★★

RSPP	0.575 (17º)
RSM	0.102
SDE	0.208
SRU	0.128
PCR	0.137

Guarulhos - SP

POP: 1,379,182
HDI: 0.763
Cluster: 1

Star-rating: ★★★★

RSPP	0.794 (10º)
RSM	0.165
SDE	0.284
SRU	0.177
PCR	0.168

Ibirité – MG

POP: 180,204
HDI: 0.704
Cluster: 4

Star-rating: ★★

RSPP	0.350 (11º)
RSM	0.069
SDE	0.076
SRU	0.152
PCR	0.053

Indaiatuba – SP

POP: 251,627
HDI: 0.788
Cluster: 2

Star-rating: ★★★

RSPP	0.608 (20º)
RSM	0.129
SDE	0.291
SRU	0.082
PCR	0.106

Ilhéus – BA

POP: 162,237
HDI: 0.690
Cluster: 4

Star-rating: ★★★

RSPP	0.527 (5º)
RSM	0.026
SDE	0.095
SRU	0.185
PCR	0.221

Itabira – MG

POP: 120,060
HDI: 0.756
Cluster: 3

Star-rating: ★★★

RSPP	0.537 (23º)
RSM	0.102
SDE	0.113
SRU	0.100
PCR	0.221

Itapevi – SP

POP: 237,700
HDI: 0.735
Cluster: 3

Star-rating: ★★★

RSPP	0.554 (21º)
RSM	0.191
SDE	0.095
SRU	0.100
PCR	0.168

Jacareí – SP

POP: 233,662
HDI: 0.777
Cluster: 2

Star-rating: ★★★★

RSPP	0.788 (6º)
RSM	0.131
SDE	0.24
SRU	0.196
PCR	0.221

Jaboatão dos Guararapes – PE

POP: 702,298
HDI: 0.717
Cluster: 3

Star-rating: ★★★

RSPP	0.505 (24º)
RSM	0.095
SDE	0.132
SRU	0.193
PCR	0.084

Jaraguá do Sul – SC

POP: 177,697
HDI: 0.803
Cluster: 2

Star-rating: ★★★

RSPP	0.557 (27º)
RSM	0.102
SDE	0.208
SRU	0.109
PCR	0.137

Ji-Paraná – RO

POP: 128,969
HDI: 0.714
Cluster: 3

Star-rating: ★★

RSPP	0.334 (36º)
RSM	0.102
SDE	0.095
SRU	0.084
PCR	0.053

Joinville – SC

POP: 590,466
HDI: 0.809
Cluster: 2

Star-rating: ★★★

RSPP	0.599 (22º)
RSM	0.165
SDE	0.170
SRU	0.149
PCR	0.115

João Pessoa – PB

POP: 809,015
HDI: 0.763
Cluster: 2

Star-rating: ★★★★

RSPP	0.782 (7º)
RSM	0.155
SDE	0.265
SRU	0.172
PCR	0.19

Jundiaí – SP

POP: 418,962
HDI: 0.822
Cluster: 2

Star-rating: ★★★★

RSPP	0.677 (17º)
RSM	0.158
SDE	0.095
SRU	0.204
PCR	0.221

Lauro de Freitas – BA

POP: 198,440
HDI: 0.724
Cluster: 3

Star-rating: ★★★

RSPP	0.582 (16º)
RSM	0.062
SDE	0.132
SRU	0.166
PCR	0.221

Londrina – PR

POP: 569,733
HDI: 0.778
Cluster: 2

Star-rating: ★★★★

RSPP	0.725 (12º)
RSM	0.122
SDE	0.19
SRU	0.193
PCR	0.221

Linhares – ES

POP: 173,555
HDI: 0.724
Cluster: 3

Star-rating: ★★★

RSPP	0.487 (28º)
RSM	0.122
SDE	0.132
SRU	0.128
PCR	0.106

Maceió – AL

POP: 1,018,948
HDI: 0.721
Cluster: 3

Star-rating: ★★★★

RSPP	0.676 (6º)
RSM	0.129
SDE	0.208
SRU	0.172
PCR	0.168

Maracanaú – CE

POP: 227,886
HDI: 0.686
Cluster: 4

Star-rating: ★★★

RSPP	0.496 (7º)
RSM	0.069
SDE	0.151
SRU	0.160
PCR	0.115

Mossoró – RN

POP: 297,378
HDI: 0.720
Cluster: 3

Star-rating: ★★★★

RSPP	0.733 (3º)
RSM	0.102
SDE	0.265
SRU	0.144
PCR	0.221

Mesquita – RJ

POP: 176,103
HDI: 0.737
Cluster: 3

Star-rating: ★★

RSPP	0.39 (35º)
RSM	0.095
SDE	0.132
SRU	0.100
PCR	0.062

Natal – RN

POP: 884,122
HDI: 0.763
Cluster: 2

Star-rating: ★★★★

RSPP	0.762 (8º)
RSM	0.131
SDE	0.208
SRU	0.202
PCR	0.221

Novo Gama – GO

POP: 115,711
HDI: 0.684
Cluster: 4

Star-rating: ★

RSPP	0.178 (17º)
RSM	0
SDE	0.044
SRU	0.103
PCR	0.031

Osasco – SP

POP: 698,418
HDI: 0.776
Cluster: 2

Star-rating: ★★★

RSPP	0.484 (37º)
RSM	0.102
SDE	0.113
SRU	0.100
PCR	0.168

Olinda – PE

POP: 392,482
HDI: 0.735
Cluster: 3

Star-rating: ★★★

RSPP	0.592 (13º)
RSM	0.119
SDE	0.208
SRU	0.149
PCR	0.115

Parnamirim – RN

POP: 261,469
HDI: 0.766
Cluster: 3

Star-rating: ★★★

RSPP	0.457 (30º)
RSM	0.129
SDE	0.113
SRU	0.131
PCR	0.084

Patos – PB

POP: 107,605
HDI: 0.701
Cluster: 4

Star-rating: ★★★

RSPP	0.576 (4º)
RSM	0.069
SDE	0.095
SRU	0.191
PCR	0.221

Paulista – PE

POP: 331,774
HDI: 0.732
Cluster: 3

Star-rating: ★★★★

RSPP	0.642 (11º)
RSM	0.060
SDE	0.151
SRU	0.21
PCR	0.221

Patos de Minas – MG

POP: 152,488
HDI: 0.765
Cluster: 3

Star-rating: ★★★

RSPP	0.559 (20º)
RSM	0.129
SDE	0.195
SRU	0.014
PCR	0.221

Petrópolis – RJ

POP: 306,191
HDI: 0.745
Cluster: 3

Star-rating: ★★★★

RSPP	0.645 (10º)
RSM	0.165
SDE	0.095
SRU	0.196
PCR	0.19

Pindamonhangaba – SP

POP: 168,328
HDI: 0.773
Cluster: 2

Star-rating: ★★★★

RSPP	0.733 (11º)
RSM	0.165
SDE	0.221
SRU	0.179
PCR	0.168

Piracicaba – SP

POP: 404,142
HDI: 0.785
Cluster: 2

Star-rating: ★★★★

RSPP	0.759 (10º)
RSM	0.165
SDE	0.227
SRU	0.147
PCR	0.221

Pinhais – PR

POP: 132,157
HDI: 0.751
Cluster: 3

Star-rating: ★

RSPP	0.144 (43º)
RSM	0
SDE	0.082
SRU	0
PCR	0.062

Porto Velho – RO

POP: 529,544
HDI: 0.736
Cluster: 3

Star-rating: ★★★

RSPP	0.491 (27º)
RSM	0.086
SDE	0.113
SRU	0.070
PCR	0.221

Pouso Alegre – MG

POP: 150,737
HDI: 0.774
Cluster: 2

Star-rating: ★★★

RSPP	0.539 (31º)
RSM	0.086
SDE	0.132
SRU	0.131
PCR	0.19

Queimados – RJ

POP: 150,319
HDI: 0.680
Cluster: 4

Star-rating: ★

RSPP	0.106 (18º)
RSM	0
SDE	0.044
SRU	0
PCR	0.062

Presidente Prudente – SP

POP: 228,743
HDI: 0.806
Cluster: 2

Star-rating: ★★★

RSPP	0.547 (29º)
RSM	0.122
SDE	0.095
SRU	0.141
PCR	0.19

Recife – PE

POP: 1,645,727
HDI: 0.772
Cluster: 1

Star-rating: ★★★★

RSPP	0.769 (11º)
RSM	0.095
SDE	0.227
SRU	0.226
PCR	0.221

Ribeirão das Neves – MG

POP: 334,858
HDI: 0.684
Cluster: 4

Star-rating: ★★

RSPP	0.263 (15º)
RSM	0.036
SDE	0.095
SRU	0.100
PCR	0.031

Rio Branco – AC

POP: 407,319
HDI: 0.727
Cluster: 3

Star-rating: ★★★

RSPP	0.609 (12º)
RSM	0.138
SDE	0.132
SRU	0.202
PCR	0.137

Ribeirão Preto – SP

POP: 703,293
HDI: 0.800
Cluster: 2

Star-rating: ★★★★

RSPP	0.693 (16º)
RSM	0.165
SDE	0.114
SRU	0.193
PCR	0.221

Rio de Janeiro – RJ

POP: 6.718,903
HDI: 0.799
Cluster: 1

Star-rating: ★★★★★

RSPP	0.852 (6º)
RSM	0.129
SDE	0.246
SRU	0.256
PCR	0.221

Rio Verde – GO

POP: 235,647
HDI: 0.754
Cluster: 3

Star-rating: ★★★

RSPP	0.583 (15º)
RSM	0.102
SDE	0.158
SRU	0.155
PCR	0.168

Santa Barbara d'Oeste – SP

POP: 193,475
HDI: 0.781
Cluster: 2

Star-rating: ★★★

RSPP	0.587 (23º)
RSM	0.131
SDE	0.240
SRU	0.100
PCR	0.115

Salvador – BA

POP: 2,873,347
HDI: 0.759
Cluster: 1

Star-rating: ★★★★★

RSPP	0.868 (3º)
RSM	0.165
SDE	0.227
SRU	0.256
PCR	0.221

Santos – SP

POP: 433,311
HDI: 0.840
Cluster: 2

Star-rating: ★★★★★

RSPP	0.853 (1º)
RSM	0.191
SDE	0.259
SRU	0.183
PCR	0.221

São Caetano do Sul – SP

POP: 161,127
HDI: 0.862
Cluster: 2

Star-rating: ★★★

RSPP	0.509 (34º)
RSM	0.102
SDE	0.133
SRU	0.052
PCR	0.221

São Jose do Rio Preto – SP

POP: 460,671
HDI: 0.797
Cluster: 2

Star-rating: ★★★★

RSPP	0.759 (9º)
RSM	0.191
SDE	0.19
SRU	0.158
PCR	0.221

São Carlos – SP

POP: 251,983
HDI: 0.805
Cluster: 2

Star-rating: ★★★★

RSPP	0.704 (15º)
RSM	0.062
SDE	0.291
SRU	0.183
PCR	0.168

São Paulo – SP

POP: 12,252,023
HDI: 0.805
Cluster: 1

Star-rating: ★★★★★

RSPP	0.944 (2º)
RSM	0.227
SDE	0.284
SRU	0.212
PCR	0.221

São Pedro da Aldeia – RJ

POP: 104,476
HDI: 0.712
Cluster: 3

Star-rating: ★★

RSPP	0.235 (40º)
RSM	0.026
SDE	0.095
SRU	0.114
PCR	0

Sete Lagoas – MG

POP: 239,639
HDI: 0.760
Cluster: 3

Star-rating: ★★★

RSPP	0.548 (22º)
RSM	0.102
SDE	0.208
SRU	0.100
PCR	0.137

Sertãozinho – SP

POP: 125,815
HDI: 0.761
Cluster: 3

Star-rating: ★★★★

RSPP	0.65 (9º)
RSM	0.129
SDE	0.157
SRU	0.196
PCR	0.168

Sinop – MT

POP: 142,996
HDI: 0.754
Cluster: 3

Star-rating: ★★

RSPP	0.305 (38º)
RSM	0
SDE	0.044
SRU	0.155
PCR	0.106

Sumaré – SP

POP: 282,441
HDI: 0.762
Cluster: 3

Star-rating: ★★

RSPP	0.297 (39º)
RSM	0.067
SDE	0.076
SRU	0.070
PCR	0.084

Taubaté – SP

POP: 314,924
HDI: 0.800
Cluster: 2

Star-rating: ★★★★

RSPP	0.664 (19º)
RSM	0.122
SDE	0.209
SRU	0.166
PCR	0.168

Suzano – SP

POP: 297,637
HDI: 0.765
Cluster: 3

Star-rating: ★★★

RSPP	0.446 (32º)
RSM	0.129
SDE	0.132
SRU	0.100
PCR	0.084

Teresina – PI

POP: 864,845
HDI: 0.751
Cluster: 3

Star-rating: ★★★★

RSPP	0.776 (2º)
RSM	0.105
SDE	0.227
SRU	0.223
PCR	0.221

Timon – MA

POP: 169,107
HDI: 0.649
Cluster: 4

Star-rating: ★★

RSPP	0.313 (13º)
RSM	0.102
SDE	0.088
SRU	0.060
PCR	0.062

Tucuruí – PA

POP: 113,659
HDI: 0.666
Cluster: 4

Star-rating: ★★★

RSPP	0.437 (9º)
RSM	0.069
SDE	0.076
SRU	0.124
PCR	0.168

Tubarão – SC

POP: 105,686
HDI: 0.796
Cluster: 2

Star-rating: ★★★

RSPP	0.533 (33º)
RSM	0.036
SDE	0.113
SRU	0.163
PCR	0.221

Ubá – MG

POP: 115,225
HDI: 0.724
Cluster: 3

Star-rating: ★★

RSPP	0.317 (37º)
RSM	0.033
SDE	0.063
SRU	0
PCR	0.221

Uberaba – MG

POP: 333,783
HDI: 0.772
Cluster: 2

Star-rating: ★★★

RSPP	0.497 (35º)
RSM	0
SDE	0.145
SRU	0.131
PCR	0.221

Uruguaiana – RS

POP: 126,970
HDI: 0.744
Cluster: 3

Star-rating: ★★★

RSPP	0.453 (31º)
RSM	0.036
SDE	0.095
SRU	0.155
PCR	0.168

Uberlândia – MG

POP: 691,305
HDI: 0.789
Cluster: 2

Star-rating: ★★★

RSPP	0.556 (28º)
RSM	0.102
SDE	0.132
SRU	0.100
PCR	0.221

Varginha – MG

POP: 135,558
HDI: 0.778
Cluster: 2

Star-rating: ★★★★

RSPP	0.675 (18º)
RSM	0.093
SDE	0.189
SRU	0.171
PCR	0.221

Vila Velha – ES

POP: 493838
HDI: 0.800
Cluster: 2

Star-rating: ★★★

RSPP	0.573 (26º)
RSM	0.129
SDE	0.208
SRU	0.152
PCR	0.084

Vitória da Conquista – BA

POP: 338,480
HDI: 0.678
Cluster: 4

Star-rating: ★★★

RSPP	0.605 (3º)
RSM	0.069
SDE	0.214
SRU	0.100
PCR	0.221

Vitória – ES

POP: 362,097
HDI: 0.845
Cluster: 2

Star-rating: ★★★★

RSPP	0.722 (13º)
RSM	0.122
SDE	0.208
SRU	0.172
PCR	0.221

Vitória de Santo Antão - PE

POP: 138757
HDI: 0.640
Cluster: 4

Star-rating: ★★

RSPP	0.347 (12º)
RSM	0.060
SDE	0.095
SRU	0.131
PCR	0.062

APPENDIX C – TUTORIAL TO IDENTIFY PRIORITY SS DIMENSIONS FOR ACTION IN NEW CITIES

This appendix presents a tutorial for Brazilian cities with more than 100,000 inhabitants to apply the results of this research to estimate their RSP (in general and for SS dimensions) and compare it with the average value of their cluster. This procedure will enable the city to identify the possible priority SS dimensions for action and the best-practices adopted by similar cities. This approach will provide valuable insight and offer data-driven evidence for the transfer of good experiences from best to underperforming city. However, it is essential to follow the next steps and collect the data according to the form provided.

STEP 1: To collect and encode RSI data

To estimate the SS dimensions RSPP of a new city it is necessary to collect some RSI. The collection form is available here. The following figures present the questions on this collection form. Some of these RSI are available in DATASUS and IPEA secondary and official databases. After, to perform the RSI codification according to the values provided in Tables 12 to 16, available in section 4.2 of this document.

UNIVERSIDADE FEDERAL DO CEARÁ

GTTEMA

petran
Programa de pós-graduação em Engenharia de Transportes

Research: Road Safety Policies Benchmarking in Brazilian cities

Dear, thank you for your visit.
Completing this questionnaire will help us to obtain indicators to evaluate road safety policies in Brazil.

City: Population (IBGE):

Contact e-mail: HDI (IBGE):

Filling Instructions

The framework of the five dimensions was used to structure the following questionnaire. There will be three blocks of questions that can be answered by more than one person holding the requested information. The questionnaire can be answered in stages, if you do not have the information for a particular question, it can be completed or edited later. Filled data will be saved automatically (as long as you are online).

Part I: Road Safety Management

ROAD SAFETY MANAGEMENT | SAFER DRIVING ENVIRONMENT | SAFER VEIHCLES | SAFER ROAD USER | POST-CRASH RESPONSE

1. Does the city have a mobility plan?

- ☐ No
- ☐ In elaboration
- ☐ Yes

2. Is there a unified road crash database? Is it used?
(Consolidates information from police and health agencies)

- ☐ Does not have database
- ☐ It has a database, but not unified
- ☐ Yes, unified and applied for diagnosis only
- ☐ Yes, unified and applied for diagnosis and strategies evaluation

3. Does the city have a target to reduce road traffic deaths and injuries?

*Selecionar uma ou mais respostas

- ☐ No
- ☐ Yes, fatality crashes only
- ☐ Yes, fatality and injury crashes
- ☐ Yes, all crashes severity

Part II: Safer Driving Environment and Safer Veihcles

ROAD SAFETY MANAGEMENT | SAFER DRIVING ENVIRONMENT | SAFER VEIHCLES | SAFER ROAD USER | POST-CRASH RESPONSE

4. Does the city have a department or sector of engineering/traffic signaling?

- ☐ No
- ☐ Yes

5. If yes, how many employees?

A:

6. Does the city have incentive policies for active mobility?

*Select one or more answers.

- ☐ No
- ☐ Cycling infrastructure
- ☐ Complete and active streets
- ☐ Sidewalks with greater or equal free movement range
- ☐ Public bicycle system
- ☐ Sidewalk widening (physical or painting)
- ☐ Others

7. Does the city have enforcement equipment on roads?

- ☐ No
- ☐ Yes, fixe type
- ☐ Yes, static type
- ☐ Yes, both

8. Has the city peformes image enforcement (video enforcement) in the last year?

- ☐ Doesn't have the system
- ☐ No
- ☐ Yes

9. What is the regulated speed of the city's arterial roads (predominantly)?

- ☐ 60 km/h or more
- ☐ 50 km/h
- ☐ Below 50km/h

Part III: Safe Road Users and Post-crash Response

ROAD SAFETY MANAGEMENT | SAFER DRIVING ENVIRONMENT | SAFER VEIHCLES | SAFER ROAD USER | POST-CRASH RESPONSE

10. How often has the city performed checkpoint in the past year?

- ☐ Did not perform
- ☐ At least once a month
- ☐ At least once a week
- ☐ More than three times a week
- ☐ More than five times a week
- ☐ All day

11. Do the checkpoint have an exclusive focus on the DRINKING AND DRIVING?

- ☐ Never
- ☐ Rarely
- ☐ Partially
- ☐ Often
- ☐ Ever

12. Does the city have a traffic education department/sector?

- ☐ No
- ☐ Yes

13. Does the city produce its own road safety campaigns?

- ☐ No
- ☐ No, use State or National campaign
- ☐ Yes

14. What is the ambulance rate per 100,000 inhabitants of the city (see DATASUS database)?

A:

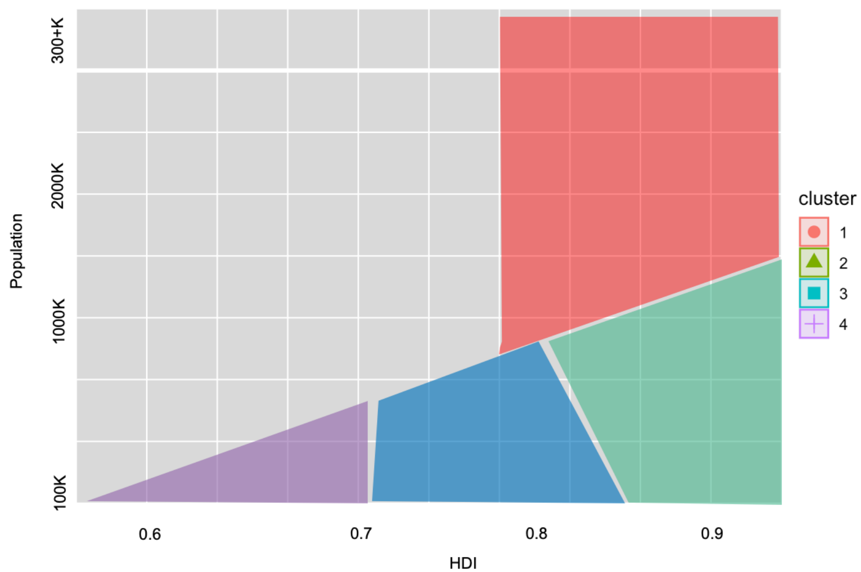
15. What is the ICU rate per 100,000 inhabitants of the city (see DATASUS database)?

A:

THE END! THANKS FOR YOUR COLLABORATION.

STEP 2: To identify the city cluster

Based on the HDI value and the number of inhabitants, plot the information in the graph below to identify which cluster the city fits into.



STEP 3: To estimate the RSPP (general and for SS dimensions)

Based on the RSI coded, utilizar as esquacoes da tabela a seguir para calcular os RSPP. After, to define the star-rating of the city based on the graphic scale on the side.

SS Dimensions	EQUATIONS
RSM =	(((crash_database/3)*0.814)+((mobility_plan/3)*0.507) +((targer/3)*0.601))*0.132
SDE =	(((engineering_dept/2)*0,544)+(active_mobility/4)*0,643)+(video_enforcem/1)*0,645)+(auto_enforcem/3)*0,491)+(arter_speeds/2)*0,429))*0.117
SRU =	(((checkpoints/5)*0.581)+((dd_ enforcement/3)*0.518 +((campaigns/3)*0.493) +(education_dept *0.602))*0.117
PCR =	(((ambulance_rate/2)*0.396) +((ICU_rate/3)*1.01))*0.157
RSPP = (GENERAL)	RSM+SDE+SRU+PCR

STEP 4: To identify the priorities SS dimensions for action

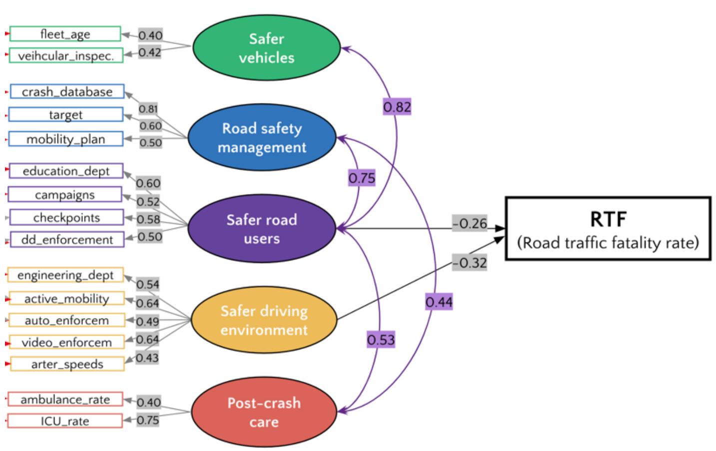
Once the city's RSPP has been calculated, compare it with the mean values of city cluster. If the RSPP is lower than the mean value, the respective dimension is an action priority. If there are more than one, prioritize the SS dimension with the higher differences in relation to the mean value of the cluster. RSPP is the highest value among the other cities in the cluster, the analyzed city is a best-in-class for the respective SS dimension.

APPENDIX D - BRAZILIAN CITY SEM SCRIPT AND RESULT

```
library(lavaan)
library(semTools)
library(semPlot)
library(psych)
library(dplyr)

SEM_BR_RSPcities <- '
RSM =~ target+crash_databasev+mobility_plan
SDE =~ engineering_dept+active_mobility+auto_enforcem+video_enforcem+arter_speeds
SRU =~ campaigns+education_dept+fiscal+checkpoints+dd_ enforcement
PCR =~ ambulance_rate+ICU_rate
SV  =~ fleet_age+vehicular_inspec
RTF ~ a*SRU + b*SDE
RSM ~~ 0*SDE
RSM ~~ c*SRU
RSM ~~ d*PCR
RSM ~~ 0*SV
SDE ~~ 0*SRU
SDE ~~ 0*PCR
SDE ~~ 0*SV
SRU ~~ e*PCR
SRU ~~ f*SV
PCR ~~ 0*SV

fitMBRZ <- cfa(model=MBRZ,data=DATASET_FINAL, std.lv = TRUE, ordered=names (DATASET_FINAL))
summary(fitMBRZ, standardized = TRUE,fit.measures=TRUE)
semPaths(fitMBRZ, whatLabels="std")
```




```
Regressions:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  dth_ind3 ~
    SRU         (a)  -0.256    0.098   -2.616    0.009   -0.256   -0.256
    SRM         (b)  -0.322    0.107   -3.002    0.003   -0.322   -0.322

                  Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
 RSM ~~
   SRM               0.000                               0.000    0.000
   SRU        (c)    0.749    0.121    6.174    0.000    0.749    0.749
   PCC        (d)    0.443    0.166    2.668    0.008    0.443    0.443
   SVC               0.000                               0.000    0.000

 SRU ~~
   PCC        (e)    0.531    0.174    3.057    0.002    0.531    0.531
   SVC        (f)    0.814    0.511    2.472    0.013    1.263    1.263


 Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   RSM =~
     Target           0.601    0.098    6.100    0.000    0.601    0.601
     data_use         0.814    0.084    9.685    0.000    0.814    0.814
     mob_plan         0.507    0.100    5.069    0.000    0.507    0.507
   SRM =~
     dep_eng          0.544    0.135    4.034    0.000    0.544    0.544
     est_vul          0.643    0.117    5.489    0.000    0.643    0.643
     eqp_fisc         0.491    0.114    4.321    0.000    0.491    0.491
     video_m          0.645    0.120    5.385    0.000    0.645    0.645
     vel_reg          0.429    0.173    2.477    0.013    0.429    0.429
   SRU =~
     camp             0.518    0.097    5.339    0.000    0.518    0.518
     dep_edu          0.602    0.117    5.128    0.000    0.602    0.602
     fiscal           0.581    0.087    6.670    0.000    0.581    0.581
     regiao           0.493    0.092    5.348    0.000    0.493    0.493
   PCC =~
     samu_hab         0.396    0.145    2.728    0.006    0.396    0.396
     uti_hab          1.099    0.304    3.611    0.000    1.099    1.099
   SVC =~
     fleet_age        0.398    0.189    2.104    0.035    0.398    0.398
     car_insp         0.316    0.158    2.001    0.045    0.316    0.316
```