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Giovani M. Avila, Mauro Cesar L. Branco & Marcos Pereira E. Lins

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Keywords: complex modelling, soft operational research, chap2 multimethodology, public transportation, urban mobility, stakeholder engagement, systems thinking, sustainable transport, participatory planning, paradox management.

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The development of sustainable urban mobility represents a major challenge for cities, especially regarding public transportation. In São Pedro da Aldeia/RJ, passengers expressed dissatisfaction with the service offered, while the concessionaire company claimed that fare revenue was insufficient to cover operating costs. This paper aimed to examine the experience and results of applying the CHAP² (Complex Holographic Assessment of Paradoxical Problems) methodology, developed at COPPE/UFRJ, in the context of public transportation in the municipality. The research adopted the CHAP² methodology, which is characterized as a multi-methodology, combining qualitative and quantitative approaches to deal with the complexity of the interrelationships and dynamics of the sector. Through this approach, aspects such as operation, sustainability, planning, infrastructure, inspection and safety of the service were analysed. The results indicate that the applied methodology proved to be an effective tool for structuring and solving issues related to the quality of public transport provision in São Pedro da Aldeia/RJ, contributing to the identification of critical issues and possible paths for improvements.

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I. INTRODUCTION

Promoting sustainable urban mobility represents one of the most significant challenges faced by contemporary cities. This means ensuring that all people have access to city services and opportunities in an inclusive and environmentally responsible manner (IDB and MDR, 2020).

The disorderly growth of urban centres, combined with the lack of territorial planning, has led to the occupation of increasingly distant areas. This type of population expansion fosters the demand for transportation and makes people need to travel longer and longer, contributing to the deepening of social and spatial inequalities (Balbim, Krause, Linke, 2016). For this reason, the public collective transportation system (TPC) emerges as an effective alternative to promote mobility in cities.

The Brazilian Constitution establishes it as an essential service, while Federal Law No. 12,578/2012 positions it as a priority in relation to individual motorized and cargo transportation. TPC provides urban mobility, transports a significantly larger number of people, takes up less road space, contributes to the rational and democratic use of roads and is an environmentally sustainable option (BRASIL, 1988; BRASIL, 2012).

Figure 1: shows the role of public transport.

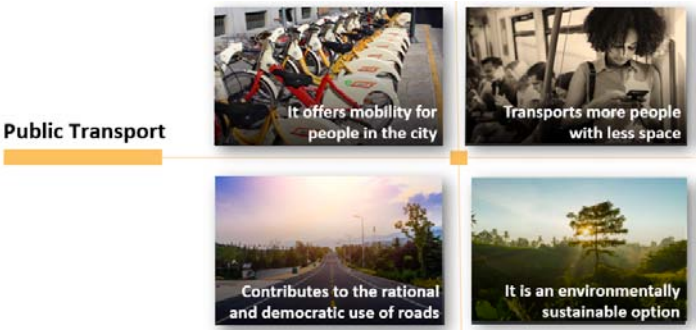


Figure 1: The Role of Public Transport

TPC plays an important role in mitigating problems arising from the large number of private vehicles on the roads, such as congestion, pollutant emissions and traffic accidents. However, investment policies that prioritize infrastructure for private vehicles, combined with the low quality of services, compromise their effectiveness and attractiveness to passengers ((Balbim, Krause, Linke, 2016); ÁVILA, 2010).

Among the cities facing these challenges, São Pedro da Aldeia, in the state of Rio de Janeiro, stands out. In the municipality, TPC was going through a period of crisis, with an imminent risk of interruption. A survey conducted by the service operator in December 2019 revealed that 63.7% of passengers were dissatisfied or very dissatisfied with the quality of the service offered. The operating company, on the other hand, claimed that the fares charged did not cover operating costs. This situation was frequently reported in local newspapers, as shown in Figure 2.

It was therefore imperative to find solutions that would enable the maintenance of the service (LIMA, 2022).

Figure 2: Recurrent Complains in Public Transport.

The problem definition starts with three stakeholders: the dissatisfied population, the operator that could not cover the costs with the current tariff, and the local government at a loss as to how to solve the problem, as shown in Figure 3.

Figure 3: Case Study Problem Definition.

It is important to emphasize that problems of this type, in which many independent agents connect and interact locally, generate counterintuitive attitudes and nonlinear responses.

They encompass a wide range of factors, causes and effects that make analysis and approach challenging.

Solving them requires a methodology that considers this inherent complexity, resulting from the multiple interrelationships and the intrinsic dynamics of the process. In this context, a new multi-methodological approach emerges, which recognizes that complex social problems cannot be adequately understood or solved through a single perspective or method.

On the contrary, it requires the application of multiple methodologies, often interdisciplinary, using the combination of qualitative and quantitative methods and the adoption of a holistic and comprehensive view of the problem (LINS, 2018; VASCONCELOS, 2018).

A summary of this approach is shown in Figure 4.

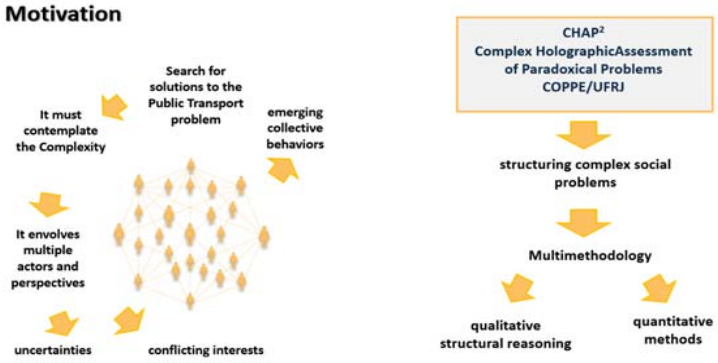


Figure 4: Motivation to Apply CHAP² in Public Transport

To address this type of complex problem, this study adopted the CHAP² (Complex Holographic Assessment of Paradoxical Problems) methodology developed at the PSIGMA Laboratory (Problem Structuring and Indicators Group for Modelling and Assessment) of COPPE/UFRJ.

It is a multi-methodological approach developed to address complex social problems. Through this, crucial issues were identified and addressed, ranging from the operation and sustainability of the service to planning, infrastructure, monitoring and security.

Thus, this work presents the experience and results of the application of this multi-methodology in solving problems related to public transportation in São Pedro da Aldeia/RJ but also seeks to contribute to the academic literature in improving methodological strategies aimed at solving complex urban problems, providing subsidies for more effective and sustainable public policies. The CHAP² multi-

methodology demonstrated its effectiveness as a tool to assist in structuring and solving issues related to the quality of public transportation services in the municipality of São Pedro da Aldeia, Rio de Janeiro.

II. THEORETICAL FRAMEWORK

Classical scientific theories – such as Descartes' reductionism, Newton's mechanism and Laplace's determinism – have profoundly influenced science over the centuries, based on objectivity, isolated analysis of phenomena and predictability through mathematical laws.

These approaches treated reality as physical and ordered, seeking empirical and systematic explanations. However, they faced limitations in failing to explain emergent and complex phenomena, such as free will, leading to questions about the vision of a purely mechanistic science devoid of humanity. (KAUFFMAN, 1996; STEWART, 2014; VASCONCELOS, 2018).

Analytical thinking is showed in Figure 5, based on premises such as Simplicity, Stability, and Objectivity, has limitations in explaining collective properties emerging from a complex system and understanding interactions among components.

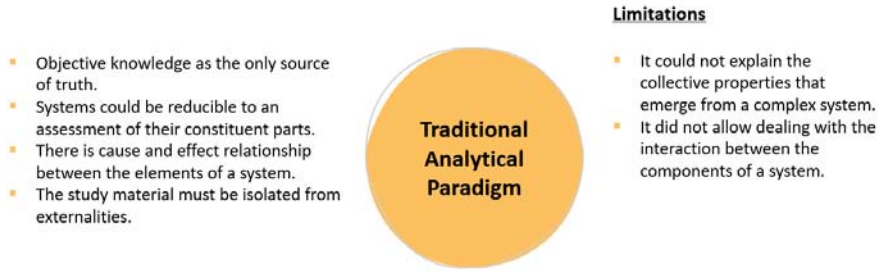


Figure 5: Assumptions of Analytical Thinking.

Edgar Morin (2005), when defining complexity, highlights that it is not simply a sum of elements, but a fabric of different interconnected parts. He suggests that complexity involves multiple elements that cannot be separated without losing the meaning of the whole. He also shows us that understanding complexity requires going beyond simplistic or reductionist analyses. It is necessary to recognize that everything is interconnected, and that the world works in a dynamic and interdependent manner.

Lins (2018) emphasizes that complex problems require dialogue to balance opposing opinions and overcome contradictions, both in interpersonal and intrapersonal relationships.

Systems science emerges as a response to these limitations, incorporating the interdependence of elements and the non-linearity of processes. Vasconcelos (2018) portrays the evolution of the mechanistic paradigm to systems science, as in Figure 8.

Thus, we work within a world characterized by the features of complex systems, which are unstable and based on intersubjective knowledge as showed in Figure 6.

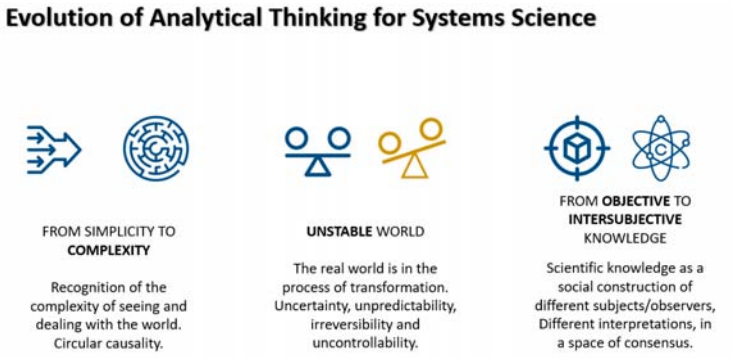


Figure 6: The Evolution of Science.

In systems science, the focus is on a holistic view of its constituent elements and the observer's relationship with this system. Problem structuring is carried out in an environment of collaborative and autonomous dialogue in which the components or participants can work together to build solutions that they themselves have identified.

It is worth noting that traditional science is inefficient in dealing with unstable problems in which the subjects themselves participate during circumstances (MINGERS, 2006; VASCO -NCELOS, 2018).

Systems Science proposes understanding a system considering connections and interactions among elements and resulting synergy, moving from deductive to inductive methods. Structuring the problem occurs through collaborative and autonomous dialogue until disputes are resolved, requiring an unbiased analyst.

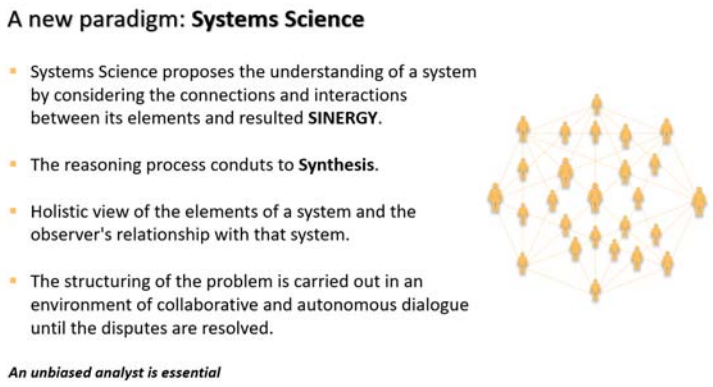


Figure 7: A new paradigm: Systems Science.

In Figure 8 we present a taxonomy from Bertalanffy to Mingers, who addressed Multimethodologies.

According to Mingers (2006), this perspective has expanded the capacity to understand and intervene in multidimensional problems, impacting several areas of knowledge.

In the field of urban mobility, this evolution has allowed the integration of technical, social, economic and environmental aspects, promoting more effective and sustainable solutions.

Source: Adapted from Mingers, 2006.

Figure 8: Contributions of Systems Science to Areas of Science.

The CHAP² methodology fits into this context as a multi-methodological approach, combining qualitative and quantitative methods to deal with paradoxical problems.

Inspired by General Systems Theory and Cybernetics, the methodology recognizes that complex social problems cannot be solved in isolation, but rather through the interaction between multiple perspectives and stakeholders, requiring a methodological framework capable of integrating different dimensions –technical, social, economic and political – simultaneously. The CHAP² methodology allows for a structured and systemic analysis of the system, favouring the construction of integrated solutions that are adaptable to the reality of each context.

By applying this methodology to public transportation in São Pedro da Aldeia, this study demonstrates how systems science enables new ways of understanding and acting on urban challenges, contributing to improving the quality of life and sustainability of cities.

2.1 Methods and Techniques

Lins (2018) describes six operational stages of CHAP², which are summarized below:

Stage I: Characterization of the real system, literature review, interviews with experts, and the formation of a working group involving decision makers. At the beginning, knowledge maps are created to understand the real system. This involves literature research and interviews with experts in the field of study, seeking technical information and personal opinions. In addition, stakeholders are selected according to criteria such as functional categories, ideologies, and worldviews, forming a working group that brings together the most diverse and representative perspectives.

Stage II: Training and orientation of agents involves seminars with the working group aimed at presenting the CHAP² methodology and promoting group engagement. Facilitators lead the seminars. Activities such as dynamics and assessments are carried out to develop the ability to think metacognitively. If necessary, individual guidance can be provided.

Stage III: Uses interviews to formulate metacognitive maps. This phase aims to capture the views of each agent, expressing the system and problems from their perspectives. The interviews are transcribed and transformed into metacognitive maps, including disagreements between agents. The maps are validated by each agent in the group and grouped by theme.

Stage IV: Workshop for developing conceptual and paradoxical maps A workshop is held to converge the representations of the agents' perspectives, aiming to accommodate and consolidate the different perspectives so that they converge towards strategic directions and actions

of common interest. Thematic maps are reviewed, and problems and solutions are prioritized. Conflicts and divergent perspectives should be highlighted in the paradoxical maps.

Stage V: Articulation with formal models, indicators and processes. Develops formal models to support decision-making. In this stage, the content of stage IV is used to create formal models that assist in decision-making. The qualitative approach (conceptual and paradoxical maps) is integrated with the quantitative approach (optimization, simulation, performance indicators, for example). Specific seminars can be held to identify and define indicators.

Stage VI: Identification and implementation of actions – Monitoring. Create an action plan with viable initiatives for this context. This final step involves identifying and implementing the actions designed by the working group. The obstacles mentioned in the paradox map are considered and the impacts of the changes on those involved are assessed.

In addition to identifying problems and solutions, the CHAP² methodology monitors the implementation process to measure and evaluate the results.

A Summary of application of CHAP² can be found in Figure 9.

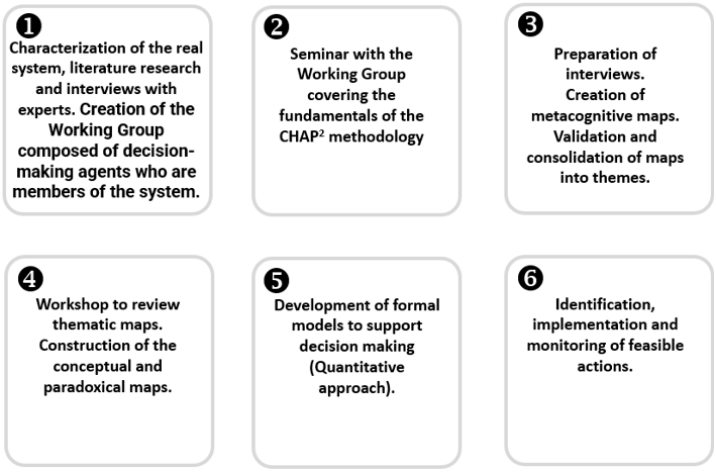


Figure 9: CHAP² Methodology in 6 Stages.

The CHAP2 methodology integrates qualitative and quantitative methods to address complex social systems. These are composed of several actors that interact with each other, generating uncertainty and conflicting interests.

Management and control are not centralized in a single entity or individual; instead, these responsibilities are distributed among the different actors in the system. Each participant plays an active role in its regulation and is the generator of the changes that occur in it. This is known as self-regulation (LINS, 2018).

The term "holographic" in the methodology suggests that, just as a hologram contains a complete image, although it is not a perfect representation of reality, complex systems can also be understood through integrated representations.

Maps or models are visual tools that allow a clearer and more intuitive understanding of these systems, helping to simplify the complexity of the real world.

These representations are holistic, that is, they incorporate all perspectives and aspects relevant to understanding the system (LINS, 2018).

The CHAP² methodology uses conceptual maps to represent knowledge and metacognitive maps, which externalize the thought process of each stakeholder participating in the study, helping to express the limitations caused by their own beliefs, experiences, inconsistencies, and

contradictions, which can make it difficult to identify real critical points and possible solutions.

The term "paradoxical problems" highlights the contradictory nature of problems in complex social systems (LINS and CABRAL, 2018; LINS and CHAGAS, 2018).

Representing reality through maps is an important tool to stimulate the construction of critical thinking and meaningful learning, through the understanding of new concepts that may contradict consolidated ideas.

The methodology seeks to promote more collaborative human interactions, replacing competition with cooperation and consensus (LINS, 2018).

The Cmap tools, available free of charge on the Institute for Human & Machine Cognition (IHMC) website, were used to prepare the maps.

Due to the study being conducted during the Covid-19 pandemic, it was agreed among the members of the Working Group to use the WhatsApp application to facilitate the communication process between the participants.

The CHAP² methodology stands out for two main characteristics. First, it is a multi-methodology that provides a bridge between the qualitative (soft) and quantitative (hard) approaches of Operational Research. This combination seeks to overcome the limitations of each method used in isolation, exploring how they can be complementary and synergistic. Second, the methodology is deeply participatory, based on the interaction and engagement of the decision-makers involved in the study.

In the next section, we will present how the 6 stages of the CHAP² methodology were applied in relation to the public transit system in the municipality of São Pedro da Aldeia/RJ, where we will contextualize how these stages were adapted or customized to local conditions, restrictions and dynamics of the stakeholders.

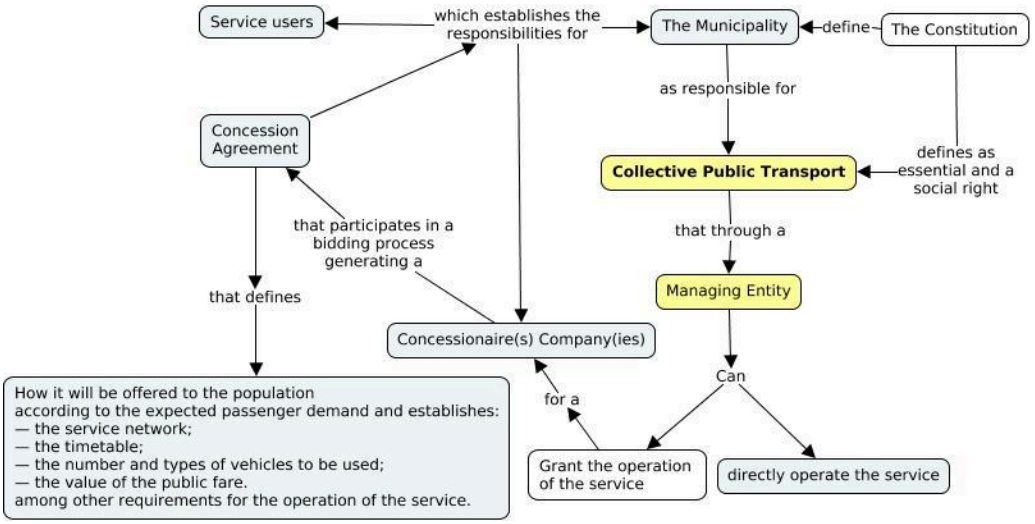
III. METHODOLOGY APPLICATION

3.1. Stage I

At this stage, the characterization of the "real" system was obtained, that is, the detailed analysis of the existing conditions in a system before proposing any intervention or change. This characterization allows us to understand the reality of the system before proposing solutions. In the context of urban mobility and public transport, for example, this means assessing and understanding how the system works.

3.1.1. TPC Operation Map

In Figure 10 we can see in the map the general view of how the operation of a public transport system run.



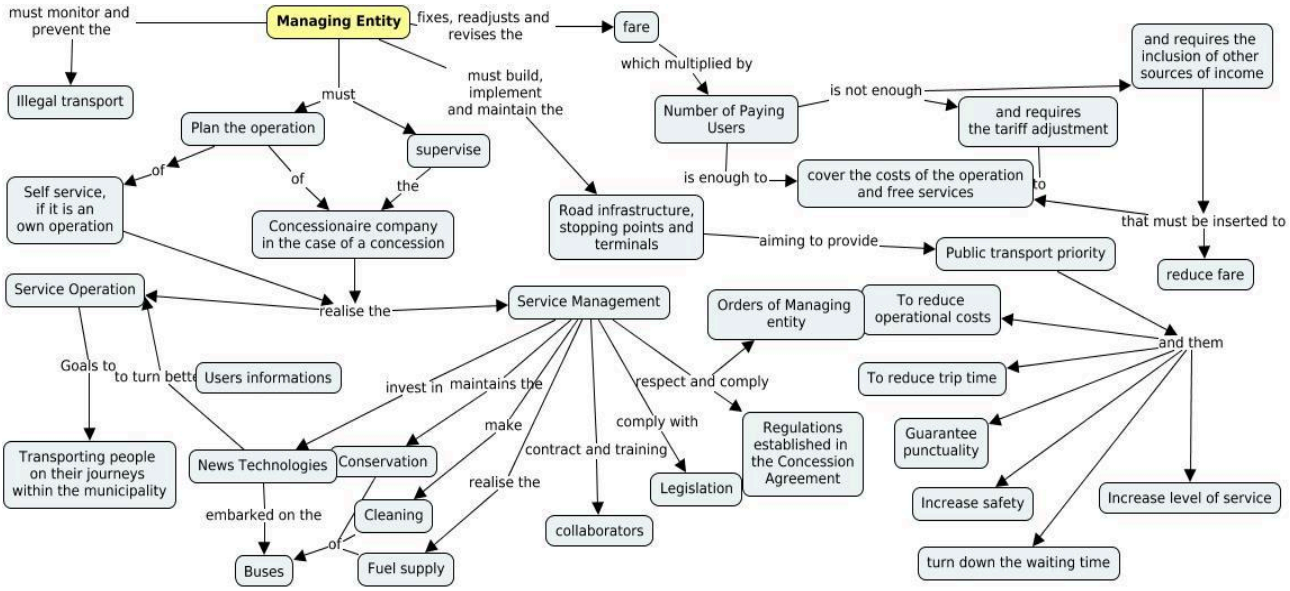


Figure 10: Maps relating the operation of a public transport system to the managing entity

3.1.2. Expert perspective

Still in stage I, the perspective of an expert was collected, aiming not only to obtain technical information, but also their personal views on what a quality and sustainable public transportation system would be like, contributing to the process of reflection on the topic.

The map in figure 11 seeks to organize and visually represent their perspectives, highlighting key concepts and their interrelationships.

The perspectives of an expert were collected, in which we sought to present his point of view on how to achieve a quality and sustainable public transport system.

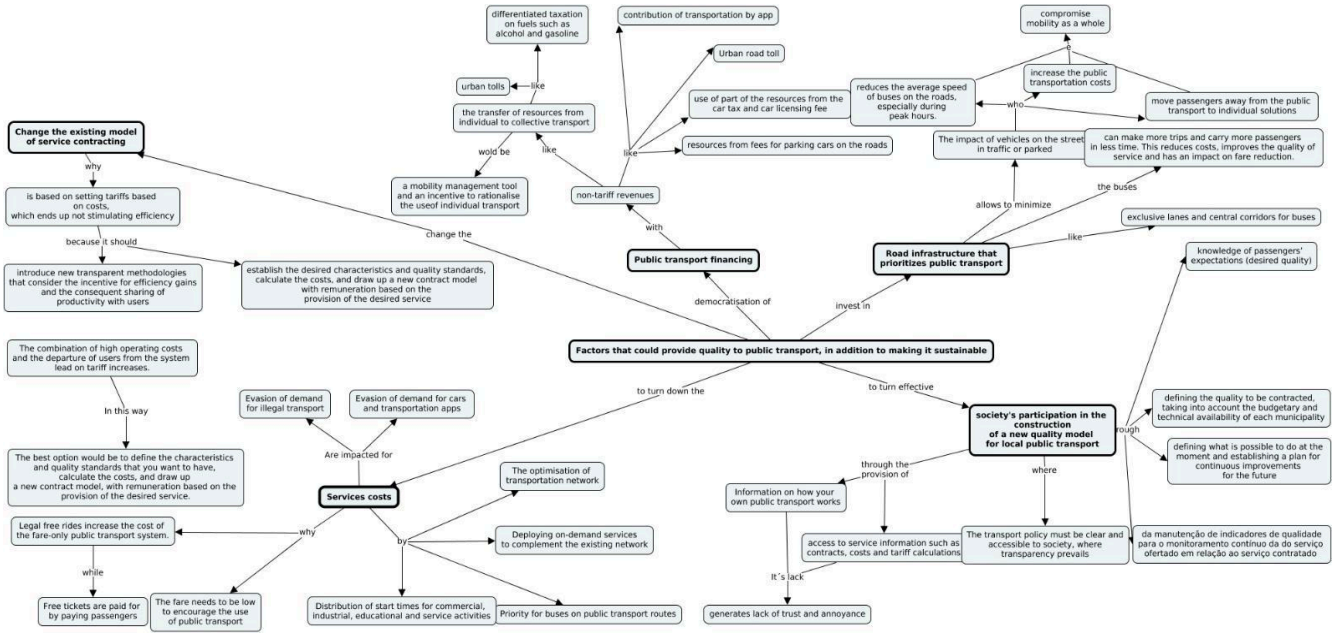


Figure 11: Map from the Specialist's perspective.

3.1.3. Mobility and Homework in São Pedro de Aldeia

According to the IBGE (Brazilian Institute of Geography and Statistics), the population of São Pedro da Aldeia, in the State of Rio de Janeiro, in 2022 was 104,029 inhabitants. The municipality is in the Lakes Region, Rio de Janeiro State, and has an area of 332,488 km². It is located approximately 2 hours from the capital of state.

Source: http://diariodotransporte.com.br - Visited in 15/2022

Figure 12: municipality of São Pedro da Aldeia – Aerial View.

The TPC in the municipality of São Pedro da Aldeia was undergoing a process of degradation. Users complained about the insufficient supply of trips, while the company operating the service maintained that the costs were not covered by the revenue earned.

Over the years, there was a decrease in the number of public transport passengers in the city, from 2,584,668 passengers in 2010 to 568,850 passengers in 2021.

The creation of so-called "shared taxis" (Municipal Law 2711/2017) and the proliferation of illegal transport (private vehicles transporting people without authorization from the municipal government) may have influenced the reduction in transported demand. Both services picked up passengers at bus stops and competed directly with the TPC, but they only operated on paved roads and during times of high passenger demand.

Public transport, on the other hand, had to follow routes and timetables established by the municipal management body. This included rural routes and the responsibility for transporting free passengers (elderly people, people with disabilities, and students in the state school system).

Individual or shared transportation apps also attracted paying passengers from public transportation, and the Covid-19 pandemic led to a reduction in the number of passengers transported.

The result found in 2021 by the tariff calculation spreadsheet defined in the concession contract showed the unsustainability of the system.

The public fare was R$4.30, while the technical fare calculated by the spreadsheet was R$11.86. This value would bring the economic and financial balance of the contract but would certainly drive users away from the system because it was above their ability to pay.

This unsustainable situation led the operating company to seek legal action for breach of contract (BRASIL, 2022).

Figure 13 shows the formation of Transport Fare where can see the percentage breakdown of transportation fare costs, mainly fuel and labour, accounting for about 70% of the total.

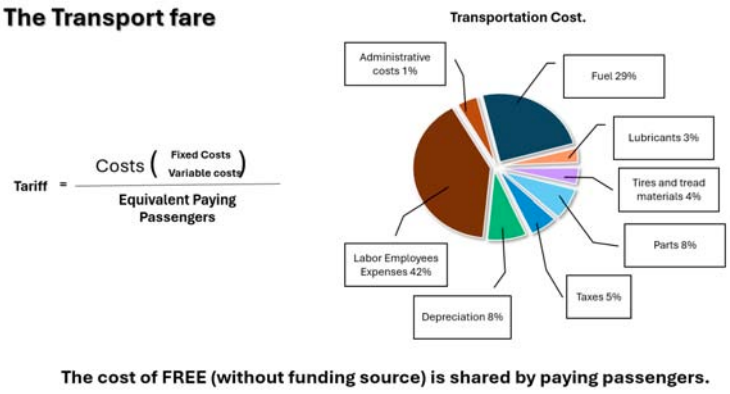


Figure 13: Transport Fare.

In Figure 14 is showed the increase in diesel prices over 20 years, from 2 to 7 Brazilian Reais (0.4 to 1.4 USD), resulting in passengers switching to other modes like cars and motorcycles.

Source: NTU 2028; ANP 2022

Figure 14: Transport Fare.

3.2. Maps Construction

The methodology considers three aspects of a complex system (individual needs, environment, and society as a whole). It proposes problem structuring by integrating perspectives from each interested party in a holistic reasoning process, aiming to find consensus solutions that support decision-making, as one can see in Figure 15.

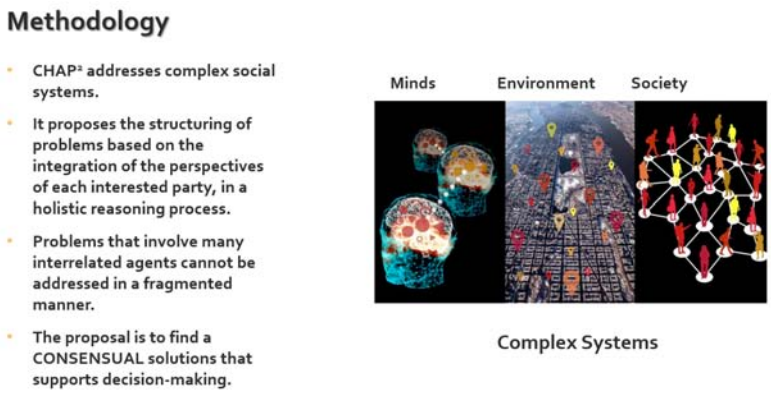


Figure 15: Complex System Considerations.

3.2.1. Stage I – Documents review, data collection and formation of the Working Group

In Stage I Extensive research was conducted on public transport documentation in government archives, and experts' perceptions of the quality of public transport were collected.

Figure 16: Stage 1.

Representatives were chosen inclusively and broadly from each stakeholder group involved in the process. Interviews were conducted to gather their perceptions, followed by the formation of the working group.

The CHAP² methodology values the criteria of qualitative representativeness, in which data collection is done through interviews with stakeholders who are part of the system, aiming to capture multiple points of view on the problem situation, ensuring that all perceptions and interests are considered. The participation of multiple stakeholders in the system requires the creation of an environment of collaboration and dialogue and can help ensure that all parties feel heard and represented in the process (LINS, 2018).

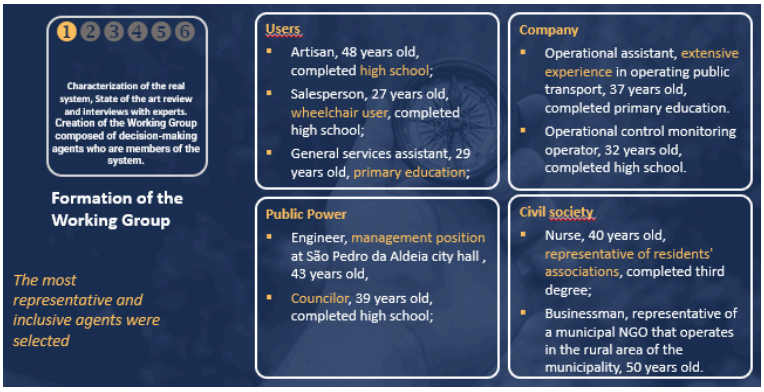


Figure 17: Stage 1 (Cont.).

In this way, the Working Group was organized, composed of the following agents:

- Four representatives of the users: they were already interacting with the company providing the service seeking solutions to the problems in the transport system in São Pedro da Aldeia.
- Two representatives of the municipal government: appointed by the City Hall.
- Two employees of the service provider: appointed by the company itself.
- Two representatives of organized civil society: invited by the City Hall.

3.2.2. Stage II – Training and Engagement

In Stage II, the agents involved must understand how the methodology works then a training seminar was held for them, having a high level of engagement, where the methodology was presented, doubts were clarified, and awareness was raised about the relevance and opportunity of contributing to the development of the TPC service in the city of São Pedro da Aldeia through participation in the study. Separate meetings were held with agents who missed the meeting, thus reaching all members of the Group.

Considering the diversity of educational backgrounds of the participants, the content was presented in a playful way, using metaphors, sketches and drawings, seeking to obtain an understanding of complex concepts that permeate the methodology, seeking engagement and the creation of an environment of collaboration and dialogue, helping to ensure that all parties feel heard and represented in the process (LINS, 2018).

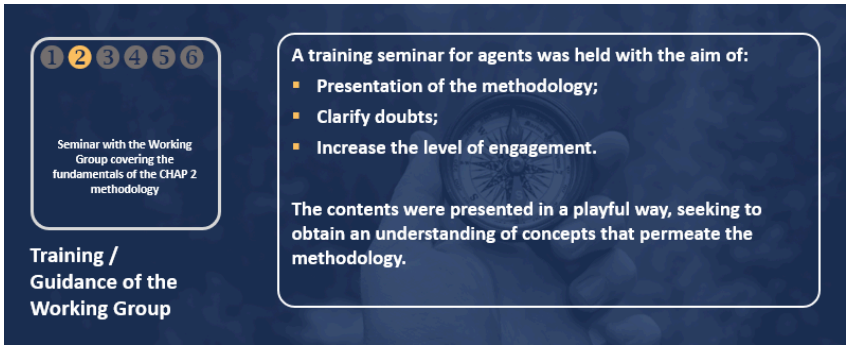


Figure 18: Stage 2 – Training.

3.2.3. Stage III – Conducting Interviews

In the third stage, interviews were conducted with the members of the Working Group to capture the perceptions of each agent, consolidating them in the form of maps.

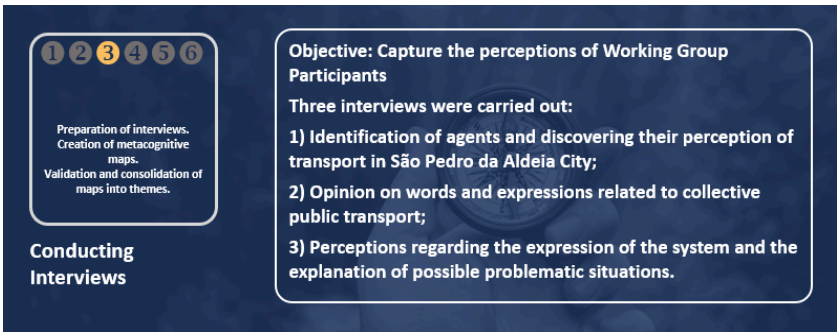


Figure 19: Stage 3 – Conducting interviews.

To this end, three stages of interviews were used. Interview 1 aimed to identify the agents and, through an open-ended question, to learn about their knowledge about transportation in São Pedro da Aldeia. In interview 2, words that were somehow linked to or referred to the quality of the TPC service were listed, aiming to broaden each agent's reflection. In addition to the script used, with the words or expressions above, the interviewed agent was allowed to add any information that he or she considered important to report.

In interview 3, we sought to extract from each member of the Working Group the way in which the system manifests itself or is perceived and the explanation of possible problematic situations. After the interviews, metacognitive maps were

prepared for each of the participating agents. In a workshop, the maps were validated by each participant and, considering the content of each map, the predominant themes were identified and classified by the Working Group in order of relevance, as shown in the Table 1:

Table 1: Definition of Themes.

Temas	Decision-Making Agents										
	US1	US2	US3	US4	PP1	PP2	CS1	CS2	SCO1	SCO2	Total
Infrastructure, planning and supervision	1	1				1	1		1	1	7
Service operation	1	1	1	1	1	1	1	1	1	1	11
Service sustainability	1	1		1	1	1	1	1	1		9
Transportation safety		1				1				1	4
Legenda											
US	System Users										
PP	Public Authority										
CS	Service Provider										
SCO	Organized Civil Society										

One method used to apply CHAP² was the development of metacognitive maps, providing a holistic view of the problem and the needs of each agent involved.

The individual maps were aggregated into a single map divided into themes, as shown in Figure 20.
Themes:

- Infrastructure, planning and supervision (green)
- Service operation (blue)
- Service sustainability (yellow)
- Transportation Safety (orange)

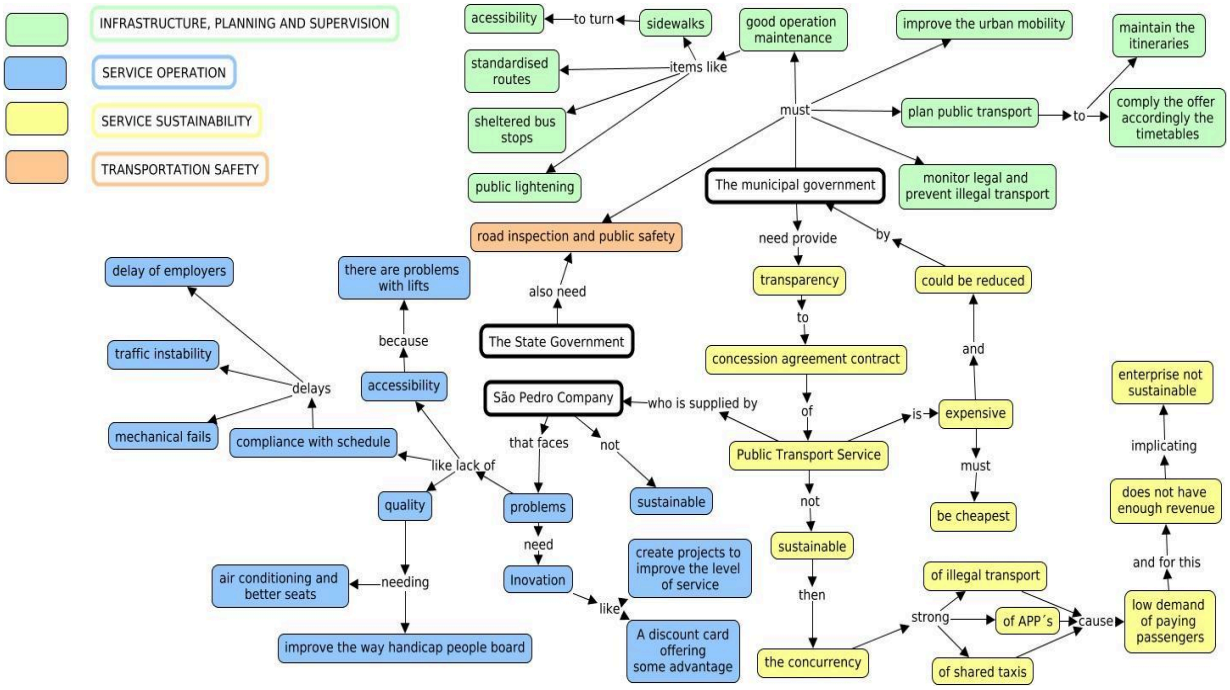


Figure 20: Consolidated metacognitive map (by topic).

3.2.4. Stage VI - Conceptual and Paradoxical Models

To organize and consolidate the representations of the agents' perspectives, a workshop was held in the fourth stage to deepen the discussion on the problems of each specific topic. For each of them, the reasons were answered, the proposed solutions were listed (conceptual model) and any barriers to making them feasible were raised (paradoxical model). The results are presented in Figures 21 to 23. The creation of conceptual and paradoxical maps can be seen, presenting key questions for each participant in the system, the origin of the problem, the solutions and barriers to solving the problem, and explaining any divergences. An example involving the need to simultaneously lower the price of the tariff and increase the service offer (costs):

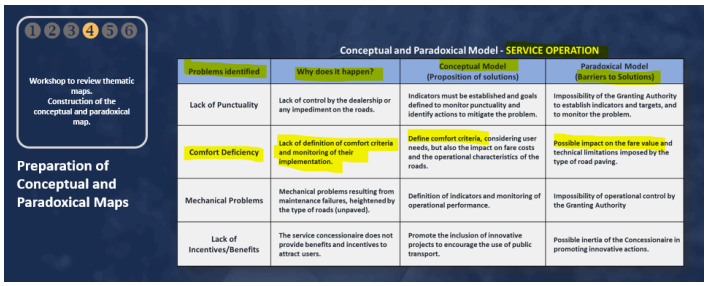


Figure 21: Conceptual and Paradoxical Model - Service Operation.

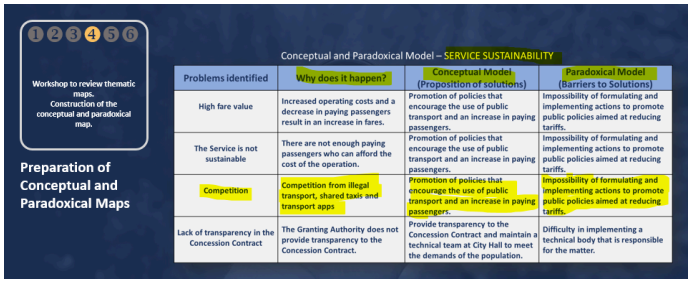


Figure 22: Conceptual and Paradoxical Model - Service Sustainability.

Another example involving the system operator is highlighted. Figure 22 shows an example of a Modal Competition problem, with the presence of ride-sharing apps (such as Uber) and competition from illegal transportation. The solution would therefore be to promote policies that encourage official public transportation and increase the number of paying passengers. However, the paradoxical model indicates the impossibility of formulating and implementing actions to promote public policies to reduce fares.

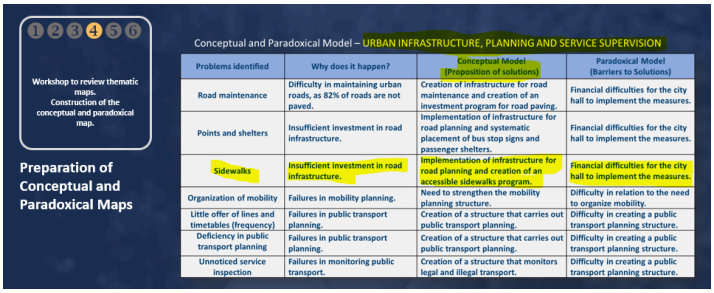


Figure 23: Conceptual and Paradoxical Model – Urban Infrastructure, Planning and Inspection.

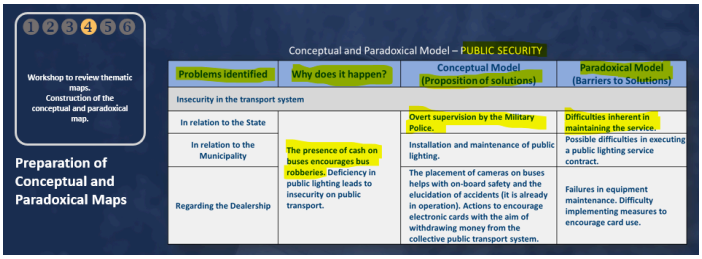


Figure 24: Aspects related to Public Security.

3.2.5 Stage V–Models to Support Decision-making

In Stage V, the formal models developed to support decision-making are articulated. In this case, performance indicators were established, as showed in figure 25.

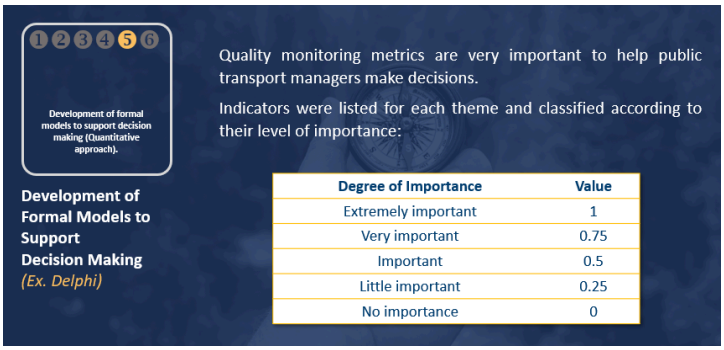


Figure 25: Quality indicators, metrics index.

Considering the content prepared by the Working Group, namely the conceptual and paradoxical maps, in Stage V we sought to identify a formal quantitative model that would assist in decision-making and regulation of the process.

According to BRASIL (2010), the implementation of performance indicators that monitor the quality of goods and services delivered to society are fundamental for public management focused on results. Bezerra (2020), through a bibliographic review, identified a total of 80 quality indicators for public transportation that were grouped into 6 domains: infrastructure, mobility, accessibility, safety, user satisfaction, and environment.

Based on the content of the conceptual and paradoxical maps, presented in figures 21 to 24, and the quality indicators listed by Bezerra (2020), those that could best measure the performance of the homework service in São Pedro da Aldeia were identified for each theme. After this definition, each of them was classified by degree of importance according to the Working Group. Thus, the level of importance of each indicator was identified, by Theme, as showed in Tables 2 to 5.

Table 2: Indicators and degree of importance for the Working Group - Service Delivery.

Indicator - SERVICE DELIVERY	degree of importance
Departure Punctuality - Percentage of trips that departed on time (more than 5 minutes late or more than 1 minute earlier).	0,88
Occupancy index - Rate of people standing per square meter.	0,79
Vehicle cleaning - User opinions through research.	0,75
Accident Rate per Kilometer - Percentage of accidents per total mileage traveled.	0,75
Trips interrupted by mechanical breakdown - Percentage of trips interrupted by mechanical breakdown related to scheduled trips.	0,75
Internal Temperature - User opinions through research.	0,71
Trip Fulfillment - Percentage of trips not taken in relation to scheduled trips.	0,71
Vehicle Age - Classification referring to the year of manufacture.	0,67
Internal Noise - User opinions through research.	0,42

Table 3: Indicators and degree of importance for the Working Group - System Sustainability.

Indicator - SYSTEM SUSTAINABILITY	degree of importance
Users' Perception Regarding the Fare Value - User opinion through research.	0,92
Commitment to transportation expenses - Percentage of transportation costs in relation to individual income.	0,88
Equivalent Passenger Index per Kilometer (IPKe) - It shows the relationship between the number of paying passengers transported and the kilometers traveled. The higher the indicator, the more productive the transport system will be, resulting in lower costs for the user of the service.	0,88
Economic Coverage Level - Percentage of revenue in relation to expenses determined in the concession contract spreadsheet. (Indicates whether the operating cost of the lines is being covered by the tariff revenue earned.	0,83
Discounts and Freebies - Percentage of passengers who do not pay the fare or there is no source of funding (free of charge).	0,75

Table 4: Indicators and degree of importance for the Working Group - Urban Infrastructure, Planning and Service Supervision.

Indicators - URBAN INFRASTRUCTURE, PLANNING AND SERVICE SUPERVISION	degree of importance
Physical Accessibility Index of bus terminals and stops - Percentage of the number of accessible facilities in relation to the total number of facilities (terminals and stopping points for people with disabilities).	0,92
Percentage of Safe Crossings - Percentage of Crossings (from the sidewalk segment) that comply with Legal Safety and Quality Requirements.	0,88
Road Signage - Drivers' perception regarding the state of signage on roads that carry public transport.	0,88
Condition of the roads - User assessment regarding the condition of the road.	0,83
Correctly Identified Points - Percentage of bus stops effectively identified.	0,83
Presence of Covered Shelters at Bus Stops - Percentage of covered shelters in relation to bus stops.	0,83
Paved Roads - Percentage of paved roads in relation to the total mileage of the collective public transport network.	0,75
Condition/Conservation of Bus Stops - Portrays users' perception of bus stops.	0,71

Table 5: Degree of importance of indicators for the Working Group -Safety in Public Transportation

Indicators – SAFETY IN PUBLIC TRANSPORTATION	degree of importance
Safety perception when walking to Bus Stops - User perception regarding security when walking to bus stops.	0,75
Safety perception at Bus Stops - User perception regarding security at bus stops.	0,71
Safety perception of Vehicle - User perception regarding security of vehicle.	0,79

3.2.6. Etapa VI – Results and Implementation

In Step 6, showed in figure 26, was identified actions that cater to both supplies, i.e., operators, and the Public Authority, highlighting the main initiatives of this set, such as contract sustainability, moderate fares, and the creation of an information system for the user.

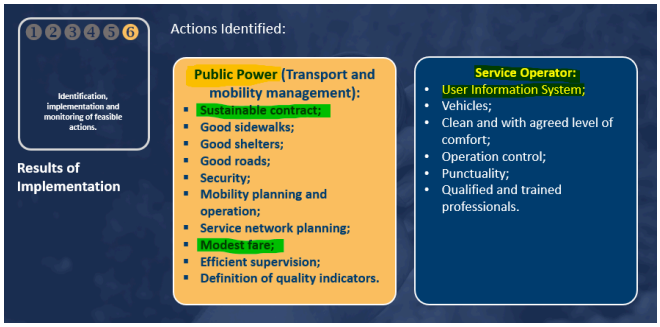


Figure 26: Stage 6 – Results of implementation.

The study highlighted the need for profound and urgent changes in the municipal public transportation system, both in terms of service quality and the system's unsustainability.

It would be inevitable to introduce extra-tariff revenues into the system to cover the deficit between revenues and costs. However, there was great resistance to the City Hall disbursing funds to finance the service. This seems to have led the City Hall to make a first attempt, carrying out a bidding process for the concession of the transportation system along the same lines as the previous concession.

The attempt did not yield practical results, since the winning company was disqualified for not presenting the number of buses defined in the bidding notice.

The City Hall then decided to bid for a different format than the previous one for contracting the provision of the service, contemplating a new governance model, which considered some of the suggestions listed in the study. The implementation of this new model brought transformative changes to the system. The decision was made to rent buses with drivers, paying for the service per kilometre travelled, making the system sustainable, improving comfort and safety features, increasing the number of trips available and reducing the amount paid by users. The City Hall decided to change the fare from R$4.30 to R$2.50, assuming responsibility for paying the difference between the cost and the revenue earned.

Figure 27 shows the results of the implementation and the topics covered by the application of this methodology, highlighting the

expansion of the service offered, fare reduction, and financing.

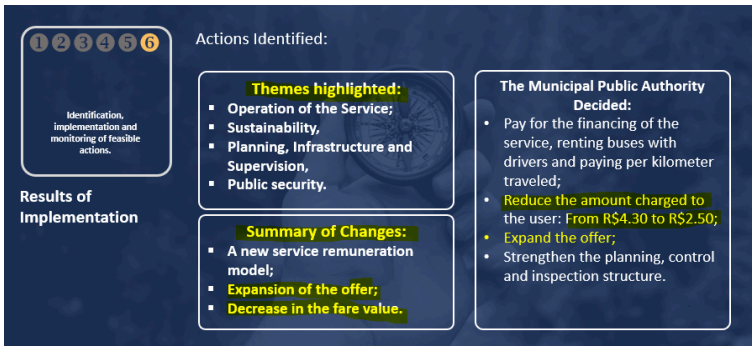


Figure 27: Stage 6 (Cont.).

Based on the new bidding model, the management structure was strengthened to accommodate functions related to service management.

The service planning, control, and supervision structure was expanded to meet the responsibilities required by the new governance process. In addition, quality improvement requirements were included in the new bidding process, such as: monitoring cameras, air conditioning, geore- ferencing system, new visual identity, and an average age of the vehicle fleet of no more than five years from manufacture.

The final considerations presented in Figure 28 show the finding that there was full adoption by users, comparing the number of paying passengers before and after the implementation of the actions.

The graph shows data from January 2022 to August 2022, where we observe a tripling of the number of paying passengers.

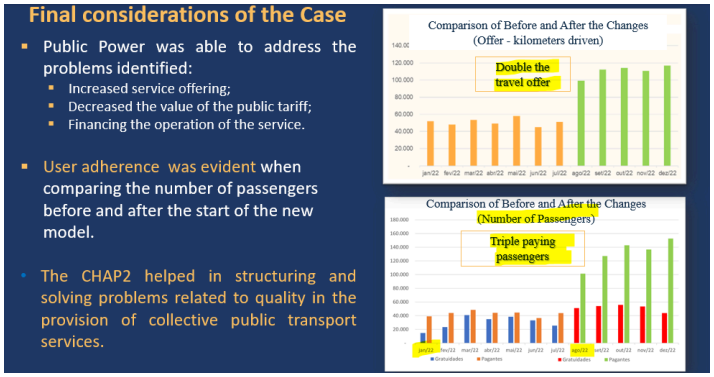


Figure 28: Final Considerations

With the new management logic implemented, the City Hall assumes the leading role in organizing and managing the security demands in the system, and actions were identified under the responsibility of the state and municipal government and the TPC service operator itself.

Intensified monitoring by security agencies, improved public lighting and the implementation of the elimination of the use of cash on buses are measures that could be adopted.

IV. CONCLUSION

The application of the CHAP² methodology in the context of São Pedro da Aldeia demonstrated its potential to address complex social problems related to urban mobility and did so in a structured and participatory manner.

The process allowed for the construction of a shared diagnosis and the engagement of stakeholders in the search for viable solutions. However, the experience revealed challenges that deserve attention, such as the need to maintain active participation throughout the stages and the challenge of aligning expectations among the different actors involved.

A central contribution of this study was the adoption of a multi-methodological approach to solving complex social problems, allowing for a holistic approach, enabling the formulation of strategies for the evolution of public transportation in the city of São Pedro da Aldeia/RJ.

The findings of this research highlight that, although the CHAP² methodology is a powerful tool for structuring decision-making, its effectiveness depends on the capacity of local institutions to implement and maintain the proposed actions. Establishing indicators for monitoring can be a way to strengthen the continuity of initiatives, although their sustainability cannot be guaranteed without a long-term institutional commitment. Thus, this study not only reinforces the relevance of CHAP² as an instrument for participatory management of urban mobility but also points to ways to improve its implementation. It is recommended that future studies explore strategies to strengthen communication and trust among participants, in addition to deepening the analysis of how the lessons learned can be replicated in other municipalities.

It is recognized that this study has limitations, especially regarding the time taken to monitor the actions and the depth of the analysis of long-term impacts. However, by using CHAP² in its multi-methodological approach to address complex social problems, it is expected that this research will contribute to the advancement of discussions on participatory planning and urban mobility in local contexts. Finally, it is important to highlight the fundamental role of academia in supporting municipalities, assisting in the formulation of public policies, and generating tangible results for society.

4.1. Rcommendeations and Suggestions for Future Work

It is important to monitor the new model chosen in São Pedro da Aldeia of the collective public transport system in relation to the quality and sustainability of the service.

It would be advisable to develop other studies, contemplating other methodologies that address complex systems, with the objective of evaluating the effectiveness of the implementation of new actions that could be undertaken.

Declaration of competing interest

The authors declare that there are no potential competing interests.

CRediT authorship contribution statement

All unreferenced figures and tables were prepared by the author.

Mauro Cesar L. Branco: Writing – review & editing,

Giovani M. Avila: Writing – review & editing, Validation, Conceptualization Supervision.

Marcos Pereira E. Lins: Writing – original draft, Supervision.

Data availability

Data will be made available on request.

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