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Unveiling Public Innovation Management: What Data Mining Reveals by Analyzing Brazilian Experiences?

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ABSTRACT

Objective: the purpose of this article is to explain public sector innovation management, based on Brazilian experiences in public administration, relating six dimensions of innovation: drivers, facilitators, barriers, capabilities, outcomes, and impacts of innovation. **Method:** concerning qualitative methods, we analyze institutional documents about innovation experiences by applying content analysis and methodological triangulation among researchers. Regarding quantitative methods, we structured databases to operationalize the analysis, using data mining through the Apriori algorithm to identify association rules between the research constructs. **Results:** the results show 37 association rules that describe public innovation: human resources management for innovation, technology management for innovation, user knowledge, search for problem-solving, co-production between partners, and public co-producers. **Conclusion:** as a contribution, the research provides theoretical and empirical insights to improve the conceptual accuracy of the phenomenon and inform decision-making regarding policies and programs for managing public sector innovation.

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INTRODUCTION

Public sector innovation, or public innovation, is on the political and managerial agenda and has attracted the attention of researchers and professionals in different countries (Bekkers & Tummers, 2018; Criado et al., 2021; Cinar et al., 2022) in the 21st century. One of the triggers of interest in the subject is the contribution that innovation makes to improving public services, increasing trust in the state, and promoting citizenship, among other benefits (De Vries et al., 2016; Rubalcaba et al., 2022). Hjelmar (2021) states that innovation is synonymous with creating public value by improving quality, efficiency, employee satisfaction, or greater citizen participation in constructing solutions.

Criado et al. (2025) reviewed the last two decades of public sector innovation literature and argued for the importance of studies on the relationship between antecedents, strategies, structures, mechanisms, and types of innovation results. Thøgersen (2022) argues that the literature on the topic is still grasping how management practices influence the conditions needed to develop and implement innovations in public organizations. In other words, it is important to know which variables and their relationships can facilitate (or inhibit) innovation processes, and how to mobilize support, provide resources, increase knowledge, and work to establish an innovative culture in organizations (Thøgersen, 2022).

Pradana et al. (2022) suggest that empirical research into the different conditions for innovation in the public sector can strengthen practices and decisions by public managers. For these authors, innovation is sustainable when critical factors or events — such as political and managerial aspects, behavioral characteristics, and contextual factors — are identified and managed.

Commonly, the innovation process is dynamic and comprises factors that condition its occurrence in organizations and the public sector (Cinar et al., 2024; Organization for Economic Cooperation and Development (OECD), 2020); Demircioglu & Audretsch, 2017). From drivers to impacts, the process requires close attention from researchers, managers, and public employees, observing the variations present in each phase of innovation management and how it contributes to improving public services, public policies, and the delivery of public value to society (Hjelmar, 2021; Osborne et al., 2022).

Cunningham (2005) and Koch and Hauknes (2005) were the first authors to define and describe drivers, facilitators, and barriers in public sector innovation, analyzing the experiences of the public health sector. For them, drivers represent pressures that lead to innovation or support its rationale. Facilitators are factors that enhance the development, diffusion, or acceptance of innovation. Barriers are factors that militate against the drivers and facilitators and need to be overcome for the successful implementation of innovation. These constructs depict a generic set of factors that impact the inception, development, implementation, and eventual success of innovations.

Organizational capabilities for innovation and how organizations co-create innovation with their stakeholders are important variables or conditions for the success of innovation in public organizations. Boon et al. (2023) highlight the importance of studying stakeholders' contributions to innovations, helping public organizations receive different types of ideas in the development process.

The innovation process shows how the conception, generation, selection, and implementation of ideas produce significant tangible changes in public organizations (specifically) and the public sector (generally). The outcomes of innovation refer to the locus and focus of public innovation (Criado et al., 2025), describing types (product/service, process, organizational, communication) and modes (radical, incremental, improvement) of innovation. The impacts of innovation represent positive effects on the quality of public services and public policies, as well as on organizational management and the relationship between society and the state (Cinar et al., 2021; De Vries et al., 2016; Demircioglu & Audretsch, 2017; Demircioglu, 2018).

Given the above, we formulated the following research question: How can public sector innovation management be explained? Based on the analysis of Brazilian public innovation experiences, the general aim of this article is to explain innovation management in the public sector, relating drivers, facilitators, barriers, capabilities, outcomes, and impacts of innovation. We used data mining to test the relationships between variables in this research.

In general terms, the research field of public innovation is still moving toward theoretical and methodological consolidation, reinforcing the need for cumulative production of knowledge on the topic (Chen et al., 2020; Cinar et al., 2022; Hjelmar, 2021). Thus, this article seeks to assess the relationships between the constituent constructs of the phenomenon, searching for empirical evidence, as suggested by Criado et al. (2025), about how drivers, facilitators, barriers, and capabilities influence the outcomes of innovation, and how these relationships influence the impacts of innovation in the Brazilian context. This article aims to identify opportunities for theoretical and methodological advancement regarding public sector innovation, testing propositions that clarify which factors influence the successful adoption, initiation, development, and implementation of innovations, as suggested by Liarte et al. (2025). Additionally, this paper seeks to understand public sector innovation management, contributing to making managers more aware, knowledgeable, and prepared to use resources to implement innovations in public organizations, as indicated by Demircioglu (2024), based on

empirical evidence of the relationships between drivers, facilitators, barriers, capabilities, outcomes, and impacts of innovation in Brazilian public organizations. We hope the results of the data analysis may contribute to the programs, policies, projects, and practices that public organizations carry out, aiming to achieve positive impacts on citizens' quality of life.

THEORETICAL FRAMEWORK

In recent years, literature reviews have sought to offer a more comprehensive overview of aspects of public innovation (or public sector innovation), such as concepts, types, drivers, barriers, facilitators, capabilities, processes, outcomes, and impacts (Boon et al., 2023; Cinar et al., 2024; Chen et al., 2020; Criado et al., 2025; De Vries et al., 2016).

According to De Vries et al. (2016), Criado et al. (2025), Demircioglu (2024), and Liarte et al. (2025), public sector innovation studies seek to identify why and what to innovate. The literature shows that innovation objectives ("What to innovate for?") comprise the ultimate value of innovation, the reason for innovative experiences, and demonstrate how innovative practices, policies, and services are adopted and implemented, identifying the key aspects of this topic in public organizations (Criado et al., 2025; Demircioglu, 2024; Liarte et al., 2025). Hijal-Moghrabi et al. (2020) argue that innovation in the public sector can be understood as an institutional consequence of reform movements in the 20th century. These authors show that ever-increasing demands, escalating costs, rapid technological changes, and shortages of financial and other resources imply new modes of governance, structures, and practices. In other words, these factors will continue to be the focus of significant reform and innovation efforts in the public sector.

Bloch (2011) and Bloch and Bugge (2013) state that public innovation occurs to address social problems, increase efficiency, and improve the quality of services, user satisfaction, online services, and working conditions. In addition to the highlighted objectives, Voorberg et al. (2015), De Vries et al. (2016), Torfing (2018), Criado et al. (2025), and Demircioglu (2024) show that innovation aims to involve citizens and private sector partners in initiatives to solve wicked problems in the public sector. Figenschou et al. (2024) argue that open innovation in the public sector can be an effective strategy for transparency, inclusivity, and public value.

The theoretical framework of this research is organized into six main topics: drivers, facilitators, barriers, capabilities, outcomes, and impacts. The literature describes drivers, facilitators, and barriers as antecedents of public innovation (Cinar et al., 2019; Nam,. 2019). Innovation drivers refer to pressures to innovate. Innovation facilitators represent factors that enhance its development, diffusion, or acceptance. Innovation barriers represent factors that need to be overcome for the successful implementation of the innovation (Cunningham, 2005; Koch & Hauknes, 2005).

Cunningham (2005) and Koch and Hauknes (2005) suggest drivers such as: (a) problem orientation (search for problem solutions); (b) non-problem orientation (emphasis on improvement and efficiency); (c) political impulse (response to critical events and political pressures); (d) legal obligations; and (e) technological factors (introduction or availability of new technologies). In this research, we decided to follow the papers of Cunningham (2005) and Koch and Hauknes (2005) regarding the drivers of public innovation.

Bloch (2011) complements the drivers described by Cunningham (2005) and Koch and Hauknes (2005) by suggesting aspects such as the relationships of public organizations with their suppliers and direct users, and the pressures arising from citizens and civil society. In addition, Bekkers et al. (2013) propose drivers such as resource allocation, traditions of the state, governance and public service, and the legal culture of the public sector, among those previously mentioned.

According to Cunningham (2005), Koch and Hauknes (2005), Bugge et al. (2011), and Bloch and Bugge (2013), mainly based on the categorization proposed by De Vries et al. (2016), Cinar et al. (2019), and Nam (2019), facilitators refer to material and financial resource availability, teamwork, top management commitment, human resource development, openness to experimentation, and data integration. Barriers to public innovation refer to resistance to innovate, human resource unavailability, material and financial resource unavailability, conflicts of interest, power concentration, and data fragmentation. These authors state that facilitators and barriers depict aspects of structure and organizational conditions for innovation, managers' and leaders' behaviors, and people's behaviors and attitudes when facing the challenge of innovation.

Innovation capabilities describe the organizational attributes that make innovation a competence of the organization, allowing it to adapt to the environment sustainably. According to Bloch (2011), Hughes et al. (2011), Arundel and Huber (2013), Valladares et al. (2014), Daglio et al. (2014), Borins (2014), and Sørensen (2016), the constituents and capabilities of innovation are the following: leadership for innovation, strategic intention for innovation, human resources for innovation, innovation project management, technology management for innovation, user knowledge, and organizational flexibility (organicity). According to these authors, co-production is an innovation capability and refers to the involvement and collaboration of stakeholders in developing innovations in the public sector, fostering collaborative governance between

the state and society. In this research, we decided to follow the work of these authors to describe items about innovation capability in public organizations.

The public sector innovation outcomes characterize types (Lykkebo et al., 2021) and modes (Djellal et al., 2013) that refer to the locus and focus of public innovation (Criado et al., 2025). Bloch (2011) and Lykkebo et al. (2021) present the following types to describe innovation outcomes: product or service, process, organizational, and communication. Product innovation introduces a new or significantly improved service or product compared to existing services or goods in a public organization, including significant improvements to the characteristics of the service or good, customer/user access, or how people use it. Process innovation implements a method for producing and delivering services and goods that is new or significantly improved compared to existing processes in a public organization. Organizational innovation implements a new way to organize or manage work that differs considerably from existing methods in a public organization. Finally, communication innovation implements a new way to promote the organization or its services and goods, or new ways to influence other actors' behavior. Despite the variety of types of innovation in the literature, in this research, we decided to follow the work of Bloch (2011) and Lykkebo et al. (2021) regarding the typology of public innovation (Copenhagen Manual).

The understanding of the public sector innovation context is supported by Djellal et al. (2013), who present a typology of innovation modes with a conceptual transposition of the literature on services. According to these authors, innovating in the public sector involves the following modes: radical, incremental, improvement, recombination, and formalization. Radical innovation creates a new set of service characteristics that did not exist in the reality of the public organization. Incremental innovation adds, subtracts, or replaces an existing feature in the organization. Improvement innovation alters the quality or property of existing characteristics without adding, removing, or replacing organizational attributes. Recombination innovation associates or disassociates technical features of the organization or some final aspect of the service or product that the organization delivers in the public context. Innovation by formalization is the formatting and standardization of technical characteristics of the organization (Djellal et al., 2013). In this research, we also decided to follow the work of Djellal et al. (2013) regarding the typology of innovation in public services, emphasizing the three main modes: radical innovation, incremental innovation, and improvement innovation.

Impacts of public innovation refer to its effects, as suggested by Osborne and Brown (2005), Eggers and Singh (2009), Bloch et al. (2009), Sørensen and Torfing (2011), Bloch (2011), Hughes et al. (2011), Arundel and Huber (2013), Daglio et al. (2014), Borins (2014), Sørensen (2016), Lykkebo et al. (2021), Criado et al. (2025), Demircioglu (2024), and Liarte et al. (2025). According to these authors, the impacts of innovation are related to organizational aspects (performance, climate, and organizational image) and public service effects (delivery quality, satisfaction, and social quality of life). Table 1 presents each variable and its definitions, contributing to the formulation of the theoretical research model and its hypotheses in this research.

Table 1. Summarization of research variables.

Theoretical constructs	Constituent definition	Research variables
Drivers	The drivers represent pressures that lead to the innovation or support its rationale.	Problem orientation; non-problem orientation (improvement and efficiency); political impulse; legal obligation; technological factors
Facilitators	The facilitators represent factors that enhance the development, diffusion, or acceptance of innovation.	Institutional communication; availability of material and financial resources; teamwork; legitimation; human resources training; data integration
Barriers	The barriers represent factors that militate against the drivers and the facilitators and need to be overcome for the successful implementation of innovation.	Resistance to innovate; unavailability of human resources; unavailability of financial resources; conflict of interest; limited deadlines; data fragmentation; process fragmentation; infrastructure limitations
Capabilities	Innovation capabilities refer to the organizational competences and practices that mobilize and allocate resources for the success of innovation.	Leadership for innovation; strategic intention for innovation; human resources for innovation; innovation project management; technology management for innovation; user knowledge; organizational flexibility; and co-production (co-production with partners and citizens, the role of co-producers — developer, co-developer, and information provider —, and the nature of co-producers — public sector, private sector, and third sector)
Outcomes	Innovation outcomes refer to the types and modes of innovation.	Radical innovation; incremental innovation; improvement innovation; product/service innovation; process innovation; organizational innovation; communication
Impacts	Innovation impacts refer to positive effects or improvements in organizational and/or service components.	Performance improvement; reputation improvement; organizational climate improvement; new or significantly improved services and their components (delivery, satisfaction, quality); improvement in the quality of life of society

Note. Elaborated by the authors.

The discussion on public sector innovation, undertaken in this section, allows inferring relationships between the theoretical constructs to contribute to the demystification of the phenomenon and the cumulative production of knowledge on the topic (Criado et al., 2025). In this way, we can formulate exploratory models of public innovation as suggested by Djellal et al. (2013), Daglio et al. (2014), Borins (2014), Sørensen (2016), De Vries et al. (2016), Pradana et al. (2022), Criado et al. (2025), Demircioglu (2024), and Liarte et al. (2025).

RESEARCH PROPOSITIONS

The literature reviews carried out allow us to raise research propositions to guide the study effort to elucidate how to manage public sector innovation, as suggested by Hjelmar (2021) and OECD (2020). Therefore, we organized the propositions raised below according to Daglio et al. (2014), Borins (2014), Sørensen (2016), De Vries et al. (2016), Pradana et al. (2022), Criado et al. (2025), Demircioglu (2024), and Liarte et al. (2025). In this regard, the literature describes the innovation drivers, as suggested by Cunningham (2005), Koch and Hauknes (2005), Pradana et al. (2022), Criado et al. (2025), and Demircioglu (2024). They induce the search for problem solutions, efficiency and improvements, political impulse, legal impositions, and technological factors. Drivers make innovation efforts materialize, resulting in significant changes that contribute to improving the public sector (Bloch, 2011; Bekkers et al., 2013).

Cunningham (2005), Koch and Hauknes (2005), Bugge et al. (2011), Bloch and Bugge (2013), De Vries et al. (2016), Cinar et al. (2019), Pradana et al. (2022), and Criado et al. (2025) show that facilitating factors can contribute to the occurrence of innovations, acting as enabling variables for innovative initiatives in the public sector.

Cunningham (2005), Koch and Hauknes (2005), Bugge et al. (2011), Bloch and Bugge (2013), De Vries et al. (2016), Cinar et al. (2019), Pradana et al. (2022), and Criado et al. (2025) show that barriers can compete to block the occurrence of innovations, acting as variables that make innovative initiatives in the public sector unfeasible.

Valladares et al. (2014), Bloch (2011), Hughes et al. (2011), Arundel and Huber (2013), Daglio et al. (2014), Borins (2014), Sørensen (2016), Pradana et al. (2022), and Criado et al. (2025) demonstrate that organizational capabilities contribute to innovations, acting as enhancers of positive outcomes in the public sector. Leadership for innovation, strategic intention for innovation, human resources for innovation, innovation project management, technology management for innovation, user knowledge, organizational flexibility, and co-production, among other capabilities mentioned in the literature, stand out. Borins (2002), Albury (2005), Lee et al. (2012), Cartensen and Bason (2012), Puttick et al. (2014), and Tonurist et al. (2015) reinforce that innovation in the public sector is sustainable when it is based on collaboration and broad stakeholder engagement. Voorberg et al. (2015) and Torfing (2018) identified outcomes of co-production or collaboration in the innovation process. These authors argued that the intensive involvement of citizens and different stakeholders increases the impact of innovations in the public sector. The arguments described above allow the formulation of Proposition 1: the occurrence of drivers, facilitators, barriers, and capabilities is associated with the occurrence of modes and types of innovation.

Osborne and Brown (2005), Eggers and Singh (2009), Bloch et al. (2009), Sørensen and Torfing (2011), Bloch (2011), Hughes et al. (2011), Arundel and Huber (2013), Djellal et al. (2013), Daglio et al. (2014), Borins (2014), Sørensen (2016), Lykkebo et al. (2021), Criado et al. (2025), Demircioglu (2024), and Liarte et al. (2025) report that innovation outcomes, evidenced in modes and types of innovation, contribute to generating direct and indirect impacts of innovative initiatives in the public sector. These authors reinforce the importance of studies that empirically demonstrate the effects of innovation on creating public value. This gives rise to Proposition 2: the occurrence of drivers, facilitators, barriers, capabilities, modes, and types of innovation is associated with the occurrence of innovation impacts.

The research framework presented aims to understand and explain the relationships between the constructs related to public innovation management. As suggested by De Vries et al. (2016), Criado et al. (2025), Demircioglu (2024), and Liarte et al. (2025), testing these propositions can provide opportunities for progress in the cumulative production of knowledge about public sector innovation. In addition, the research can demonstrate patterns of how innovation occurs under the influence of contextual, organizational, and human variables, contributing to a broader understanding of public sector innovations.

INVESTIGATION METHOD

The present study is explanatory research based on multiple cases, since it aims to identify the factors that determine or contribute to the occurrence of the researched phenomena, deepening the knowledge of reality by explaining reasons (Greene & David, 1984). Furthermore, we sought to construct a database

for future comparative work and theory formulation (Eisenhardt, 1989). Thus, using a multimethod approach, the research aims of this study sought to understand the relationships between the constructs of public innovation.

This study is qualitative and documentary research since we examine textual documents of different natures that have not yet received analytical treatment or that we can reexamine to achieve new or complementary interpretations (Miles et al., 2018). This research can also be characterized as quantitative, as it numerically addresses the theoretical constructs through statistical analysis, which is descriptive (frequencies) and based on data mining (association rules).

Data collection and analysis procedures

To reach the aim proposed for this study, we collected qualitative data about innovation experiences classified and awarded in public sector innovation contests from 1999 to 2019. The information sources used for data collection were the detailed reports of 346 experiences (266 awarded, 80 classified), considering the availability of information needed to identify the constructs and variables of interest in this study. We included the classified experiences because they were analyzed and approved to the final phase in the contests. All experiences were considered as innovation cases by the evaluation boards. We obtained them from the Public Sector Innovation Contest repository of the Brazilian National School of Public Administration (ENAP). The report of each innovation experience was based on guidelines and a standard questionnaire designed to collect data and information about the projects or innovation experiences.

The analysis of data from these experiences was carried out through content analysis, defined as a comprehensive examination of the structure and elements of the collected content to clarify the concepts present (Laville & Dionne, 1999). We approached the documents according to the stages of content analysis proposed by Mayring (2014) and Krippendorff (2018). To achieve the research objective, we defined the *ex-ante* analytical categories based on the literature on the topic (Mayring, 2014) for the unitizing and sampling processes, identifying which content from the experiences was relevant to be analyzed (Krippendorff, 2018). Regarding the coding process, we coded the data according to the theoretical constructs and variables (Table 1), using a specific protocol for content registration to reduce the data volume (Krippendorff, 2018; Mayring, 2014). Subsequently, we interpreted and inferred the raw data to make them understandable and to meet the research objective (Krippendorff, 2018).

Qualitative data supported the modeling of the quantitative dataset for performing data analyses. A two-step information collection protocol supported the reliability of the dataset creation. The first stage involved creating and evaluating the data collection protocol to standardize how to detect information about the research's theoretical constructs. This stage was supported by a triangulation technique among researchers in several rounds to reach consensus about the variables and their descriptors (Denzin, 2012). To ensure a higher level of reliability in the data collection process, we used the investigator triangulation technique. Denzin (2012) explains that this type of triangulation aims to detect or minimize researcher bias. In this study, researchers from a research group certified by the National Council for Scientific and Technological Development (CNPq) and affiliated with a federal public university independently coded the variables and the content of the experiences, then compared the data to obtain the final dataset used in quantitative analyses.

The second stage consisted of creating the dataset and inputting data regarding the research constructs. We coded the constructs into binary dichotomous variables, with 1 indicating the presence of the variable in the experience report and 0 indicating its absence in the analyzed cases. To analyze the dataset, we applied artificial intelligence techniques, specifically data mining with association rules, to extract relationships between constructs related to public sector innovation. We used data mining to identify relationships based on the proposed theoretical model. Fayyad et al. (1996) state that data mining allows the analysis of large volumes of data through discovery algorithms, producing the enumeration of models or patterns that help identify and interpret relationships between research constructs.

We submitted the data for analysis using WEKA software version 3.9.6, which generates association rules using the Apriori algorithm, as proposed by Agrawal et al. (1993). This technique is applicable to categorical and nominal data and reveals associations between constructs that may be unclear, thus enhancing the data analysis. Association rules aim to find frequent descriptive patterns that represent the probability of a set of items appearing in each case, given that another item is present (Zhang, C., & Zhang, S., 2003; Yabing, 2013).

Agrawal and Srikant (1994) argue that the Apriori algorithm enables the identification of association patterns between variables, facilitating the discovery of robust association rules and ensuring that the connections between these elements are extracted systematically, replicably, and in an evidence-based manner. The Apriori algorithm offers a model based on the frequency of occurrence of patterns, as it automatically filters the most relevant combinations and eliminates spurious relationships. Furthermore, this technique improves the predictive capacity of the analysis by identifying hidden relationships between key variables of public innovation, making inferences more reliable and empirically grounded.

RESULTS AND DISCUSSION

We organized the results into two subsections. The first addresses the descriptive results of the studied variables, and the second presents the most reliable association rules obtained through the Apriori algorithm analysis.

Table 2. Most awarded public organizations and the thematic category of innovation experiences.

Most awarded public organizations*	
Organization	Freq.
Empresa Brasileira de Correios e Telégrafos	20
Ministério da Saúde	18
Hospital de Clínicas de Porto Alegre	15
Instituto Nacional do Seguro Social	13
Receita Federal do Brasil	12
Ministério do Desenvolvimento Social e Combate à Fome	11
Thematic category of innovation experience	
Thematic categories	Freq.
Improvement of work processes	50
Citizen services	45
Technology and information management	45
Institutional arrangements for public policies	39
Strategic planning and management	39
Innovation in organizational processes in the Federal Executive Branch	25
People management and development	18
Evaluation and monitoring of public policies	16
Innovation in organizational processes, services, or public policies in the State Executive Branch	15
Simplification and streamlining of procedures	11
Innovation in services or public policies in the Federal Executive Branch	10
Organizational and infrastructure management	09
Articulation of partnerships	08
Citizenship and social inclusion	04
Participation and social control	02

Note. Elaborated by the authors. * More than 10 times in the period.

Descriptive results

Table 2 provides a detailed breakdown of the frequency of the most awarded public organizations and the thematic categories of the innovation experiences.

The results show the most frequent themes in the contests. The top five were: improvement of work processes, citizen services, technology and information management, institutional arrangements for public policies, and strategic planning and management. This reinforces the priorities of innovation teams in addressing problems or challenges in bureaucracy, services, and public policies, confirming the findings of Voorberg et al. (2015), Torfing (2018), Boon et al. (2023), and Criado et al. (2025). Table 3 presents the descriptive statistics of drivers, facilitators, and barriers of public innovation.

Table 3. Descriptive statistics of drivers, facilitators, and barriers of public innovation.

Research variables	
Drivers	Freq.
Non-problem orientation (improvement and efficiency)	154
Problem orientation	146
Legal obligation	37
Political impulse	32
Technological factors	25
Facilitators	Freq.
Teamwork	194
Material and financial resources availability	190
Legitimation	173
Human resources training	124
Institutional communication	102
Data integration	65
Barriers	Freq.
Resistance to innovate	144
Human resources unavailability	102
Limitation of infrastructure	86
Data fragmentation	78
Process fragmentation	78
Conflict of interests	77
Financial resources unavailability	52
Deadline limitation	23

Note. Elaborated by the authors.

The results highlight the most frequent pressures for innovation in the public sector: continuous improvement and problem resolution. In other words, the innovation teams are mobilizing efforts and resources to deliver significant changes in services, processes, and public policies (Cunningham, 2005; Criado et al., 2025; Koch & Hauknes, 2005). These results confirm what Bloch (2011) and Bekkers et al. (2013) suggest.

Facilitators and barriers identified in the innovation experiences show how teams and public organizations are dealing with contextual and behavioral factors that influence innovation efforts. The dichotomy between facilitators and barriers was confirmed by the results. For example, when an innovation experience has support and legitimation from top management, it helps mitigate resistance and resource unavailability (Cinar et al., 2019; Cunningham, 2005; Koch & Hauknes, 2005).

Table 4 presents the descriptive results of innovation capabilities: leadership for innovation, strategic intent for innovation, human resources for innovation, innovation project management, technology management for innovation, user knowledge, organizational flexibility, and co-production (co-production with partners and citizens/the role of co-producers — developer, co-developer, and information provider; and the nature of co-producers — public sector, private sector, and third sector).

Table 4. Descriptive statistics of innovation capabilities.

Research variables	
Innovation capabilities	Freq.
Co-production	250
Human resources for innovation	245
Innovation project management	228
Technology management for innovation	218
Leadership for innovation	192
Organizational flexibility	169
User knowledge	156
Strategic intent for innovation	74
Sub-variables of co-production	Freq.
Co-production with partners	214
Co-production with citizens	36
Co-productor as developer	19
Co-productor as co-developer	182
Co-productor as information provider	59
Public co-productor	195
Private co-productor	57
Third sector co-productor	44

Note. Elaborated by the authors.

The most frequent innovation capabilities were co-production, human resources, project management, and technology management. These results confirm the findings in the literature, which describe organizational capabilities as enhancers of innovations and public value, according to Bloch (2011), Hughes et al. (2011), Arundel and Huber (2013), Daglio et al. (2014), Borins (2014), and Sørensen (2016). However, the least frequent innovation capabilities were strategic intention, user knowledge, organizational flexibility, and leadership. This could be related to the specific dynamics of public organizations in Brazil, where bureaucratic mechanisms limit autonomy to innovate. To overcome these limitations, innovation teams seek partnerships and external resources to enhance the feasibility of projects and innovation experiences, as stated by Brudney and England, (1983), Djellal et al. (2013), Voorberg et al. (2015), Torfing (2018), Boon et al. (2023), and Criado et al. (2025).

Additional results show the profile of public innovation co-production. The pattern identified is: (1) more partnerships with public organizations than with private and third-sector partners; and (2) more co-developer partners than developer and information provider partners. These results highlight the importance of prioritizing open innovation in the public sector to enhance the interest of different actors and stakeholders in engaging in innovation projects and strengthening the public innovation ecosystem, as suggested by Voorberg et al. (2015), Torfing (2018), Boon et al. (2023), and Criado et al. (2025).

Table 5 presents descriptive results of types of innovation (product/service, process, organizational, communication), as suggested by Lykkebo et al. (2021), and modes of innovation (radical, incremental, improvement), as proposed by Djellal et al. (2013).

Table 5. Descriptive statistics of types and modes of innovation (outcomes).

Research variables	
Types of innovation	**Freq.**
Product/Service	99
Process	110
Organizational	103
Communication	34
Modes of innovation	**Freq.**
Radical	60
Incremental	138
Improvement	148

Note. Elaborated by the authors.

The results demonstrate the most frequent types of public sector innovation. Innovations focused on product/service, processes, and organizational management reveal the locus of innovation efforts to implement improvements in work procedures, routines, practices, and management models in public organizations, as suggested by Daglio et al. (2014), Borins (2014), Sørensen (2016), and Lykkebo et al. (2021). Incremental and improvement innovations were more frequent than radical innovations. Djellal et al. (2013), Voorberg et al. (2015), and Criado et al. (2025) state that radical innovations are expected when public organizations or the public sector face deep transformations and unprecedented socio-economic crises. Therefore, significant changes in services, processes, and management models depict how innovations occur and what their level of novelty is.

Table 6. Descriptive statistics of impacts of innovation.

Research variables	
Impacts of innovation	Freq.
Organizational management improvement	259
Service delivery improvement	240
Organizational image improvement	115
Organizational climate improvement	45

Note. Elaborated by the authors.

Table 6 describes the impacts of innovation on organizational aspects and service delivery in the public sector. The results show how innovations contribute to improvements from different perspectives of public organizations. Improvements in image or reputation, climate, and management indicate the value of innovation projects or experiences led by public servants and innovation teams, as well as the impact of new or significantly transformed services on quality of life and problem-solving for citizens (Arundel & Huber, 2013; Bloch, 2011; Borins, 2014; Daglio et al., 2014; Hughes et al., 2011; Sørensen, 2016).

Association rules with Apriori algorithm

We applied data mining and association rules to reach the proposed aim and enhance understanding regarding innovation management in the public sector (Criado, 2021; Wirtz et al., 2019). The Apriori algorithm was applied to the dataset to deliver association rules, which contain antecedents and consequents followed by the total quantity of the construct in the database and the respective measures of interest (support, confidence, lift, leverage, and conviction). For interpreting the support values, it is necessary to consider results within the interval |0, 1|. The range of confidence values is |0, ∞| and >1, indicating a rule with increased confidence. Lift means the model effectiveness, whose inter-

val must be between |0, ∞|. Leverage, on the other hand, must present results between |-1, 1|. Finally, conviction, developed as an alternative to the confidence measure, has an acceptable interval between |0, ∞|. We configured WEKA version 3.9.6 to use the Apriori algorithm with a minimum support of 10% and 30,000 rules to explore higher relationships between antecedents and consequents and to apply the predefined measures and patterns set by the software. Results are presented with a confidence interval of 90% or greater.

The results were organized according to the research propositions, and strategies were implemented to identify association rules useful for revealing strong and potential associations among research variables. Agrawal and Srikant (1994) highlight that the Apriori algorithm uses support, confidence, lift, leverage, and conviction to evaluate the relevance of association rules. Support measures the frequency of item occurrences in the database, ensuring the statistical significance of associations. Confidence indicates the probability of an item being selected given that another has already been chosen, reflecting the strength of their relationship. Lift assesses the degree of dependence between items, distinguishing meaningful associations from those that occur merely by chance. Leverage measures the deviation between the observed frequency and the expected frequency if the items were independent, while conviction analyzes how much the presence of one item reduces uncertainty about the occurrence of the other. These metrics are essential for correctly interpreting extracted patterns, allowing the filtering of irrelevant associations and the identification of statistically significant and applicable relationships.

Han et al. (2023) state that confidence and lift are important parameters to evaluate frequent patterns and the precision of association rules. However, these authors highlight the trade-off between discovering more associations and ensuring their relevance. The decision regarding minimum confidence thresholds and minimum support thresholds belongs to the user or researcher and depends on the nature of the field or knowledge area.

According to Liu et al. (1998), a problem with association rules mining is the discovery of interesting or useful rules. Sometimes biases prevent the identification of potential rules and induce the production of strong but incomprehensible association rules, according to these authors. Considering the suggestions by Han et al. (2023) and Liu et al. (1998), we decided to explore the dataset and depict the association rules, looking for potential relationships that help to understand the dynamics of public innovation based on the heterogeneity of innovation experiences analyzed in this research. Results are presented with a confidence interval of 90% or greater.

Proposition 1 was tested on the same dataset, as suggested by Voorberg et al. (2015), Torfing (2018), Boon et al. (2023), Criado et al. (2025), Demircioglu (2024), and Liarte et al. (2025). The antecedents in the association rules are the variables related to drivers, barriers, facilitators, and innovation capabilities. The consequents refer to modes and types of innovation. The results generated 15 association rules, and the confidence interval between 50% and 55% suggests moderately reliable predictive patterns. Thus, the findings demonstrate that the associations found are useful for predictive inferences but do not constitute absolute cause-and-effect relationships. Due to these metrics and results, we decided not to describe the 15 association rules specifically.

Despite the metrics of the Apriori algorithm, findings confirm that, in the public sector, innovations tend to be incremental due to the need for continuity of public services, the complexity of governance systems, and the aim to avoid ruptures and crises (Borins, 2014; Mulgan, 2014; Osborne & Brown, 2005). Proposition 1 was partially confirmed by the metrics and results previously presented.

The test of Proposition 2 was conducted with all variables in the same dataset. The precedents in the association rules are the constructs related to drivers, barriers, facilitators, innovation capabilities, modes, and types of innovation in the public sector. The consequents refer to innovation impacts in the public sector, such as improvement in service delivery, improvement in organizational management, improvement in organizational climate, and improvement in organizational image. The results generated association rules with 80% or greater confidence. The significant results are associated with the consequents 'improvement in the delivery of public services' and 'improvement in organizational management.'

Table 7. Association rules — innovation drivers, barriers, facilitators, capabilities, modes, and types (precedents) — service delivery improvement (consequents).

Association rules	Confidence	Lift	Leverage	Conviction
Product Innovation = YES Driver Problem Orientation = YES 43 ==> Service Delivery Improvement = YES 41	95%	1.37	0.03	4.39
Product Innovation = YES Capability Co-production with Partners = YES Driver Problem Orientation = YES 37 ==> Service Delivery Improvement = YES 35	95%	1.36	0.03	3.78
Product Innovation = YES Facilitator Human Resources Training = YES 39 ==> Service Delivery Improvement = YES 36	92%	1.33	0.03	2.99
Product Innovation = YES Facilitator Human Resources Training = YES Capability Human Resources for Innovation = YES 38 ==> Service Delivery Improvement = YES 35	92%	1.33	0.02	2.91
Product Innovation = YES Facilitator Material and Financial Resources Availability = YES Capability User Knowledge = YES 38 ==> Service Delivery Improvement = YES 35	92%	1.33	0.02	2.91
Product Innovation = YES Capability Co-production with Partners = YES Facilitator Material and Financial Resources Availability = YES 42 ==> Service Delivery Improvement = YES 38	90%	1.30	0.03	2.57
Product Innovation = YES Capability Co-production with Partners = YES Capability User Knowledge = YES 42 ==> Service Delivery Improvement = YES 38	90%	1.30	0.03	2.57
Product Innovation = YES Capability Co-production with Partners = YES Facilitator Material and Financial Resources Availability = YES Capability Project Management for Innovation = YES 42 ==> Service Delivery Improvement = YES 38	90%	1.30	0.03	2.57
Product Innovation = YES Capability Organizational Flexibility = YES 50 ==> Service Delivery Improvement = YES 45	90%	1.30	0.02	2.55
Product Innovation = YES Capability Co-production with Partners = YES Capability Organizational Flexibility = YES 40 ==> Service Delivery Improvement = YES 36	90%	1.30	0.02	2.45
Product Innovation = YES Capability Co-production with Partners = YES Public Co-productor = YES Facilitator Material and Financial Resources Availability = YES 39 ==> Service Delivery Improvement = YES 35	90%	1.29	0.02	2.39
Product Innovation = YES Capability Co-production with Partners = YES Public Co-productor = YES Facilitator Material and Financial Resources Availability = YES Capability Project Management for Innovation = YES 39 ==> Service Delivery Improvement = YES 35	90%	1.29	0.02	2.39
Total: 12 rules generated				

Note. Elaborated by the authors.

The association rules related to the improvement in the delivery of public services show that this outcome is enhanced by product innovations, co-production with partners, human resources development, user knowledge on services, resource availability, human resources management, and the search for problem-solving. These results are essential for the persistence of innovation in the public sector. Co-production with partners fosters a collaborative environment that enables public servants, managers, and leaders to develop and implement new solutions or improvements in their organizations. The literature argues that effective innovations depend on real and engaged co-production with citizens and society. However, the results show the prevalence of public co-producers in the innovation experiences in the Brazilian context. These findings are novel in the public sector innovation field. In general, the results reinforce Proposition 2 and confirm the propositions by Daglio et al. (2014), Borins (2014), Sørensen (2016), De Vries et al. (2016), Lykkebo et al. (2021), Boon et al. (2023), Criado et al. (2025), Demircioglu (2024), and Liarte et al. (2025).

Table 8. Association rules — innovation drivers, barriers, facilitators, capabilities, modes, and types (precedents) — organizational management improvement (consequences).

Association rules	Confidence	Lift	Leverage	Conviction
Organizational Innovation = YES Facilitator Legitimation = YES Capability Technology Management for Innovation = YES 40 ==> Organizational Management Improvement = YES 39	97%	1.30	0.03	5.03
Organizational Innovation = YES Capability Leadership for Innovation = YES Capability Technology Management for Innovation = YES 38 ==> Organizational Management Improvement = YES 37	97%	1.30	0.02	4.78
Organizational Innovation = YES Capability Human Resources for Innovation = YES Capability Technology Management for Innovation = YES 49 ==> Organizational Management Improvement = YES 47	96%	1.28	0.03	4.11
Improvement Innovation = YES Organizational Innovation = YES 46 ==> Organizational Management Improvement = YES 44	96%	1.28	0.02	3.86
Organizational Innovation = YES Driver Problem Orientation = YES 41 ==> Organizational Management Improvement = YES 39	95%	1.27	0.02	3.44
Organizational Innovation = YES Facilitator Teamwork = YES Capability Technology Management for Innovation = YES 40 ==> Organizational Management Improvement = YES 38	95%	1.27	0.02	3.35
Organizational Innovation = YES Capability Human Resources for Innovation = YES Capability Organizational Flexibility = YES 40 ==> Organizational Management Improvement = YES 38	95%	1.27	0.02	3.35
Organizational Innovation = YES Capability Technology Management for Innovation = YES 77 ==> Organizational Management Improvement = YES 73	95%	1.27	0.04	3.87
Organizational Innovation = YES Facilitator Human Resources Training = YES 38 ==> Organizational Management Improvement = YES 36	95%	1.27	0.02	3.18
Organizational Innovation = YES Capability Co-production with Partners = YES Capability Human Resources for Innovation = YES 37 ==> Organizational Management Improvement = YES 35	95%	1.26	0.02	3.10
Organizational Innovation = YES Facilitator Legitimation = YES 54 ==> Organizational Management Improvement = YES 51	94%	1.26	0.03	3.39
Organizational Innovation = YES Capability Co-production with Partners = YES 51 ==> Organizational Management Improvement = YES 48	94%	1.26	0.03	3.21
Organizational Innovation = YES Non-problem Orientation (Improvement and Efficiency) = YES 47 ==> Organizational Management Improvement = YES 44	94%	1.25	0.03	2.95
Organizational Innovation = YES Public Co-Productor = YES 46 ==> Organizational Management Improvement = YES 43	93%	1.25	0.02	2.89
Organizational Innovation = YES Facilitator Legitimation = YES Capability Leadership for Innovation = YES 46 ==> Organizational Management Improvement = YES 43	93%	1.25	0.02	2.89
Organizational Innovation = YES Capability Leadership for Innovation = YES 61 ==> Organizational Management Improvement = YES 57	93%	1.25	0.03	3.07
Organizational Innovation = YES 103 ==> Organizational Management Improvement = YES 96	93%	1.25	0.05	3.24
Organizational Innovation = YES Facilitator Teamwork = YES 58 ==> Organizational Management Improvement = YES 54	93%	1.24	0.03	2.92
Organizational Innovation = YES Capability Co-production with Partners = YES Public Co-Productor = YES 43 ==> Organizational Management Improvement = YES 40	93%	1.24	0.03	2.70
Organizational Innovation = YES Facilitator Material and Financial Resources Availability = YES Capability Technology Management for Innovation = YES 43 ==> Organizational Management Improvement = YES 40	93%	1.24	0.02	2.70
Organizational Innovation = YES Capability Human Resources for Innovation = YES 71 ==> Organizational Management Improvement = YES 66	93%	1.24	0.04	2.98
Organizational Innovation = YES Co-productor as Co-developer = YES 41 ==> Organizational Management Improvement = YES 38	93%	1.24	0.02	2.58
Organizational Innovation = YES Capability Co-production with Partners = YES Co-productor as Co-developer = YES 41 ==> Organizational Management Improvement = YES 38	93%	1.24	0.02	2.58
Organizational Innovation = YES Capability Co-production with Partners = YES Capability Technology Management for Innovation = YES 41 ==> Organizational Management Improvement = YES 38	93%	1.24	0.02	2.58
Organizational Innovation = YES Public Co-Productor = YES Capability Technology Management for Innovation = YES 38 ==> Organizational Management Improvement = YES 35	92%	1.23	0.02	2.39
Total: 25 rules generated				

Note. Elaborated by the authors.

The results generated 25 association rules and indicate that these rules are statistically relevant for understanding public innovation management. The confidence interval between 92% and 97% suggests highly reliable predictive patterns. A lift greater than 1.23 confirms that the constructs analyzed have a dependence relationship beyond what is expected by chance. A leverage metric above 0.02 indicates an existing correlation, although not an extremely strong one. A conviction between 2.39 and 5.03 indicates that the antecedent reduces the chance of error in predicting the consequent, reinforcing a reliable and deterministic relationship. Thus, the findings demonstrate that the associations found are useful for predictive inferences and configure cause-and-effect relationships.

The association rules related to the improvement in organizational management demonstrate that this result is enhanced by organizational and improvement innovations, legitimation, technology management, human resources management, and the search for problem-solving. Co-production with

partners fosters a collaborative environment that enables public servants, managers, and leaders to develop and implement new solutions or improvements in their organizations. The results show the prevalence of public co-producers in the innovation experiences in the Brazilian context. These findings are novel in the public sector innovation field. In general terms, the findings corroborate Proposition 2 and reinforce the propositions by Daglio et al. (2014), Borins (2014), Sørensen (2016), De Vries et al. (2016), Lykkebo et al. (2021), Criado et al. (2025), Demircioglu (2024), and Liarte et al. (2025).

FINAL CONSIDERATIONS

Based on the analysis of Brazilian public innovation experiences and the application of data mining, this article explained public sector innovation management by relating drivers, facilitators, barriers, capabilities, outcomes, and impacts of innovation.

In contemporary public management, governments and public administrations are shifting from a stability-oriented role (in the sense of the bureaucratic model) to an approach oriented toward the ability to respond to adaptive circumstances, aiming for flexibility and positive changes, with a focus on governance and high public value. The perspective is that public organizations not only react to crises (economic, political, and social) but also act proactively in solving problems and discovering new opportunities to create public value for society.

Bloch (2011), Hughes et al. (2011), Sørensen and Torfing (2011), Daglio et al. (2014), Arundel and Huber (2013), Borins (2014), Bugge and Bloch (2016), Criado et al. (2025), Demircioglu (2024), and Liarte et al. (2025) highlight the relevance of studying the antecedents of innovation to identify the necessary conditions for institutional actions aimed at innovation, as well as offering support to public innovation projects and initiatives.

The present study intended to contribute to scientific advancement on public innovation by collecting, analyzing, producing, and sharing information, knowledge, and relevant innovation experiences in the Brazilian public sector, based on the research's theoretical model and the data analysis undertaken. The results identified 37 association rules that explain the impacts of public innovation. Human resources for innovation, technology management for innovation, user knowledge, search for problem-solving, co-production between partners, and public partners as public co-producers are important variables for public managers to enhance improvements in organizational components, public services, and their effects on citizens and society.

Practical implications can be inferred based on the results of this research. The empirical analysis shows the importance of diagnosing capabilities and antecedents of innovation in public organizations before proposing initiatives or innovation projects. It reveals critical factors or resources for the success of innovation projects, and innovation managers and leaders must be constantly aware of this, prioritizing the allocation of resources focused on these variables within public organizations.

Thøgersen (2022), Pradana et al. (2022), Criado et al. (2025), Demircioglu (2024), and Liarte et al. (2025) highlight that research on innovation contributes to consolidating public sector innovation as a state strategy, government programs, and sustainable public administration. The results imply improvements in public decision-making and provide insights for the development of training programs for public servants and teams engaged in innovation projects, the development of processes, methodologies, and patterns for innovation management, and the formulation of indicators for monitoring and evaluating public sector innovation projects and initiatives, as suggested by Heichlinger et al (2014) and Gault (2016).

The limitations of this research are related to theoretical and methodological aspects since data collection was limited to technical and organizational reports on innovation experiences in the Brazilian public sector, at the federal, state, and municipal levels, with varying numbers of awarded initiatives depending on their origin. The research does not present primary data to corroborate these reports, which is important for future research. Interviews and focus groups with public servants and managers can reveal new insights about the relationships found in this study.

Finally, we expect that this research agenda and future studies will advance toward systematizing knowledge to equip managers and public employees to conduct creative processes of generation, selection, implementation, and dissemination of innovative ideas for the public sector, considering broad stakeholder collaboration and engagement.

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