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Original Article

An Initial Exploration of Non-Functional Requirements Specifications Applied to Smart Cities Traffic-Focused Systems Development

Jackson dos Santos Roque da Silva[1], Giovani Fonseca Ravagnani Disperati[2], Antonio Angelo de Souza Tartaglia[3]

[1,2,2]Federal Institute of Education, Science and Technology of São Paulo, São Paulo, Brazil.

[1]Corresponding Author : jackson.roque@aluno.ifsp.edu.br

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Abstract *- The exponential growth of urban centers, exemplified by São Paulo and Rio de Janeiro in Brazil, has profound implications for urban mobility and the well-being of residents. This article delves into the potential of "smart cities" and their technological applications, specifically within the domain of urban mobility. The focus extends to technologies deployed in smart cities to improve urban mobility and reduce accidents, notably Intelligent Transportation Systems (ITS). These systems leverage communication and information technologies to manage city traffic effectively, contributing to sustainable urban mobility goals. However, the development of such systems demands meticulous attention to non-functional requirements, emphasizing reliability and performance. The analysis culminates in addressing barriers to services and technologies for smart cities in Brazilian roadways, specifically examining accidents on the President Dutra Highway. Proposals for implementing technologies like IoT and AI-based monitoring systems are presented. The study underlines the significance of managing non-functional requirements in developing smart city systems. The findings provide a foundation for future explorations, offering insights into the potential tools that could be implemented on the Presidente Dutra Highway, Guarulhos, São Paulo, promoting safety for both drivers and the broader population.*

Keywords *- IoT, ITS, Non-Functional Requirements, Smart Cities, Software engineering.*

1. Introduction

The growth of large Brazilian cities, such as São Paulo and Rio de Janeiro, impacts urban mobility and affects the population who use the various means of transportation available, such as vehicles, motorcycles, and public transport like buses, trains, and subways. Discussions revolve around the time spent commuting, safety during the journey, the conditions of the environment in which people travel, and how they impact people's quality of life and economic productivity.

In such context, the emerging "smart cities" are harnessing technologies that promise to positively impact the lives of their inhabitants, particularly in the realm of urban mobility. These cities encompass all modes of transportation, offering a range of tools to facilitate travel and circulation, ultimately benefiting urban mobility. When contemplating the cities of the future, the concept of smart cities, or intelligent cities, is intrinsic due to the high level of innovation they incorporate. Information technology, the use of Artificial Intelligence (AI) tools, and Internet of Things (IoT) devices play crucial roles in implementing these innovations.

According to Folha [1], the Brazilian Association of Technical Standards (ABNT) tested a smart city certification in São José dos Campos in 2021, which involves MaaS, or Mobility as a Service, integrating various modes of transportation, including bicycles, the metro, ride-sharing, and bus. The utilization of intelligent infrastructure in smart cities can also enhance urban mobility. This encompasses, for instance, the implementation of smart traffic lights that adjust automatically to vehicle flow or the installation of sensors on roadways that can alert drivers to congestion or accidents.

Smart cities also encompass technologies that can be used to reduce traffic accidents, such as Intelligent Transportation Systems (ITS). According to Pumatronix [2], "Intelligent Transport Systems (ITS) can be defined as a series of technological solutions contributing to the improvement of urban mobility and, consequently, the advancement of smart cities.". ITS involves systems that utilize communication and information technologies to manage city traffic, incorporating sensors, cameras, and other devices to collect real-time traffic data. Based on this data, ITS can enhance traffic efficiency, manage vehicle flow, and alleviate roadway congestion. With all that has been presented, it can be identified that smart cities possess tools that enable innovation and sustainability, promoting improvements for their inhabitants and protecting the planet.

In the context of Intelligent Transportation Systems (ITS) development, an important point of attention arises: ensuring non-functional requirements. Non-functional requirements are characteristics that do not directly affect a system's core functionality but are equally essential, such as reliability and performance. In the realm of smart city systems development, carefully considering non-functional requirements plays a crucial role in building reliable and effective systems that are dependable, secure, economically viable, and, therefore, sustainable in the long term. However, ensuring non-functional requirements is known to come with challenges, ranging from understanding user needs to accurately defining and verifying the requirements themselves. This paper thus addresses the identified research gap by conducting an analysis of barriers in the development of services and technologies for smart cities, particularly in the context of motor vehicle roadways in Brazil, considering the guaranteeing of non-functional requirements. The assessment includes examining accident rates on the President Dutra Highway, reviewing potential technologies for smart cities to mitigate accident impacts, and delving into the crucial aspect of managing non-functional requirements in dedicated smart city systems, exemplified by Intelligent Transportation Systems (ITS). The objective is to contribute valuable insights for the development of smart city systems, ensuring they meet non-functional requirements and effectively address challenges in the realm of urban mobility.

2. Theoretical Basis

The 5G technology is poised to revolutionize the way cities are connected, with this connectivity bringing benefits through the advent of the Internet of Things (IoT), allowing the connection of various devices to the 5G network. Systems and instruments that were once simple, such as lampposts and traffic lights, can now be improved to communicate with each other and other devices. This demand and evolution have led to the need for a connection network that enables devices to communicate with low latency, high transfer rates, and without signal loss, as stated by Ferracioli [3]. The world is also becoming increasingly urban, presenting challenges to regional and municipal public managers and city residents regarding development and the right to live in a city [4][24].

According to Weiss [4], in response to these challenges, many cities globally have sought to equip themselves with new technological capabilities to implement higher levels of intelligence in public administration and service provision to citizens and organizations operating within them. The discussion on urban planning gained prominence in the mid-1980s when the globalization process intensified social and structural challenges [5]. Engel [6] suggests that socioeconomic and sociodemographic processes directly impact the quality of life of people residing in urban centers, necessitating local public managers to reconsider new concepts in urban planning. In this regard, according to the United Nations [7], there were fewer than twenty cities worldwide with a population exceeding 1 million inhabitants a century ago. By 2010, this number had increased to 436, and projections already indicated over 500 cities with a population above 1 million inhabitants by the end of 2015. The same study shows that the global population, projected for 2050, is expected to jump from 7.3 to approximately 9.5 billion people, with the urban population rising from 3.9 to around 6.3 billion people. This implies that while the world population will have grown by about 30.4% from 2015 to 2050, the urban population, in the same period, will have grown by about 60.2%. In this context, Leite [8] emphasizes decision-making at the local level concerning social issues with a direct impact on people's lives. Considering the growth of urban perimeters, Deakin [9] explains that the debate surrounding Smart Cities discusses the future of conglomerate zones, along with the implementation of the internet as the basis for integrating digital infrastructure systems, renewable data management systems, energy, and cloud computing in a regional innovation of the Internet of Things and Information and Communication Technologies (ICT). In this sense, according to the European Commission [10], a Smart City is one that utilizes network services to enhance its management.

According to Vasconcellos [11], with the advent of urbanization, urban dynamism and mobility systems started to operate with low quality and high costs. In response, the concept of Smart Cities emerges to address and mitigate problems generated by rapid urbanization and population growth, such as energy supply, waste management, and transportation (mobility), through more efficient resource utilization [12]. Carvalho [13] points out that the lack of statistical data, both in quantity and quality, regarding traffic accidents in urban areas limits and complicates the decision-making process for responsible municipal managers. In this context, Tischer [14] emphasized the importance of applied research for the better development of urban mobility in their study. One way of achieving this goal is through using Intelligent Transport Systems (ITS), which encompass a variety of technologies, including smart traffic lights, traffic cameras, and congestion sensors. As highlighted by Zheng [15], these technologies enable real-time traffic monitoring. The collected data can be utilized to adjust traffic light timings, guide traffic flow, and inform drivers about alternative routes, ultimately reducing congestion.

Cities like London, UK, have implemented advanced collision detection systems using surveillance cameras and sensors to monitor traffic [24]. These systems identify risky behaviors, such as dangerous overtaking, and can provide real-time alerts to authorities and drivers. Smart cities also promote the use of electric vehicles and efficient public transportation to reduce dependence on individually owned fossil fuel-powered vehicles. Stockholm, Sweden, implemented an urban toll system that discourages the use of private cars in the city center, encouraging the use of public transportation and bicycles.

Furthermore, Artificial Intelligence (AI) and Big Data have proven valuable for analyzing traffic patterns and predicting accidents. According to Santos et al. [16], cities might be able to utilize machine learning algorithms to predict accident locations based on historical traffic - an approach that could serve as an example for future implementations in emerging smart cities in Brazil. Machine learning algorithms analyze this information to detect risky behaviors, providing a way to identify potentially dangerous situations and facilitate a swift response from traffic authorities. Following international best practices, the Brazilian city of João Pessoa has adopted an intelligent traffic light system named 'TrafGO' to expedite vehicle flow and enhance urban mobility [17].

With the growth of the Internet of Things (IoT), precise sensors aligned with data transmission could become crucial for collision detection systems in smart cities in Brazil. Surveillance cameras and sensors scattered throughout smart cities can monitor the behavior of vehicles and pedestrians. This technology could provide accurate information, helping prevent accidents along the routes where drivers are traveling. Mobility apps like Waze, Google Maps, Ecovias, and websites like CET (State Traffic Company) and CCR Concessionaire use real-time traffic data and routing algorithms to guide drivers' journeys. These applications not only help drivers avoid congestion but also contribute to traffic monitoring, providing valuable information to municipal and state authorities.

In this context, Intelligent Transport Systems (ITS) could be crucial in mitigating such accidents and enhancing overall road safety. By leveraging advanced technologies, ITS can address various factors contributing to accidents. Five of those factors are listed below.

Real-time Traffic Monitoring: ITS can provide real-time traffic monitoring through sensors and cameras, enabling instant identification of congestion, accidents, or high-risk zones. This information can be used to alert drivers, implement adaptive traffic control measures, and reroute traffic to alleviate potential hazards.

Smart Traffic Management: ITS offers the capability for smart traffic management, optimizing signal timings, and dynamically adjusting traffic flow. This can reduce congestion, minimize abrupt stops, and enhance overall traffic efficiency, thereby lowering the risk of accidents.

Predictive Analytics: ITS can predict potential accident-prone areas and times by analyzing historical traffic data. Authorities can implement preemptive measures, such as increased patrolling, enhanced signage, or targeted awareness campaigns, to address specific challenges highlighted by the data.

Communication Between Vehicles (V2V) and Infrastructure (V2I): ITS facilitates communication between vehicles and infrastructure. Through Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication, vehicles can exchange information about their speed, location, and potential hazards. This communication network can enhance situational awareness and contribute to accident prevention.

Enhanced Emergency Response: In the event of an accident, ITS can contribute to faster emergency response. Automated systems can detect incidents promptly and notify emergency services, reducing response times and potentially saving lives.

In the realm of developing software systems tailored for applications in smart cities, ensuring the fulfillment of non-functional requirements is paramount for the efficacy and sustainability of these complex urban environments. Non-functional requirements, encompassing aspects such as reliability, performance, security, scalability, and maintainability, collectively mold the success and functionality of smart city solutions.

Reliability is pivotal in ensuring the continuous and dependable operation of interconnected systems within smart cities. Performance considerations are essential to manage these applications' dynamic and data-intensive nature, optimizing data processing efficiency and response times. Security becomes a critical concern to safeguard against cyber threats and unauthorized access, preserving the integrity of interconnected systems. Scalability is imperative to accommodate the growing volume of data generated by diverse devices and sensors in smart city environments. Maintainability contributes to the long-term viability of smart city solutions, enabling seamless adaptation to evolving technological landscapes. The meticulous attention to and fulfillment of these non-functional requirements are indispensable for the sustained evolution of smart city technologies, promoting enhanced urban living and addressing the multifaceted challenges encountered by modern cities. As smart city initiatives continue to expand, adherence to non-functional requirements becomes a critical facet of software development practices to ensure the resilience and effectiveness of these technologically advanced urban systems. Furthermore, those solutions also need to be economically viable in order to be seriously considered. In this context, ensuring non-functional requirements for smart city systems applied to road safety becomes comparable to critical systems and those utilizing IoT.

It is acknowledged that non-functional requirements are of great importance in developing systems, especially critical systems. As such, an initial review of methods to ensure non-functional requirements smart cities applications is proposed.

3. Materials and Methods

In the pursuit of enhancing Intelligent Transportation Systems (ITS) and addressing non-functional requirements, this study follows a systematic approach. Emphasis was placed on identifying key factors for ensuring reliability, performance, and efficiency in ITS development. Additionally, an examination of accident data on the Dutra Highway was conducted to establish a baseline, providing a real-world context for the study. The selection of the Presidente Dutra Highway is strategic, as it emerges as a focal point with a higher incidence of both accidents with victims and, more critically, fatalities.

Examining accident data, including the distinction between accidents with victims and fatal incidents, helps identify specific challenges on the Presidente Dutra Highway. This analysis facilitates evidence-based decision-making for implementing effective safety measures, optimizing traffic management, and ultimately improving road safety in the region.

By merging insights from the literature with empirical data, the research aims to establish a baseline that could be further explored to evaluate ITS solutions that effectively reduce the number of fatalities, particularly considering the fulfilment of non-functional requirements and their documentation. This methodological approach ensures a well-rounded investigation into the development of ITS, incorporating both theoretical foundations and practical considerations grounded in real-world scenarios.

4. Results and Discussion

4.1. Analysis of Accidents on Presidente Dutra Highway in the Guarulhos Section

According to the Traffic Accident Management Information System of the State of São Paulo [18], the first quarter of 2023 witnessed 1,152 fatalities due to accidents on the roads of São Paulo, nine more than the same period in the previous year [18].

In the heatmap report presented in InfosigaSP [18], specifically on the Presidente Dutra Highway in Jardim Otawa, Cumbica, Guarulhos, SP, a higher number of "accidents with victims" is indicated by blue points. However, specific sections of the Presidente Dutra Highway on this heatmap reveal that the road is the location with the highest number of fatalities, indicated by red points and a greater concentration of heat spots. Figure 1 presents the heatmap of fatalities in the aforementioned President Dutra Highway section.

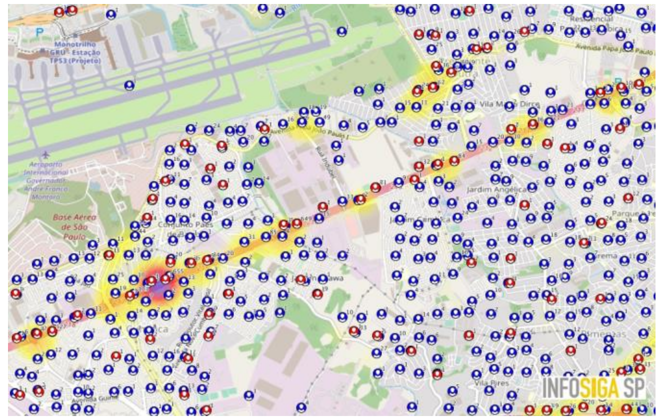

Fig. 1 Heatmap - Distribution of blue points representing accidents with victims and red points representing fatalities on Presidente Dutra Highway, Jardim Otawa, Cumbica, Guarulhos, SP.

The heatmap shows a higher concentration of heat spots near the red point of the distribution, close to the SP-060 BR-116 section on Presidente Dutra Highway, where a total of 631 deaths from traffic accidents were recorded. The data was collected from 2018 to 2022. Figure 2 provides a closer view of the area where the highest number of fatalities was concentrated.

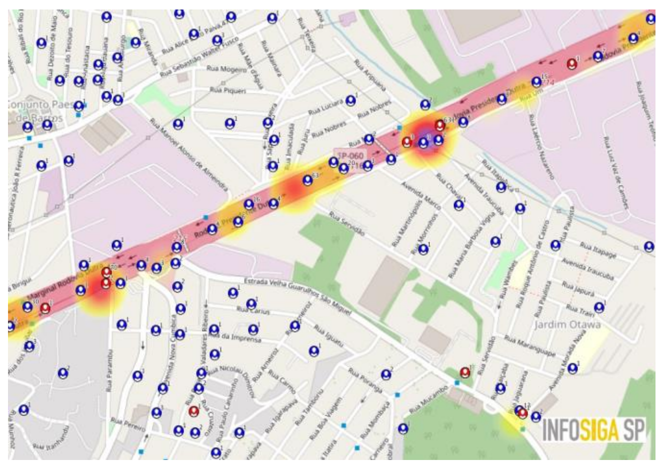

Fig. 2 Heatmap with distribution showing the highest number of fatalities on Presidente Dutra Highway, Jardim Otawa, Cumbica, Guarulhos, SP.

The presented data reveals a concerning number of fatalities on the Presidente Dutra Highway in São Paulo, emphasizing the need to thoroughly investigate the possible causes behind this surge. Several factors may contribute to the rise in accidents and fatalities. Infrastructure issues, such as road conditions, signage adequacy, and the absence of safety features, could influence the higher number of accidents with victims.

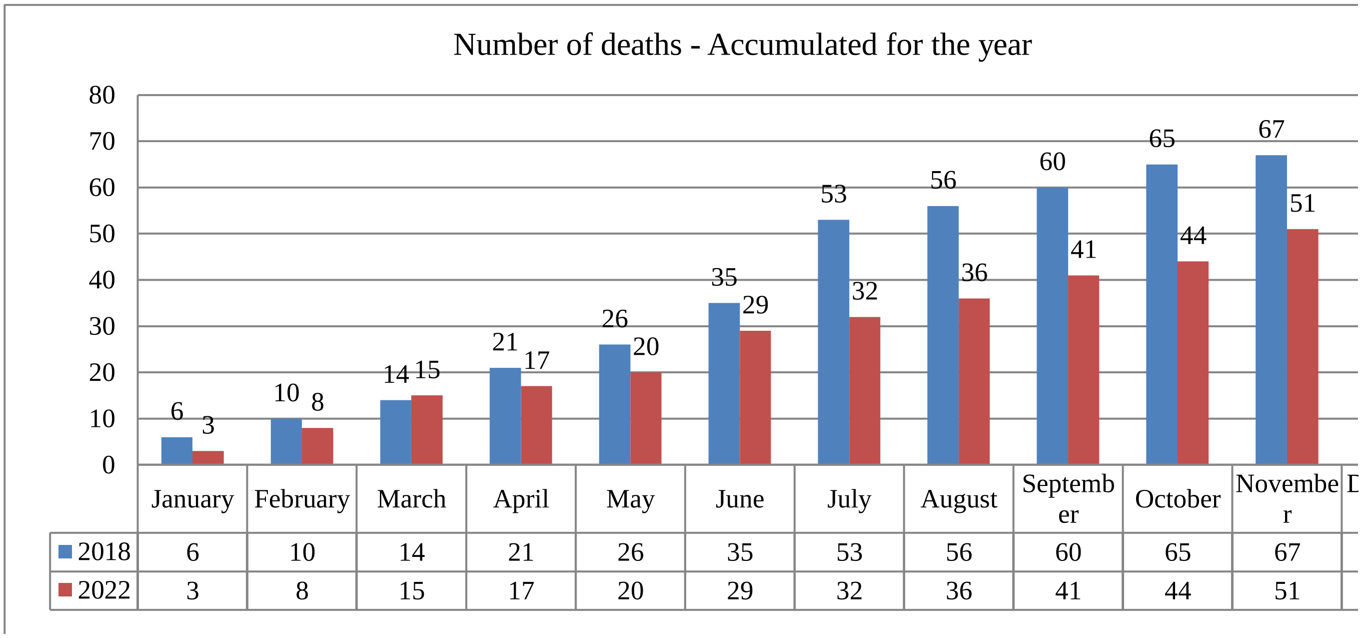

Fig. 3 Cumulative number of deaths from January to December on Presidente Dutra Highway, Jardim Otawa, Cumbica, Guarulhos, SP. Comparison between the years 2018, represented by yellow bars, and 2022, represented by blue bars

The concentration of fatalities in specific sections of the highway suggests potential hotspots that warrant closer scrutiny. Factors like speeding, inadequate enforcement of traffic regulations, and the presence of high-risk zones may contribute to the increased fatality rates in these areas. Environmental conditions, including weather and visibility, could play a role in the accidents. Additionally, socioeconomic factors, such as population density and urban development, might contribute to the overall risk on the highway. Studying these factors comprehensively could provide valuable insights into devising targeted interventions and preventive measures to reduce fatalities. Analyzing the temporal aspect of the data, trends over the years are considered to identify patterns or recurring issues. In this context, Figure 3 depicts the cumulative deaths month by month, drawing a comparative analysis between the year 2018, highlighted in yellow, and the year 2022, in blue.

The data indicates a trend of decreasing fatalities. The factors contributing to this trend can be diverse, ranging from an economic downturn due to the COVID-19 pandemic, given the area's significant concentration of industries and truck traffic, to undisclosed measures taken by surveillance and enforcement authorities. In this context, Intelligent Transport Systems (ITS) could contribute to the qualitative analysis of this data, providing concrete insights from experiences and assisting in enhancing traffic conditions and reducing the number of accidents and, consequently, fatalities.

In this context, it is important to understand how systems can be designed to assist in monitoring and reducing accidents. To this end, a survey was conducted to identify some of the main applications demonstrated in the literature.

4.2. A brief review of software solutions applied to highway safety

Jackson et al. developed a system that collects elevated video data of roadway locations, extracting microscopic traffic parameters like user trajectories, lane changes, and speeds. The authors used open-source automatic tracking tools to process the collected video data, allowing analysis of road user behaviour at specific locations or assessing safety treatment effectiveness.

Vishal et al. [19] align the IoT concept with road infrastructure for smart applications, focusing on leveraging IoT technologies in smart cities to mitigate the risk of run-off-road collisions. With all vehicles IoT-enabled and connected, the system offers an efficient method to swiftly navigate emergency service vehicles through the road. This automated IoT system enhances accuracy and precision by combining cost-effective antenna technology and internet platforms.

Taha [20] explains that the road safety approach, known as the Safe System (SS), prioritizes safety by design for vehicles, road networks, and users. Aligned with the World Health Organization's (WHO) recommendations, SS is globally adopted. However, it primarily focuses on the medium-to-long term. The work aims to enhance SS with a short-to-medium-term dynamic road safety assessment, introducing a cost-effective IoT architecture. The presented architecture enables a robust computational core for assessing road safety dynamically, introducing a novel and scalable metric. Machine learning, particularly Hidden Markov Models (HMMs), is applied in the metric computation core. The proposed architecture's impact is demonstrated through safety-based route planning.

Singh et al. [21] state that the UN 2030 agenda emphasizes improving the transportation system for safe, affordable, and sustainable transport, including enhanced road safety, and technologies like the Internet of Things (IoT) and artificial intelligence (AI) play a crucial role in achieving this agenda on highways. The author's study highlights the importance of digitalization in creating a sustainable environment on highways, focusing on smart highway lighting, traffic management, renewable energy sources, smart displays, and AI integration, and proposed architectures for smart highway lighting and traffic management are discussed. The study also emphasizes the benefits of real-time applications, AI integration for road safety, and the use of deep learning in edge-based vision nodes. The recommendations include smart reflectors, renewable energy adoption, vehicle-to-vehicle communication, and smart lampposts for highway digitalization.

The utilization of IoT and AI for safety-based applications on roads aligns with what was initially outlined in the theoretical basis: smart city applications should heavily leverage sensors, devices interconnected through mobile networks, and data processing systems that provide insights for traffic analysis and improvement conditions. This aids in reducing the number of fatalities on highways. Integrating technologies from areas such as IoT and artificial intelligence emerges as the foundation for constructing systems focused on road safety in the context of smart cities. Thus, the question arises: how to ensure that the requirements of these systems, particularly the non-functional ones, are met?

4.3. Assurance of non-functional requirements in smart cities systems development

Santana et al. [22] present a literature review aiming to address, among other questions, the requirements that a software platform for smart cities must fulfill. By analyzing twenty-two different platforms and examining and classifying their functional and non-functional requirements, the authors identify the following categories of non-functional requirements: interoperability, scalability, security, privacy, context awareness, adaptation, extensibility, and configurability. The authors note that interoperability, security, and scalability requirements are the most common. Thus, the study highlights the importance of carefully specifying such non-functional requirements.

Mahalank et al. [23] conducted an analysis of non-functional requirements for an IoT-based traffic management unit, influencing design decisions based on parameters such as cost, sensitivity, complexity, storage capacity, development process, response criteria, and environmental impact. The authors aimed to optimize the IoT design process at the system design level, resulting in the creation of template documentation and a checklist for Non-functional Requirement Analysis. The authors also provided a specifiable design path to guide actions during the deployment phase, as the minimal checklist derived from Non-Functional Requirement Analysis works as a practical guideline for design implementation. In this context, Non-Functional Requirement Analysis serves as a practical guide for implementing software designs in the field of smart cities.

These studies, therefore, provide an initial foundation supporting the idea of the importance of ensuring non-functional requirements when developing smart city systems. Ensuring non-functional requirements in smart cities involves a comprehensive understanding of interoperability, scalability, and security categories. The methodologies presented by these studies, including checklist creation and systematic analysis, provide practical guides for implementing software designs in smart cities' dynamic and complex environments. In this sense, the research indicates that ensuring non-functional requirements for smart city systems is not different from traditional system models. Thus, a well-known approach to assurance involves setting goals and objectives, as widely accepted in the academic community and discussed by authors like Sommerville [26]. In this approach, a goal is established, such as a general expected quality of the system, for instance, security or scalability in the case of smart city systems. Then an objective is defined to achieve that purpose. In other words, a goal could be the system's scalability, and the associated objective would be the ability to handle a specific number of requests.

The challenges, therefore, can be summarized as follows: 1) Non-functional requirements can impact the system architecture as a whole. To ensure that performance requirements are met, for example, architectures optimizing communication between components may need to be adopted; 2) Non-functional requirements may require implementing a series of functional requirements for their assurance.

4.4. Proposal of a template for non-functional requirements

Given those known challenges, a simple yet elegant solution is to present the identified non-functional requirements in a tabular format. A template for writing down those requirements is presented in Table 1. The User Goal section outlines the overarching objective or goal from the user's perspective. It reflects the high-level aim that the system or software should achieve to meet user expectations. The Objectives section specifies objectives that are measurable criteria used to validate whether the user's overall goal is achieved. The Measurement section provides a clear and quantifiable way to assess the system's success concerning non-functional requirements. In the Associated Functional Requirements section, the functional requirements that are directly associated with achieving the specified non-functional goals are listed. These requirements detail the functionalities and features that the system must have to support the desired non-functional attributes.

Table 1. Template and an example proposal

NFR	Description
User goal	The high-level goal of the user
Objectives	The objective of the NFR
Measurement	Definition of measurement of the NFR achievement
Associated FR	List of associated functional requirements

5. Conclusion

This study provides a review and real-world scenario analysis that establish a crucial foundation emphasizing the significance of non-functional requirements in developing smart city systems. Exploring categories such as interoperability, scalability, and security provides essential insights for comprehensive non-functional requirement assurance. The methodologies proposed, including checklist creation and systematic analysis, offer practical guidance in navigating the dynamic and intricate landscape of smart cities.

The reviewed research suggests that ensuring non-functional requirements for smart city systems aligns with established practices, involving defining clear goals and objectives. It is concluded thus that the challenges lie in addressing the holistic impact on system architecture and the potential need for implementing associated functional requirements to ensure non-functional requirements.

Furthermore, it can be identified that smart cities have tools that enable innovation and sustainability, promoting improvements for their inhabitants. Based on the Presidente Dutra Highway, Guarulhos, São Paulo, monitoring systems through the usage of IoT and AI need to be further explored in future studies. Considering the data gathered and the explored literature, this study presents a starting point for this exploration. Traffic management in smart cities must be economically viable, optimizing available financial resources and minimizing operational costs. In this context, the guaranteeing of non-functional requirements of an economically viable set of systems plays a vital role in the design and implementation of traffic systems with the goal of reducing accidents, as they are essential to ensure that traffic is efficient, safe, sustainable, and accessible to all citizens. Applications such as using a system of equipment embedded in vehicles or deployed on the road with real-time signaling can inform drivers about events on the road, preventing accidents and providing information for management through Artificial Intelligence (AI). The use of Internet of Things (IoT) sensors could alert drivers about conditions on the road, enhancing safety. Intelligent and efficient traffic light management could provide suitable conditions for the flow of vehicles to remain in circulation. These are some crucial points that could be further evaluated and discussed as tools to be implemented on the Presidente Dutra Highway, Guarulhos, São Paulo, bringing safety and quality of life for drivers on the highway and, consequently, the general population. For such applications to be seriously considered, this study provides a simple yet elegant model for tabular documentation of non-functional requirements in the realm of smart city system development. This represents an initial step in the exploration and definition of non-functional requirements supported by the literature, and therefore, further studies demonstrating its effectiveness are necessary. As such, this can be seen as a starting point for more in-depth explorations that may take place in the future.

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