FEDERAL UNIVERSITY OF SANTA CATARINA
TECHNOLOGICAL CENTER OF JOINVILLE
TRANSPORT AND LOGISTICS ENGINEERING

CAIO TRAMONTIN VOLPATO

ANALYSIS OF DIFFERENT GEOPROCESSING TOOLS IN THE EVALUATION OF A VACCINE DISTRIBUTION CENTER: A CASE STUDY IN THE SOUTHERN REGION OF SANTA CATARINA

Joinville
2023

CAIO TRAMONTIN VOLPATO

ANALYSIS OF DIFFERENT GEOPROCESSING TOOLS IN THE EVALUATION OF A VACCINE DISTRIBUTION CENTER: A CASE STUDY IN THE SOUTHERN REGION OF SANTA CATARINA

Monography submitted as a requirement to obtain a bachelor’s degree in the Graduate Course of Transport and Logistics Engineering of the Joinville Technological Center of the Federal University of Santa Catarina.

Prof. Dra. Simone Becker Lopes

Joinville
2023

CAIO TRAMONTIN VOLPATO

ANALYSIS OF DIFFERENT GEOPROCESSING TOOLS IN THE EVALUATION OF A VACCINE DISTRIBUTION CENTER: A CASE STUDY IN THE SOUTHERN REGION OF SANTA CATARINA

This monography has been judged and approved as a partial requirement for obtaining the Bachelor of Transport and Logistics Engineering degree at the Federal University of Santa Catarina, Technological Center of Joinville.

Joinville (SC), December 07, 2023.

Examining board:

Prof. Dra. Simone Becker Lopes
Advisor
UFSC - Joinville

Prof. Dra. Christiane Wenck Nogueira Fernandes
Member
UFSC - Joinville

Prof. Me. Natan Bissoli
Member
UFSC - Joinville

I dedicate this work to my father, mother and sister for always encouraging me to seek knowledge and pursue my dreams. *Vi voglio bene*!

"Your work is going to fill a large part of your life, and the only way to be truly satisfied is to do what you believe is great work. And the only way to do great work is to love what you do".

Steve Jobs, 2010.

RESUMO

Esta pesquisa visa avaliar a eficácia de distintas ferramentas de geoprocessamento para a implementação de rotas rodoviárias na rede de distribuição de vacinas no sul de Santa Catarina, Brasil, utilizando o software SIG QGIS. O estudo foca na importância da rede de frios relacionada ao transporte de imunobiológicos, especialmente para a logística humanitária como a distribuição de vacinas, e introduz a logística de saúde pública no contexto de Santa Catarina. A revisão teórica examina conceitos de SIG, rede de distribuição de vacinas e logística essenciais para entender os desafios da distribuição eficiente de suprimentos. Utilizando dados do IBGE, OpenStreetMap e Google Cloud, a metodologia emprega o software QGIS para mapear as rotas atuais e propostas e avaliá-las com base na distância e eficiência logística. Os resultados indicaram diferenças entre as rotas atuais e as rotas propostas na rede de distribuição, destacando a ferramenta que oferece maior eficiência. O estudo conclui enfatizando as implicações dos resultados para a logística de suprimentos em Santa Catarina, destacando a importância da escolha adequada das ferramentas de geoprocessamento.

Palavras-chave: Logística humanitária. Rede de distribuição de vacinas no Brasil. SIG. Geoprocessamento. QGIS.

ABSTRACT

This research aims to evaluate the effectiveness of distinct geoprocessing tools for implementing road routes to the vaccines distribution network in south of Santa Catarina, Brazil, using GIS QGIS software. The study focuses on the importance of the cold chain related to immunobiologicals transport, especially for humanitarian logistics such as vaccine distribution, and introduces public health logistics in the Santa Catarina context. The theoretical review examines GIS, vaccine distribution network, and logistics concepts essential to understanding efficient supplies distribution challenges. Using IBGE, OpenStreetMap and Google Cloud data, the methodology employs QGIS software to map the current and proposed routes and evaluates them based on distance and logistical efficiency. The results indicated differences between the current routes and the routes proposed in the distribution network, highlighting the tool that offers greater efficiency. The study concludes by emphasizing the implications of the findings for supplies logistics in Santa Catarina, highlighting the importance of choosing the appropriate geoprocessing tools.

Keywords: Humanitarian logistics. Vaccines distribution network in Brazil. GIS. Geoprocessing. QGIS.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

CENADI	Central Nacional de Armazenamento e Distribuição de Imunobiológicos
CGNPI	Coordenação Geral do Programa Nacional de Imunizações
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
GIS	Geographic information systems
IBGE	Instituto Brasileiro de Geografia e Estatística
INPE	Instituto Nacional de Pesquisas Espaciais
NGO	Non-governmental organization
ORS	OpenRouteService
OSM	Open Street Maps
SC	Santa Catarina
SES	Secretaria de Estado da Saúde
SP	São Paulo
SCM	Supply chain management
UDVE	Unidades Descentralizadas de Vigilância Epidemiológica

SUMMARY

1 INTRODUCTION

In catastrophic events, such as natural disasters and humanitarian crises, ensuring the basic conditions for human survival is a primary concern involving medical assistance and supplies, such as medicine, food, or shelter (ERGUN et al., 2010). The catastrophic events give these operations a high level of intensity, where intensity can be measured by the number of tasks to be executed divided by the product of time and available resources (TOMASINI; WASSENHOVE, 2009). Both the public and private sectors allocate capital, time, and labor towards developing strategies to mitigate the consequences of crises, aiming to accelerate the delivery of essential supplies (KOVÁCS; SPENS, 2009). These include food, clothing, medicine, and skilled personnel, ensuring their availability to victims in the shortest possible timeframe.

The rapid assessment of immediate needs and their dissemination is considered crucial for the practical impact of the intervention. However, as stated by Ergun et al. (2009) and Tatham e Christopher (2018), the affected country's government and armed forces take a prominent role in the preparation phase, ensuring essential services and access, often because mobility activities are intrinsically linked to economic conditions, existing social infrastructure and national policies.

On the other hand, non-governmental organizations (NGOs) often play the role of primary responders in natural disasters. Specifically large international NGOs are notable for their readiness to respond to crises, dedicating themselves to providing medicines, medical assistance, food support, and recurring essential supplies (TATHAM; CHRISTOPHER, 2018).

Humanitarian interventions after a disaster are typically characterized by an acute urgency (TOMASINI; WASSENHOVE, 2009). In Brazil, the vaccination campaign against Covid-19 started in January 2021, when the public administration was responsible for disseminating inputs, logistics goods and services, technology information and communication, social and advertising communication and training aimed at vaccination (BRASIL, 2021).

Due to the uncertainties and challenges associated with the distribution of vaccines against Covid-19, it was necessary to resort to the knowledge and practices of humanitarian logistics to ensure the implementation of large-scale vaccination. In this sense, the existing structure of the vaccine distribution network, which was already used for the distribution of other supplies, was used to meet the transport and specificities of vaccines against Covid-19. This approach allowed for adequate dose storage, maintaining controlled temperature, and ensuring their integrity during transport and distribution (BRASIL, 2023).

However, every disaster brings together a new set of actors with different resources and commitment levels (TOMASINI; WASSENHOVE, 2009). The vaccine distribution network proved essential to enable the logistics of its vaccine doses, providing a broad and efficient reach in immunizing the population. Moreover, the success of large-scale immunization efforts depends on a reliable distribution network to avoid misplacement and temperature fluctuations, for example.

This study proposes improvements to the vaccine distribution network in a case study in south of Santa Catarina (SC), through distinct geoprocessing tools using QGIS. The comparative analysis of current routes with new created routes, using data from the Brazilian Institute of Geography and Statistics (IBGE, in Portuguese), OpenStreetMap (OSM), and Google Cloud, aims to identify the most efficient geoprocessing tool, thus contributing to reducing costs and delivery times. The objective of this study is to enhance routes in distribution management for humanitarian and public health purposes.

1.1 OBJECTIVES

This study aims to evaluate geoprocessing tools using GIS QGIS and to propose a new regional level in the vaccine distribution network of in a case study in the south of SC, thereby enhancing logistics practices for humanitarian and public health purposes. The study is guided by the following objectives:

1.1.1 Main Objective

The main objective is to compare the performance and outcomes of various geoprocessing tools available in QGIS in a case study in the south of SC. This comparison aims to understand the relative advantages and limitations of each tool within the context of supply distribution logistics.

1.1.2 Specific Objectives

- To comprehend the functioning of the vaccine distribution network in a case study in the south of SC.
- To investigate the available geoprocessing tools in QGIS and their application in the study.
- To implement distinct APIs for the analysis of routes between municipalities.
- To evaluate the outcomes and compare the results of each tool.

1.2 JUSTIFICATION

The State of Santa Catarina faces various challenges, such as climate change and natural disasters like occurrences of floods, flooding and landslides (SIEBERT, 2017), which can interfere with the maintenance of an efficient and effective transport of its immunobiologicals distribution network (SILVA; FLAUZINO, 2017), a vital component for transport and preservation of supplies integrity and their timely availability to the population. The enhancement of the existing distribution logistics is not just a matter of increasing operational efficiency but an urgent necessity to ensure public health. In a world increasingly guided by technological advancements, the study of logistics through Geographic Information Systems (GIS) emerges as a promising strategy to address such challenges.

The primary objective of this study is to create new routes from the current distribution of the vaccines in a case study in the south of SC, expecting to strengthen the health system’s response, increasing the efficiency of the supply chain and ensuring that supplies, such as vaccines, reach all municipalities promptly and in suitable conditions. This goal aligns with global public health objectives, which emphasize the need for robust and resilient distribution systems, especially in geographically and logistically complex regions.

The second objective of this research is to perform a comparative analysis between the current geoprocessing tools available in the market, specifically those offered by QGIS, using shapefiles provided by IBGE, Google Cloud, and OpenRouteService. Comparing these tools is crucial to understand their capabilities and limitations in the context of geoprocessing. The choice of an appropriate geoprocessing tool has direct implications on the overall efficiency of the Brazilian public agencies to provide general data on the roads under its jurisdiction.

Therefore, this study contributed to enhancing the logistics of the vaccine distribution network in a case study in the south of SC by conducting comprehensive comparisons between the available geoprocessing tools using distinct databases. It emphasized the key differences and potential limitations of these tools, thereby providing valuable insights to contribute to more effective distribution logistics.

1.3 STUDY STRUCTURE

The introductory section established general concepts, highlighting the relevance of the research and outlining the importance of the vaccine distribution network and humanitarian logistics in the context of public health in SC. It presented the general and specific objectives of the study. Following this, the literature review explores key concepts of the study, emphasizing GIS concepts and including the structure of the current vaccine distribution network with its respective importance in humanitarian logistics in Brazil, providing an essential context for understanding the methodologies applied and interpreting the presented results.

In the third section, the methodology of the study is presented, describing the development of a plugin for QGIS that integrates geoprocessing tools using databases from OpenRouteService, Google Cloud, and the IBGE. The methodology details how the plugin was utilized to create and compare routes between the current scenario and a proposed scenario, with the implementation of a new distribution center.

The fourth section presents the results through maps that comparatively illustrate the displacement between the current trajectories and those proposed by the new distribution center. This section highlights which geoprocessing tool provided the best performance in terms of efficiency, based on the total distance traveled.

The fifth section synthesizes the findings of the study, emphasizing the contribution of the developed Plugin to create new routes between the new distribution center and the current vaccine distribution network in a case study in south of SC. The conclusions reinforce the practical utility of this study in guiding the selection of geoprocessing tools and offer recommendations for applying the research findings in other scenarios. Furthermore, implications for future research are discussed, suggesting directions for subsequent studies that could expand knowledge in the field and further improve the logistics of supplies distribution.

Finally, in the sixth section, the bibliographic references are presented, and the seventh section describes the code developed in Python for the plugin used in this study.

2 LITERATURE REVIEW

The principal concepts pertinent to logistics, the vaccines distribution network in Brazil, and the Geographic Information System (GIS) were presented in this section, contributing to the literature review of this study. The concepts of logistics were explored with the intent to establish a foundation for understanding the complexities inherent in the transportation of supplies through the vaccines distribution network, which is divided into different levels of administration. Moreover, general information about GIS was introduced, highlighting its functionality for mapping and optimizing routes.

2.1 INTRODUCTION TO LOGISTICS

In this section, the concept of supply chain management (SCM) and its relation to contemporary logistic systems were explored, assuming a significant role in commercial and humanitarian operations, such as planning, implementation, and efficient control of the flow of goods, information, and resources. Furthermore, concepts of humanitarian logistics were addressed, related to the principles of SCM but delineated by a context of urgency and the need for rapid response to emergencies, often characterized by time and resource constraints.

Therefore, understanding SCM and humanitarian logistics is important for this study, as they provide a framework for logistical processes to address humanitarian issues, contributing to the study of the vaccines distribution network in SC.

2.1.1 Humanitarian logistics

As mentioned by Kovács e Spens (2009) and Siebert (2017), humanitarian logistics deals with disasters that range from earthquakes, tsunamis, hurricanes, epidemics, droughts, famines, terrorist attacks, and war situations to a combination of several disasters that may coincide. Humanitarian relief operations can be classified into several categories, such as emergency relief, which offers an immediate response to disasters; essential or subsistence relief; rehabilitation relief, which aims to reinstate daily life; and development relief, designed to enhance systems.

The term "disaster" is generally defined as a disruption that significantly affects a system, threatening its priorities and goals (WASSENHOVE, 2006). Disasters can be categorized based on their cause, either as natural or man-made, and by their predictability and speed of occurrence, distinguishing between sudden-onset and slow-onset disasters (COZZOLINO, 2012). As shown in Table 1, this categorization leads to the identification of four distinct types of disasters, that may be interlinked, where one type of disaster, like a calamity, might lead to others, such as plagues or crises, each varying in their logistic demands (COZZOLINO, 2012).

Table 1 – Distinct types of disasters

Category	**Type of disasters**
Calamities	Natural disasters characterized by sudden onset, such as earthquakes, hurricanes and tornadoes
Destructive actions	Caused by human activities, these have a sudden onset and include events like terrorist attacks and industrial accidents
Plagues	Slow-onset disasters of natural origin, such as famines, droughts, and widespread poverty
Crises	Man-made, slow-onset disasters like political and refugee crises, necessitating prolonged and complex logistic interventions

Source: Author (2023).

Humanitarian logistics encompasses a dynamic and complex field that extends beyond the immediate response to disasters. It plays a pivotal role in ensuring that aid reaches the most vulnerable populations effectively and efficiently. This field demands adaptability and innovation to address the unique challenges presented by each humanitarian crisis. The versatility of humanitarian logistics lies in its ability to cater to diverse needs, ranging from basic necessities to more specialized aid, across different phases of disaster response and recovery.

Tomasini e Wassenhove (2009) highlight that in humanitarian contexts, the traditional profit-making incentive is often absent, being replaced by the urgency for a rapid and lifesaving response. This shift in focus can result in a fire fighting behavior, characterized by reactive and immediate actions, along with a tendency towards frequent reinvention of processes and solutions, rather than building on existing knowledge and practices.

There are complexities of humanitarian logistics that can turn its network into a challenging process. One critical aspect of humanitarian logistics is the need for robust coordination among various stakeholders, including international aid organizations, local governments, and community groups. Effective coordination ensures that resources are not duplicated and that aid reaches those who need it most without unnecessary delays. Collaboration is particularly crucial in complex emergencies where multiple agencies operate simultaneously. As mentioned by Overstreet et al. (2011), the humanitarian logistics are influenced by:

- Unknowns: specific factors influence the efficiency and effectiveness of the logistics response, for example, the road infrastructure and equipment available.

- Time: while a delay in the commercial supply chain is costly regarding productivity and customer satisfaction, a delay in the humanitarian supply chain could mean the difference between life and death for those most severely impacted by the disaster.
- Trained logisticians: there needs to be more logisticians experts with practical experience in relief operations, as the experience in coordinating is more critical than disaster plans in these situations.
- The media and funding: donors (governments, aid agencies, and people) react with generosity to well-publicized disasters but tend to lose interest when disasters are not covered extensively by the media.
- Equipment and information technology: donors intend to help those impacted by the disaster, so funding for equipment and other technologies to share information can be limited.
- Interference: human interference can disturb the proper distribution of aid.

Effective management of humanitarian supply chains must be capable of responding to multiple interventions, often on a global scale, as quickly as possible and within a short time frame (WASSENHOVE, 2006). In the contemporary era of globalization, this necessity applies equally to the private sector as it does to humanitarian organizations (OVERSTREET et al., 2011). This perspective underscores the increasing complexity and demand for agility in supply chain management across various sectors, driven by the need for rapid response and adaptability in an interconnected global environment.

In contrast to logisticians in the private sector, humanitarian logistics professionals consistently face uncertainties. According to Wassenhove (2006), they are often uncertain about when, where, what type, and how much aid will be needed, as well as the sources and frequency of these needs, representing fundamental elements for establishing an efficient supply chain. This uncertainty is compounded by the fact that both demand and supply can fluctuate significantly during a relief operation. Humanitarian workers frequently deal with unexpected events, which may require them to abruptly disengage from one disaster response and move to another.

Operating under challenging conditions and typically constrained resources, these professionals face additional pressures, including high levels of stress and staff turnover. This environment can hinder the ability to invest in learning and improvement, fostering a culture focused on immediate crisis response rather than long-term strategic planning.

Moreover, humanitarian logistics involves a comprehensive understanding of local contexts, including cultural, political, and socio-economic factors. Awareness of these elements is crucial in designing and executing effective logistic strategies that are sensitive to the needs and dynamics of the affected communities. This understanding helps in navigating local infrastructures, customs, and regulations, which can significantly impact the delivery and distribution of aid.

Also places a strong emphasis on sustainability and resilience. In recent years, there has been a growing recognition of the need to develop logistic solutions that not only address immediate relief but also contribute to the long-term recovery and resilience of affected communities (OVERSTREET et al., 2011). This involves building local capacities, supporting sustainable practices, and ensuring that logistic interventions do not adversely impact the local environment or socio-economic conditions.

Therefore, humanitarian logistics corresponds to the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption to alleviate the suffering of vulnerable people (OVERSTREET et al., 2011).

2.1.2 Supply chain management

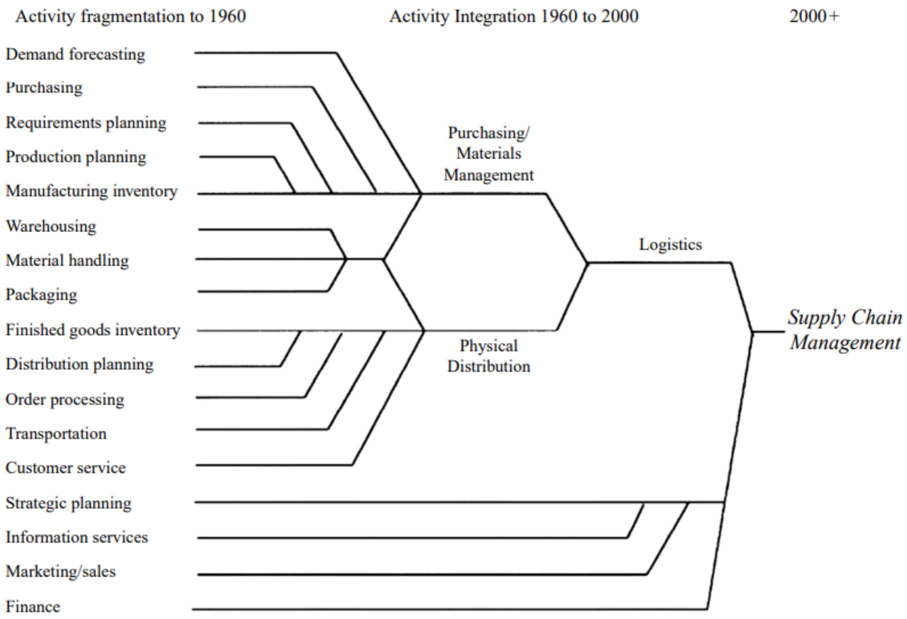
As stated by Ballou (2007), the primary objective of SCM is to leverage opportunities from the integrated management of product flow between channel members. Meanwhile, the understanding of SCM, shown in Figure 1, has been modified through the last decades. While logistics primarily concentrates on the physical movement of goods and individuals from an origin to a destination, supply chain management emphasizes the relationships among various actors that facilitate such movements (COZZOLINO, 2012).

This distinction highlights the broader scope of SCM, which encompasses not only the transportation aspect but also the intricate network of interactions and collaborations necessary for effective movement along the supply chain. According to Council of Supply Chain Management Professionals (2023), the functions of SCM typically encompass various departments or activities within an organization, such as:

- Purchasing/Procurement: involves sourcing and acquiring raw materials, parts, and finished goods from suppliers.
- Production/Manufacturing: convert raw materials into finished goods or products, but also involves processes like assembly, quality control, and packaging.
- Logistics: deals with the transportation, warehousing, and distribution of products.
- Marketing and sales: is responsible for understanding customer needs, creating demand, and consequently facilitating the sales process.
- R&D (research and development): designs new products or improves existing ones based on market needs and technological advancements.
- After-sales service and support: represents the post-sales activities and customer support.
- Finance: impacts SCM through budgeting, costing, and financial forecasting related to its activities.

- Digital system: integrates the SCM functions, ensuring real-time data flow and providing reports.

Figure 1 – Evolution of supply chain management



Source: Ballou (2007).

Besides the often-used strategy of SCM has an objective of minimizing supply chain costs due to customer service requirements, the new emphasis were on designing and operating the supply chain to enhance the revenues of the firm in such a way as to maximize contribution to profit (BALLOU, 2007).

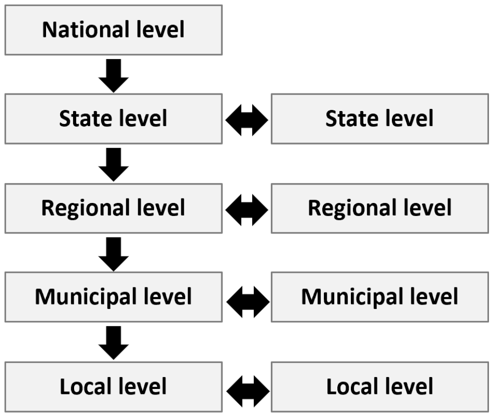
A contemporary view of SCM is to think of it as managing a set of processes, where a process is a group of activities relevant to achieving a defined objective (BALLOU, 2007). Nonetheless, actions in the humanitarian world are often uncoordinated, spontaneous, unsolicited, and disparate (TOMASINI; WASSENHOVE, 2009), once the specific causes of disasters and the timing of humanitarian aid can influence these actions (KOVÁCS; SPENS, 2009).

It is essential to understand the concepts of humanitarian logistics and SCM for an appropriate appreciation of the functioning of the vaccine distribution network in Brazil, for example. Humanitarian logistics, with its emphasis on rapid and efficient responses to emergency situations, provides valuable insights into dealing with logistical challenges under critical circumstances, such as vaccine distribution. On the other hand, SCM offers a framework to comprehend the integration and effective management of product flows, information, and resources throughout the distribution network.

2.2 IMMUNOBIOLOGICALS TRANSPORT NETWORK IN BRAZIL

The structure of the Brazilian cold chain for the transport of immunobiologicals permeates the three spheres of government (Union, States, Federal District, and Municipalities), organizing in instances, with distribution and storage flows occurring vertically, according to the Cold Chain Manual of the National Immunization Program of the Ministry of Health (BRASIL, 2013). It may occur horizontally depending on specific epidemiological and emergencies, as shown in Figure 2.

Figure 2 – Immunobiologicals distribution network organized into administrative spheres



Source: BRASIL (2013).

The national level, represented by the General Coordination of the National Immunization Program (CGPNI, in Portuguese) (BRASIL, 2023), is responsible for the immunization plan, covering activities such as management support, immunobiologicals management, technical and scientific incorporation and standardization, administrative support, and information system. Furthermore, the national instance has two important physical structures: the GGPNI, responsible for management, located in the Federal District, and the National Central for Storage and Distribution of Immunobiologicals (CENADI, in Portuguese), located in Rio de Janeiro (BRASIL, 2013).

As described in the Brazilian cold chain manual for immunobiologicals transport (BRASIL, 2013), the distribution of vaccines to the end user of the chain occurs through regional, municipal, and local levels, which offer different types of support to the higher body, such as operations planning, vaccination schedules and vaccine applications in remote regions. Given the support, the end user of the chain, represented by the Brazilian population, benefits from an organized vaccination strategy, reducing the total time of the distribution chain.

However, upon receiving doses from the higher instance, the state level assumes responsibility for the administrative, logistical, and technical support necessary to ensure the efficient and safe performance of activities related to the storage and transportation of vaccines to instances below the distribution chain (BRASIL, 2023). According to BRASIL (2013), the state level is organized into 27 state storage and distribution centers for immunobiologicals, generally located in the capitals of the Brazilian federated units and under the technical-administrative responsibility of the state immunization coordination of the state health departments.

In terms of physical structure, the state level is organized into 27 state storage located throughout the national territory. During the Covid-19 pandemic, the batches of vaccines received by the state level came from the Logistics Distribution Center of the Ministry of Health, located close to Guarulhos airport, in São Paulo (BRASIL, 2013).

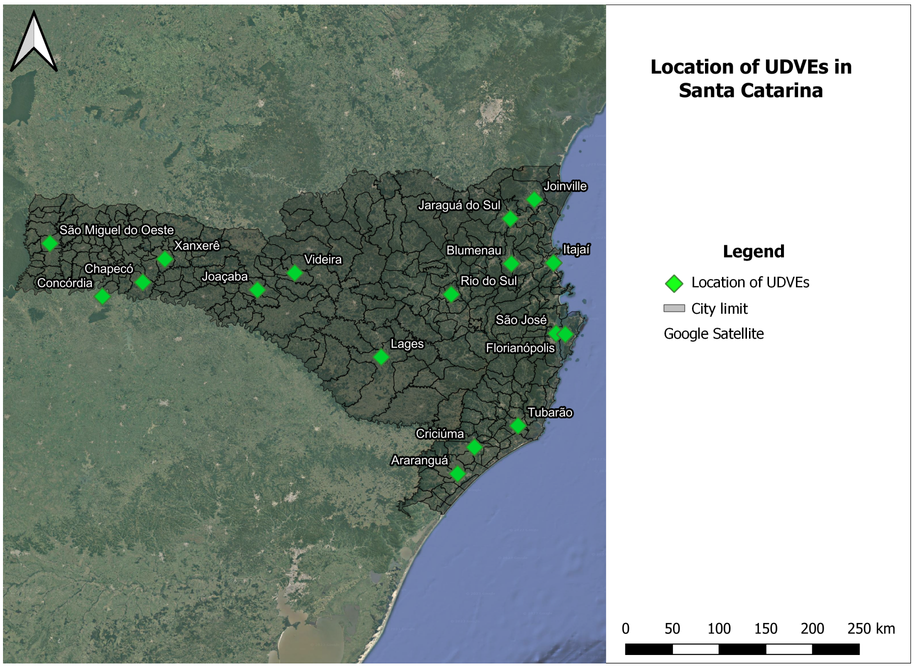
2.2.1 Vaccines distribution network in Santa Catarina

The state level in SC for immunobiologicals transport is represented by the central state of cold chain located in the city of São José (SANTA CATARINA, 2021). Logistical support between the instances of the distribution chain has become effective, as batches of vaccines are received at the Florianópolis airport, located close to São José. However, for distribution to other instances (regional, municipal, and local), it is possible to use the federal roadway, named as *BR-101* and the state highways, facilitating transport to other municipalities.

As stated in the vaccination plan against Covid-19, released by the government of SC, in addition to the central state of cold chain for immunobiologicals transport, there are 17 regional units of the State Department of Health (SES, in Portuguese) with specific storage locations for vaccines and general supplies (SANTA CATARINA, 2021). Firstly, the state center is responsible for distributing vaccine doses to those regional centers in SC, which distribute to the municipalities within the coverage areas (BRASIL, 2023). In this way, the vaccine distribution process is carried out in stages, ensuring broad coverage in SC.

The regional units of SC, also known as Decentralized Epidemiological Surveillance Units (UDVE, in Portuguese), as illustrated in Figure 3, responsible for distributing vaccines and other supplies, are located in the cities of Florianópolis, Blumenau, Joinville, Itajaí, Chapecó, Criciúma, Mafra, Tubarão, Rio do Sul, Videira, Lages, Jaraguá do Sul, Araranguá, Joaçaba, São Miguel do Oeste, Xanxerê and Concórdia (SANTA CATARINA, 2021).

Figure 3 – UDVE locations in Santa Catarina



Source: Author (2023).

As stated by the Government of Santa Catarina, the distribution flow is organized from the federal level to the local level (SANTA CATARINA, 2021), according to the following steps:

a) Logistics complex of the Ministry of Health, in the city of Guarulhos (SP).
b) Central State of Cold Chain for immunobiologicals transport, in the city of São José (SC).
c) Distribution of supplies to other regional units of SES.

After the supplies were delivered to the regional distribution centers in SC, the Municipal Health Departments are responsible for collecting the vaccine doses and distributing them among the municipality's health units (SANTA CATARINA, 2021). This process allows the population to be immunized in a coordinated and comprehensive manner, ensuring that vaccines reach the population.

To understand the cold chain for immunobiologicals transport enabled this study to identify critical points and potential areas for improvement in the distribution network of SC, once it represents the necessary infrastructure for the preservation and transportation of supplies under controlled temperature conditions.

To accurately represent the current distribution of immunobiologicals across the State of Santa Catarina, such as the transportation of Covid-19 vaccines, it was necessary to utilize tools associated with the concept of Geographic Information Systems (GIS). The need for creating maps to identify distribution locations and the road transport routes used between these sites necessitated the application of

GIS technology. This approach enabled a detailed spatial analysis, providing a visual representation of the distribution network and the logistic pathways employed for vaccine transportation across the region.

2.3 GEOGRAPHIC INFORMATION SYSTEM (GIS)

Geographic Information Systems (GIS) are computer systems designed to store and process geographic information about locations, represented by coordinates and location attributes, facilitating geographic information management and allowing quick analysis and automation of map creation (MARBLE, 1990). According to Longley and Ceshires (2017), the GIS is a collection of tools related to geoprocessing that improve the efficiency and effectiveness of handling information about geographic objects and events.

Geoprocessing represents a key operation in GIS, primarily focused on the manipulation and analysis of GIS data. Typically, a geoprocessing task involves taking an input dataset, applying a specific operation, and producing an output dataset as a result. According to Esri (2022), frequent geoprocessing tasks encompass a variety of procedures such as overlaying geographic features, selecting and analyzing features, processing topologies and rasters, as well as converting data formats. The core utility of geoprocessing lies in its ability to define, manage, and analyze information, thereby facilitating informed decision-making processes.

However, there are limits to the kinds of procedures and practices that can be automated when turning data into information. While latitude and longitude offer precise Earth locations, they fail to provide information about the size or accuracy of the located objects, which may cause precision loss in computer software.

For centuries, latitude and longitude lines have been pivotal in location description on Earth, greatly advancing fields like cartography, geography, and surveying through refined geodetic grids (DUTTON, 1999). The fusion of aerospace and computer technology has transformed location determination into a sophisticated practice, essential in various aspects of society. However, many GIS developers and users might not realize that reliance on these coordinates, and their projections, can limit software capabilities in processing and mapping locational data, particularly in handling issues related to scale, accuracy, and data quality (DUTTON, 1999).

GIS is widely used in various sectors for spatial analysis, mapping, and decision-making. Most GIS databases do not record locations in latitude and longitude but use planar projections instead, often preferred by primary geodata collectors like military and government agencies for their standardization in surveying and mapping (DUTTON, 1999).

Besides, the label 'GIS' describes many things, such as software tools for certain well-defined functions and digital representations of various aspects of the geographic world in the form of datasets (LONGLEY; CHESHIRE, 2017). Moreover, to process large volumes of data, satisfactory computer hardware are required, for example the popular tools such as ArcGIS (proprietary software), QGIS (open source software) and mapping platforms like OpenStreetMaps and Google Cloud.

ArcGIS, a widely recognized proprietary software, stands as a crucial tool for processing large volumes of geospatial data. Characterized by its comprehensive suite of GIS capabilities, ArcGIS offers robust data visualization, analysis, and mapping features. As definied by Esri (2023), its primary strength lies in its advanced spatial analysis, data integration, and detailed mapping functionalities.

On the other hand, QGIS, an open-source software, presents itself as a versatile alternative to proprietary GIS tools. Known for its flexibility and community-driven development, QGIS supports a wide range of geospatial data formats and offers a rich set of GIS functionalities. As stated by (QGIS, 2023), it provides capabilities for data visualization, spatial analysis, and map creation, similar to ArcGIS, but with the added advantage of being freely accessible and modifiable. The open-source nature of QGIS fosters a collaborative environment, encouraging continuous improvements and innovations from its user community.

As one of the primary file formats in QGIS, the shapefile is a vector data format crucial for encapsulating geographical features. It stores locational, geometrical, and attribute information of these features. Shapefiles primarily come in three types: point, line, and polygon. A point shapefile, represented by a single x,y coordinate, is versatile and can depict a range of geographical entities, from cities to wind turbines or garbage cans, depending on the map's scale (Iowa State University Extension and Outreach, 2023).

Line shapefiles, which have length and direction but no area, connect at least two x,y coordinates and are commonly used to represent linear features like roads, water lines, or rivers. Polygons, as two-dimensional closed figures with a minimum of three sides, delineate areas and are widely used to represent buildings, agricultural fields, or other defined boundaries.

In addition to these GIS tools, mapping platforms like OpenStreetMap and Google Cloud play significant roles in the realm of geospatial data processing. OpenStreetMap, a collaborative project to create a free editable map of the world (OpenStreetMap, 2023), is renowned for its crowdsourced data, which provides an up-to-date and detailed representation of geographical features. It is particularly useful for projects that require extensive and diverse geographical information from around the globe.

Google Cloud, encompassing a suite of cloud computing services, offers powerful mapping and data processing capabilities through its APIs and services

(Google Cloud, 2023). It is known for its scalability, reliability, and extensive data handling capacity, making it a suitable choice for projects demanding high computational power and storage. The integration of Google Cloud in GIS projects facilitates efficient data processing, analysis, and visualization.

Case studies involving the use of GIS serve as specific examples to demonstrate how GIS can effectively address problems or facilitate information sharing across various industries. According to Bahaire e Elliott-White (1999), the impact assessment and simulation hold growing significance in the realm of tourism development, then GIS can be instrumental in auditing environmental conditions, evaluating the suitability of locations for proposed developments and also to highlight areas of tourist interest in a specific region (JOVANOVIĆ, 2016).

Besides, as noted by Roberts et al. (2010), the GIS also may be used in marine geospatial ecology to illustrate predictions for dolphins habitat. As described by Fletcher-Lartey e Caprarelli (2016), the GIS may be used in health services with the aim of mapping household and community practices to understand disease risk in areas under study.

According to Marble (1990), the GIS comprises sophisticated computer software that contains the following major components:

- Data entry system: collects and processes spatial data from existing maps and remote sensors.
- Data storage and retrieval system: organizes spatial data efficiently, enables its rapid retrieval for subsequent analysis, and facilitates accurate updates to the spatial database.
- Data manipulation and analysis system: performs tasks such as changing the data shape based on user-defined rules.
- Data reporting system: displays the original and manipulated data.

The 1990s consolidated the use of GIS as an instrument to support decision-making. Therefore, the data reporting system features the results in tabular or cartographic form and incorporates digital cartography approaches (EMBRAPA, 2011), such as digital image processing, spatial analysis, 3D modeling, representing a significant change compared to traditional cartographic approaches (MARBLE, 1990). Each GIS have their own data modeling approach, leading to variations in how real-world phenomena are represented. Decisions in these systems range from how to organize hydrographic features to determining cell sizes in raster-based systems and modeling spatial relationships in vector databases (DUTTON, 1999).

Later, the advancement of computers allowed the dissemination of GIS technology. According to Bolfe, Matias e Ferreira (2008), Câmara (1996) and EMBRAPA (2011), the first projects implemented in Brazil from 1984 to 1990 were the survey of the remnants of the Brazilian Atlantic Forest, performed by *IMAGEM Sensoriamento*

Remoto, the mapping of risk areas for planting corn, wheat and soybean crops in the entire Southern Region of Brazil, carried out by *CPAC/EMBRAPA*, and the study of the geological characteristics of the *Recôncavo* basin, through the integration of geophysical, altimetric and remote sensing data, conducted by *CENPES/Petrobrás*.

Then, as stated by Câmara (1996), the geoprocessing sector in Brazil can be divided into:

- Cadastral: urban and rural registration applications, typically performed by city halls.
- Automated cartography: is carried out by institutions that produce basic and thematic mapping.
- Environmental: is composed of areas of agriculture and regional planning to use data integration to produce thematic maps, terrain models, and remote sensing images, for example.
- Concessionaires/Networks: the GIS can be used by concessionaires of water, electricity, and telephony.

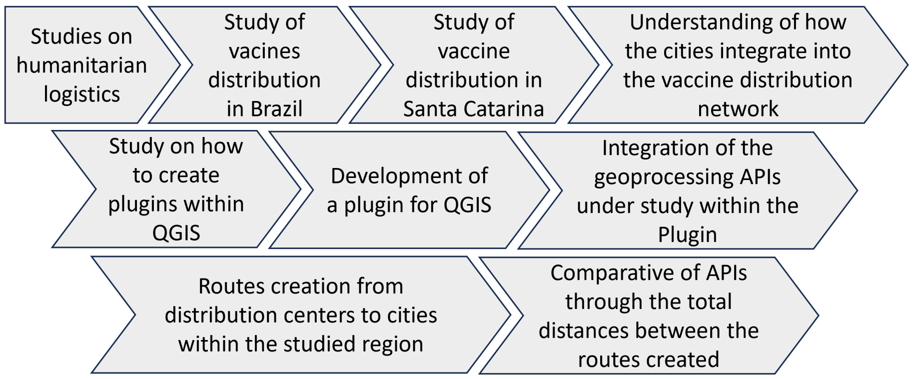
Furthermore, each segment has its characteristics and requires specific solutions (CâMARA, 1996). Hence, the journey between the purchase of the software and an operational result from the user is considerable, as it involves aspects such as the generation of geographic data, availability of methodologies, adequate working practices, and mechanisms for disseminating the results obtained (EMBRAPA, 2011).

Historically, the development of GIS in Brazil has evolved significantly, transitioning from initially limited and localized systems to more sophisticated and globalized platforms, with the common use of internationally developed software and databases. The GIS emerged as an essential tool to integrate the study due to its ability to analyze and visualize spatial data effectively. The understanding of GIS was crucial as it offers an advanced means for mapping distribution routes and to review itineraries, offering a sophisticated tool for visualizing the logistical pathways of immunobiologicals routes transport.

3 METHODOLOGY

This study is structured into distinct stages of research, as illustrated in Figure 4, aimed at acquiring bibliographic and technical knowledge to compose the research findings. However, this study is characterized as exploratory research due to its involvement in bibliographic surveys, stimulation of understanding of themes, and the use of results from interviews conducted by authors Lopes, Volpato e Fernandes (2022), where it was possible to obtain data on how municipalities in SC integrate within the vaccine distribution network.

Figure 4 – Research stages



Source: Author (2023).

The initial phase of this study encompassed a comprehensive exploration of humanitarian logistics and the vaccines distribution network in Brazil, with a particular focus on vaccine distribution in SC. This involved a detailed study of the existing vaccines distribution network and its operational mechanisms, as well as an analysis of how cities in SC integrate into this network.

The subsequent part of the study focused on the development of practical solutions within QGIS. This included an extensive study on how to create plugins within QGIS, followed by the actual development of a plugin designed for this research. In addition to this process was the integration of distinct geoprocessing APIs within the plugin, a step that combined both the theoretical understanding and practical application of GIS technology in addressing the research objectives.

The final segment of the research involved applying the developed plugin to create routes from distribution centers to cities within the studied region. The shapefiles used in QGIS were made available by the IBGE in 2020, containing information on the general infrastructure of the municipalities in SC. This practical application allowed a comparative analysis of the APIs based on the total distances between the routes found.

While using geoprocessing tools, new transport routes were calculated, considering criteria such as shorter distance traveled and ease of access to municipalities. Simulations and comparative analyses were conducted to identify the most efficient routes in terms of distance in distributing the vaccines doses. However, each route created was individually evaluated by the author, as the region of study was familiar to him, thereby enriching the analysis of the results

Through the QGIS software, cartographic maps were created for the purpose of illustrating the transport routes. These maps highlighted the municipalities involved in the vaccines distribution network, including information such as geographic location, suggested routes and estimated travelled distance. Further, the current distribution of vaccines was analyzed, considering the transport routes and the costs involved in terms of travelled distance.

There are several tools dedicated to obtaining and processing georeferenced data, such as ORS Tools and various APIs from Google Cloud. However, this study utilized QGIS as the central software for creating maps and for geoprocessing data obtained from Google Cloud, OSM, and the IBGE through shapefiles.

Furthermore, this study developed a plugin that synthesized geoprocessing APIs into a single layout. This plugin was designed to simplify the use of geoprocessing tools, making them more accessible and user-friendly. Integrating these APIs into one unified interface significantly enhanced productivity by allowing the researcher to manage and process data within QGIS more efficiently.

3.1 QGIS WITH SHAPEFILES FROM IBGE DATABASE

In this study, data provided in the shapefile format by the IBGE were essential for the use of QGIS's network tools. The QGIS software requires specific input files, such as point and line shapefiles, representing geographical elements like origin and destination locations, in addition to the road networks that comprise pathways between given points. These shapefile archives were fundamental for carrying out geoprocessing and detailed spatial analysis, enabling precise evaluation of distribution routes among the cities in a case study in south of SC. The integration of these geospatial data was crucial for mapping existing routes and proposing new itineraries.

In the road line shapefile, there is a table of attributes containing general information about the roads, such as jurisdiction, pavement, operational, acronym, and number of lanes. Regarding jurisdiction, the roads were classified as federal, state, and unknown. However, of the 46,828 roads registered in the shapefile of IBGE, only 4,621 have complete information, representing only 9.87% of the roads in SC.

To find the shortest distance between points using QGIS, the "network analysis" feature in the toolbox can be used through the shapefiles of the roads and points that were registered in advance and activated within the QGIS software.

3.2 OPENROUTESERVICE (ORS) AND OPENSTREETMAP (OSM)

The QGIS software includes a variety of add-ons, notably community-developed plugins, that enhance its overall functionality. Specifically in the area of geoprocessing, the ORS Tools plugin is notable for its integration of the OSM database, consequently enriching its capabilities. Prior registration is required to use the ORS functionalities through an API key received to validate the user using the OSM database. As it is a free and collaborative tool, there are restrictions on the amount of data to be processed per simulation.

However, the ORS team provided an API key, that was requested via email for educational purposes, with an elevated processing limit. This enhanced access was crucial for the analyses conducted. Thereby, the integration of the OSM database with the features of the ORS API offered a comprehensive and reliable methodology for determining travel distances between designated points.

3.3 DIRECTIONS API FROM GOOGLE CLOUD

Renowned globally for its comprehensive and detailed geographic data, Google Maps plays a pivotal role in GIS researches. A fundamental aspect of many geospatial studies involves the accurate calculation of distances between origin and destination points. Similar to OSM, the Google Maps database is utilized for land mapping, among other uses, and encompasses essential information about roads, including pavement types, tolls, and transportation modes.

A notable distinction between the Google Maps and OSM databases lies in the entities managing them. They are developed by a private corporation and a non-profit organization, respectively, with the latter involving user participation in the platform. To use the ’Directions API’ service, it was necessary to register on the Google Cloud platform and obtain an API key, thereby enabling the implementation of various geoprocessing functionalities through algorithms.

However, as the objective of this study is to calculate the travel distance by land transport between previously registered sites, it was defined in the algorithm that the mode of transport is "driving" and that, in the point shapefile, all dots between the first and last registered will be considered as waypoints, representing intermediate sites between the beginning and end of the route.

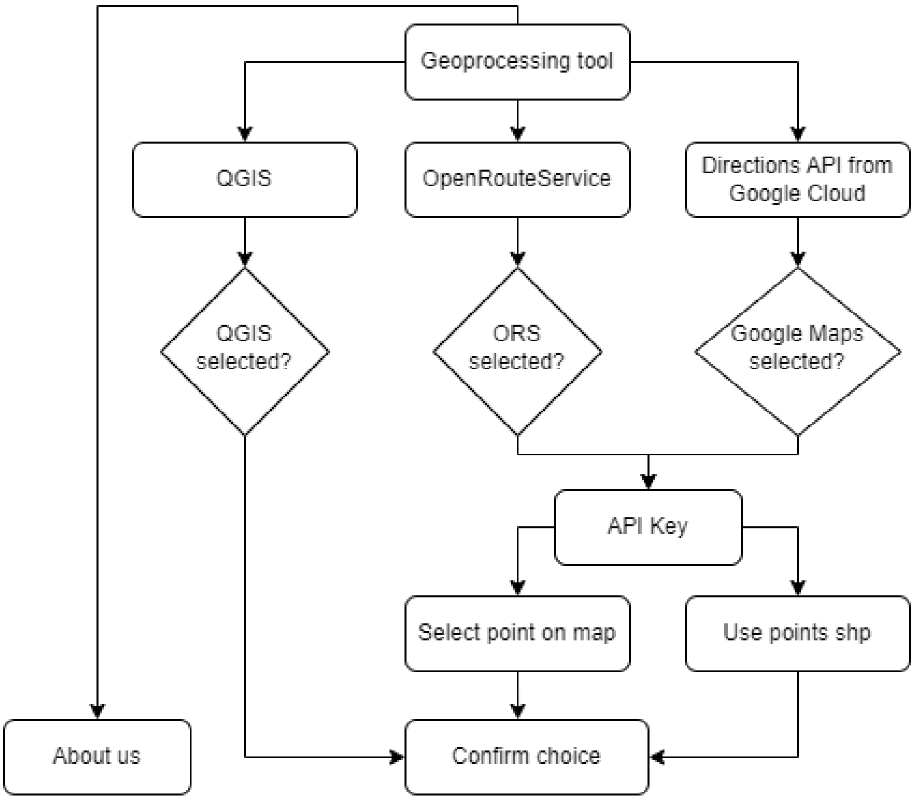
3.4 PILOT PLUGIN DEVELOPED

In order to validate the results obtained by previous tools, the Pilot Plugin was developed in Python to calculate the developed route after selecting points of interest on the map or loading the shapefile with previously registered points. The Qt Designer software, integrated within the QGIS, was used to develop the Pilot Plugin, with custom widgets for creating the user interface. When placing widgets in the plugin interface, it was necessary to synchronize them in the algorithm.

The plugin algorithm was structured according to Figure 5, adopting road transport as a way of transportation. Distinct resources were used for geoprocessing and graphic editing to create visual route shapefiles, such as those developed for the QGIS software and the "openrouteservice" and "googlemaps" tools, allowing geoprocessing through registered APIs from OSM and Google Cloud. Therefore, three analysis methods were considered in the Pilot Plugin, namely:

- QGIS - as inputs, shapefiles of roads and registered dots were treated using the native QGIS tool to calculate the shortest distance between displacements.
- ORS - it is possible to select points on the map or use the shapefiles of registered points using the OSM database to calculate displacement.
- Google Maps - similar to the ORS method, using the API obtained from Google Cloud.

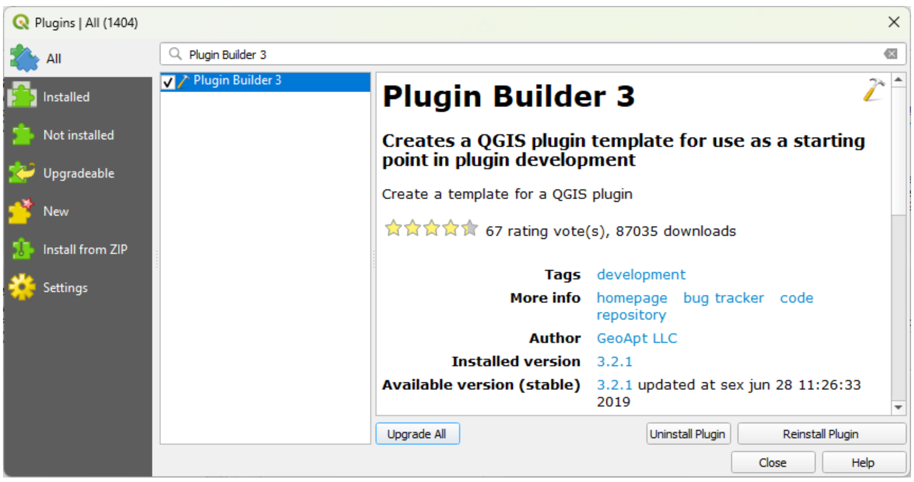
Figure 5 – Pilot Plugin flowchart.



Source: Author (2023).

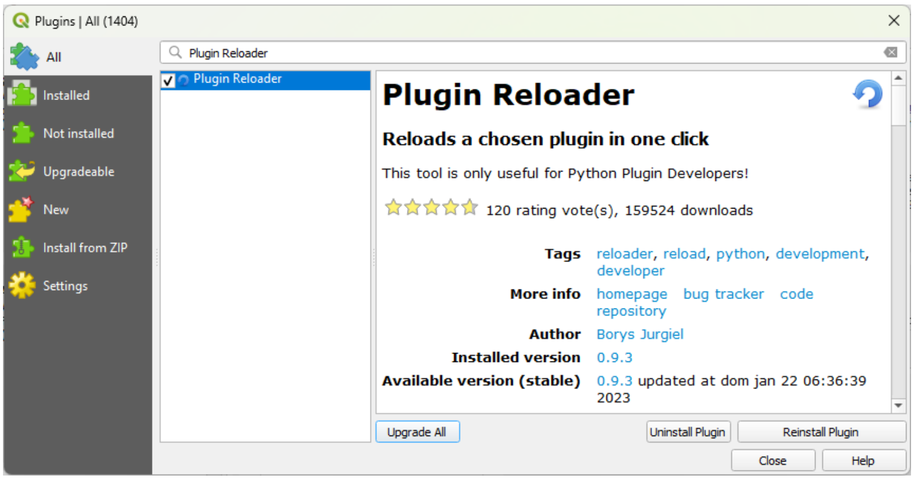
In the advanced stages of this research, upon completion of the Pilot Plugin's coding phase, it became necessary to utilize two specific plugins from the QGIS add-on library: "Plugin Builder 3" and "Plugin Reloader," as depicted in Figures 6 and Figure 7, respectively. The initial step involved registering a blank plugin within the QGIS library to start the development of the user interface.

Figure 6 – Plugin Builder 3 in the QGIS



Source: Author (2023).

Figure 7 – Plugin Realoder available in the QGIS

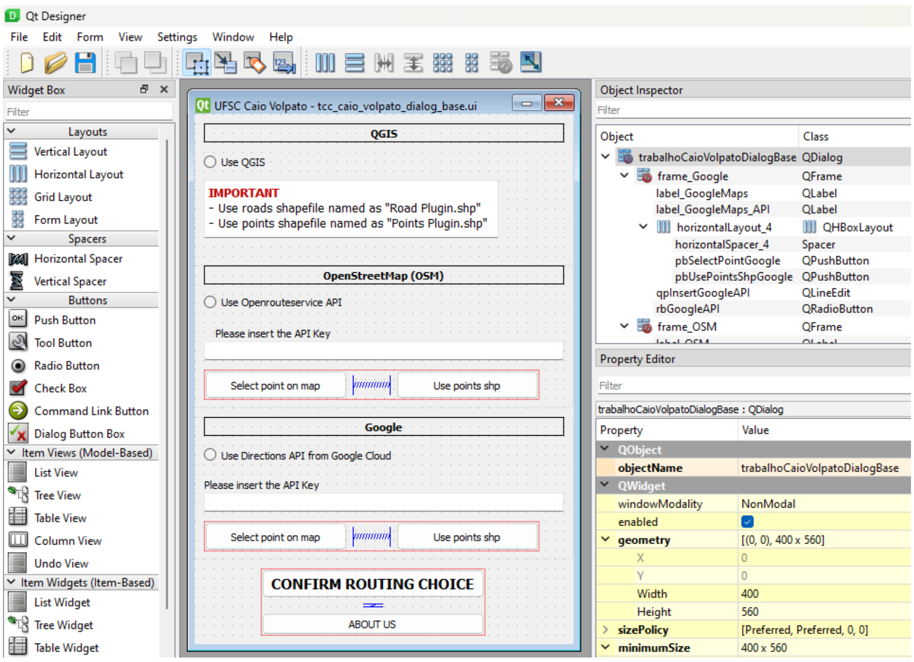


Source: Author (2023).

The first files for the coding and customization of the Pilot Plugin were created through the template generated by "Plugin Builder 3". Subsequently, for efficient testing and debugging within QGIS, the "Plugin Reloader" allowed a faster loading and unloading of the plugin, facilitating iterative adjustments without the need for manual installation and uninstallation following each modification.

After setting up the plugin structure, the Qt Designer was used to create the necessary user interface widgets and then integrate these features through Python coding, as demonstrated in Figure 8. Later, the plugin was functional for use.

Figure 8 – Qt Designer layout integrated within the QGIS



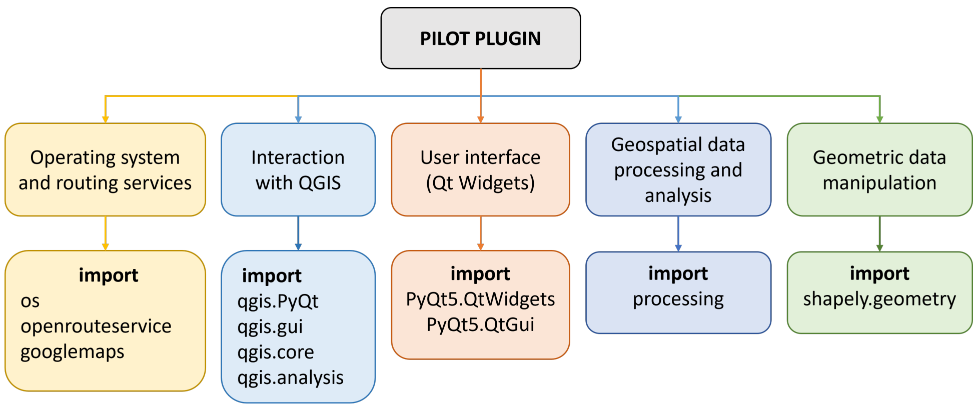
Source: Author (2023).

Throughout the research, significant challenges were encountered in seeking literature that fully elucidated the relationship between QGIS and QT Designer for the development of algorithms in Python. The available online literature proved to be scarce and often insufficient to provide a comprehensive understanding of the interaction between these development tools. Consequently, it became essential to search for detailed technical documentation of each tool used, as well as to immerse in tutorial videos provided by the YouTube community. These alternative strategies were fundamental in acquiring the necessary technical knowledge for the formulation of the proposed algorithm and for achieving the objectives of this study.

3.4.1 Pilot Plugin code structure

The libraries and modules used in the Pilot Plugin code can be divided into four main groups, listed in Figure 9. Each of these groups is used for different purposes in the plugin. While *os* and the geoprocessing tools (*openrouteservice* and *googlemaps*) are used for accessing external web services and handling system data, the QGIS-related libraries (*qgis.PyQt*, *qgis.gui*, *qgis.core*, *qgis.analysis*) are essential for integrating the plugin with QGIS software, interacting with the user, and processing geospatial data. The *shapely.geometry* is an additional library for geometric calculations that can complement the functionalities of QGIS.

Figure 9 – Pilot Plugin code structure



Source: Author (2023).

Each feature has its own purpose and functionalities, as detailed in Appendix A. For the construction of the algorithm, additional functions available within the libraries were utilized, responsible for integrating the buttons into the layout of the plugin and ensuring the proper execution of the geoprocessing APIs.

As presented in Appendix B, the functionality of selecting origin and destination points on the QGIS map was also coded within the algorithm, treating these as inputs for the functions that handle the graphical part, subsequently creating shapefiles of points. For the line shapefiles, containing the created routes, it was first necessary to implement the algorithm of the APIs to generate an output containing the trajectory between the points under study. This trajectory was then coded to be displayed within the QGIS map.

4 DATA ANALYSIS AND RESULTS DISCUSSION

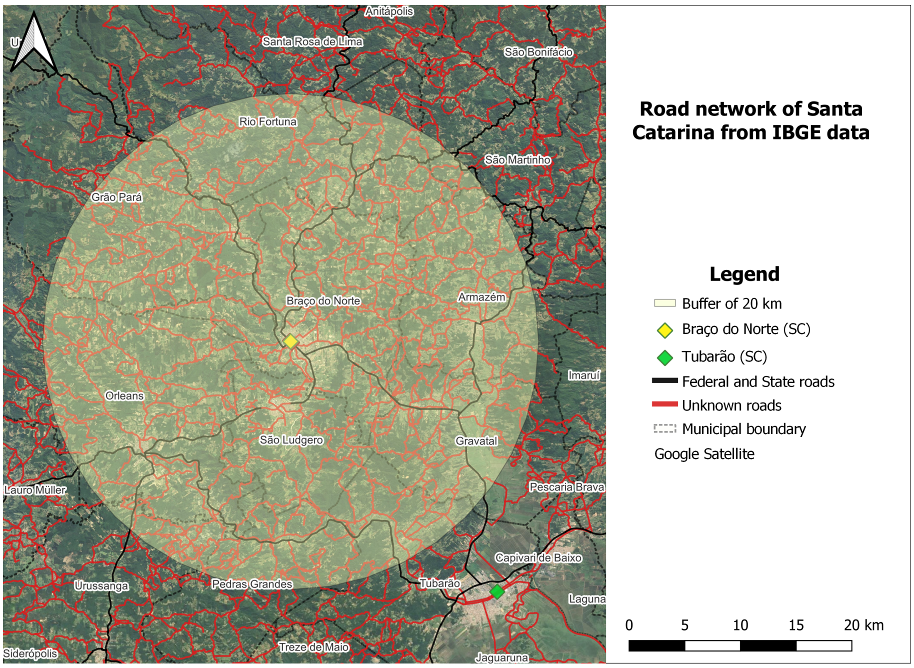
In the following sections, the tools from QGIS, ORS (OpenRouteService), and Google Cloud are outlined and utilized to conduct a comparative assessment within this research. The use of these tools facilitates the visualization of the study's findings through the creation of shapefiles.

4.1 STUDY AREA DEFINITION

In a comprehensive assessment of the tools developed, an examination was conducted on a region situated in the southern region of SC, where the distribution routes of vaccines among neighboring municipalities were examined. The purpose was to investigate how these road traffic routes could be developed using geoprocessing tools, contributing to the composition of a new distribution network.

The city of Braço do Norte was hypothetically chosen in this research to represent a new UDVE in the distribution network of Santa Catarina because it is a region familiar to the author. To create a visual representation, the Figure 10 contains a hypothetically 20 km buffer encircling the city of Braço do Norte. This delineation was employed to determine the municipalities that would be incorporated through the geoprocessing tools in order to create road routes.

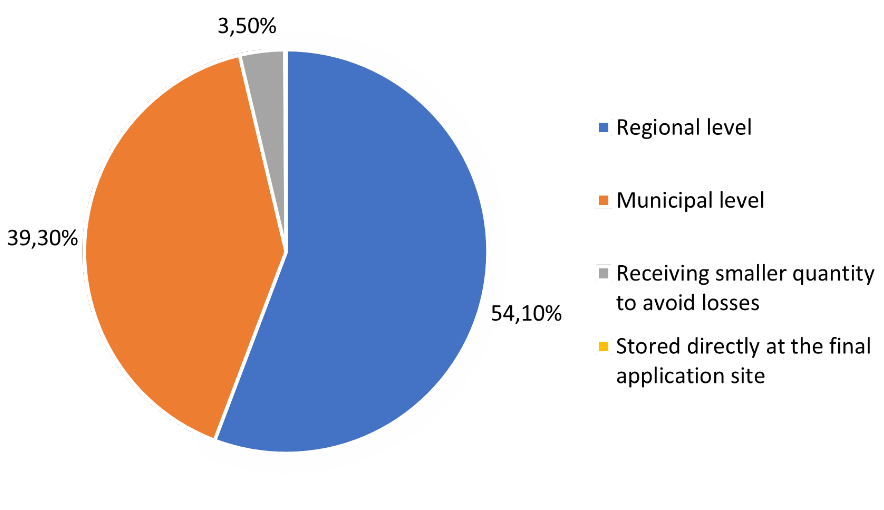
Figure 10 – Buffer of 20 km in the study area



Source: Author (2023).

In addition, data were obtained from the study conducted by authors Lopes, Volpato e Fernandes (2022), involving interviews with cities in SC through an online form to gather information about vaccine distribution, providing detailed insights of how the municipalities integrate into the distribution network, the storage locations of the received vaccines, and primarily from where they received the vaccine doses, as presented in Figure 11.

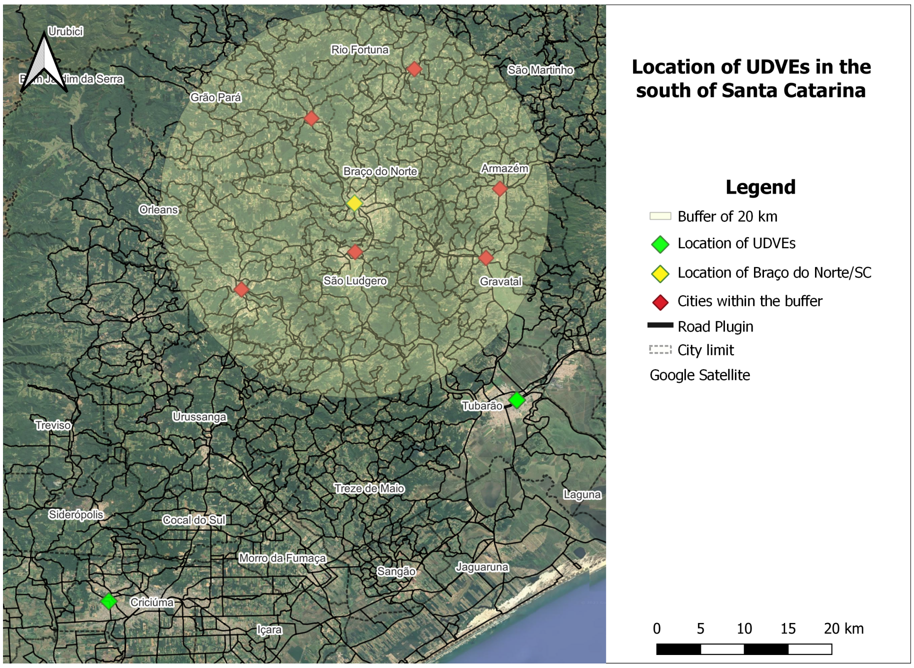
Figure 11 – Where are the large batches of vaccines stored before reaching the final application site in the municipality



Source: Author (2023) adapted from Lopes, Volpato e Fernandes (2022).

Notably, according to SANTA CATARINA (2021), the UDVEs located in the city of Tubarão and Criciúma, as shown in Figure 12, oversees the provision of resources for the adjacent municipalities in the region under study. Therefore, road routes were created with the intention of restructuring the vaccine distribution routes, since each city, even those located far away, is tasked with collecting supplies directly from the regional units in Tubarão or Criciúma.

Figure 12 – Location of UDVEs in the south of Santa Catarina

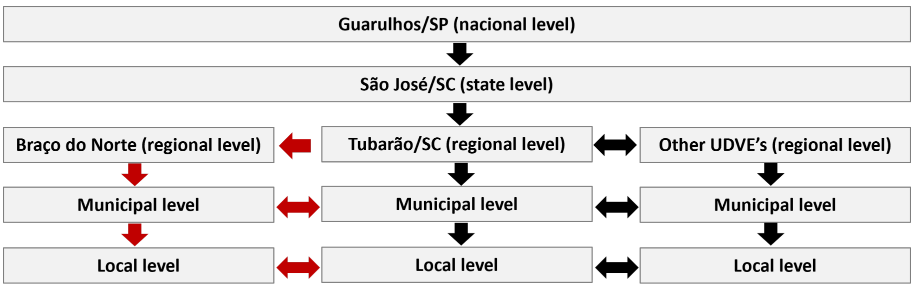


Source: Author (2023).

Besides, due to being located in the middle of the created buffer, Braço do Norte has a strategic geographical placement and connectivity to other municipalities that are situated at greater distances from Tubarão. In the current distribution, the municipalities highlighted by the created buffer are receiving vaccine doses from the UDVE of Tubarão. However, when hypothetically considering the city of Braço do Norte as a distribution center, new routes were created to carry out the road transport of these supplies.

When considered Braço do Norte as a new stage in vaccine distribution network, the current network were adapted according to Figure 13. Therefore, there are two stages following the state level, with the regional level being composed of the existing UDVE in Tubarão, representing the first regional level, and the new center proposed in Braço do Norte, representing the second regional level, in addition to the regional level originated by other UDVEs in SC.

Figure 13 – Adapted vaccines distribution network organized into administrative spheres



Source: Author (2023).

If any unforeseen circumstances arise that render Braço do Norte incapable of functioning as a distribution site, it would still be feasible to transport supplies via the existing road network for vaccine distribution to the municipalities within the region under study. This contingency plan ensures that vaccine distribution remains uninterrupted, demonstrating the resilience and adaptability of the cold chain for immunobiologicals transport of Santa Catarina in the face of potential disruptions.

For the development of new vaccine distribution routes in this study, the following assumptions were made: the mode of transportation is limited to road transport, the road infrastructure is in good condition for traffic, only one vehicle is employed for distribution, the average speed performed were 60 km/h, and the city of Braço do Norte possesses adequate resources to store vaccine doses designated for neighboring municipalities. The routes created are situated in flat terrain, assuming uniform travel conditions, enabling the calculation of travel time based on the relationship between the distance traveled and the average speed considered.

These premises sustain the logistical planning and route creating, ensuring that the proposed distribution strategy is both feasible and effective within the defined constraints and operational conditions.

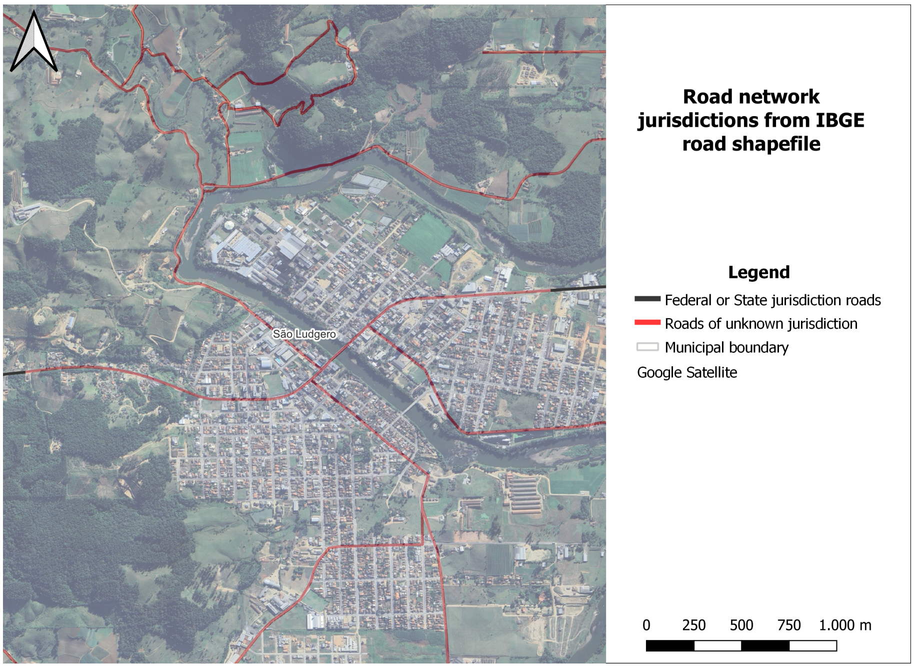
4.1.1 Constraints for creating routes

Throughout the evaluation and execution of the presented geoprocessing tools, some limitations were identified that could significantly affect the accuracy in calculating distances and creating routes. These limitations include the need for up-to-date data on road conditions, such as construction, temporary closures, or permanent changes in road layout. Additionally, incompatibility between different mapping systems can result in discrepancies in route information. The absence of data on paving types or specific traffic restrictions in certain areas also contributes to potential errors in route projection. If these issues are not adequately corrected or considered, they may result in inaccurate routes.

When calculating distances between cities to create routes for road transport, it is possible to select dots in QGIS's map close to sites of interest, such as health departments, in the region under study to compose a point shapefile.

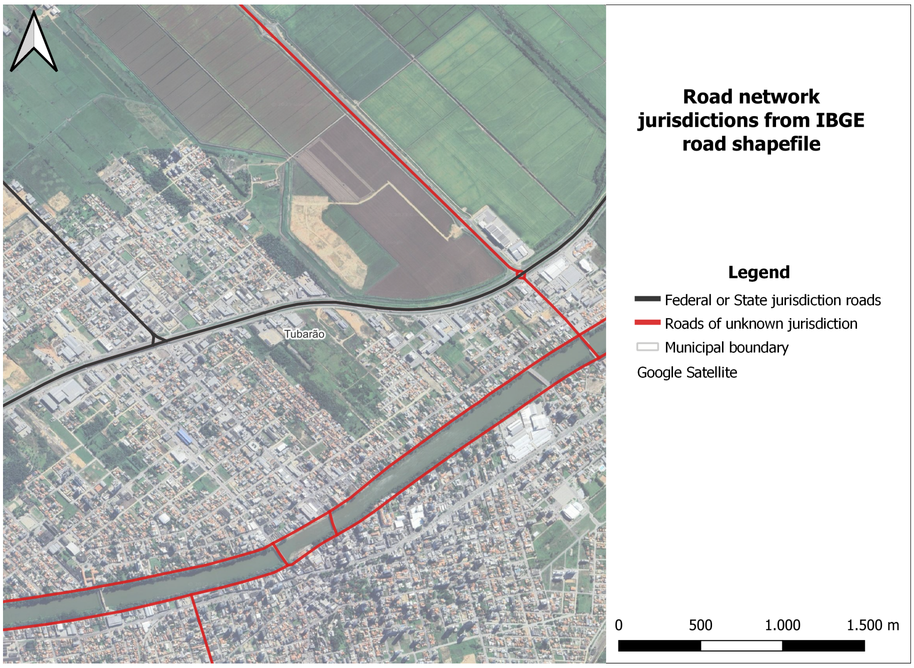
Roads of known and unknown jurisdiction were considered, respecting the limit of the municipality under study, since the majority of roads, represented by line segments, according to the shapefile provided by IBGE, are of unknown jurisdiction, as demonstrated by Figure 14 and Figure 15. If the user has a shapefile with points of interest, it is possible to insert it into QGIS to use it to create routes.

Figure 14 – Road network jurisdictions in São Ludgero (SC)



Source: Author (2023).

Figure 15 – Road network jurisdictions in Tubarão (SC)



Source: Author (2023).

Besides, there are interrupted line segments in the road shapefile made available by IBGE, as indicated in Figure 16. This gap negatively affected route calculation through the network analysis tool since the QGIS uses the road shapefile as input data for route calculation. Correcting these interruptions was essential to guarantee the integrity of the data and allow an accurate calculation of routes, thus contributing to the efficiency of logistical planning.

Figure 16 – Gap in the road network of Braço do Norte (SC)

Source: Author (2023).

For correction, new line segments were created between these points, forming links between the beginning of a segment and the end of other unconnected neighboring segments. In most of the compromised locations, bridges were identified between unconnected points. If they are not corrected, the route proposed by the QGIS tool could present another an adequate travel distance.

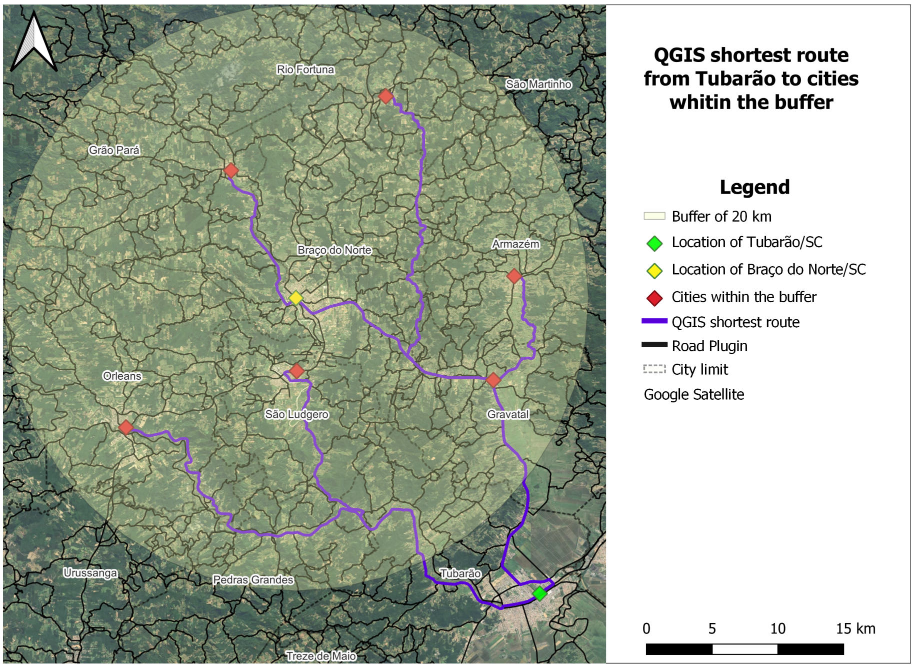
In order to showcase the distinctive features of each tool examined, the Pilot Plugin algorithm was implemented without incorporating the topography of the roads while generating the suggested routes. This approach was followed to illustrate how the algorithm calculates the shortest distance between two points through the API without accounting for any constraints or relevant conditions such as road jurisdiction, paving types, and temporary closures on the road.

4.2 QGIS API WITH IBGE DATABASE

The native "network analysis" tool in the QGIS software was employed to measure the distance between origin and destination points. This tool not only facilitates the computation of the shortest distance between individual points but also between a specified origin or destination and a layer of points. However, this method necessitates a road shapefile to execute its geoprocessing functionality. For this study, the required shapefile was sourced from IBGE, ensuring accurate and region-specific data.

The outcomes of this approach are presented in Figure 17. Therefore, the trajectory commences in the city of Tubarão and stretches to the cities within the buffer of the study area, as delineated in Figure 10, though the entire charted distance amounts to 287,68 kilometers.

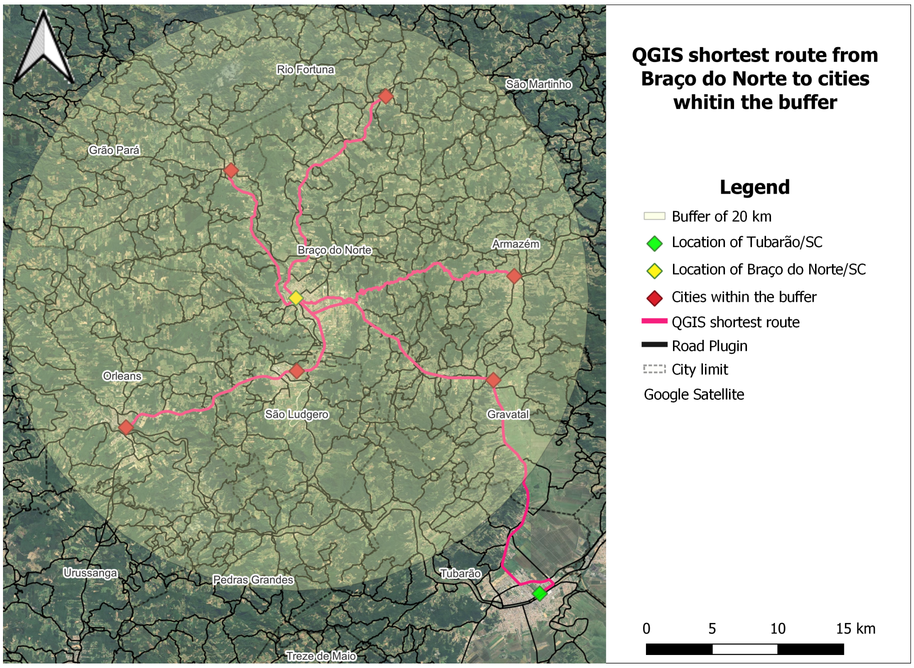
Figure 17 – QGIS shortest route from Tubarão to cities whitin the buffer



Source: Author (2023).

However, in Figure 18, it is possible to see how distribution logistics performed from the center in the city of Braço do Norte to the cities within the buffer defined in Figure 10, then the total charted distance sums up to 145 kilometers.

Figure 18 – QGIS shortest route from Braço do Norte to cities whitin the buffer



Source: Author (2023).

Therefore, compared to the current system, the route calculated from Braço do Norte shows an approximate reduction of 50,4% in the overall distance cities would need to travel to obtain essential supplies, representing a time reduction of 142.68 minutes. The comparative distances between municipalities are detailed in Table 2.

Table 2 – Distances (in km) calculated by the network analysis in QGIS with IBGE shapefiles.

City	From Tubarão	From Braço do Norte
Armazém	33.70	22.30
Braço do Norte	39.74	-
Grão Pará	53.19	13.45
Gravatal	21.61	18.14
Orleans	46.87	22.49
Rio Fortuna	54.97	21.22
São Ludgero	37.60	7.66
Tubarão	-	39.74
Total	287.68	145.00

Source: Author (2023).

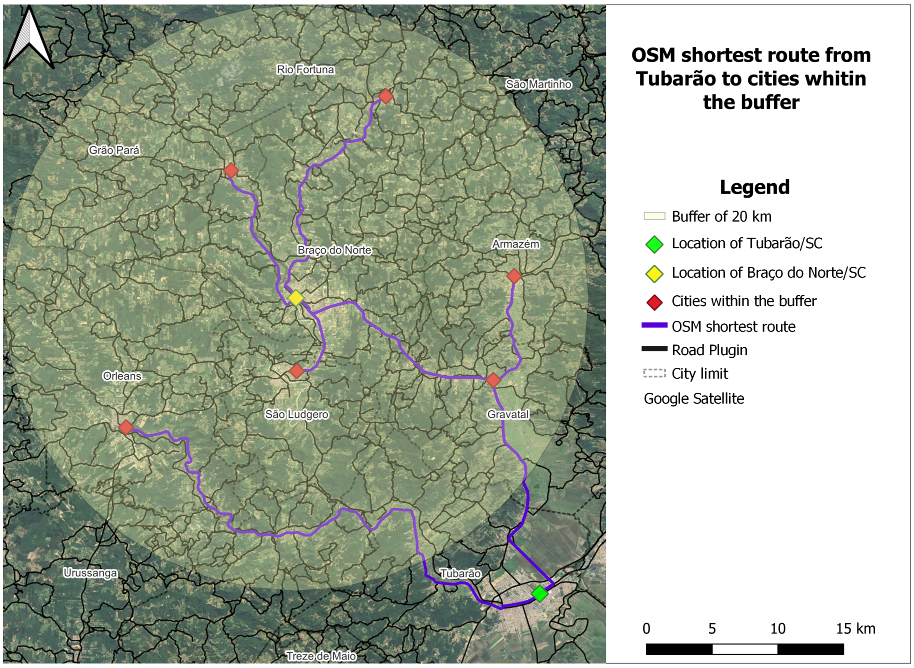
Nonetheless, it is imperative to mention that while the "network analysis" tool provides valuable insights, the method might not always consider intricate nuances like road topology or the actual condition of the pavements. As a result, the derived routes sometimes deviate from the continuous paved roads, leading to potential disparities in the route conditions and distances calculated.

4.3 OPENROUTESERVICE (ORS) API

The OpenStreetMap (OSM) is a recognized database that provides a wide range of geographic information for accurate and comprehensive analysis. Regardless, the distance between origin and destination points is a crucial metric in many geospatial analyses. Then, this distance was calculated accurately through ORS API using the OSM database, allowing a deeper understanding of the displacement dynamics involved.

The trajectory of Figure 19 starts in Tubarão and extends to all cities within the buffer area, as demonstrated in Figure 10, covering a total mapped distance of 286.85 kilometers. However, it is essential to note that the methodology did not consider specific factors such as road topology or pavement conditions. Consequently, some route deviations were made with a primary focus on minimizing distance. This approach led to routes that occasionally do not stick to paved and continuous roads, potentially resulting in inaccurate representation of the actual distances and route conditions.

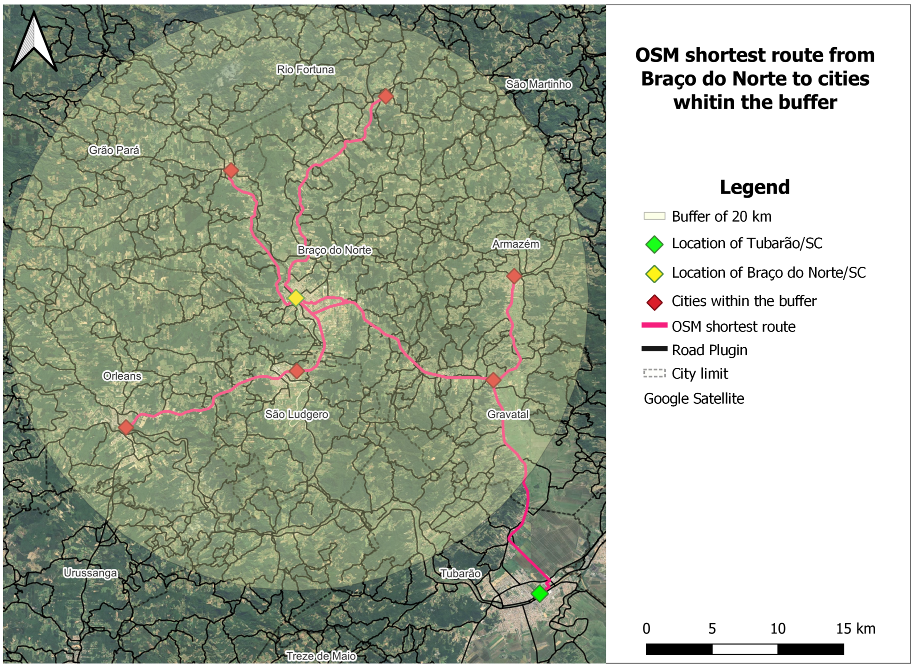
Figure 19 – OSM shortest route from Tubarão to cities whitin the buffer



Source: Author (2023).

Nevertheless, the proposed route covering cities within the buffer shown in Figure 10 and extending to Braço do Norte, is depicted in Figure 20. When compared to the current vaccines distribution network, a reduction of 52.20% is observed in the total distance that cities would need to cover to obtain essential supplies, meaning a time reduction of 137.12 minutes. The comparative distances between municipalities are detailed in Table 3.

Figure 20 – OSM shortest route from Braço do Norte to cities whitin the buffer



Source: Author (2023).

Table 3 – Distances (in km) calculated by ORS API.

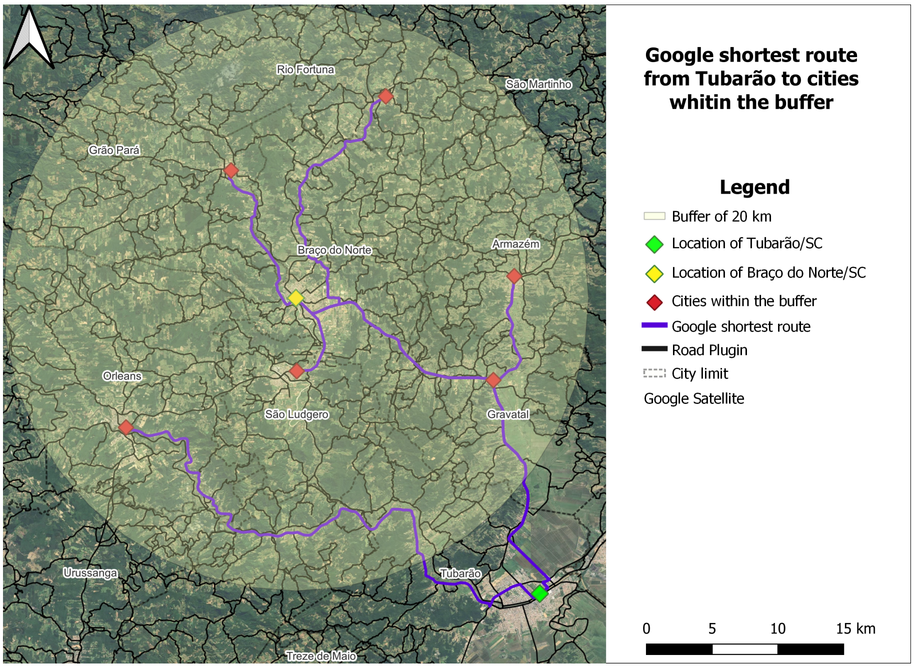
City	From Tubarão	From Braço do Norte
Armazém	29.59	28.18
Braço do Norte	38.08	-
Grão Pará	51.44	13.46
Gravatal	19.62	18.21
Orleans	46.72	22.50
Rio Fortuna	59.32	21.55
São Ludgero	42.08	7.68
Tubarão	-	38.15
Total	286.85	149.73

Source: Author (2023).

4.4 DIRECTIONS API FROM GOOGLE CLOUD

The procedure initiated in Tubarão is depicted in Figure 21 and extends to the most distant city included in the study buffer of Figure 10. This journey spans a distance of 285.12 kilometers, covering all cities within the designated buffer. Within the framework of the Pilot Plugin, it is crucial to note that the Directions API from Google Cloud prioritizes travel time as the primary attribute, according to its documentation. Otherwise, the APIs from QGIS and OSM prioritize the shortest distance as the primary attribute.

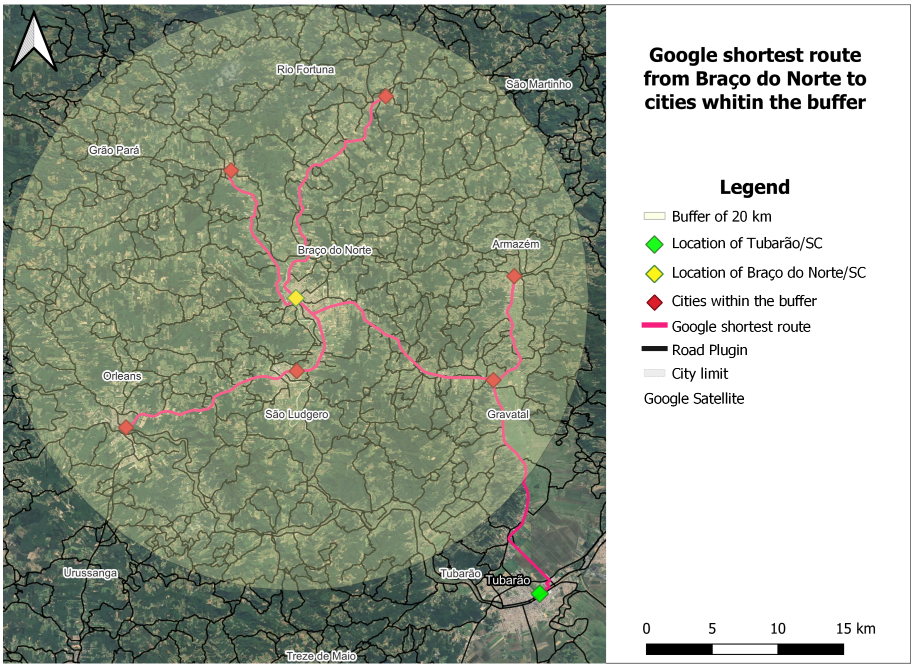
Figure 21 – Google shortest route from Tubarão to cities whitin the buffer



Source: Author (2023).

Further, the created route, calculated by Google API, encompassing cities within the buffer of Figure 10 and reaching Braço do Norte, is shown in Figure 22. Regarding the current vaccines distribution network in SC, a significant reduction of 52,29% is achieved in the total distance, representing a time reduction of 136.04 minutes. The comparative distances between municipalities are detailed in Table 4.

Figure 22 – Google shortest route from Braço do Norte to cities whitin the buffer



Source: Author (2023).

Table 4 – Distances (in km) calculated by Directions API.

City	From Tubarão	From Braço do Norte
Armazém	29.00	28.16
Braço do Norte	37.94	-
Grão Pará	51.26	13.45
Gravatal	19.80	18.20
Orleans	47.73	22.49
Rio Fortuna	57.14	21.30
São Ludgero	42.25	7.67
Tubarão	-	37.81
Total	285.12	149.08

Source: Author (2023).

4.5 COMPARISON BETWEEN THE ROUTES CREATED

A significant difference is how to calculate the desired routes through the roads considered by the QGIS, ORS, and Directions API databases, once they used IBGE shapefiles, OSM data and Google Cloud information, respectively, but each with a distinct algorithm. For example, when moving between Braço do Norte and Armazém, each tool proposed different routes and consequently different distances, as shown in Table 5.

Table 5 – Distances (in km) calculated between the routes created.

	Tubarão			Braço do Norte		
City	QGIS	OSM	Google	QGIS	OSM	Google
Armazém	33.70	29.59	29.00	22.30	28.18	28.16
Braço do Norte	39.74	38.08	37.94	-	-	-
Grão Pará	53.19	51.44	51.26	13.45	13.46	13.45
Gravatal	21.61	19.62	19.80	18.14	18.21	18.20
Orleans	46.87	46.72	47.73	22.49	22.50	22.49
Rio Fortuna	54.97	59.32	57.14	21.22	21.55	21.30
São Ludgero	37.60	42.08	42.25	7.66	7.68	7.67
Tubarão	-	-	-	39.74	38.15	37.81
Total	287.68	286.85	285.12	145.00	149.73	149.08

Source: Author (2023).

It is observable that the Directions API exhibited the greatest reduction in distance traveled by the municipalities when the route started in Braço do Norte and no longer in Tubarão, as noted in Table 6. Statistically, the reductions of 52.20% and 52.29% presented by the ORS and the Directions API, respectively, are similar, necessitating the consideration of additional criteria when selecting the tool. Such criteria may include factors like a lower number of turns in the itinerary. This nuanced analysis highlights the importance of not only assessing the quantitative metrics but also considering qualitative aspects of route efficiency and practicality in the decision-making process for tool selection.

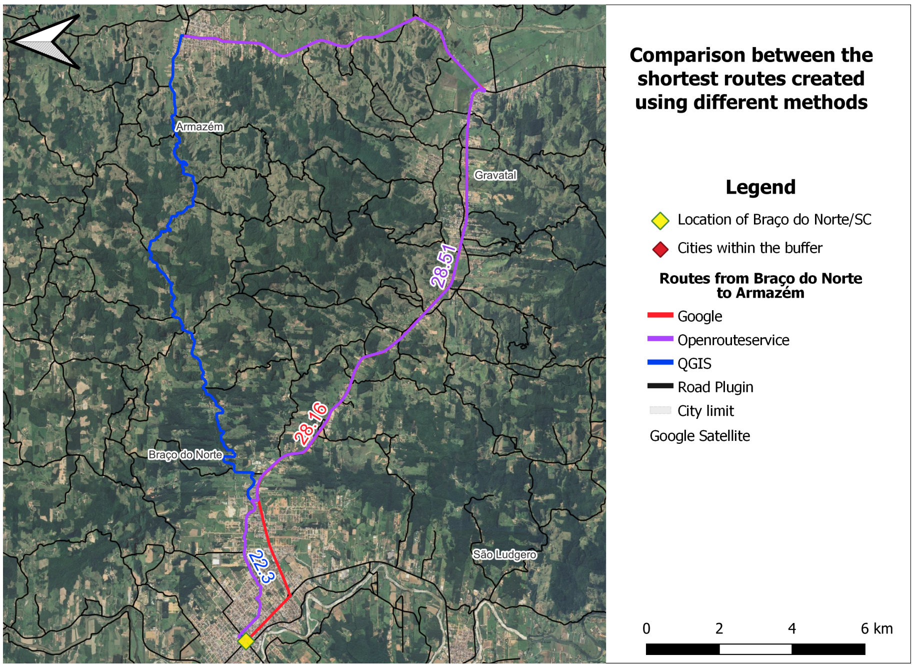
Table 6 – Distances reduction using distinct geoprocessing tools.

	QGIS	ORS	Directions API
Reduction (%)	50.40%	52.20%	52.29%

Source: Author (2023).

If the maps are enlarged, it is possible to identify locations where the geoprocessing tools differ in their decisions. For example, when leaving the city of Braço do Norte to Armazém, the algorithms considered different routes to leave the city center, as indicated in Figure 23. However, when observing the maps created, the route proposed by Directions API is the most recommended, as there are few turns, and the route is entirely on asphalt pavement.

Figure 23 – Comparison between the shortest routes created using different methods



Source: Author (2023).

5 CONCLUSIONS

In this study, QGIS, ORS, and the Directions API from Google Cloud were employed to generate routes and their corresponding cartographic maps. However, each tool presented different distances and routes. Hence, it is essential for GIS users to evaluate these tools, comprehending the disparate outcomes that may arise when alternating between distinct algorithms and databases for proposing routes between specified points, ensuring the reliability and accuracy of the geoprocessing within GIS applications.

The shapefiles provided by the IBGE exhibited limitations that impacted the analysis. In particular, within the road file of SC, only 9.87% of the roads had complete information across all columns, imposing significant constraints on the development and enhancement of the Pilot Plugin. The lack of comprehensive data on characteristics such as pavement type or road jurisdiction curtailed the plugin's capacity to implement detailed geoprocessing restrictions and preferences for the use of the QGIS API, since its inputs were shapefiles sourced from the IBGE. This data gap indicated the need for more robust and detailed databases to enhance the accuracy of geoprocessing and logistical analysis in the context of route creation.

However, with the provision of a comprehensive shapefile of the roads in SC, encompassing detailed information about terrain, pavement type, and jurisdiction, it would be feasible to enhance the Pilot Plugin to include advanced restriction options. While the APIs from Google Cloud and ORS offer data on road conditions, the integration of these specifics into the Pilot Plugin was not performed in this study, given that the shapefile used in QGIS does not has full information. The decision to not implement road restriction options was deliberate, aiming to maintain a uniform and comparative analysis across the geoprocessing tools, thus allowing an equitable evaluation of the capabilities of the different APIs in line with the original objectives of the study.

For the region under study, located in the south of SC, geoprocessing methods using ORS and QGIS revealed the generation of atypical traffic routes for the studied region. According to the shapefiles provided by IBGE, a notable feature of these routes is the frequent inclusion of unpaved roads, which do not have a specified jurisdiction or infrastructure classification.

In contrast, the Google Cloud tool demonstrated greater effectiveness when proposing itineraries, opting primarily for federal and state highways. These roads are the region's most practical and commonly used due to their well-developed infrastructure. This difference in results suggests greater precision and adaptability of the Google Cloud tool in recognizing and prioritizing more suitable routes for travel in the studied area.

The modification proposed in the current vaccines distribution network is a specific change in the existing logistics of the UDVE of Tubarão, which can be seen in Figure 13. This change was designed to accommodate the unique requirements and logistical demands of this particular region.

Therefore, when the road routes calculated started in Braço do Norte, the distribution network time decreased by 136,04 minutes, representing a reduction of 52,29%, considering an average speed of 60 km/h and the geoprocessing tool of Directions API, since the vaccines received in São José were first be transported to Tubarão and later to Braço do Norte, being collected by neighboring cities. If the QGIS API is considered, there will be a reduction of 50.40% in the distance traveled and 142.68 minutes in travel time, respectively. For the ORS API, the reduction in the distance traveled and travel time will be 52.20% and 137.12 minutes, respectively.

In a normal situation, where there is only refueling and no urgency for supplies, it is justifiable to start the distribution network in the hypothetical city of Braço do Norte in order to achieve savings in travel, representing a lower monetary cost for each city. However, it is essential to highlight that the proposed network is contextual and may not directly apply to other regions of Santa Catarina.

For implementations in different locations, it is recommended to carry out preliminary studies to identify target cities and evaluate the specific logistical needs of each area. These studies must consider regional variables such as infrastructure, climate, population density, and specific demand for health services to ensure that any adaptation proposed for the vaccines distribution network are efficient and appropriate to local needs.

5.1 FUTURE RESEARCH SUGGESTIONS

For future studies, it is suggested that the Pilot Plugin be enhanced to include features that allow the application of road restrictions, enabling users to select routes with specific attributes, such as pavement type, number of lanes, presence or absence of tolls, and other relevant characteristics. Such development would allow for more detailed customization of geoprocessing tools, tailoring it to specific logistical needs and enhancing the accuracy of distribution analyses. The implementation of these restriction options would not only contribute to the functionality of the plugin but also significantly to transportation logistics, particularly in scenarios requiring careful consideration of road conditions when proposing new routes.

When conducting geoprocessing in smaller regions, it is feasible to manually correct some of the limitations inherent in the IBGE shapefiles, especially when they are used as inputs. Disruptions in the trajectory of roads in line shapefiles can be readily rectified within QGIS. However, a meticulous investigation of each route by the user is required. An indication of flaws in the shapefile arises when attempting to execute network analysis tools within QGIS, as the software often displays an error pointing to a failure in the shapefile, highlighting the need for precise and careful adjustments to ensure data integrity and accuracy in geographical analyses.

Moreover, if alternative transportation modes such as aerial delivery are considered, it would be valuable to explore the potential of using drones for vaccine distribution. This approach is particularly relevant given the existing use of drones for the transportation of goods in Brazil and medical supplies in Rwanda, for example. However, such an exploration would necessitate a thorough examination of the transportation process, especially considering the specific requirements and constraints associated with immunobiologicals, such as their durability and refrigeration needs. This line of study could significantly contribute to the development of innovative and efficient distribution methods in the field of humanitarian logistics and public health.

Furthermore, it is possible to execute the traveling salesman algorithm to transport essential supplies to local units, proposing that distribution be carried out by visiting cities with the lowest number of vehicles, for example. As in the current model, each city needs to go to the responsible UDVE to collect supplies through the traveling salesman for non-emergency situations, aiming to maintain the concept of humanitarian logistics.

Therefore, it is desirable to identify overall improvements in the vaccines distribution network of Santa Catarina, such as reducing pollutant emissions through fewer vehicles in circulation and lowering the cost of road transport incurred by the cities.

BIBLIOGRAPHY

BAHAIRE, T.; ELLIOTT-WHITE, M. The application of geographical information systems (gis) in sustainable tourism planning: A review. **Journal of Sustainable Tourism**, Taylor & Francis, v. 7, n. 2, p. 159–174, 1999.

BALLOU, R. H. The evolution and future of logistics and supply chain management. **European business review**, Emerald Group Publishing Limited, v. 19, n. 4, p. 332–348, 2007.

BOLFE, É. L.; MATIAS, L. F.; FERREIRA, M. C. Sistemas de informação geográfica: uma abordagem contextualizada na história. **Geografia**, v. 33, n. 1, p. 69–88, 2008.

BRASIL. **Manual de Rede de Frio do Programa Nacional de Imunizações**. 2013. Available in: https://bvsms.saude.gov.br/bvs/publicacoes/manual_rede_frio4ed.pdf. Access in: June 04, 2023.

BRASIL. **Lei Nº 14.124, de 10 de março de 2021**. 2021. Dispõe sobre as medidas excepcionais relativas à aquisição de vacinas e de insumos e à contratação de bens e serviços de logística, de tecnologia da informação e comunicação, de comunicação social e publicitária e de treinamentos destinados à vacinação contra a covid-19 e sobre o Plano Nacional de Operacionalização da Vacinação contra a Covid-19. Diário Oficial da União, 10 mar. 2021. Available in: https://www.in.gov.br/en/web/dou/-/lei-n-14.124-de-10-de-marco-de-2021-307745858. Access in: March 07, 2023.

BRASIL. **Rede de Frio**. 2023. Access in: March 26, 2023. Disponível em: https://www.gov.br/saude/pt-br/assuntos/saude-de-a-a-z/c/calendario-nacional-de-vacinacao/rede-de-frio.

Council of Supply Chain Management Professionals. **SCM Definitions and Glossary of Terms**. 2023. Access in: June 04, 2023. Disponível em: https://cscmp.org/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms.aspx.

COZZOLINO, A. Humanitarian logistic. **SpringerBriefs in Business**, 2012.

CâMARA, G. **Desenvolvimento de sistemas de informação geográfica no Brasil: desafios e oportunidades**. [S.l.], 1996. Palestra proferida na Semana de Geoprocessamento do Rio de Janeiro.

DUTTON, G. H. **A hierarchical coordinate system for geoprocessing and cartography**. [S.l.]: Springer, 1999. v. 79.

EMBRAPA. **A evolução histórica dos Sistemas de Informações Geográficas**. [S.l.], 2011.

ERGUN, O. et al. Humanitarian supply chain management-an overview. In: SCHLOSS DAGSTUHL-LEIBNIZ-ZENTRUM FÜR INFORMATIK. **Dagstuhl seminar proceedings**. [S.l.], 2009.

ERGUN, O. et al. Operations research to improve disaster supply chain management. **Encyclopedia of operations research and management science**, John Wiley & Sons Hoboken, NJ, v. 6, p. 3802–3810, 2010.

Esri. **GIS Dictionary**. 2022. https://webhelp.esri.com/arcgisserver/9.3/java/geodatabases/definition_frame.htm. Access in: September 10, 2023.

Esri. **About ArcGIS - Overview**. 2023. https://www.esri.com/en-us/arcgis/about-arcgis/overview. Access in: September 10, 2023.

FLETCHER-LARTEY, S. M.; CAPRARELLI, G. Application of gis technology in public health: successes and challenges. **Parasitology**, Cambridge University Press, v. 143, n. 4, p. 401–415, 2016.

Google Cloud. **Google Cloud Documentation - Overview**. 2023. https://cloud.google.com/docs/overview?hl=pt-br. Access in: September 10, 2023.

Iowa State University Extension and Outreach. **QGIS Digitizing I: Creating New Shapefiles**. 2023. https://store.extension.iastate.edu/product/QGIS-Digitizing-I-Creating-New-Shapefiles. Access in: September 10, 2023.

JOVANOVIĆ, V. The application of gis and its components in tourism. **Yugoslav journal of operations research**, v. 18, n. 2, 2016.

KOVÁCS, G.; SPENS, K. Identifying challenges in humanitarian logistics. **International Journal of Physical Distribution & Logistics Management**, Emerald Group Publishing Limited, v. 39, n. 6, p. 506–528, 2009.

LONGLEY, P. A.; CHESHIRE, J. A. Geographical information systems. In: **The Routledge Handbook of Mapping and Cartography**. [S.l.]: Routledge, 2017. p. 251–258.

LOPES, L. H.; VOLPATO, C. T.; FERNANDES, C. W. N. Desafios logísticos e indicadores de desempenho na distribuição das vacinas para covid-19: um estudo de caso no estado de santa catarina. **Anais do 42º Encontro Nacional de Engenharia de Produção**, Enegep Foz do Iguaçu, p. 4–11, 2022.

MARBLE, D. F. Geographic information systems: an overview. **Introductory readings in geographic information systems**, Taylor & Francis London and Bristol, PA, v. 3, n. 4, p. 8, 1990.

OpenStreetMap. **About OpenStreetMap**. 2023. https://wiki.openstreetmap.org/wiki/About_OpenStreetMap. Access in: September 10, 2023.

OVERSTREET, R. E. et al. Research in humanitarian logistics. **Journal of humanitarian logistics and supply chain management**, Emerald Group Publishing Limited, v. 1, n. 2, p. 114–131, 2011.

QGIS. **About QGIS**. 2023. https://qgis.org/en/site/about/index.html. Access in: September 10, 2023.

ROBERTS, J. J. et al. Marine geospatial ecology tools: An integrated framework for ecological geoprocessing with arcgis, python, r, matlab, and c++. **Environmental Modelling & Software**, Elsevier, v. 25, n. 10, p. 1197–1207, 2010.

SANTA CATARINA. **Plano Estadual de Vacinação contra a COVID-19**. 2021. Available in: https://www.coronavirus.sc.gov.br/wp-content/uploads/2021/02/plano_campanha_vacinacao_covid_19_sc_edicao_2.pdf. Access in: May 06, 2023.

SIEBERT, C. Mudanças climáticas e desastres naturais em santa catarina: Impactos socioterritoriais e avaliação das políticas públicas. **XVII Encontro Nacional da Associação Nacional de Pós-Graduação e Pesquisa em Planejamento Urbano e Regional. São Paulo**, p. 1–22, 2017.

SILVA, M. d. N.; FLAUZINO, R. F. **Rede de frio: gestão, especificidades e atividades**. [S.l.]: Editora Fiocruz, 2017.

TATHAM, P.; CHRISTOPHER, M. **Humanitarian logistics: Meeting the challenge of preparing for and responding to disasters**. [S.l.]: Kogan Page Publishers, 2018.

TOMASINI, R.; VAN WASSENHOVE, L. **Humanitarian logistics**. [S.l.]: Springer, 2009.

VAN WASSENHOVE, L. N. Humanitarian aid logistics: supply chain management in high gear. **Journal of the Operational research Society**, Taylor & Francis, v. 57, n. 5, p. 475–489, 2006.

APPENDIX A - LIBRARIES AND MODULES USED IN PILOT PLUGIN

Feature	Description
os	Module that provides functions to interact with the operating system.
openrouteservice	A Python client for accessing the ORS API, which provides OSM-based geoprocessing and other geospatial services.
googlemaps	Library for accessing the Google Maps API, enabling functionalities such as geocoding, geoprocessing, and other map-related services
qgis.PyQt	Integration of PyQt with QGIS, used to access and create user interface (UI) elements within the QGIS environment
qgis.gui	Contains classes for GUI elements related to the QGIS map, such as map tools (e.g. QgsMapToolEmitPoint).
qgis.core	Provides the core functionality of QGIS, such as classes for vector layers (QgsVectorLayer), features (QgsFeature), and geometry (QgsGeometry).
qgis.analysis	Module for geospatial analysis, such as network processing and vector analysis.
PyQt5.QtWidgets	Classes for creating the user interface, such as dialogs.
PyQt5.QtGui	Contains classes for graphic elements and user interaction, such as colors (QColor).
shapely.geometry	To allow the manipulation and analysis of planar geometric shapes, like points, lines, and polygons.
processing	QGIS module that provides access to the QGIS processing framework, which includes algorithms for geospatial analysis and geoprocessing.

Source: Author (2023).

APPENDIX B - PILOT PLUGIN CODE IN PYTHON

```python
import os
import openrouteservice
import processing
import googlemaps

# QT Designer
from qgis.PyQt import uic
from qgis.PyQt import QtWidgets
from PyQt5.QtWidgets import QDialog, QApplication, QTextEdit,
    QPushButton, QMessageBox
from PyQt5.QtWidgets import QButtonGroup
from qgis.gui import QgsMapToolEmitPoint

# Criar e carregar layer de rotas no QGIS
from qgis.core import QgsVectorLayer, QgsFeature, QgsGeometry,
    QgsVectorFileWriter, QgsProject, QgsSimpleLineSymbolLayer,
    QgsSymbol, QgsRendererCategory, QgsCategorizedSymbolRenderer,
    QgsPointXY, QgsWkbTypes, QgsMapLayer
from qgis.PyQt.QtGui import QColor
from qgis.analysis import *
from qgis.core import QgsPointLocator

from shapely.geometry import Point

# Carregar o arquivo .ui file
FORM_CLASS, _ = uic.loadUiType(os.path.join(
    os.path.dirname(__file__), 'tcc_caio_volpato_dialog_base.ui'))

class trabalhoCaioVolpatoDialog(QtWidgets.QDialog, FORM_CLASS):
    def __init__(self, iface, parent=None):
        # Constructor
        super(trabalhoCaioVolpatoDialog, self).__init__(parent)

        # Permite acessar o QGIS
        self.iface = iface
        #User interface from Designer through FORM_CLASS
        self.setupUi(self)
```

```

        # print_about_us        self.pbPrintAboutUsClicked.clicked.
           connect(self.print_about_us)

        # Inicializa a lista onde as coordenadas serao salvas
        self.coordinates_list = []

        # Conecta o botao a funcao de selecionar pontos no mapa
        self.pbSelectPointOSM.clicked.connect(self.
           start_selecting_point)
        self.pbSelectPointGoogle.clicked.connect(self.
           start_selecting_point)
        # Conecta os botoes a funcao de usar o shp de pontos
        self.pbUsePointsShpOSM.clicked.connect(self.use_points_shp)
        self.pbUsePointsShpGoogle.clicked.connect(self.
           use_points_shp)

        # Configura o QgsMapToolEmitPoint
        self.point_tool = QgsMapToolEmitPoint(self.iface.mapCanvas
           ())
        self.point_tool.canvasClicked.connect(self.
           handle_point_selected)

        # Configura as APIs do OSM e Google
        self.client = None

        # Criando o grupo para os botoes de radio
        self.bgRoutingMethod = QButtonGroup(self)
        self.bgRoutingMethod.addButton(self.rbOpenStreetMapAPI)
        self.bgRoutingMethod.addButton(self.rbQGIS)
        self.bgRoutingMethod.addButton(self.rbGoogleAPI)

        # Conectar os RadioButtons a uma funcao que decide qual
           roteamento usar
        self.pbConfirmRoutingChoice.clicked.connect(self.
           decide_routing_method)

# Botao que apresenta informacoes sobre o projeto
    def print_about_us(self):
        QMessageBox.information(self, "ABOUT US",
            """Hello!
```

```
    This plugin was made by Caio Tramontin Volpato,
    a student in the Universidade Federal de Santa Catarina.

    Have a great day!""")

# Funcao para carregar o shp de Points Plugin
    def use_points_shp(self):
        # Tente obter a camada pelo nome "Points Plugin"
        point_layers = QgsProject.instance().mapLayersByName("Points Plugin")
        if not point_layers:
            QMessageBox.critical(self, "Error", "Points Plugin layer not found in the project!")
            return

        # Certifica que ha apenas um shp nomeado como "Points Plugin"
        point_layer = point_layers[0]

        # Limpar a lista de coordenadas existentes
        self.coordinates_list = []

        # Adicionar todos os pontos da camada   lista de coordenadas
        for feature in point_layer.getFeatures():
            geom = feature.geometry()
            self.coordinates_list.append((geom.asPoint().x(), geom.asPoint().y()))

        if not self.coordinates_list:
            QMessageBox.warning(self, "Warning", "No coordinates provided!")
            return coordinates_list

        # Comentei comando abaixo e inclui coordinates_list no return acima
        #self.decide_routing_method()

# Funcoes para selecionar os pontos no mapa
    def start_selecting_point(self):
        # Ativa o QgsMapToolEmitPoint para comecar a pegar pontos
```

```
        self.iface.mapCanvas().setMapTool(self.point_tool)

    def handle_point_selected(self, point, button):
        # Adiciona o ponto   lista. Note que estamos invertendo X e Y, deixando como (lon, lat)
        self.coordinates_list.append((point.x(), point.y()))

        # Desativa a ferramenta apos a selecao
        self.iface.mapCanvas().unsetMapTool(self.point_tool)

        # Verifica se atingimos 5 pontos
        if len(self.coordinates_list) >= 5:
            QMessageBox.information(None, "Information", "The maximum number of points has been added.")
            #print(self.coordinates_list)  # imprime as coordenadas no terminal
            return

        # Pergunte ao usuario se deseja adicionar outro ponto
        reply = QMessageBox.question(None, "Question", "Do you want to select another point?", QMessageBox.Yes | QMessageBox.No)

        if reply == QMessageBox.Yes:
            self.start_selecting_point()
        else:
            if not self.coordinates_list:
                QMessageBox.warning(self, "Warning", "No coordinates provided!")
                return
            #self.decide_routing_method()

# Funcao para criar o shapefile. Espera coordenadas (lon, lat)
    def create_and_load_route_layer(self, coordinates):
        # A funcao cria uma camada vetorial de linha ("LineString") com sistema de coordenadas EPSG:4326 (WGS 84).

        # Esta camada eh temporaria e armazenada na memoria, nao sendo salva em disco por padrao.
        route_layer = QgsVectorLayer("LineString?crs=EPSG:4674", "Calculated Route", "memory")
```

```

        # O provedor de dados eh uma interface que permite interagir diretamente com os dados subjacentes da camada.
        prov = route_layer.dataProvider()

        # Cria-se um recurso geomehtrico do tipo linha a partir das coordenadas fornecidas.
        feature = QgsFeature()

        # A funcao 'fromPolylineXY' converte uma lista de pontos (coordenadas) em uma linha (geomehtrica).
        # A lista de pontos eh derivada das coordenadas fornecidas.
        feature.setGeometry(QgsGeometry.fromPolylineXY([QgsPointXY(coord[0], coord[1]) for coord in coordinates]))

        # O recurso criado eh adicionado a camada usando o provedor de dados.
        prov.addFeature(feature)

        # Estilizacao, definindo a cor e largura da linha
        symbol = QgsSymbol.defaultSymbol(route_layer.geometryType())
        symbol.setColor(QColor(255, 0, 0))  # vermelho
        symbol.setWidth(1)  # tamanho 1

        # Aplica-se o simbolo definido   camada e dispara-se um repintar, garantindo que as atualizacoes de estilo sejam visiveis.
        route_layer.renderer().setSymbol(symbol)
        route_layer.triggerRepaint()

        # A camada eh adicionada ao projeto QGIS atual para que seja visivel no canvas do mapa.
        QgsProject.instance().addMapLayer(route_layer)

        # Limpar a lista de coordenadas
        self.coordinates_list = []

# DECIDIR QUAL MehTODO USAR (OSM, QGIS OU GOOGLE)

```

```python
    def decide_routing_method(self):
        if self.rbOpenStreetMapAPI.isChecked():
            self.configure_client_OSM_API()
            self.calculate_route_using_OSM(self.coordinates_list)
        elif self.rbQGIS.isChecked():
            self.calculate_route_using_QGIS()

        elif self.rbGoogleAPI.isChecked():
            self.configure_client_Google_API()
            self.calculate_route_using_Google(self.coordinates_list)

        else:
            QMessageBox.warning(self, "Warning", "Please select a routing method!")

# OPEN STREET MAP

    def calculate_route_using_OSM(self, coordinates):
        if not hasattr(self, 'client') or not self.client:
            QMessageBox.warning(self, "Warning", "Please configure the API key first!")
            return

        try:
            # Usar o cliente configurado para calcular a rota
            route = self.client.directions(coordinates=coordinates, profile='driving-car', format='geojson')

            # Aqui voce pode processar o resultado da rota como desejar.
            # Por exemplo, voce pode extrair as coordenadas e exibir no QGIS, etc.
            # Como exemplo simples, estou apenas imprimindo a rota no terminal.
            print(route)

            # Extrair as coordenadas da rota
            route_coordinates = route['features'][0]['geometry']['coordinates']

```

```
            # Chamar a funcao para criar e carregar a layer de rota no QGIS
            self.create_and_load_route_layer(route_coordinates)

            # Se voce quiser mostrar algo para o usuario no final:
            QMessageBox.information(self, "Route Calculated", "The route has been successfully calculated!")

        except Exception as e:
            # Isso ira pegar qualquer erro que ocorrer durante a solicitacao ou processamento.
            # Mostra uma mensagem de erro ao usuario com a descricao do problema.
            QMessageBox.critical(self, "Error", f"An error occurred while calculating the route: {e}")

    def configure_client_OSM_API(self):
        api_key = self.qpInsertOpenStreetMapAPI.text()  # Obtendo a chave API da QLineEdit
        if api_key:
            self.client = openrouteservice.Client(key=api_key)
            QMessageBox.information(self, "Info", "Client successfully initialized!") # Mensagem informando que a conexao foi bem-sucedida

        else:
            # Caso a QLineEdit esteja vazia, informe o usuario
            QMessageBox.warning(self, "Warning", "Please enter a valid API key!")
            return

# QGIS (cost retorna em layer units, precisa multiplicar por 100.000 para ter em metros)

    def calculate_route_using_QGIS(self):

        point_layer = QgsVectorLayer("C:\\CAIO TRAMONTIN VOLPATO\\UFSC\\TCC\\TCC\\Shapefiles criados\\Points Plugin.shp", "Points", "ogr")
        road_layer = QgsVectorLayer("C:\\CAIO TRAMONTIN VOLPATO\\UFSC\\TCC\\TCC\\Shapefiles criados\\Road Plugin.shp", "
```

```
Roads", "ogr")

        # Certifique-se de que as camadas foram carregadas corretamente
        if not point_layer.isValid() or not road_layer.isValid():
            QMessageBox.warning(self, "Error", "Failed to load layers!")
            return

        # Supondo que voce queira calcular o caminho do primeiro ponto para o ultimo ponto da camada de pontos:
        start_point = point_layer.getFeature(0).geometry().asPoint()
        end_point = point_layer.getFeature(point_layer.featureCount() - 1).geometry().asPoint()

        parameters = {
            'INPUT': road_layer,
            'START_POINT': start_point,
            'END_POINT': end_point,
            'OUTPUT': 'memory:ShortestPath'  # Esta eh uma camada de memoria para armazenar o resultado
        }

        result = processing.run("qgis:shortestpathpointtopoint", parameters)
        # O resultado sera uma nova camada que voce pode adicionar ao seu projeto QGIS:
        shortest_path_layer = result['OUTPUT']
        QgsProject.instance().addMapLayer(shortest_path_layer)
        QMessageBox.information(self, "Route Calculated", "The shortest route has been successfully calculated!")

# GOOGLE MAP

    def configure_client_Google_API(self):
            api_key = self.qpInsertGoogleAPI.text()  # Obtendo a chave API da QLineEdit

            if api_key:
                self.gmaps_client = googlemaps.Client(key=api_key)
```

```python
                QMessageBox.information(self, "Info", "Google Maps client successfully initialized!") # Mensagem informando que a conexao foi bem-sucedida

            else:
                # Caso a QLineEdit esteja vazia, informe o usuario
                QMessageBox.warning(self, "Warning", "Please enter a valid API key!")
                return

    def calculate_route_using_Google(self, coordinates_list):
        if not hasattr(self, 'gmaps_client'):
            QMessageBox.warning(self, "Warning", "Google Maps client is not initialized!")
            return

        # Aqui assume que coordinates_list contem pelo menos dois pontos: origem e destino.
        # Adicionar verificacoes para lidar com menos pontos se necessario.
        # Necessario inverter pois coordinates_list esta como (lon, lat)
        self.coordinates_list = [(lat, lon) for lon, lat in coordinates_list]
        origin = self.coordinates_list[0]
        destination = self.coordinates_list[-1]
        print(f"Origin: {str(origin)} and destination: {str(destination)}")

        try:
            # Obtenha a rota usando a API de direcoes do Google Maps
            result = self.gmaps_client.directions(
                origin,
                destination,
                mode="driving",
                waypoints=self.coordinates_list[1:-1] if len(self.coordinates_list) > 2 else None, # pontos intermediarios
                optimize_waypoints=True
            )
```

```python

            if result:
                polyline = result[0]['overview_polyline']['points']
                print(polyline)
                route_coordinates = self.decode_polyline_using_Google(polyline)

                # Exibir a rota no mapa, lembrando que a coordenada deve ser (lon, lat)
                route_coordinates = [(lon, lat) for lat, lon in route_coordinates]
                self.create_and_load_route_layer(route_coordinates)

            else:
                QMessageBox.warning(self, "Warning", "No route found!")
        except Exception as e:
            QMessageBox.warning(self, "Error", f"An error occurred: {str(e)}")

    def decode_polyline_using_Google(self, polyline_str):
        # Decodifica uma string de polyline do Google Maps para uma lista de tuplas (latitude, longitude).
        index, lat, lng = 0, 0, 0
        coordinates = []

        while index < len(polyline_str):
            shift, result = 0, 0
            while True:
                byte = ord(polyline_str[index]) - 63
                index += 1
                result |= (byte & 0x1F) << shift
                shift += 5
                if not byte >= 0x20:
                    break
            dlat = ~(result >> 1) if result & 1 else (result >> 1)
            lat += dlat

            shift, result = 0, 0
            while True:
                byte = ord(polyline_str[index]) - 63
```

```
                index += 1
                result |= (byte & 0x1F) << shift
                shift += 5
                if not byte >= 0x20:
                    break
            dlng = ~(result >> 1) if result & 1 else (result >> 1)
            lng += dlng

            coordinates.append((lat * 1e-5, lng * 1e-5))

        return coordinates
```