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ARTICLE

Model for measuring airport innovation

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ABSTRACT

Identifying and measuring innovation at airports becomes necessary not only to point out the elements of its management or infrastructure to be improved, but also to raise opportunities for innovation, with the aim to collaborate for the best efficiency of air transport. In this sense, this study concerns innovation management applied to airports given the limitations in the state of the art related to measuring innovation in this type of organization. The integrated perception of different airport stakeholders has been collected from a survey with 70 Brazilian professionals specialized in the subject, namely researchers, airports, airlines, and the aeronautics industry managers, in a proposal to measure the level of airport innovation from different indicators. The results proposed an algorithm for an Airport Integrated Innovation Index (AI^3), composed by 38 measurable variables related to innovation practices, procedures, and infrastructure elements such as new biometric passenger identification systems, real-time passenger flight tracking systems, new types of runway pavement, and actions to reduce airport operational restrictions. This model can be used in airports of different categories (national or international) and sizes (small, medium, or large). It may be adapted for different countries and contexts according to their markets and organizational cultures.

KEYWORDS | Air transport; Innovation measurement; Innovation planning.

1. Introduction

Innovation is widely recognized as one of the keys to businesses' survival and profitability in environments of constant technological change and competition. In the case of airports, technological change is an integral part of the business, and it encompasses everything from check-in, handling of luggage and cargo, security procedures, passenger comfort, boarding, and so on. As for competition, even though some airports may constitute natural monopolies under certain conditions, many local and regional airports face growing competition from alternative modes of transportation such as long-haul buses and high-speed trains. Finally, international hubs provide the first glance of a nation to foreign visitors, thus sidelining with other local features in attracting businesses and tourists.

Further elaborating on the need for innovation at airports, several authors identified specific aspects. Airport innovation planning and management must consider both the market needs and consumer satisfaction, as discussed by Chen, Batchuluun, and Batnasan (2015), or meet travelers' needs by personal aero mobility (COHEN, 2010), to ensure safety regulations procedures (KOH, 2007) and obtain incentives for transport innovation funds (WIESENTHAL; CONDEÇO-MELHORADO; LEDUC, 2015). Additionally, Nicolau and Santa-María (2012), along with Franke (2007) and Pereira and Caetano (2015) pointed out the need to match the pace of innovation of airlines in the operations and their evolving business models. Furthermore, Heracleous and Wirtz (2009) highlighted that airlines have innovation strategies of their own that must be matched, while Grahamn, Hall and Morales (2014) and Slayton and Spinardi (2016) noted that the changing characteristics of aircrafts often require adjustments at airports. In general, societal trends toward environmental issues, inclusiveness, open skies agreements, heightened flows of passengers and cargo, and so on. All pose challenges for airport managers, requiring tools and decisions for innovation planning and management.

The preceding summary points to the wide range of possible aspects that fall within the broad concept of innovation, especially in the context of airports. In this study, innovation is understood as the commercial success of new ideas, materialized in new products, services, or processes (DOGDSON; GANN; SALTER, 2008). Airports can be defined as companies equipped with runways for aircraft landing and takeoff, buildings, and equipment, capable of receiving passengers and cargo (YOUNG; WELLS, 2011). In the intersection of both concepts, **airport innovation is considered in this study as the introduction of new products, services, or processes that improve the performance of airports in their business of handling air transportation of passengers and/or cargo**.

Perhaps because of the diversity of aspects in which it is possible to seek innovation, many studies present proposals for measuring airport innovation in highly specific ways—focusing, for example, on airport marketing (HALPERN, 2010), innovations in services only (CHEN; BATCHULUUN; BATNASAN, 2015), and development of new airport infrastructure (GIL; MIOZZO; MASSINI, 2012), among others. Thus, to support the decision making of airport managers and authorities, this study identifies a need for an integrated approach to airport innovation, ensuring the comparability between airports in competitive settings and offering an objective overview of the business, especially considering the needs of a diverse set of stakeholders.

Therefore, the present study first identifies the main variables associated with integrated airport innovation, treated as "integrated" because it considers the perceptions of different expert stakeholders such as researchers, airports, airlines, and aeronautics industry managers. In the sequence, an effort was made to try to measure the variables associated with airport innovation from the perception of these professionals, active in the Brazilian air transport market. These professionals were consulted due to the need to consider managerial technical parameters inherent to airport procedures. The variables and their respective levels of relevance are presented in a simple and practical algorithm to finally derive the Airport Integrated Innovation Index (AI^3).

The choice of Brazil and its professionals as a location for the present study is attributed to the significant number of airports in the country, which implies a comparative preeminence of air transportation when compared to other countries. The country has a total of 2,739 aerodromes, 2,183 of which are private and 556 public, of which 168 (6%) were used by commercial aviation in 2019 (ANAC, 2020). In addition, in the last 10 years (2009–2018), the country experienced significant growth in regular air passenger transport, from 69,7 million paid passengers transported in 2009 to 117.6 million in 2018—a growth close to 70% in the period (ANAC, 2019), which justifies the particular interest in this study.

This paper is organized into five sections, including this introduction: the following section presents a summary of the literature review; Section 3 presents the methodology, which is followed by the calculation of the AI³ in Section 4; finally, Section 5 concludes with a discussion about the advantages of the AI³, its limitations, and directions for further applications.

2. Literature review

Indicators used to measure innovation in organizations are commonly presented in the literature from the analysis of input variables, e.g., R&D investment and schooling time of employees, and output variables, such as the profit from new product sales and the number of new patents registered (BRATTSTRÖM *et al.*, 2018; OECD, 2004), with the practice of adopting indicators based on the perception of the organization's stakeholders being less common.

In a recent study on the topic with the analysis of possible indicators used to measure innovation, Carayannis, Goletsis, and Grigoroudis (2018), considering the actors University, Industry, Government and Civil Society, pointed out that, among the analyzed variables, in the case of the University and the Civil Society, the "total of public investments in R&D" has the greatest relative importance. In the case of Industry, "new doctorate graduates" has the greatest relative importance, and, in the case of Government, the main variable is the "contribution of manufacturing high technology products exports to trade balance."

In addition, different innovation indicators are also identified in the literature, as in the case of the study by Dobni, Klassen, and Nelson (2015) on the 1,000 largest companies in the USA based on revenues, which demonstrate that "employee empowerment," "knowledge generation," and "employee skills and creativity" are among the most relevant in the organizations studied. Moreover, Dobni and Klassen (2021) clarify that highly innovative organizations use—in what the authors call methods and technologies of their management processes—tools such as open innovation and design thinking. Thus, it is noted that the measurement of innovation in organizations is based on efficiency indicators (inputs and outputs) and the management practices adopted. The measurable indicators identified are considered quantitative variables in this study.

Then, given the complexity of an airport, analyzing innovations in this type of organization must consider different elements in its management and physical structure. In this sense, airport innovation has been analyzed under different aspects in the literature, mostly falling into three categories. The first category comprises studies that analyze specific innovations in study cases, focusing on the results of their introduction. The second category focuses on understanding the drivers of airport innovation, that is to say, which factors are predominant in the introduction of specific innovations. Generalizing the results is usually difficult due to the stark variation in contexts that different airports experience as well as their size, geographical location, and/or model of management. Finally, the third category comprises preliminary attempts to integrate innovation matters, presenting and discussing them as key predecessors of this paper.

As an example of the first category, focusing on the need to maximize efficiency, Kalakou, Psaraki-Kalouptsidi, and Moura (2015) highlight that new technologies for passenger processing, such as the possibility of self-service check-in, as well as biometric identification in security control, can lead to increased airport capacity. Likewise, Boussadia (2009) presents the possibilities of using biometric sensors by scanning the passengers' iris, face, and hands to expedite passenger processing. Negri, Borille, and Falcão (2019) suggest to consider not only the availability of these technologies but also the conditions and willingness of passengers to use them.

Digging into innovations targeted at passengers, Chen, Batchuluun, and Batnasan (2015) describe two relatively recent trends in costumer care at airports. One relates to the use of social media as a means of communication used by airports, facilitating information for users. The other is the concept of airport micro-hotel, in which passengers can access in-terminal cabins and boxes for rest during short periods. Airports such as London Heathrow Airport (LHR), London Gatwick Airport (LGW), Munich Airport (MUC), and Moscow Sheremetyevo Airport (SVO) already employ similar concepts, displaying positive feedback from users. The introduction of similar services may be viewed as highly innovative in other large airports worldwide, but it is unclear whether and how smaller airports would benefit.

In a study conducted at Amsterdam Schiphol Airport (AMS), Silvester *et al.* (2013) considered different future scenarios for the use of electric vehicles at the airport, connecting the airside to the landside, providing fast links between vehicles and aircrafts as well as links between the airport and the subway system. While electric vehicles may no longer be viewed as cutting edge innovations in themselves, the way in which they are used in airport operations provides an interesting example of process innovation. Finally, Matin-Domingo and Martín (2016) sought to identify the most innovative airport, looking at a broad sample of 75 European airports and taking the adoption of mobile internet and PC-Website as reference. According to the study, only Amsterdam Schiphol Airport (AMS), Copenhagen Airport (CPH), London Heathrow Airport (LHR), and London Stansted Airport (STN), about 5%

of the total airports analyzed, are considered successful innovators in this field. This is because these airports not only adopted new technologies or new services relatively early—especially free Wi-Fi, auto website in mobile devices, or easy access through apps—but they have already reached "maturation" in the use of these technologies, providing stable and reliable services.

Regarding efforts for a better understanding the possible drivers of airport innovation, in the second category of studies here considered, Arif, Gupta, and Williams (2013) demonstrate that innovations have been implemented by the government at three airports in the United Arab Emirates with the purpose of meeting passengers' expectations as well as strengthening customer loyalty. Among the variables highlighted by passengers are airport employees' kindness when providing information, airport accessibility, provision of seats for resting and waiting for the flight, quality, and variety of services in relation to different religions and cultures, and others.

Still, inquiring into the drivers of innovation at airports, but now focusing on airport infrastructure projects, Gil, Miozzo and Massini (2012) consider the potential for innovation in airports through the adoption of different technologies. Analyzing the case of Terminal 5 at London Heathrow Airport (LHR), the authors demonstrated that the adoption of the technologies analyzed is determined by the expectations of profitability and the capacity of implementing these new technologies in daily operations.

More broadly, to identify how the literature on air transport has recently developed the theme of innovation, Caetano and Alves (2019), using the systematic literature review, present the main authors and their respective focus on airport innovation, as shown in Table 1.

From the studies summarized in Table 1, focused on categories 1 and 2, it is observed that most of the literature consists on specific case studies that highlight specific types of innovations—either intraorganizational in nature, such as those pointed out by Ahn and Min (2014), Arvidsson *et al.* (2006), and Doll and Karagyozov (2010), or reflecting the needs of the passengers, as in Arif, Gupta and Williams (2013), Chen, Batchuluun and Batnasan (2015), and Grant *et al.* (2013). Two relevant gaps exist in the literature from the standpoint of airport managers: one is that decision making related to the management of innovation could benefit from an integrated approach that allows airports to be easily and objectively compared, and its strengths and weaknesses identified. The other is that it could be useful to understand how different categories of stakeholders perceive each airport's strengths and weaknesses.

TABLE 1
Main authors and focus on airport innovation

Authors	Innovation focus
Ahn and Min (2014)	Operational Efficiency
Arif, Gupta and Williams (2013)	Customer Services
Arvidsson et al. (2006)	Organizational Climate
Boussadia (2009)	Electronic Security Equipment
Chen, Batchuluun and Batnasan (2015)	Services Innovation
Doll and Karagyozov (2010)	Financing Structure
Gil, Miozzob and Massini (2012)	Development of New Infrastructure
Grant et al. (2013)	Services Innovation
Halpern (2010)	Marketing Innovations
Silvester *et al.* (2013)	Integration Between Electric Vehicles and Local Energy Infrastructure
Sulmona, Edgington and Denike (2014)	Border Control

Source: Caetano and Alves (2019).

In this light, in the third category of studies considered here, one approach to an integrated study of airport innovation was presented by Halpern (2010), who illustrate airport marketing based on a survey of managers at 84 different European airports as well as the innovative profile of these airports using 10 different variables. These refer to the modification of equipment or services, which reduce costs or increase airport efficiency. The results of this study demonstrated that the level of innovation significantly influences these airports' marketing performance, considering the attraction of new routes, maintenance, and the increase in existing routes in terms of the number of passengers.

Finally, the study that comes closest to the current proposal, though applicable to airlines rather than airports, is that of Nicolau and Santa-María (2012), who provide an econometric analysis of different variables. The authors presented the conditional innovation variance (h_{it}) concerning the organization's financial risk in its market value, according to Equation 1 adapted from the authors.

$$h_{it} = \exp\{ c_i + \xi_1 D_{t+2} NBM + \xi_2 D_{t+2} ACS + \xi_3 D_{t+2} NT + \lambda_{ij} \left| \frac{\varepsilon_{t-j}}{h_{it-j}^{\frac{1}{2}}} \right| + \delta_{ij} \frac{\varepsilon_{t-j}}{h_{it-j}^{1/2}} + \gamma_{ij} \ln(h_{it} - k)\} \quad (1)$$

where c_i refers to an autonomous coefficient, ξ_1 the sensitivity of the autonomous coefficient of the conditional variance in the period considered, ξ_2 and ξ_3 the innovation-type impact in terms of new business model (NBM), advanced consumer segmentation (*ACS*), and new technologies (*NT*), the binary variables (D_{t+j}), analyzed during period *j*, in the days, is related to the impact following the announcement of the implemented innovation, λ_{ij} is the sensitivity of the conditional variance in relation to the error term, δ_{ij} is the asymmetric effect on the conditional variance, γ_{ik} is the sensitivity of the conditional variance to its lags, and the term $\frac{\varepsilon_{t-j}}{h_{it-j}^{1/2}}$ originates from the EGARCH model (Nelson, 1991). The respective coefficients are presented in Equation 2.

$$h_{it} = \exp\{ \underset{(-12.15)}{-0.626} + \underset{(3.19)}{0.276} D_{t+2}NBM \underset{(-3.13)}{-0.352} D_{t+2}ACS \underset{(-1.12)}{-0.144} D_{t+2}NT + \underset{(13.58)}{0.247}\left|\frac{\varepsilon_{t-j}}{h_{it-j}^{1/2}}\right| \underset{(-1.21)}{-0.014}\frac{\varepsilon_{t-j}}{h_{it-j}^{1/2}} + \underset{(172.8)}{0.943}\ln(h_{it-k})\} \quad (2)$$

According to Equation 2, the main results of the study demonstrated that, in the case of the analyzed airline and considering the three binary variables—new business model (NBM; coefficient 0.276), advanced consumer segmentation (ACS; -0.352), and new technologies (NT; -0.144)—market segmentation presents itself as the business' lowest risk variable from the implementation of innovation. This study, however, has limitations in the reduced number of variables considered and their relationship with airport innovations management.

The literature on innovation clarifies that users of a particular product or service, such as passengers, should also participate in the innovation process, so that their needs are met and lead to social well-being (GAMBARDELLA; RAASCH; VON HIPPEL, 2016). However, it is considered that consumers' needs are exhaustively studied by the companies of the sector and contemplated in the answers of the professionals participating in this study. Additionally, several past contributions have been made in this regard (for example, CORREIA; WIRASINGUE; BARROS, 2008; GRAHAM, 2005; YEH; KUO, 2003); therefore, this study considered only the opinions of researchers, airports, airlines, and aeronautics industry managers. This choice was motivated by simplicity and cost considerations in data collections as well as the need to build a proposal based on experts' knowledge of airport characteristics.

In conclusion, the present study succeeds Halpern's (2010) integrated approach and expands it by employing a broader set of innovation-related variables, enabling a wider set of managerial analyses. It also builds on Nicolau and Santa-María's (2012) method of calculation. Therefore, a normalized index that summarizes a broad set of variables is here proposed, providing a ready-to-use tool for managerial decision making.

3. Data collection

The execution of this study followed four different phases. The first phase consisted of identifying relevant variables associated with innovative airports. The literature has presented innovations in a compartmentalized manner, focusing on topics such as marketing, project management, and new services—for example, in individual studies. Thus, it was deemed necessary to conduct a review of the different variables presented in the studies (state of the art) and to combine them with variables identified with the reality of the airports (state of the practice).

Therefore, in addition to the variables collected in the literature, it is also included variables from the experience of certain airports, such as real-time flight tracking through Flightradar24 at Cork Airport (ORK), the ecological panel of air conditioning system at Singapore Changi Airport (SIN), and ergonomic seats that turn into beds at Helsinki Airport (HEL), among others.

Initially, 54 variables that could be associated with airport innovation were identified in this first phase of the study. For the validation of these variables and the identification of their level of relevance in airport innovation, this research recorded the perception of professionals working in the Brazilian air transport market who are researchers on the subject as well as airports, airlines, and aeronautics industry managers. In the second phase of the research, self-administered structured pilot questionnaires were developed and sent by email to the interviewees, who answered the electronic form.

A pilot questionnaire, with 54 variables, was sent to a research group in air transport innovation management that comprised 11 researchers, of whom seven responded promptly by pointing out necessary improvements. The number of questions was reduced to 51, eliminating possible redundancies, and then sent to air transport and airport researchers, students, and teachers of aeronautical fields of studies in Brazil for a second round of testing; 22 answered questionnaires were collected.

After the second round of the pilot questionnaire application, in the third phase of the research, descriptive statistics were calculated for the next improved 50 quantitative questions considered in the questionnaire. The mean of the analysis variables ($\bar{u}$) in each question ranged from 6,0 to 9,4. A filter was applied to the analysis of the main questions presented, and only the questions that presented $\bar{u} \geq 7.0$ in the researchers' evaluation were considered. Based on this preliminary statistical exploration of the pilot questionnaires, 12 variables were excluded from the final version due to low receptiveness by the specialists consulted.

After the pilot study, among the excluded variables were, for example, the "kindness and helpfulness in the service provided by airport employees," which did not reach $\bar{u} \geq 7.0$ despite being considered in the study by Arif, Gupta, and Williams (2013), as well as "length and width of the landing and takeoff runways," already defined in the Airport Planning Manuals of the project aircrafts and in the ICAO Annex 14. The decision to keep the variables with average values greater than or equal to 7.0 in the model can be characterized as an arbitrary choice (BIGGS *et al.*, 2009). However, in this study, this reference value was used because it is close to the scores of 70% presented in the literature for innovative organizations in the analysis of different variables associated with innovation metrics such as innovation influence, implementation, intent, and infrastructure (DOBNI; KLASSEN; NELSON, 2015; DOBNI; KLASSEN, 2021).

The final questionnaire contained 39 questions—the first one being related to the identification of the respondent's profile. These questionnaires were sent to about 200 professionals during the period between October 2016 and January 2017, for which there were 82 responses (about 40% of the questionnaires sent). In the selection of the survey participants, considering that airport innovation should be identified based on the opinion of different stakeholders, have been identified possible managers of airports, airlines, aeronautics industry, and researchers.

Regarding the particularities of airport structures, it was decided to classify the innovations variables into four groups according to their managerial implications: G1: passengers and luggage processing; G2: information, communication, and passenger services; G3: runway, courtyard and physical elements of the airport; G4: airport business. The list of the 39 variables analyzed in each of these four groups is presented in Annex 1.

Finally, has been derived a relevance index for each variable from the respondents' opinions. Respondents were requested to rate the relevance of each of the 38 airport innovations variables from 1 to 10. The 39th question was treated separately because it has non-ordinal categorical responses. In this question, respondents were asked what type of airport governance is better recommended to innovative approaches. The possible answers were "public and federal," "public and state," "public and municipal," "private," and "other."

In total, 82 questionnaires were collected, and after the exclusion of a few observations due to incomplete and technically insufficient answers (BIGGS *et al.*, 2009), a total of 70 answered questionnaires were considered valid. Table 2 presents the distribution of the interviewees' profiles for these valid questionnaires, considering airport managers as managers from the Brazilian public (i.e., Infraero and DAESP) or private (i.e., GRU and Inframérica Airports) enterprises of airport infrastructure and management, research in air transport and airports from public and private institution of research, aeronautics industry managers (i.e., Embraer and Boeing), and airline managers (i.e., Latam Airlines and Gol Airlines).

TABLE 2
Profiles of respondents and number of valid questionnaires

Profile	n
Airport manager	25
Researcher in air transport and/or airports	19
Aeronautics industry manager	18
Airline manager	8
Total	**70**

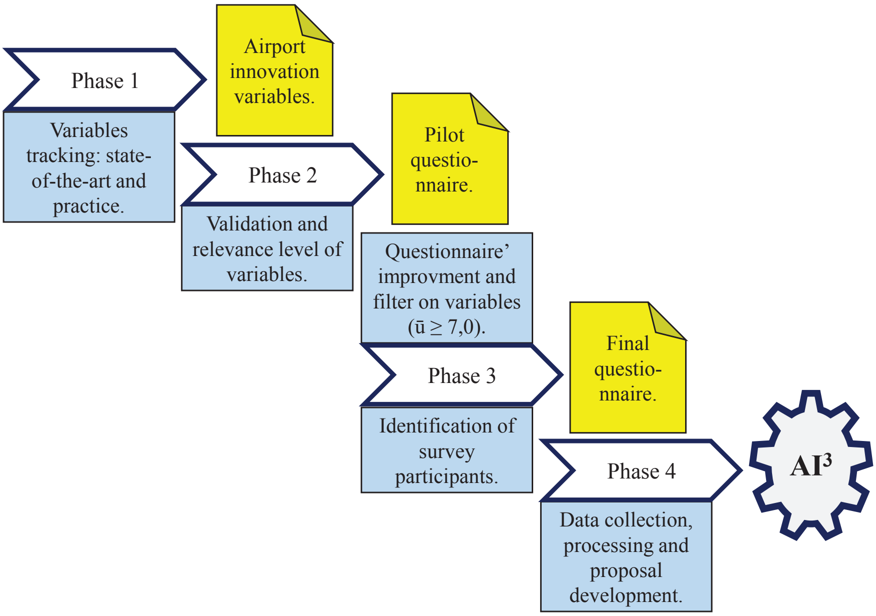
Source: Authors.

The fourth phase of the research consisted of data analysis, which used statistical tools to analyze the correlations between variables, tests, and representativeness calculations of a given variable in relation to the others. Thus, in this phase, the medians $\bar{u}$ of the variables analyzed have been used.

It is believed that the use of the median as a reference in these analyses can better represent the reality of the responses collected from the interviews as it contains the value at the central point of the sample's responses. This same choice can also be successfully identified in the study of Cui *et al.* (2020), on public transport, or in that of Suh and Ryerson (2019) on airport forecasts.

With the possibility of identifying the level of airport innovation based on certain variables, a general equation for the identification of the Airport Integrated Innovation Index (AI^3) was proposed. Figure 1 presents a summary of the main phases of the study activities.

FIGURE 1
Phases of the study activities



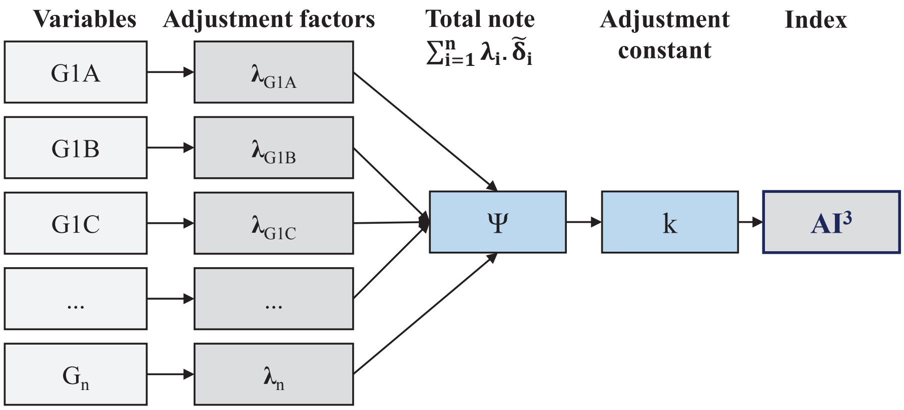
Source: Authors.

As Figure 1 summarizes, the activities of the study went through Phase 1 with a theoretical foundation, then followed to practical validations with professionals working in the sector in Phases 2 and 3, which made the development of a proposal in Phase 4 feasible.

A complete representation of the composition scheme of the AI^3 algorithm can be identified in Figure 2.

According to Figure 2, each variable analyzed has a particular value of $\bar{u}$ and λ, whose sum of its products is, in turn, multiplied by a constant κ, resulting in a value for AI^3, as discussed in the results.

FIGURE 2
AI³ Algorithm



Source: Authors.

4. Results

This section presents the results of the study—first, with the analysis of the inputs investigated and its theoretical interfaces; then, with the algorithm for the proposed model and the equations for the Airport Integrated Innovation Index (AI^3) based on the level of relevance of these variables; and finally, as an application of the AI^3 to a hypothetical airport.

4.1 Description of inputs and theoretical interfaces

All the 37 variables analyzed for applying the method, except *G4A* (form of governance), were satisfactory in respect to their level of relevance for airport innovations. The $\bar{u}$ response for each variable ranged between 7 and 10, which makes a sample $\bar{u}$ of 8.0 on a scale of 1 to 10. The results show that all 37 variables are relevant for innovation in airports, which provides validation for the previous steps in variable identification.

In addition to these 37 variables, respondents were inquired about which form of airport governance is best in their opinion with respects to airport innovation approaches. Out of the 70 respondents, a large majority (48 or about 70%) responded that "private governance" is the best way, followed by 13 respondents who answered "federal public airport," and eight respondents pointed to other types of governance, such as public investments and private operations costing, resulting in a public–private partnership (PPP). This kind of partnership, according to Costa and Ribeiro (2019), can result in a significant reduction of 70% of public spending in airport management. Only one respondent answered that "municipal public airport" is the best form of governance. When the responses to this variable are disaggregated by the profile of respondents, it becomes clear that there is near consensus around private governance among researchers and from airlines and aeronautics industry managers.

The only category that showed support for other forms of governance, especially public governance, was that of airport managers. Since many of the airport managers interviewed served in public airports, this could be interpreted as self-bias in defense of current working conditions. As for the other stakeholders, the results point to unequivocal support for private airport management as far as the conditions for innovation are concerned. This result may, however, reflect the current stage of public policy debate in the observed country, which has undertaken significant concessions of airports to private operators in recent years. Therefore, it must exercise caution when making international generalizations.

Table 3 displays which innovations variables, reported by each group of respondents and having the lowest and the highest levels of comparative relevance, are identified by the median $\bar{u}$. As the respondents' perceptions are likely to vary as a function of their particular experience in the air transportation industry, such disaggregated analysis shows different priorities for different stakeholders. While the variable "Presentation of elements related to culture, local fauna and flora […]" was the least relevant for three of the profiles of respondents, aeronautics industry managers disagreed, pointing out "New charging forms for airport services […]" as the least relevant variable. As for the variables with the highest reported relevance, aeronautics industry and airline managers converged on "Ways to reduce queues in immigration control […]," while researchers showed higher appreciation for "New instrument control systems for approaching aircraft," and airport managers suggested "Mobile internet for passengers […]" as the most highlighted innovation.

Some of the variables stood out due to the high values reported by all respondents. In particular, the variable *G1A* ("New systems of biometric identification of passengers") displayed $\bar{u}$ = 9.5. Thus, it has been identified that any new systems reducing passenger processing time while maintaining or increasing safety, such as hand, face, and iris scanners, are highly relevant to the airport. This is in line with the study presented by Kalakou, Psaraki-Kalouptsidi, and Moura (2015), in which the authors demonstrated the relevance of this variable through the real gains in airport capacity with these key technologies. In light of such improvements, expensive investments in the physical expansion of terminals could be avoided.

TABLE 3

Innovation with lower and higher relevance by the profile of the respondent ($\bar{u}$)

Profile	Innovation with lower relevance	Innovation with higher relevance
Airport manager	**G4L**: Presentation of elements related to culture, local fauna, and flora, such as regional arts, animals, and plants (7.0).	**G2E**: Mobile internet for passengers in the terminal (10).
Researcher in air transport and/or airports		*G3F*: New instrument control systems for approaching aircraft (10).
Airline manager		**G1G**: Ways to reduce lines in immigration control (for international airports) (9.0).
Aeronautics industry manager	**G4B**: New charging forms for airport services, such as boarding / landing fees, landing / takeoff, use of the yard, etc. (7.5).	

Source: Authors.

In addition, variable *G2E* ("Availability of mobile internet for passengers in the terminal") presented high relevance $\bar{u}$ = 10. It has been identified that such innovation becomes relevant by making the internet signal via Wi-Fi not only available at different points in the terminal but also freely accessible to passengers. This can be achieved through partnerships between airport management and mobile media companies. This result corroborates the one presented by Matin-Domingo and Martín (2016) concerning the airports of Amsterdam Schiphol (AMS), Copenhagen (CPH), London Heathrow (LHR), and London Stansted (STN), which were considered innovative in this respect. Newbold (2020) also argued about the need for airports to remain constantly up to date on technological communication options, not only to improve passenger experiences but also to optimize airport operations.

The variable *G3F* ("Development of new instrument for aircraft approaching control systems") was also one of the most relevant points by the interviewees, presenting $\bar{u}$ = 10, which demonstrates the need for constant development of technologies to support the pilots' activities at aircraft landing.

On the other hand, some variables displayed a lower level of relevance, such as the variables *G4L* ("Presentation of elements related to culture, local fauna and flora"), *G2D* ("Possibility of bathing place at the airport"), and *G4B* ("New ways of charging for airport services") with $\bar{u}$ = 7.0, 7.0 and 7.5, respectively.

In the case of *G4L*, however, it is noteworthy that airports in regions with a touristic profile tend to use such strategies to draw attention to nearby tourist attractions. This is the case of the Jewel in the hall at Singapore Changi Airport (SIN), the display of images of Italian monuments at Rome Leonardo da Vinci-Fiumicino Airport (FCO), or monuments of regional tuiuius birds outside the Campo Grande Airport (CGR).

In the case of *G2D*, the low $\bar{u}$ = 7.0 in this study may be related to the fact that most respondents were linked to regionally or, at most, nationally relevant airports. Bathing facilities may become especially appreciated in international hubs, where passengers make connections between multiple long-haul flights; at Dubai Airport (DXB), for example, bathing facilities are intensely used.

In the case of *G4B*, which reflects managerial measures to encourage the attraction of new flights and routes, or the maintenance of existing ones, airlines and airports can negotiate effective partnerships to create the conditions for the attractiveness of new routes and passengers. This recommendation is in line with Casadesus-Masanell and Ricart (2010), who presented the success case of the low-cost strategy adopted in Ryanair's business model. It is believed that the success of this strategy was possible through the implementation of the open innovation approach (CHESBROUGH, 2006) in European airports, combining the interests of airports, airlines, aeronautics industry, and passengers in a proposal that was innovative and much in the spirit of integration proposed in this paper.

All other variables presented high relevance with regard to the development of new technology, products, services, and processes in airport innovation management. In the next section, the methodology to measure the relative weight of each variable and construct the algorithm proposed to the Airport Integrated Innovation Index (AI^3) is presented.

4.2 Proposed model

For the development of an Airport Integrated Innovation Index (AI^3), it has been performed a descriptive statistical analysis of the respondents' answers and identified the standard error, variance, median, and maximum and minimum values, among others for each variable analyzed. The median $\bar{u}$ of each variable was employed to yield a normalized index because it is less sensitive to sample outliers. The minimum and maximum values of $\bar{u}$ identified corresponded to 7.0 and 10, respectively.

As each variable had its own value of $\bar{u}$, it was necessary to develop an adjustment factor, λ, in the coefficients of the variables in order to normalize them, taking the lowest value as a reference. This adjustment factor consists of the ratio between the median of variable "*x*," $\bar{u}_x$, and the minimum sample median, $\bar{u}_{min}$ = 7.0. Equation 3 illustrates the case of the variable *G1A*, whose λ equals 1.36.

$$\lambda_{G1A} = \frac{\tilde{u}_{G1A}}{\tilde{u}_{min}} = \frac{9.5}{7.0} = 1.36 \tag{3}$$

In this case of Equation 3, this value demonstrates that the variable *G1A* presents a relevance index 36% higher than the variable with the $\bar{u}_{min}$ (*G4L* and *G2L*), whose λ would be equivalent to 1.0, which also demonstrates different levels of relevance for the adopted variables.

The identification of these adjustment factors was necessary to ensure the comparability between all variables, which would otherwise be measured on different scales. The other coefficients can be identified in Annex 1 and also in the general equation of AI.[3]

The next step was to simulate a possible variable qualification δ in the case of the evaluations of these variables in airports by opinions from passengers or collaborators as a numerical scale from 1 (not innovative) to 10 (highly innovative). To identify the total value of the notes for the variables, Ψ, the sum of the product of the qualification scores median, $\tilde{\delta}$, by their respective coefficients is realized according to Equation 4.

$$\Psi = \sum_{i=1}^{n} \lambda_i . \tilde{\delta}_i \tag{4}$$

For the δ in practical cases, the median between the qualification scores obtained in each of the variables analyzed should be adopted to reduce the sensitivity of the measure to the outliers of the evaluation. Considering 10 as the maximum qualification score in each of these variables in Equation 4, the total value maximum possible, Ψ_{max}, was obtained in this study considering the 37 variables analyzed and their respective λ between the minimum and standard 1 (G2D and G4L) and the maximum 1.43 (G2E, GEG, and G3F). Thus, the Ψ_{max} identified here equals 453.57. The variable G4A was not included in this calculation since it refers to a qualitative variable concerning the form of airport governance.

With the purpose of defining a range between 1, avoiding undefined operations in the equations, and 10 for the AI^3, an adjustment constant, κ, was identified from the ratio of that maximum index, 10, by Ψ_{max}, 453.57, corresponding to the value of $\kappa = 22.048.10^{-3}$. With this, the value of AI^3 can be obtained through the product between Ψ and κ, according to Equation 5.

$$AI^3 = \Psi . \kappa + \varepsilon \tag{5}$$

The term ε at Equation 5 represents the error caused by variables not considered in the study and unobserved attributes. By the following reasoning and merging the equations, the general model is presented in Equation 6.

$$AI^3 = \Psi . \kappa + \varepsilon = \sum_{i=1}^{n} (\lambda_i . \tilde{\delta}_i) . \kappa + \varepsilon \tag{6}$$

The details of Equation 6 and all variables analyzed and their respective λ can be identified in Equation 7.

$$AI^3 = [1.36.G1A + 1.29.(G1B + G1D + G1E + G1G + G1H + G2A + G2F + G3A + G3E + G4E + G4G + G4I + G4M + G4P + G4Q + G4R) + 1.21.G1C + 1.14.(G1F + G2B + G2C + G3B + G3C + G3D + G4C + G4D + G4F + G4H + G4J + G4N + G4O) + G2D + G4L + 1.43.(G2E + G2G + G3F) + 1.07.G4B].22.048.10^{-3} + \varepsilon \tag{7}$$

The AI^3 presented in Equation 7 displays a simplified structure to facilitate its application by researchers or airport managers to the identification of airport innovation level.

4.3 Application of the AI³ to a hypothetical airport

To illustrate the simplicity and usefulness of the AI^3 in the management of airports, a numerical simulation of a possible application of this proposal is proposed in Table 4. In this case, this hypothetical application could be performed using the four groups of analysis in large or small airports in which elements such as new biometric passenger identification systems (*G1A*) and new and more efficient x-ray systems for luggage (*G1B*) can be identified.

Random scores were assigned to the variables assumedly collected from the stakeholders or even the organization's customers—passengers *p*—through interviews or user satisfaction surveys regarding a hypothetical airport innovative operation.

In this example, when asked about a certain element of the airport infrastructure, passengers should rate their perception of its level of innovation on a scale of 1 to 10, according to hypothetical responses from passengers *p1*, *p2,* and *p3* referring to items *G1A*, *G1B*, and *G1C*.

TABLE 4
Numerical simulation of the use of the AI³

	G1A	G1B	G1C	n
p1	8.0	4.0	5.0	...
p2	10	4.0	10	...
p3	8.0	5.0	2.0	...
...	...	...	...	...
$\bar{u}$	8.0	4.0	5.0	...
λ	1.36	1.29	1.21	...
$\Psi = \sum_{i=1}^{n} \lambda_i . \tilde{\delta}_i$	22.09			
$AI^3 = \Psi.\kappa + \varepsilon$	5.72			

Source: Authors.

In the example presented in Table 4, the hypothetical airport obtained the score 5.72 in its innovation index, considering the interval from 1 to 10. This is a proportional score obtained from the calculation score 0.487, considering 3.86 of the 45.35 of the instrument's λ. This index provides an overview of how innovative the airport is, thus enabling comparisons across several airports if survey data are available. It also allows for a breakdown of variables, which favors the identification of priority fields for improvement. In the case of this simulation, the innovation priorities could be given to the elements associated to the variable *G1B*, which obtained the lowest $\bar{u}$ between respondents and a significant λ. This would suggest, for example, a necessity for developing and implementing new systems of luggage e-rays.

It is also possible to calculate an individualized AI^3 for each of the analysis groups (AI^3_{GX}). This may be useful in case previous priority is given to any of these groups. Considered the same principles of Equations 3, 4, 5, 6 and 7 for each analysis group, the respective equations are proposed in Table 5.

TABLE 5
Different equations proposed for individualized analysis within groups

Group	AI^3_{GX} Equation	κ_G value
G1: passengers and luggage processing.	$AI^3_{G1} = [1.19.G1A + 1.13.(G1B + G1D + G1E + G1G + G1H) + 1.06.G1C + G1F].\kappa_{G1} + \varepsilon$	$11.268.10^{-2}$
G2: information, communication and passenger services.	$AI^3_{G2} = [1.29.(G2A + G2F) + 1.14.(G2B + G2C) + G2D + 1.43.(G2E + G2G)].\kappa_{G2} + \varepsilon$	$11.480.10^{-2}$
G3: runway, courtyard and physical elements of the airport.	$AI^3_{G3} = [1.13.(G3A + G3E) + G3B + G3C + G3D + 1.25.G3F].\kappa_{G3} + \varepsilon$	$19.231.10^{-3}$
G4: airport business.	$AI^3_{G4} = [1.07.G4B + 1.14.(G4C + G4D + G4F + G4H + G4J + G4N + G4O) + 1.29.(G4E + G4G + G4I + G4M + G4P + G4Q + G4R) + G4L].\kappa_{G4} + \varepsilon$	$6.554.10^{-3}$

Source: Authors.

In the equations presented in Table 5, the adjustment factors were re-adjusted considering the $\bar{u}_{min}$ of each group, and the adjustment constant of each of the groups (κ_G) was calculated. In these equations for each of the four different groups, the values for AI^3_{Gx} vary from 1 to maximum 10. It must be noted that the variable G4A refers to the form of governance analyzed and is not included in the calculation of the indexes. These equations are proposed to further facilitate the identification of the innovation index in each of the analyzed groups.

5. Conclusion

Airports are considered in this study not only because of their significant role in transport and national integration, but above all in their participation in the scientific and technological development of certain regions (CIMOLI *et al.*, 2007; DIEGUES; ROSELINO, 2006, ZANDIATASHBAR; HAMIDI; FOSTER, 2019). Airport innovation consists of significant improvements that optimize processes, reduce costs, increase revenue, and improve the quality of airport services, or increase user comfort and convenience. In this study, the main factors for defining an innovative airport and the weights that express their relative importance were identified based on expert interviews. Then, a normalized measurement of an airport's level of innovation, the Airport Integrated Innovation Index (AI^3), was proposed.

The AI^3 displays certain characteristics that make it suitable to assist managerial level decisions. First, its simple specification makes it versatile enough to be applied to airports irrespective of their size and location. Second, by focusing on the expert's opinions, calculating the index is not particularly costly in terms of data collection. Third, it simplifies the comparison between different airports that may compete in a given relevant market. Finally, it enables a micro-level visualization of an airport's strengths and weaknesses according to the opinions of different categories of experts when the calculation is broken down to each of its component parts. By analyzing the information provided by the AI^3, airport managers can make strategic decisions vis-à-vis competing for airports or other modes of transportation. Such decisions may include the prioritization of certain aspects of innovation for investment over time and marketing decisions to highlight key innovations. The information facilitated by the AI^3 could even provide subsidies to debates in the realm of public policy and regulation.

The AI^3's versatility is partly due to the fact the weights capturing each innovation factor's relative importance are calculated within the dataset obtained for a given airport; thus, it considers the experts' opinion about that given airport alone, enabling wide comparability between airports once the normalized index is obtained.

A limitation of this model is related to the quantification of the subjective perceptions of different airport stakeholders in relation to the variables associated with innovation in this specific type of organization, which can generate certain biases in measuring the level of airport innovation based on the proposed adjustment coefficients. Thus, it is recommended to use the principle of parsimony in the analysis of the values generated with the calculations, which is just a mathematical indication in the definition of priority areas for investments in innovation based on the variables considered.

The application of this tool in the analysis of airports of different sizes and characteristics makes it possible to standardize the index considering all or most of the proposed variables. However, one point worthy of note is that such comparison should not be done without considering each airport's geographical and cultural context, as well as the relevant market in which it operates. It must also be noted that, for managerial purposes, the prioritization of a group of variables over the others also depends on the airport's context since some variables may present greater relevance or planning demands in specific situations.

The theoretical gaps pointed out, regarding the little integration between different areas of airport innovation analysis, can be identified here as filled by considering, during model development, the participation of professionals and experts in both the management of airport innovation itself (CHEN; BATCHULUUN; BATNASAN, 2015; GIL; MIOZZO; MASSINI, 2012; GRAHAMN; HALL; MORALES, 2014; HALPERN, 2010), as well regarding the management of innovation in airlines (FRANKE, 2007; HERACLEOUS; WIRTZ, 2009; NICOLAU; SANTA-MARÍA, 2012; PEREIRA; CAETANO, 2015), and the aeronautics industry (CIAMPA; NAGEL, 2020; COHEN, 2010; SLAYTON; SPINARDI, 2016; WIESENTHAL; CONDEÇO-MELHORADO; LEDUC, 2015;), these being the main players in decision-making at airport management.

This study also collaborates with the literature to propose a set of variables associated with innovation applicable in airport structures; that is, it analyzes the concept of innovation related to new products, services, or processes in order to group the perceptions of different professionals active in Brazilian air transport market with airports as the object of study. Its contribution to the literature in an attempt to measure the innovation level through different indicators is also evident.

Further studies and applications could be performed in the sense of calculating the AI^3 for groups of airports across and within relevant markets or by relating the level of innovation in different airports to performance measures. The use of the Brazilian reality in this study was only a reference model; thus, conducting studies in other countries among their airport managers, organizational cultures, and local stakeholders could provide a different number of classifications and even identify new variables for the model according to those market realities.

Finally, comparing the AI^3 with passenger satisfaction surveys would enable to gauge the level of alignment between experts, who often are related to airport management and customers. These applications could provide valuable guidelines for airport management.

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ANNEX 1
Analysis variables in airport innovation identified in the literature and in practice

Group	Analysis variables	Adjustment factors (λ)
G1: passengers and luggage processing	A. New biometric passenger identification systems, such as hand, face, and iris scanners that improve passenger identification time.	1.36
	B. New and more efficient x-ray systems for luggage.	1.29
	C. Self-service kiosks, shared between airlines, for the check-in and printing of boarding pass by the passenger.	1.21
	D. Self-service kiosks for baggage dispatch.	1.29
	E. New baggage management systems, such as automation, identification—use of chip and radio frequency identification (RFID), handling, transportation, and tracking of its real-time location by the passenger.	1.29
	F. Use of electric vehicles to transport passengers and baggage from the airport to the aircraft or between terminals.	1.14
	G. Ways to reduce lines in immigration control (for international airports).	1.29
	H. Airport support for passengers in cases of flight delays or cancellations.	1.29
G2: information, communication and passenger services	A. Ways to present information to passengers in transit during connections at the airport.	1.29
	B. Format and comfort of the seats in the waiting lounge.	1.14
	C. New ways to rest at the airport, such as micro hotel, cabins, and boxes to lie down or sleep while waiting for the flight.	1.14
	D. Possibility of bathing at the airport.	1.00
	E. Mobile internet for passengers in the terminal.	1.43
	F. Real-time passenger flight tracking systems.	1.29
	G. External access to the airport, such as public transport links, pedestrian crossings, access to vehicles, etc.	1.43
G3: runway, courtyard and physical elements of the airport	A. Distribution of runways, such as landing and takeoff, distance, and positioning in relation to the terminal.	1.29
	B. New types of runway pavement, such as the use of better performance or eco-efficient materials.	1.14
	C. New types of patio pavement, maneuvering areas, and aircraft parking.	1.14
	D. New control and monitoring systems for vehicles or objects in the airport yard.	1.14
	E. New systems of identification of objects and animals in the influence areas of movement, landing, and takeoff of aircraft.	1.29
	F. New instrument control systems for approaching aircraft.	1.43

(proceed)

ANNEX 1
Analysis variables in airport innovation identified in the literature and in practice

Group	Analysis variables	Adjustment factors (λ)
G4: airport business	A. What, in your opinion, would be the best way (governance) to manage the airport?	-
	B. New charging forms for airport services, such as boarding / landing fees, landing / takeoff, use of the yard, etc.	1.07
	C. Actions from the airport to capture new routes, maintain or extend flight schedules on existing routes.	1.14
	D. Carrying out market research by the airport to support the decisions of airlines and the aeronautics industry.	1.14
	E. Actions to reduce airport operational restrictions, such as night flights, ground equipment sharing, etc.	1.29
	F. Carrying out strategic marketing actions, such as airport promotions, collaborations with local tourism companies, hotels, transfers, rental companies, other airports, etc.	1.14
	G. Flexibility of operating rates and prices, such as incentives, discounts, and promotions for airlines, commercial establishments, and passengers.	1.29
	H. Airport support for new airlines or expanding companies.	1.14
	I. New forms of treatment and disposal of waste generated during the flight.	1.29
	J. New in the structure and internal and external architecture of the terminal, such as lighting, building design, flooring, and coatings.	1.14
	L. Presentation of elements related to culture, local fauna, and flora, such as regional arts, animals, and plants	1.00
	M. New terminal temperature control and conditioning systems as the choice of the best energy source, definition of areas of greatest demand, etc.	1.29
	N. New airport security system, plus surveillance cameras and presence of uniformed security guards in the common areas of the airport.	1.14
	O. Forms of access to taxi, public transport, and car rental points.	1.14
	P. New layout of the shipping lines that improve the use of the space and the boarding time of passengers.	1.29
	Q. Use of renewable natural resources at the airport, such as solar energy, water reuse, natural lighting, etc.	1.29
	R. Use of new equipment to reduce noise at the airport.	1.29

Source: Authors.