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ABSTRACT

This article proposes a risk management maturity model focused on the public sector and developed for Brazilian public organisations, the PRisk-MM. The PRisk-MM contains 5 levels of maturity and 23 maturity attributes related to 15 dimensions. The model was elaborated following the scientific rigour found in the literature on maturity models, being divided into 2 main phases: the development of the model and its validation in 5 public organisations of 2 state governments. The development of the PRisk-MM is based on a previous study conducted by De Lorena and Costa, who proposed a reference model with attributes and key contingent factors for public organisations using data collected in the federal and state governments of Brazil. The assessment procedure of the model uses triangular fuzzy numbers to better treat the subjectivity and ambiguity of human judgement when analysing maturity dimensions and their attributes. Moreover, the PRisk-MM is adaptive to governments' contexts and, once applied, presents prescriptions on what organisations must do to develop their risk management implementation. Since the Prisk-MM demonstrates practical implications as a government tool, policymakers are expected to use it to assess the public organisations' status of maturity and compare their performance in implementing RM.

Introduction

Enterprise-wide risk management (ERM) has been recognised as fundamental to organisational success and, as a discipline, it has been developed briskly over the last decade (Woods 2022). In order to be effective and impact the value creation in organisations, ERM needs to reach mature patterns of implementation, thus leaving a silo-based approach to become integrated and embedded in both strategic planning and operational routine (Farrell and Gallagher 2015). For such, mature organisations in ERM are expected to present risk governance, a greater engagement of top managers, more formal and frequent reports, to articulate better risk appetites in strategic planning, etc. (Beasley, Branson, and Pagach 2015; Lundqvist 2015). Nonetheless, achieving mature levels of ERM is not so easy because not always is the connection between the ERM system and the strategic planning as strong as desired, indicating that it is limited to a supportive organisational culture with staff sharing information about key risks, along with

the requirement of sufficient leadership and top management commitment (Viscelli, Hermanson, and Beasley 2017). These findings indicate that achieving ERM maturity is a process that needs progressive efforts, considering attention to processes and structures, as well as to people and culture.

Regarding specifically the public context, public organisations are surrounded by factors that particularly influence their efforts to reach higher levels of maturity in the public sector risk management (RM) (De Lorena and Costa 2023; Rainey and Chun 2005; Woods 2022). Some examples are related to the fact that they have more formal authority, are more exposed to external control, have more limited managerial procedures, deal with more debatable goals, have top managers that are influenced by political pressures and have a more expository role, etc. (Rainey and Chun 2005). Consequently, the practical challenges that public organisations face in implementing RM are more compelling (Woods 2022), and achieving more mature RM levels in this context is a very slow process (Brazil and Ministério da Economia (ME) 2022).

A tool that may help to accelerate the achievement of public sector RM maturity is the maturity model (MM). MMs are used to evaluate the current maturity level of a certain domain and to assist the organisation in increasing such domain's capability, thus implying an evolutionary progress to reach a predefined target (De Bruin et al. 2005; Mettler 2011). Therefore, MMs display a path of improvement that guides the organisations (Santos-Neto and Costa 2019). The recognition of the benefits and relevancy of MMs is observed through the increased number of publications since 2002 (Santos-Neto and Costa 2019). Although emerged in computing and software engineering, MMs have been applied to several other domains such as the medical sector, supply chain management, education, IT outsourcing, e-governance, project management, and business process management (Santos-Neto and Costa 2019; Wendler 2012). Nonetheless, in this article, we discuss the lack of publications about public sector risk management maturity models (PSRMMM).

To address this gap, this article introduces the PRisk-MM, a PSRMMM for the Brazilian public organisations. Hence, the PRisk-MM assesses the public organisations' maturity in RM considering 5 levels of maturity and 23 attributes distributed into 15 dimensions. The model is based on a previous study conducted by De Lorena and Costa (2023) once they presented attributes and key contingent factors that are significant to build PSRMMMs, thus demonstrating a sound theoretical foundation that most MMs do not disclose (Mettler 2011; Wendler 2012). Moreover, the assessment procedure of the PRisk-MM uses triangular fuzzy numbers to better treat the subjectivity and ambiguity of human judgement, being validated in 5 public organisations of 2 different state governments in Brazil.

The advantages of adopting the PRisk-MM are as follows. Firstly, the model provides a clear and objective assessment procedure, as exposed in the subsequent sessions of this article. Secondly, the model is adaptative to governments, that is, through the assignment of weights to the dimensions, it is possible to ask government policymakers (GPMs) to give more importance to the dimensions that are more significant to the context of the governments. Finally, the PRisk-MM is prescriptive for public organisations because it provides them with possible actions to be implemented and thus improve their RM. The PRisk-MM is expected to become a government tool and be applied in the Brazilian public context to help improve public sector RM.

The maturity models for ERM

MMs are tools to evaluate the maturity or level of sophistication of a selected domain, considering a comprehensive set of criteria (De Bruin et al. 2005). The main idea consists of increasing the capability of such domain within the organisation, implying an evolutionary progress to accomplish a target from an initial stage to a desired end stage (Mettler 2011), representing a

path of improvement that guides the organisations (Santos-Neto and Costa 2019). Therefore, every type of maturity model displays a set of levels that represents the progression of the domain, as well as measured objects that are commonly known as capabilities or attributes (Wendler 2012).

MMs present various benefits to the organisations. To begin with, they are a simple and effective way of measuring the quality of the organisations' processes (Santos-Neto and Costa 2019; Wendler 2012). Secondly, they enable organisations to understand their current level of maturity and identify the necessary steps to reach higher levels of maturity through planning specific actions (Macgillivray et al. 2007a; Santos-Neto and Costa 2019). Moreover, they strengthen businesses by ensuring the organisations have the operational conditions to manage the desired changes (Santos-Neto and Costa 2019). Furthermore, they may boost greater levels of organisational learning by making the staff reflect about their work practices and communicate the gaps and needs for change (Bititci et al. 2015). Finally, they can be used for benchmarking purposes, enabling organisations to compare themselves to others from the same industry (Macgillivray et al. 2007a).

The interest in maturity and MMs has proliferated across many different domains, especially during the last decade, given the growing number of related articles (Santos-Neto and Costa 2019). Most publications focus on software engineering and on information technology/system management as MMs were first thought within the information systems literature (Santos-Neto and Costa 2019; Wendler 2012). Nonetheless, regarding the specific RM domain, few studies have been proposed in comparison to the number of MMs already published (Santos-Neto and Costa 2019). Yet, when it comes to the notion of ERM, the number of articles is still lower, as demonstrated in Table 1.

Table 1 compares the technical aspects of eight ERM MMs found in the literature. The first conclusion is that no MM has been thought specifically for RM in the public sector, endorsing the arguments found in De Lorena and Costa (2023). Conversely, these MMs were developed focusing on supply chain, water utility sector, construction projects, and firms in general. For instance, Domańska-Szaruga (2020) advocates that her model suits both private and public organisations without distinction, with the argument that all organisations need to mitigate risks despite their different objectives. Therefore, this MM focuses specifically on the development of the ERM culture. Nonetheless, this view has been contradicted by the argument that RM principles are identical for both sectors, but that in practice the challenge for the public sector is more substantial as different features are observed (Rainey and Chun 2005; Woods 2022).

The second conclusion implies that all ERM MMs describe the development process of the models, as well as the levels and attributes. Exceptionally, only Zhao, Hwang, and Low (2013) do not describe a set of maturity levels because their model uses the fuzzy set theory to calculate a global index of maturity to position the firm. Most articles in Table 1 apply a top-down approach to design their ERM MMs. Within this approach, levels are defined first, and then the measures are developed to fit such definitions (De Bruin et al. 2005). Oliva (2016), on the other hand, performs the bottom-up approach, in which the requirements and measures are established first, and then the definitions are written as a reflection of those (De Bruin et al. 2005).

Regarding the assessment procedures, Zou, Chen, and Chan (2010) and von Kanel et al. (2010) do not reveal how their models classify the organisations into a maturity level. The remaining articles use simple measures such as weighted scores (Domańska-Szaruga 2020; Hoseini, Hertogh, and Bosch-Rekveldt 2019), and more elaborate measures such as fuzzy numbers that can be combined with Multicriteria Decision-making Analysis (MCDA) (Feitosa, Carpinetti, and Almeida-Filho 2021; Zhao, Hwang, and Low 2013), and multinomial logistic regression (Oliva 2016).

Moreover, five ERM MMs mentioned to have been empirically validated, five were applied, and only two provided prescriptions. The lack of validation and prescriptions is strongly criticised by Wendler (2012) and Santos-Neto and Costa (2019) after conducting Systematic Literature

Table 1. List of ERM MMs found in the literature.

Reference	Application scope	ERM MM aspects					
		Development process	Description of levels	Description of attributes	Assessment procedures	Prescription	Validation	Application
Feitosa, Carpinetti, and Almeida-Filho (2021)	Supply chain	X	X	X	X			X
Oliva (2016)		X	X	X	X		X	
Zhao, Hwang, and Low (2013, 2014)	Construction projects	X		X	X		X	X
Hoseini, Hertogh, and Bosch-Rekveldt (2019)		X	X	X	X		X	
Zou, Chen, and Chan (2010)		X	X	X			X	X
von Kanel et al. (2010)	General firms	X	X	X		X		
Domańska-Szaruga (2020)		X	X	X	X			X
Macgillivray et al. (2007a, 2007b)	Water utility sector	X	X	X	X	X	X	X

Reviews. Prescriptive MMs are deemed relevant because they indicate how to approach maturity improvement of the evaluated domain (Santos-Neto and Costa 2019). Alternatively, the lack of validation is a crucial point before the application, demonstrating weakness in the MMs; hence, this is possibly the reason why several developed MMs have demonstrated little use in practice (Wendler 2012). The MMs listed in Table 1 were validated by interviewing experts and/or by being tested in case-studies. Regarding the application of the models, Zhao, Hwang, and Low (2013, 2014) and Macgillivray et al. (2007a, 2007b) published their MMs in two articles – one for the development, and the other for the application, while others preferred to describe the development and application in the same article as pilot tests (Domańska-Szaruga 2020; Feitosa, Carpinetti, and Almeida-Filho 2021; Zou, Chen, and Chan 2010).

Yet, but not found in the literature, the Brazilian Federal Court of Accounts (in Portuguese, *Tribunal de Contas da União – TCU*) released a PSRMMM directed to public auditors of Brazil (Brazil Tribunal de Contas da União (TCU) 2018). Despite such a great initiative for the country, TCU's model does not provide prescriptions for improvements, nor does it mention previous validation. Therefore, it does not demonstrate to follow all the rigour that an MM elaboration deserves.

Methodology

Observing the criticism as to the MM conception that academics bring in systematic literature reviews (e.g. Santos-Neto and Costa 2019; Wendler 2012), the PRisk-MM was thought with the aim to become a useful PSRMMM for the Brazilian public organisations by reflecting their context and considering the scientific rigour an MM must have. Hence, the PRisk-MM was inspired by the typical phases proposed by Mettler (2011) and De Bruin et al. (2005) to design an MM, thus reflecting the Design Science Research as it is related to a problem-solving paradigm in the organisational context (Dresch, Lacerda, and Antunes 2015; Hevner et al. 2004). Figure 1 below depicts the steps used to develop and validate the model.

The development of the PRisk-MM comprises three steps: the identification of the problem or need, the scope definition, and the design *per se*, which was divided into four substeps. Substeps 3.2 (Establishment of attributes and levels) and 3.3 (Establishment of measures and prescription), in particular, were based on the study developed by De Lorena and Costa (2023). This study presents 5 levels of maturity with a set of variables identified throughout a consistent statistical path analysis applied to data collected from Brazilian public organisations.
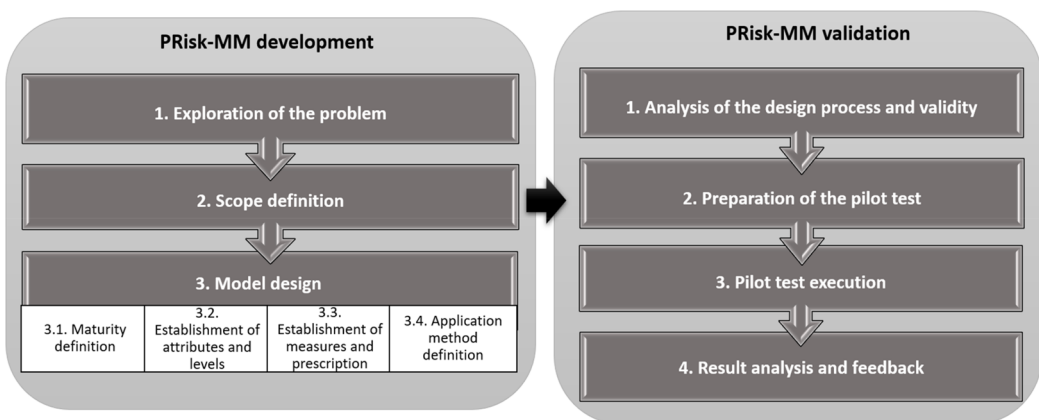

Figure 1. PRisk-MM development and validation.

These variables reflect contingent factors and public sector RM attributes, thus incorporating the features and needs of the audience the PRisk-MM is devoted to.

The next phase, the PRisk-MM validation, consists of four main steps that were carried out as a pilot test in 5 public organisations of 2 Brazilian state governments. The details on how the pilot tests occurred and their results are exposed later.

PRisk-MM development

The first step of the development phase was the exploration of the problem which comprised the identification of the real need for a new PSRMMM that could be directed to public organisations. Empirically, the PRisk-MM is valuable as a government tool because auditors are generally in charge of assessing RM implementation in public organisations, and consequently of identifying their maturity status (De Lorena et al. 2022; Woods 2009). In Brazil, these auditors are considered GPMs because they not only evaluate public sector RM maturity, but also provide guidelines for implementation, training sessions and even consultancy services (De Lorena et al. 2022). The public sector RM maturity evaluation is considered part of the controlling role GPMs generally exert over public organisations (Rainey and Chun 2005). Moreover, within a single government, the PRisk-MM can be used to compare the organisations' performances in implementing public sector RM. The PRisk-MM may also be useful to public organisations when the interest is to conduct self-assessments and to identify what needs to be improved.

In the theory, there was a scientific gap in the literature involving the lack of a specific MM for public sector RM. For this purpose, ERM MMs were sought in the literature using the academic research 'Web of Sciences' and 'Scopus' databases with keywords 'maturity model', 'multilevel model' and 'maturity level' combined with 'risk management'. The results were then filtered to only include articles classified into fields related to 'business' or 'management'. During the analysis, articles that did not provide new MMs or publications not classified as articles were excluded. As a result, from an initial list of 53 papers, the final list comprised 12 articles, 10 of which represented new ERM MMs directed to different application scopes, and 2 which discussed theories regarding ERM maturity.

The next step was the model scope definition. This step is considered the most important as decisions here influence all the following steps (De Bruin et al. 2005; Mettler 2011). Regarding the domain focus, the PRisk-MM is specific to public sector RM implementation with an organisational level of analysis because it evaluates public sector RM as part of the corporate governance, considering its integration to both organisational strategy and operations. Besides, the PRisk-MM is tailored to a management-oriented audience as the idea is to address managerial needs when self-assessments are performed within the public organisations, and to GPMs because they evaluate the performance of public organisations on behalf of the governments (De Lorena and Costa 2023).

The third step was the model design, comprising: (1) the definition of maturity, (2) the establishment of attributes and levels, (3) the establishment of measures and prescription, and (4) the application method. Regarding the first aspect, maturity definition, the PRisk-MM combines the focus on processes and structures, as well as on people and culture (Mettler 2011). The focus on processes and structures implies the importance of centring maturity on public sector RM activities and work practices to deliver more effective procedures. Attributes related to RM process and to strategy integration, for instance, reflect this maturity focus. Alternatively, the focus on people and culture considers the maturity of staff skills and proficiency in public sector RM execution. Attributes related to RM awareness and top management commitment are good examples as these attributes emphasise people's behaviour.

Thereafter, based on De Lorena and Costa (2023), the maturity levels were established for the PRisk-MM considering the same labels and definitions the authors proposed in their maturity

reference model. Therefore, the PRisk-MM is meant to be theory-driven because this reference model is rooted in a literature review that comprised contingent factors and PSRMMM attributes. This feature brings a consistent theoretical foundation for the PRisk-MM's development (Mettler 2011), from which the contingent factors are considered an important aspect that makes the PRisk-MM special for public organisations. Moreover, the PRisk-MM's design process follows a bottom-up approach because the reference model's significant variables (or maturity attributes) were identified first, with the definitions of the levels (Table 2) being a reflection of those (De Bruin et al. 2005).

The maturity attributes represent what needs to be measured within an MM, considering that they must be mutually exclusive and collectively exhaustive (De Bruin et al. 2005). Hence, the PRisk-MM was populated with the attributes used in the multinomial logistic regression De Lorena and Costa (2023) performed, being complemented with two more attributes: A3 and A4 (see Appendix A, supplementary material). These attributes represent the organisational governing body (that may or may not be presented in the form of a committee) and the focal point (a person, a team, or a department with the responsibility to lead public sector RM implementation and behave as the second line of defence) (The IIA and INTOSAI 2022). In De Lorena and Costa (2023), these attributes were referred to as variables 'RMcomm' and 'RMspec', being withdrawn from their final analysis because in their first statistical analysis, using CATPCA, the variables did not show a good fit to public sector RM maturity. Nonetheless, in their study they were dummies representing the existence or not of a risk-related committee and an RM specialist duly formalised. In the PRisk-MM, attributes A3 and A4 give emphasis not on their formalised existence, but on their role, composing the leaderships The IIA and INTOSAI (2022)

Table 2. Description of the PRisk-MM's maturity levels.

Maturity levels	Description
Ad hoc	At this level, RM is silo-based and presents little formality. The organisations do not have the support from top management and the staff do not understand the importance of RM. Therefore, employees perform RM process when it is necessary in specific situations, demonstrating no standardisation of procedures.
Initial	RM structure and risk governance features start to be planned, standardised, and formalised through a framework elaborated or adapted by a specific team, department, or committee (the focal point). Nonetheless, RM proper implementation is not yet observed. Accordingly, top management needs to actively communicate the importance of RM, and risk awareness starts to be established, fostering an initial risk culture and the notion of accountability. Level 2 shows a primitive engagement.
Constant	Level 3 requires an established public sector RM framework, with a formalised, standardised, ongoing, cyclical RM process in the organisation. It is expected, for instance, that a systematic analysis of the environment and a culture of risk thinking be in place, and that employees already demonstrate responsibility for their actions and decisions related to risks. Furthermore, risk information starts to feed the strategic planning process, and employees demonstrate an innovation-oriented culture by searching out new working methods or instruments, thus becoming more receptive to RM.
Managed and participative	At this level, top management must actively encourage the staff to participate in RM, and the communication of treatment and monitoring activities must be standardised and working appropriately. Also, staff skills, their receptivity to RM and their risk awareness are more developed, with consistent risk analysis becoming part of the organisations' strategic planning.
Strategic and integrated	This level has well-established strategic processes, such as the establishment of objectives, indicators, and more structured strategic planning to better receive and integrate the information that RM can provide, making it a more strategic tool in the organisation. For this reason, well-structured and regular risk reporting is fundamental. In addition, the accumulation of skills regarding other aspects is also paramount.

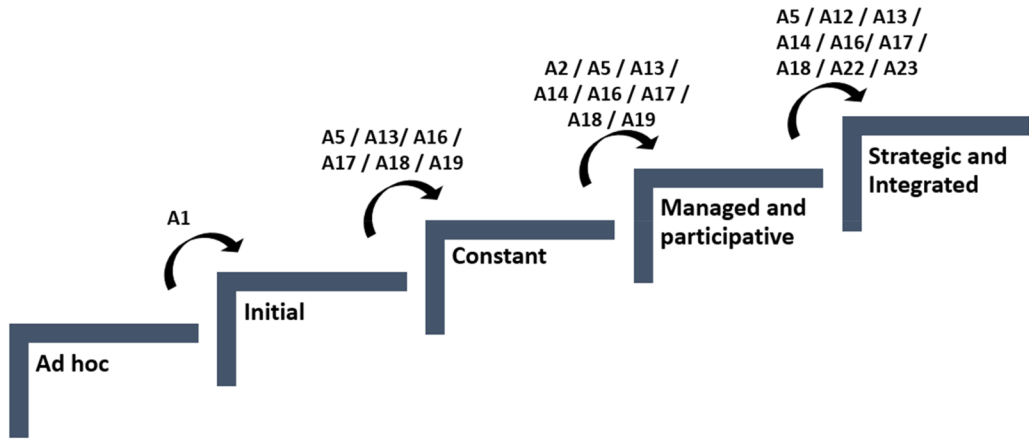Source: based on De Lorena and Costa (2023).

Figure 2. PRISK-MM's maturity levels and veto attributes.

advocates as necessary to support an RM structure. Hence, the PRisk-MM is comprised of 23 attributes distributed among 15 dimensions as described in Appendix A (see supplementary material).

Through the multinomial logistic regression De Lorena and Costa (2023) performed, it was possible to identify which variables were statistically significant to establish a maturity progression path. Hence, Figure 2 depicts the attributes that are paramount to determine the level of maturity into which a public organisation may be classified. Nonetheless, it does not mean that other attributes must be avoided during maturity assessment, which is the case of the steps that comprise the RM process (e.g. risk identification, risk analysis, and risk treatment) (De Lorena and Costa 2023). Therefore, in the PRisk-MM, the attributes displayed in Figure 2 are treated as vetoes, meaning that the organisation needs to have them applied before being classified into a determined level of maturity. For instance, supposing that organisation 'Alpha' has not yet applied attribute A18, 'Alpha' will remain at level 2 of maturity (initial), even if presenting a sufficient final score for level 3 (constant).

The assessment procedure designated for the PRisk-MM was developed based on the fuzzy set theory as detailed followingly. The result is supposed to provide a prescription containing a list of actions the public organisation may plan to execute to improve its RM system. This is deemed as very important since an MM without an improvement action plan may end up not providing substantial outcomes for the organisation under evaluation (Santos-Neto and Costa 2019). An example of the PRisk-MM's prescription list is demonstrated in Appendix B (see supplementary material).

Finally, the application method of the PRisk-MM was defined as consisting of two phases. The first one comprises its preparation by the government, when GPMs define weights for the dimensions. Such weight definition can be decided either by a single GPM or by a team, with the possibility to also assign weights to the GPMs' judgements. This feature is an advantage of the model as it provides the GPMs with the chance to adapt the PRisk-MM to the government context by giving more importance to the dimensions they deem to be more important to achieve the government objectives, thus being in accordance with the contingent theory appointed by De Lorena and Costa (2023). The second phase comprises the organisational self-assessment performed by an employee who must occupy a management position and lead the RM implementation locally. Both phases are applied through a spreadsheet,[1] and more details on how the weights are assigned and how the public organisations are self-assessed are described below.

Model assessment procedure and prescription

For both phases of the PRisk-MM application method, the calculations are based on the fuzzy set theory. This theory was developed by Zadeh (1965) with the promise to deal with nonnumerical information, presenting varying values that are associated to semantic labels. The partitions of these labels overlap to represent the transition from one state to another (Cox 1994), characterising the ambiguity in human judgement. Unlike the classic binary-valued logic, the fuzzy logic does not restrict a set of numbers to absolutes, but considers the concept of partial truth with varying degrees of membership function in the closed interval [0, 1] (Peckol 2021). Therefore, in subjective and imprecise judgements, fuzzy numbers usually provide a better set than the corresponding crisp values and play an important role when defining weakly bounded concepts such as 'few' or 'some' (Cox 1994). The fuzzy logic is particularly suitable to assess the maturity levels because it can be used in classification patterns (Zadeh 1965), and the evaluation of the attributes is generally subjective, containing linguistic concepts that represent a sense of imprecision or vagueness (Peckol 2021).

Among the existent types of fuzzy membership functions, the PRisk-MM uses the triangular type with 50% of overlap in the fuzzy membership degrees. Known as triangular fuzzy numbers (TFN), this membership function is considered simpler to specify and easier to visualise, being represented with absolute truth at the midpoint of the fuzzy set (Cox 1994). In the PRisk-MM, the input data used for the weight assignment of the dimensions have different linguistic terms from those used by the public organisations during self-assessment. The TFNs for the assignment of weights (Table 3) represent the level of importance a specific dimension has for the public sector RM implementation in the government, whereas the TFNs for the organisations' self-assessment (Table 4) represent how intense the application of a determined attribute is in the organisation. In both cases, the scores vary from 1 to 5.

During the assignment of scores for the weight definition of the dimensions, the GPMs may opt to establish different weights for their own judgements, possibly considering criteria such as the amount of knowledge one has regarding both the government context and the public sector RM domain. Therefore, the PRisk-MM regards the GPMs' tenure as government employees and specifically as RM experts. Their weights must sum 1, that is, $w_{p1} + w_{p2} + \ldots + w_{pj} = 1$. Consider the following equation for the dimension weights:

$$W_{di} = \left(W_{li}, W_{mi}, W_{ui}\right) = \sum_{j=1}^{p} w_{pj} \times \text{TFN}_{dij}\left(s_{dij}\right) \tag{1}$$

where W_{di} is the TFN of the weight for dimension i; W_{li}, W_{mi} and W_{ui} are the lower bound, the strongest membership degree and the upper bound of W_{di}, respectively; p is the number of GPMs; w_{pj} is the weight assigned to each GPM; and TFN_{dij} is the fuzzy number of score s_{dij} given by the GPM j for dimension i.

Regarding the organisation's self-assessment, the agent accountable for judging the attributes is the RM implementation leader of the public organisation. In this process, some attributes are supposed to receive a single score because they represent a general aspect of the organisation, while others have a more operational nature and therefore must be assessed with separate scores for each department of the organisation. The reason for separate judgements is that

Table 3. Linguistic terms and TFNs for the dimension scores.

Score	Linguistic terms	Correspondent TFN
1	Not important	(0.2, 0.2, 0.4)
2	Of little importance	(0.2, 0.4, 0.6)
3	Important	(0.4, 0.6, 0.8)
4	Very important	(0.6, 0.8, 1.0)
5	Essential	(0.8, 1.0, 1.0)

Table 4. Linguistic terms and TFNs for the attribute scores.

Score	Linguistic terms	Correspondent TFN
1	It is not applied yet	(0.0, 0.0, 0.25)
2	It is partially applied (a little bit)	(0.0, 0.25, 0.5)
3	It is partially applied (moderately)	(0.25, 0.5, 0.75)
4	It is partially applied (a lot)	(0.5, 0.75, 1.0)
5	It is fully applied	(0.75, 1.0, 1.0)

some departments may have a more advanced RM implementation whilst others are more imature. For this reason, the final score of such attributes is calculated considering the round mean of the individual departments' scores. The attributes under this condition are: A5, A6, A7, A9, A11, A12, A16, A17 and A18.

Hence, considering the final scores of all attributes, the PRisk-MM first fuzzifies them accordint to Table 4, and then aggregates the multiplications of each attribute fuzzified number by the fuzzified weight of its respective dimension. The equation is below:

$$M = \left(M_l, M_m, M_u \right) = \sum_{k=1}^{a} W_{di} \times \text{TFN}_{ki} \left(s_{ki} \right) \tag{2}$$

where M is the organisation's fuzzified index represented by M_l, M_m and M_u (the lower bound, the strongest membership degree and the upper bound, respectively); a_i is the number of attributes for dimension i; and TFN_{ki} is the fuzzified number of score s_{ki} for attribute k for dimension i, that in turn is multiplied by the respective W_{di} according to Equation (1).

The next step consists of the defuzzification of index M. In a fuzzy system, defuzzification is the step in which a crisp number is produced to represent a fuzzy number. Three common methods are mentioned in the literature: the centroid method, mean of maximum, and maximum criterion (Cox 1994; Negnevitsky 2005; Peckol 2021). The centroid method was chosen among them to defuzzify M because it is the most widely used technique, as well as easy to calculate (Cox 1994). The centroid method is also known as centre of gravity (COG) because it seeks to find the point where a vertical line divides the fuzzy set into two equal areas (Negnevitsky 2005). In the PRisk-MM, the defuzzification of M, that is, M_{def}, is calculated using COG as follows:

$$M_{def} = \frac{M_l + M_{m+} M_u}{3} \tag{3}$$

Besides these calculations, it is necessary to find the boundaries between levels. These boundaries strictly depend on W_{di} (Equation (1)); therefore, it is not possible to assume constant values to limit the levels as the weights may vary from government to government. To solve this issue, the PRisk-MM measures the interval between maximum M_{def} (assigning 5 to all attributes) and minimum M_{def} (assigning 1 to all attributes); then, the remaining result is divided by five, which is the number of levels the PRisk-MM supports. The equations are below:

$$Interval = M_{def\,max} - M_{def\,min} \tag{4}$$

$$limit_{level\,2} = M_{def\,min} + \frac{Interval}{5} \tag{5}$$

$$limit_{level\,3} = limit_{level\,2} + \frac{Interval}{5} \tag{6}$$

$$limit_{level4} = limit_{level3} + \frac{Interval}{5} \tag{7}$$

$$limit_{level5} = limit_{level4} + \frac{Interval}{5} \tag{8}$$

Another feature in the PRisk-MM is the existence of vetoes. As observed in Figure 2, there are attributes that are statistically significant for the levels (De Lorena and Costa 2023); therefore, for these attributes, the organisation must score at least 3 to assume that the attribute is reasonably applied. Otherwise, even displaying a sufficient M_{def} for a certain level, if a required attribute is not scored at least 3, the level is vetoed, and the organisation returns to the immediately lower level. Moreover, the PRisk-MM also demands that no attribute receives score 1 at level 5, also working as a new veto.

Once the level of maturity is defined, the PRisk-MM brings prescriptions to assist the organisation to improve its RM implementation. In this case, the PRisk-MM calculates which attributes were vetoed first, and then which attributes received lower scores. Hence, the Prisk-MM sorts the prescriptions for a maximum of thirteen most critical attributes at a time and supports the elaboration of an improvement action plan for the organisation.

PRisk-MM validation

The validation of the PRisk-MM followed the steps depicted in Figure 1. The first step, 'analysis of the design process and validity', involved the analysis of the model's content and assessment procedure. For this purpose, the state government of Pernambuco, represented by the 'Secretariat of Comptroller General of Pernambuco' (SCGE-PE), the state government of Minas Gerais, represented by the 'Comptroller General of Minas Gerais' (CGE-MG), and the Federal District government, represented by the 'Comptroller General of the Federal District' (CGDF), were chosen because they were acknowledged by the Brazilian Federal Ministry of Economy as having notorious expertise in RM discipline, as well as performing good practices (Brazil and Ministério da Economia (ME) 2022).

The first action was to contact the GPMs of those governments and arrange meetings. As observed in Table 5, separate meetings ocurred with the GPMs from the governments of Pernambuco and the Federal District, and a single meeting occurred with the GPMs from Minas Gerais. At the end of the meetings, they all gave positive feedback regarding the explanation of the assessment procedure, and then were asked to read the content of the PRisk-MM and analyse if the model could represent the real world of their RM practices with sufficient accuracy

Table 5. GPMs who validated the content of PRisk-MM.

Government leading organisations	GPMs' positions	GPMs' tenure in the organisation*	GPMs' tenure working with RM*	Meetings	
				Month/year	Duration
SCGE-PE	Director of Governance and Risks	12	2	February 2023	1h
	Executive Secretary of Audits and Governance	13	2	February 2023	2h
CGE-MG	Comptroller-general of the government	4	15	February 2023	50 minutes
	Head of cabinet	3	3		
CGDF	Coordinator of Risk Audits and Integrity	7	5	February 2023	1h30
	Coordenator of Governance	12	6	January 2023	2h

* Data provided in years.

(Mettler 2011). Correspondingly, they provided comments on the readability and comprehensiveness of the model, but no new attributes or dimensions were added. Nonetheless, new RM practices could be added to the prescriptions of the model. Therefore, the PRisk-MM was considered valid as it presented face and content validity. In this case, face validity implied that the dimensions and the attributes could translate RM practices in the public organisations, and content validity regarded how completely public sector RM was represented (De Bruin et al. 2005).

The second step followed with the preparations for the pilot tests in the governments of Pernambuco and Minas Gerais. The referred GPMs were asked to choose public organisations besides self-testing the PRisk-MM in the SCGE-PE and in the CGE-MG; hence, the GPMs from the former chose two public organisations, whereas the GPMs from the latter chose one, providing this research with a total of five pilot tests. Then, after an informal explanation was offered to the chosen public organisations, they were sent formal invitations requesting authorisation and an agenda.

Next, during the pilot test execution (step three), the first phase was to assign weights to the PRisk-MM's dimensions, so the SCGE-PE team decided to provide the scores in a group of 5 with equal weights to the respondents, that is, 20% to each. The participants were the Executive Secretary of Audits and Governance, the Director of Governance and Risks, the Coordinator of Risk Management, the Head of the Risk Management Consultancy Unit, and all the remaining members of the team of auditors who answered in concensus. The CGE-MG team, differently, decided to provide scores through a group consesus, with the participation of the Head of Cabinet and the Head of Strategic Advisory and RM, their decision being homologated by the Comptroller General of the government. The dimensions' scores were then transformed into TFN by using Table 3, and their respective aggregation formed the weights below (Table 6) according to Equation (1).

Table 6 indicates that the GPMs in the SCGE-PE recognise the 'risk appetite' dimension as being the least important for RM implementation, whereas the GPMs in the CGE-MG consider the 'receptive culture' as the least important. On the other hand, the GPMs in the SCGE-PE perceive 'top management commitment' as the most important, followed by 'focal point', 'risk assessment', 'RM monitoring', 'risk report', 'accountability' and 'organisational strategy'. Likewise, the GPMs in the CGE-MG also recognise 'top management commitment', 'risk assessment', 'RM monitoring', 'risk report' and 'accountability' as essential for the government, adding the 'risk treatment' dimension to this classification. Then, considering those weights, the

Table 6. Dimensions' weights in TFN defined during the PRisk-MM application.

|	SCGE-PE			CGE-MG		
	W_{di}			W_{di}		
Dimensions	W_{li}	W_{mi}	W_{ui}	W_{li}	W_{mi}	W_{ui}
Top management commitment	0.76	0.96	1.00	0.80	1.00	1.00
Governing body	0.68	0.88	1.00	0.40	0.60	0.80
Focal point	0.72	0.92	1.00	0.60	0.80	1.00
Context analysis	0.68	0.88	1.00	0.40	0.60	0.80
Risk assessment	0.72	0.92	1.00	0.80	1.00	1.00
Risk treatment	0.68	0.88	0.96	0.80	1.00	1.00
RM monitoring	0.72	0.92	1.00	0.80	1.00	1.00
Risk report	0.72	0.92	1.00	0.80	1.00	1.00
RM standardisation	0.64	0.84	0.96	0.40	0.60	0.80
Risk awareness	0.68	0.88	0.96	0.60	0.80	1.00
Receptive culture	0.52	0.72	0.92	0.20	0.40	0.60
Accountability	0.72	0.92	1.00	0.80	1.00	1.00
RM strategic integration	0.68	0.88	1.00	0.60	0.80	1.00
Risk appetite	0.44	0.64	0.84	0.40	0.60	0.80
Organisational strategy	0.72	0.92	1.00	0.60	0.80	1.00
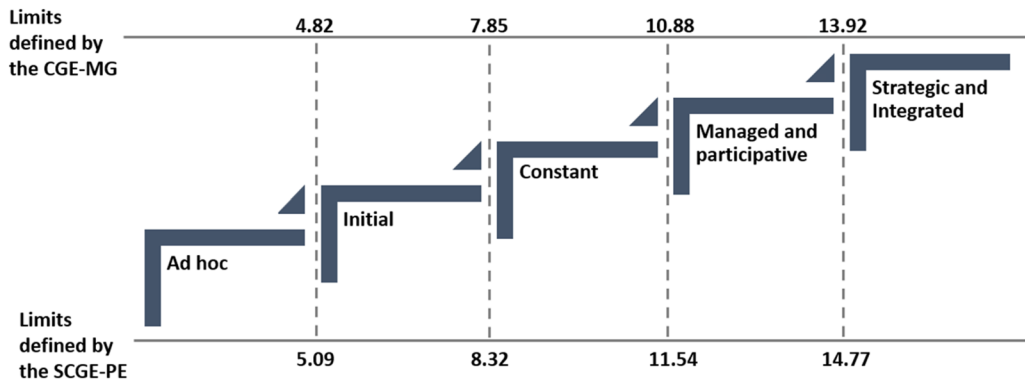
Figure 3. Calculated limits for the maturity levels of the PRisk-MM.

Table 7. Public organisations' and RM leaders' profiles.

	Public organisations' profile			RM leaders' profile		
Organisations	Type of industry	Year when RM started	Position in the organisation	Tenure working with RM*	Tenure working within the organisation*
SCGE-PE	Internal control	2021	Director of Governance and Risks	2	12
Compesa	Water utility	2018	Manager of Compliance, RM and Internal Control	3	26
Anonymous	Technology	2022	Advisor of Internal Control	2	3
CGE-MG	Internal control	2020	Head of Strategic Advisory and RM	5	10
Secretariat of treasury	Treasury	2019	Sectorial Controller	13	34

* Data provided in years.

limits of the PRisk-MM's levels were calculated by using Equations (4)–(8), and are depicted in Figure 3.

The second phase comprised the evaluation of the PRisk-MM's attributes. In this case, separate meetings were held with the public organisations, lasting on average one and a half hours. In Pernambuco, one of them, providing services in the technology industry, preferred to remain anonymous, while the other two were Compesa and the SCGE-PE itself, providing services in the water utility industry and in the internal control of the government, respectively. In Minas Gerais, one public organisation was the Secretariat of Treasury and the other was the CGE-MG itself. Table 7 provides an overview of the profiles of the organisations and of their respective RM leaders who evaluated the PRisk-MM's attributes. Table 8 provides the results obtained with the PRisk-MM's application, considering the TFN of Table 4 and Equations (2) and (3).

The fourth step comprised the results analysis and the collection of feedback. Concerning the dynamics of the attributes with veto power, only the SCGE-PE and the CGE-MG were not affected; that is, their M_{def} was compatible with levels 2 and 4 respectively. Consequently, to reach level 3, the SCGE-PE needed to improve their RM implementation internally and reach better punctuations, especially in the attributes that are vetoes for level 3 and in other attributes that had scores 1 and 2. In the case of CGE-MG, to reach level 5, the organisation needed to improve the attributes that received minimum score 3, because no score 1 or 2 were assigned.

Table 8. Results of the PRisk-MM application.

Public organisations	PRisk-MM's defuzzified index (M_{def})	Current maturity level	Attributes with veto power	Prioritised attributes for prescription
SCGE-PE	5.57	2 - Initial	None	A3, A5, A6, A7, A8, A9, A10, A11, A12, A16, A17, A18, A19
Compesa	12.39	2 - Initial	A2, A16, A18	A2, A8, A11, A15, A16, A18
Anonymous	8.68	2 – Initial	A5, A16, A18, A19	A5, A6, A7, A8, A9, A11, A12, A16, A18, A19, A22, A23
CGE-MG	13.15	4 – Managed and participative	None	A8, A11, A14, A15, A16, A17, A18, A19, A21, A23
Secretariat of Treasury	12.27	2 – Initial	A19	A1, A2, A3, A6, A15, A16, A17, A18, A19, A20, A21

As a result, the prescription for the SCGE-PE consisted of 13 prioritised attributes, whereas for the CGE-MG, 10 attributes were comprised.

On the other hand, Compesa, the anonymous organisation and the Secretariat of Treasury had enough M_{def} to reach levels 4, 3 and 4, respectively; nonetheless, they had vetoes which assigned all of them to level 2. Compesa, for example, did not reach enough scores in attributes A2, A16 and A18. The anonymous organisation, in turn, had vetoes in attribures A5, A16, A18 and A19, and the Secretariat of Treasury failed attribute A19. Consequently, their prescriptions prioritised these vetoed attributes, also adding the ones which had scores 1 and 2. In general, the organisations had poor or average performance in attributes A8, A11, A16 and A18, indicating that they need to improve the assessment of interdependencies of risks within a portfolio, assure that tactical and operational managers continuously monitor the achievement of objectives and actions to treat risks in their respective departments, assure that employees have incorporated risk thinking into their work routine naturally, and assure employees are clear about their roles in RM.

Concerning the feedback, the PRisk-MM received positive comments in all public organisations. The RM leaders believed that the model reflected their real level of maturity in RM implementation, and that all attributes could comprehensively reflect their RM practices. Except for some slight criticism, the RM leader of the CGE-MG said to agree with the result at level 4, although in some attributes he felt the organisation would be better placed at level 3. His observation, in fact, corroborates the attributes prescribed for improvement as they were all assigned score 3. Further compliments comprised the objectivety and clarity of the model by analysing the key points of RM, as well as the provision of prescriptions to help building future action plans. Nonetheless, based on their comments, one new edition was still necessary on the readibility of the attributes. As a result, the PRisk-MM had its reliability analysed and approved; testing the model was important to ensure that it could measure what was intended to, and that the results were accurate (De Bruin et al. 2005).

Conclusions

This article proposed the PRisk-MM, a PSRMMM developed for Brazilian public organisations. The model consists of 5 maturity levels and 23 attributes distributed into 15 dimensions. The maturity levels and attributes were derived from the study by De Lorena and Costa (2023), and the step-by-step used to develop the PRisk-MM was inspired in the phases proposed by Mettler (2011) and De Bruin et al. (2005). The assessment procedure uses triangular fuzzy numbers during the weight assignment of the dimensions (judged by the GPMs) and the assignment of scores of the attribute (judged by the RM leader in the organisation).

The model presents theoretical implications. To begin with, this is the first study to deliver a PSRMMM. Secondly, the PRisk-MM addresses the contingent factors that are considered significant to public sector RM maturity according to De Lorena and Costa (2023). Finally, the PRisk-MM fulfills issues that are commonly criticised by academics (Santos-Neto and Costa 2019; Wendler 2012), such as the lack of prescription, the lack of a sound theoretical basis and the lack of validation.

The PRisk-MM also has practical implications as a government tool, since GPMs are supposed to assess the organisations' status of maturity as part of the controlling role they exert over the public organisations (De Lorena et al. 2022; Woods 2009). Hence, the PRisk-MM provides a clear and objective assessment procedure besides being easily understood, and GPMs may use the Prisk-MM to compare the RM implementation performances of various organisations. Moreover, the PRisk-MM is an adaptive model due to the possibility of assigning weights to the dimensions or withdrawing dimensions from the model, thus incorporating the GPMs' perceptions on how important the dimensions are, considering the current government context. Finally, the prescriptive feature of the model provides the organisations with the chance to develop action plans and improve their RM.

This study is limited to the Brazilian context because its development procedure is based on data collected in Brazil, and its validation took place in Brazilian public organisations. Therefore, for a broader analysis, future studies could analyse the effectiveness of the PRisk-MM in public organisations from other countries. Moreover, scholars could find inspiration in the PRisk-MM development mode and create MMs for further domains, presenting prescriptions, validation and a sound theoretical background (Santos-Neto and Costa 2019; Wendler 2012).

Note

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