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PRODUCTION MANAGEMENT

An adaptive and integrated reference model for supplier selection: application to product development and serialized component supply

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Abstract
The purpose of this research is to present an adaptive and integrated reference model for the Supplier Selection Process (SSP) to integrate it into the Product Development Process (PDP) or the serialized component supply. The research methodology adopted a broad literature review on indexed databases and a logical deductive analysis of the identified constructs and factors. The two main results obtained were: compilation and categorization (moderating factors, connecting factors) of critical SSP success factors; and proposal of a reference model so that the SSP can serve the PDP and the serialized component supply. Regarding originality we can mention: (a) this reference model covers all the critical SSP success factors; (b) it makes a clear distinction between moderating and connecting factors (c) while addressing both the PDP and the serialized component supply. The considerable number of factors identified in this research suggests that the vast majority of models proposed in the literature are based on an incomplete set of variables, restricting the conceptual view of the SSP. Finally, the results contribute to reducing the risk of the SSP not adding value to the Original Equipment Manufacturers' (OEMs) strategic purpose or causing losses. Additionally, the proposed model can be adapted according to the company's business strategy.

Keywords Supplier selection · Supplier evaluation · Supplier development · Supplier integration · Supplier segmentation

1 Introduction

The increase in competitiveness in the business environment has forced Original Equipment Manufacturers (OEMs) to outsource part of their activities, directing their resources to their core competencies while seeking resources (knowledge, technologies, structures) outside their organizational boundaries [1–3]. One of the motivations for establishing partnerships with suppliers is to support product development, expecting to overcome technological challenges and reducing project deadlines and costs [4]. In the case of product development, the co-development process is complex and may cause negative effects [5] such as the risk of leaking confidential information [6], and the reduction of innovation capacity due to the lack of trust and divergence of objectives [7–9].

Another motivation for establishing partnerships is to outsource serialized components, that is, items that integrate products developed by OEMs, expecting to access new resources, reducing the cost of inventories and production, improving quality and flexibility, guaranteeing the delivery time, and reducing risks in general [10–12]. Regarding problems associated with outsourcing serialized products, the following can be mentioned: fluctuation in the frequency of service (delays, installments and failures in deliveries), reduction in the level of quality, increase in cost, reduction in service prioritization, partnership dependence, and lack of confidence. However, addressing these various factors is a complicated challenge because it involves many variables, some of which may be tradeoff situations [13, 14].

All these problems and challenges are addressed by the literature that deals with the formation and development of innovation and supply chain networks. The risk of leaking confidential information can be reduced/mitigated by

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assessing the reputation and reliability of suppliers, as well as the expectation of rewards arising from partnerships [15–18]. The fluctuation of service constancy is related to market competitiveness and supplier commitment and flexibility [19, 20]. The lack of trust between partners is related to the supplier's reputation and the OEM's image in the market [21].

What all these studies have in common is that by and large, they have two limitations: (1) the lack of conceptual separation between the moderating and connecting factors, and (2) the lack of a clear distinction between models for supplier selection that participate in the product development process (PDP) or in serialized component supply. Concerning the first problem, there are relevant factors that cannot be contractually negotiated when establishing partnerships [22], because they are factors that are characteristic of the business environment itself or are intrinsic parts of the characteristics of the partnerships themselves. These are the so-called moderating factors, among which are competitive pressure among the OEMs, competition among suppliers, and the reputation or image of the companies in the market. On the other hand, there are also factors on which their presence and intensity can be negotiated, such as the type of technology to be developed, technology ownership, and information confidentiality. Regarding the second problem, the models presented in the literature are generally incomplete and lack rigor in distinguishing between factors to select suppliers participating in the PDP and factors to select suppliers for the serialized component supply. The consequence is that several of the proposed models are supported by an incomplete group of factors which can either increase the risk of a Supplier Selection Process (SSP) failure or simply have no value to the strategic selection purpose.

The logic behind connecting these two categories of factors lies in the fact that, although a moderating factor may not be negotiable, its influence needs to be taken into consideration due to its potential to either strengthen or weaken the impact of each connecting factor. The contingency approach theory highlights the importance of monitoring factors over which a company may not have direct control, but which have the potential to offer both opportunities and limitations, threats, and risks [23]. Without this consideration, which we believe is a frequent gap in the literature, supplier selection models may overlook the type/intensity of the relationship between forces capable of positively or negatively influencing the collaboration process between OEMs and their suppliers.

Due to the aforementioned two problems (the lack of conceptual separation between the moderating and connecting factors, and the lack of a clear distinction between models for supplier selection that participate in the product development process (PDP) or in serialized component supply), the models proposed in the literature for supplier selection (Table 1), despite being methodologically robust, have limited or questionable functional validity.

These limitations justify the proposition of a reference model for supplier selection based on the following research question: what are the most important factors in the supplier selection process and how is it possible to organize them while considering the relationship between moderating factors and connecting factors? This question can be broken down into sub-questions:

a) What are the most important factors when selecting suppliers to participate in a PDP?

b) What are the most important factors when selecting suppliers to outsource serialized components?

PDP **x** serialized components

c) What are the moderating factors, that is, the factors characteristic of the business environment or that are part of the intrinsic characteristics of the partnerships themselves?

Moderating **x** connecting factors

d) What are the connecting factors, that is, those that partnerships can define and at what level they will be made available?

e) What is the best way to structure the relationship between the factors?

2 Research methodology

This research adopts a qualitative approach with an exploratory purpose on the subject. Conclusions are proposed by providing a broad literature review. The steps followed were: conducting a literature review in two large indexed databases; results analysis; and structuring the reference model.

2.1 Research protocol

The research protocol specifies how the articles were selected and which criteria were used to integrate them into this study. The procedure is described below:

a. This research is characterized as a longitudinal study of articles published in the Web of Science and Scopus databases. These databases were selected because they have broad coverage of the topic in question and offer full access to published articles.
b. The selected literature sample comprises peer-reviewed articles on supplier development from 2007 to 2021. Only a few seminal references prior to this period were used.
c. Only works published in English were considered.
d. The database search took the following keywords as a reference: supplier evaluation, supplier selection, sup-

Table 1 Outcome of the search process in the indexed databases

Contribution of articles	Tools	Authors
Identification of factors related to supplier selection (56 articles)	Deductive logic analysis (35)	Bäck and Kohtamäkim [1], Peled and Dvir [5], Westphal and Sohal [12], Akrout [24], Araujo et al. [25], Aune and Gressetvold [26], Axelsson and Wynstra [27], Barney [28], Davenport and Prusak [29], Capaldo [30], Day et al. [31], Day et al. [32], Demil and Lecocq [33], Dyer and Singh [34], Echtelt et al. [35], Fossas-Olalla et al. [36], Handfield et al. [37], Johnsen [38], Laage-Hellman et al. [39], Lawrence and Lorsch[23], Melander and Tell [40], Mortensen and Arlbjorn [19], Noshad and Awasthi [41], Rosell et al. [6], Schiele [42], Caldarelli et al. [43], Williamson [44], Wowak et al. [18], Adobor and Mcmullen [45], Whitehead et al. [46], Delbufalo and Bastl [47], Koller [48], Will [49], Westphal and Sohal [12]
	Factor analysis (6)	Bonner and Walker [7], Jayaram [50], Ragatz et al. [51], Tan et al. [20], Lui and Ngo [52], Su and Gargeya [53]
	Regression analysis (5)	Herstad et al. [2], Scandura [3], Trautrims [54], Wuyts and Geyskens [55]
	Operational research (2)	Talluri et al. [17], Yoo et al. [56]
	Structural equation model (2)	Handfield and Bechtel [57], Kou et al.[58]
	Game theory (1)	Bai and Sarkis [59]
	MICMAC analysis (1)	Govindan et al. [60]
	Differential and integral calculus (1)	Worthmann et al. [61]
	Structural selfinteraction matrix (SSIM) (1)	Singh et al. [62]
	Hypothesis test (2)	Lau et al. [63], Lee and Chan [16], Krause and Scannell [4], Fang [9]
Models for supplier selection (18 articles)	Fuzzy logic (8)	Çebi and Otay [11], Arabsheybani et al. [10], Lima Junior et al. [21], Carrera and Mayorga [64], Mirmousa and Dehnavi [65], Omurca [66], Ordoobadi [67], Rezaei and Ortt [68]
	Operational research (6)	Hosseininasab and Ahmadi [69], Li and Zabinsky [70], Rezaei et al. [71], Prasannavenkatesan and Goh [72], Wu et al. [73], Cheraghalipour and Farsad [13]
	Deductive logic analysis (2)	Chen et al. [74], Chen [75]
	QFD-QHP (1)	Dey and Bhattacharya [15]
	DEA (1)	Noorizadeh et al. [76]

plier development, supplier integration, supplier segmentation.

e. The relevance of the articles was evaluated in 4 reading stages: title, abstract, conclusion, and complete document.

In order to ensure precision in the bibliographic reference analysis, the complete set of articles downloaded from the databases was independently evaluated by each author following the same reading sequence mentioned above. The inclusion of each reference was the topic of discussion among the authors.

2.2 Outcome of the search process in the indexed databases

The configuration of keywords in the two database search engines resulted in 457 articles. It is important to highlight

that the "open access" filter was activated. These articles were initially filtered after reading the title, resulting in a total of 285 selected articles. Afterward, the abstract of each work was read, resulting in selecting 123 articles. This was followed by reading both the abstracts and conclusions, leaving a total of 81 articles. Finally, after reading all the articles, only 61 articles remained. Thirteen articles prior to the specified period (2007–2021) were added, which resulted in a total of 74 articles.

Among the 74 articles included in this review, 56 sought to demonstrate the importance of certain factors for the supplier selection process using tools such as deductive logic analysis, factor analysis, and regression analysis. The other 18 present models for supplier selection were based on fuzzy logic, operational research, deductive logic analysis, QFD-QHP, and DEA. These 18 proposed models have three significant limitations. The first is that each of them addresses a limited set of factors, which hinders the generalization of the application in real cases. The second is that none of the proposed models address supplier selection from the perspective of participation in the product development process and the provision of serialized components at the same time. The third constraint is that these models do not differentiate between moderating factors and connecting factors, which hinders the influence of independent variables (moderating factors) on dependent variables (connecting factors). These three constraints together justify the proposition of the model developed in this study. The new model aims to address these limitations and provide a more comprehensive and effective approach to supplier selection by appropriately accounting for the interplay between various factors and their impact on the collaboration process between OEMs and suppliers.

3 Literature review

The literature review is divided into two main sections: Supplier Selection to Participate in Product Development Processes and Supplier Selection to Supply Serialized Components. Within these two main sections, there are two subsections called Moderating Factors and Connecting Factors.

3.1 Supplier selection to participate in product development processes

The participation of suppliers in the PDP brings several benefits: in the short term, there are the reduction of development time and costs, the overcoming of technical challenges and the availability of innovations; and in the long term, we have access to partner technologies, and the transfer of knowledge to other projects [35]. Sections 3.1.1 and 3.1.2 point out the moderating and connecting factors relevant to the supplier selection to integrate the PDP.

3.1.1 Moderating factors—PDP

Moderating factors cannot be controlled through a business contract, and they can alter the impact of the factors usually assessed in connectivity [77, 78]. Depending on the case, results may be lower than expected due to factors preceding the supplier selection process itself, despite OEM channeling its resources and efforts to optimize its supplier base. For this reason, it is important to consider moderating factors as scoring criteria in the supplier selection.

An important moderating factor is the size of a company. Larger companies generally have better conditions for product and process innovation because of the greater access to financial, structural, and technical resources [36, 63]. Some studies even suggest that the main task in strategic supplier selection is including innovation as a parameter, such as finding which suppliers are oriented towards innovation and which are actually the most innovative ones [18, 54]. The key factor lies in the fact that a culture of innovation is responsible for the adaptability of these organizations [48]. Patent analysis and the percentage of investment in R&D can be used as operational factors when assessing the supplier's ability to innovate [54, 79].

Innovation involves risks and the ability to deal with its associated uncertainties is paramount. For this reason, the management philosophy of a company can moderate the willingness to assume the risks inherent to innovative ventures. This may also be done through support from the top administration by the establishment of collaborative ties and encouraging continuous learning. Another way of dealing with uncertainty is the interest in exchanging information/knowledge and sharing mutual advantages when these align with previously established strategic objectives [49, 80]. This form of management can contribute to addressing technological, commercial, and organizational uncertainties. Technological uncertainty relates to techno-paradigmatic problems and technological complexity; organizational uncertainty relates to the lack of partner alignment with OEM's global strategy or cultural differences; commercial uncertainty stems from the lack of knowledge about the commercial potential from the development of new technologies and if they will be absorbed by the OEM in future projects [40]. These uncertainties can be overcome by adopting a management philosophy committed to flexibility in order to adapt to changes inherent in innovation.

Market competitiveness also has a moderating role because pressure from competitors forces the OEM to consider suppliers from a strategic perspective, encouraging goal alignment and lasting collaborative links [19, 20, 72]. OEMs in stable markets tend to handle less risk and can invest less in flexibility. On the other hand, companies in unstable markets usually want to reduce uncertainty and risk associated with their projects and may use factors such as direct communication and information sharing [50].

In addition to market stability, the supplier's own stability is also important. For this reason, the OEM needs to have access to information that confirms the financial reliability of the supplier, such as market share, revenue, and profitability. This reliability can be divided into three categories: without risk, monitored, and at risk [64].

Another destabilizing factor in the business environment is the sector's growth rate. Competitiveness and opportunities tend to motivate the establishment of strategic alliances with the supplier base which helps overcome technical and financial barriers, thus allowing it to surpass competitors [81].

Managing instability and risk within an ever-changing scenario requires the use of knowledge accumulated over time. For this reason, knowledge absorption capacity (the ability to learn better and faster) also exerts a moderating force on the way the OEM configures its collaboration network or supply chain [82]. According to Cohen and Levinthals [83] absorptive capacity theory, the ability to recognize, assimilate, and apply external knowledge revolves around the existence of previously accumulated correlated knowledge. The capacity for innovation depends on this knowledge which is accumulated from interactions with other companies [84, 85], as well as internally developed knowledge, which in turn is often linked to the level of maturity in Research and Development [86]. From this perspective, knowledge acquisition about supply chains is a collective work and directly depends on the ability of the OEM to identify, assess, and select the most suitable partners with adequate infrastructure, goal alignment, and motivation to share information and resources [34]. The theoretical current of Knowledge-Based View places organizational knowledge at the center of all business resources as it is usually complex and difficult to be reproduced. Additionally, heterogeneous knowledge from the collaboration between companies is a major driving force in superior performance and sustainable competitive advantage [28, 29].

Table 2 presents all the moderating factors pointed out in this section for the supplier selection to participate in the PDP of an OEM.

3.1.2 Connecting factors—PDP

Connecting factors are those with a level or intensity that can be adjusted during the negotiation of a supply contract. The selection process should assess these factors and their possible levels of adjustments.

The first connecting factors that need to be evaluated when selecting suppliers to participate in the PDP are the technological level requirements by the OEM, how much development capacity the supplier will provide (infrastructure, resources, people), the minimum quality level required (item reliability parameters), the investment cost to manage the partnership, and the reduction cost provided to the OEM [64].

Table 2 Moderating factors for selecting PDP suppliers

Moderating factors	Authors
2.1 Supplier size: resource availability to innovate 2.2 Innovation as a parameter for selecting suppliers (which suppliers are innovation-oriented and which are the most innovative suppliers): strategic relationships, patent analysis, percentage of investment in R&D	Lau et al.[63], Fossas-Olalla et al. [36], Trautrims et al.[54], Wowak et al. [18], Koller [48], Venkatesan and Goh [79]
2.3 Management philosophy of companies: support from the top management to the establishment of collaborative ties, openness and encouragement for continuous learning	Eltantawy et al. [80], Will [49]
2.4 Technological, commercial, and organizational uncertainties 2.5 Flexibility capacity	Melander and Tell [40]
2.6 Market competitiveness of the OEM: flexibility, information sharing, direct communication	Tan et al. [20], Mortensen and Arlbjorn[19], Prasannavenkatesan and Go [72], Jayaram [50]
2.7 Supplier's financial reliability (marketshare, revenue and profitability): risk free, monitored, at risk	Carrera and Mayorga [64]
2.8 Sector growth: competitiveness and opportunities	Park et al. [81]
2.9 Capacity to absorb knowledge	Cohen and Levinthal [83], Hallikas et al. [82], Hoang and Rothaermel [84], Prajogo and Ahmed [85], Knell and Srholec [86], Dyer and Singh [34]

In fact, some factors go beyond simple cost reduction as there may be an expectation of fair reward and the attractiveness of future opportunities [18]. If the expectation of rewards matches the suppliers' aspirations with the prospect of several future opportunities, the partnership can be seen as fair and interesting. Expectation Theory supports the premise that the anticipation of future events directly affects individuals' present motivation. In other words, the strength of attraction promoted by the size of the reward and the chance of achieving it shapes partners' behaviors [87]. However, it should be noted that, in the case of companies, rewards are not the only motivational elements. Other factors, which will be discussed below, also exert influence, such as the type of innovation to be developed, the availability of resources, the availability of information, and risk control.

In general, supplier integration practices can also be used to identify the connecting factors in the selection phase such as integrating key suppliers in the PDP team, communicating directly with main suppliers, sharing project information, involving the main suppliers in defining project architectures and specifications, creating education and training programs shared with the main suppliers, maintaining common and linked information systems (EDI, CAD), and co-allocating personnel from the OEM and key suppliers [50]. These factors can be grouped into three major groups: communication and information sharing; project participation; and developing a joint program infrastructure with key suppliers [43, 50, 58].

Aligning strategic objectives shows a glimpse of future opportunities and fair rewards for both sides of the partnership as it motivates interest in sharing infrastructure, resources, information, and even a higher disposition to take risks. With the support of that strategic management perspective, prioritization of complementarity competencies can be defined. This is directly related to the clear distinction between roles, the definition of appropriate levels of involvement, the sharing of reward and risk, the definition of goals and performance measures, and the inclusion of a supplier representative linked to the PDP team [38, 88].

In this scenario, the type of innovation also needs to be considered as an important connecting factor due to its potential to generate benefits in the form of dividends, market image, new knowledge, and technologies [18]. If the desired innovation for the product is only incremental, the OEM can explore competition between suppliers in order to obtain better prices and quality, thus using only a transactional approach with its suppliers [27, 89]. There are cases where product innovation is radical, and involvement and collaboration between partners are required for the so-called relational approach [27, 51]. This type of collaboration requires the ability on the part of the OEM to demand (technically specifying the product functions) and describe non-measurable characteristics. The ability to solve problems is needed on the supplier's side, requiring concept translation, interpretation, and implementation/development skills [25, 26, 36, 39].

The most suitable collaboration structure for radical innovation is that of a cohesive core marked by a limited set of strong links with trust between partners while connected to a wide periphery of weak links responsible for new and non-redundant information [30]. Weak links allow for research and discovery of new knowledge, while strong ties allow the exchange of tacit knowledge.

Another important connecting factor is the extent of supplier involvement. This is mainly related to time (from the start of the PDP, for example), frequency (in various projects), and the importance of the supplier's role. Supplier involvement in the PDP is beneficial for the OEM, but the degree (time and frequency) of involvement needs to be carefully considered as simple supplier participation does not guarantee PDP success [56]. In addition, it should be noted that a long-term commitment with a supplier can make it lose the incentive to innovate, as it can settle from not needing to compete with other suppliers [40]. Therefore, a long-term relationship needs to be accompanied by incentive mechanisms that motivate the continuous search for new development. Among these mechanisms, a technological roadmap can be adopted to link innovation strategy to sourcing strategy and supplier selection. For this, a purchasing staff from the OEM needs to be included in the PDP teams [42].

Finally, risk is also an element that needs to be assessed when selecting suppliers. Risk is understood as the probability of an event occurring and, as a consequence, producing an unwanted effect [90]. Some very recurrent risks are information leakage and supplier dependence [6, 91, 92]. These risks can be analyzed by the OEM based on information provided by the candidate partner, and some mechanisms may be adopted as protective contractual clauses by establishing rewards and sanctions [47].

Table 3 presents all the connecting factors pointed out in this section as necessary for the supplier selection to participate in the PDP of an OEM.

3.2 Selection of serialized component suppliers

The selection of partners for serialized component supply is also influenced by moderating and connecting factors. In this case, factors change because the supplier's focus also shifts from engineering a part or component to the supply of serialized items.

Table 3 Connection factors for selecting PDP suppliers

Connecting factors	Authors
3.1 Technological level required by the OEM 3.2 Development capacity provided by the supplier 3.3 Level of minimum quality required (reliability parameters of the items) 3.4 The investment cost to manage the partnership 3.5 The expected level of cost reduction to the OEM	Carrera and Mayorga [64]
3.6 The expectation of fair reward and the attractiveness of future opportunities: alignment of strategic objectives	Wowak et al. [18], Vroom [4]
3.7 Communication and information sharing: direct communication with the main suppliers 3.8 Project participation: participation of key suppliers in the PDP team, sharing of project information, involvement of the key suppliers in defining the project specifications and the new architecture products 3.9 Infrastructure development of joint programs with key suppliers: creation of education and training programs shared with the key suppliers, common and linked information systems (EDI, CAD / CAM), coalocation of personnel from the OEM and key suppliers	Jayaram [50], Kou et al. [58], Caldarelli et al. [43]
3.10 Strategic management perspective of relationships: alignment of strategic objectives (goal synergy), prioritization of the complementarity of competencies, clear distinction between roles, definition of appropriate levels of involvement, sharing of reward and risk, goals and performance measures, and inclusion of a representative from the supplier in the PDP team	Oinonen and Falkala [88], Johnsen [38]
3.11 Type of innovation: incremental (only transactional approach – exploiting competition among suppliers), radical (relational approach – engagement and collaboration) A relational approach requires OEM's ability to demand (technically specify the product functions and describe the non-measurable characteristics) and the supplier's ability to solve problems (translate concepts, interpret and implement/develop)	Wowak et al. [18], Axelsson and Wynstra [27], Anderson et al. [89], Ragatz et al. [51], Fossas-Olalla et al. [36], Araujo et al. [25], Laage-Hellman et al. [39], Aune and Gressetvold [26]
3.12 Ability to integrate strong or weak ties: cohesive core, marked by a limited number of strong ties and hence marked by trust between partners, linked to a wide periphery of weak ties	Trautrims et al. [54], Capaldo [30], Fritsch and Kauffeld-Monz [93], Büchel et al. [94], Ozman [95], Roxenhall [96]
3.13 Extent of supplier involvement: time (since the beginning of the PDP, for example), frequency (in various projects) and the importance of the role played by the supplier; incentive mechanisms such as technological roadmap (linking innovation strategy with sourcing strategy), and inclusion of purchasing professionals in the PDP team	Yoo et al. [56], Melander and Tel [40], Schiele [42]
3.14 The risk of information leakage or security: risk of suppliers' non-compliance 3.15 The risk of vendor lock-in	Rosell et al. [6], Yan et al. [91], Lo et al. [92], Matook et al. [90], Delbufalo and Bastl [47]

3.2.1 Moderating factors—serialized components

Some research suggests that companies that invest in forming a supplier base for serialized component supply need to be aware of the influence of their own image over supplier willingness to allocate the resources and make the appropriate adaptations. Therefore, the selection needs to take into account the supplier's view of the OEM's ability to create value for the supplier itself [19, 21].

Market competitiveness can also be considered an important moderating factor, as it forces the OEM to manage its supplier base strategically, viewing the chain as a whole [19, 80]. And as the actions of one member of the chain can affect the responsiveness of its entirety, the competitive pressure generated by the presence of multiple competitors boosts suppliers to not reduce their performance [60].

This competitiveness causes uncertainty in the business environment both for the supplier and for the OEM (probability of failures), which in turn affects the total expected cost [72]. The level of uncertainty is associated with environmental factors that cause fluctuations in demand, cost, quality, and logistics [16, 70, 73, 74]. Transaction Cost Economic Theory [44] suggests that the relationship within business partnerships has a cost associated with uncertainty and asset specificity. The uncertainty of the environment is associated with the possibility of opportunistic behavior within the web of relationships. For example, partners can deliver inferior

quality products if there is no way of detecting them [55]. The specificity of the partners' assets also generates costs due to the need for adaptations made on both sides so that the synchronization of processes, the exchange of information, and the proper configuration of a constant level of quality is feasible [44]. It is also interesting to note that research shows uncertainty and specificity motivating companies to undertake long-term collaborative relationships [52] since there are great benefits such as reduced transport-associated costs, inventory, and increased level of service available to the customer [33].

The level of uncertainty associated with environmental factors can only be addressed through strategic supply management in the form of planning processes, evaluating, implementing, and controlling both strategic and routine supply decisions. Therefore, an important moderating factor is the presence of an administrative philosophy that assigns a strategic role to supply management. This is something that will certainly require top management support through the recognition of purchasing as strategic for the company [19].

Supplier reliability is also associated with overcoming uncertainties, as this is an important element that ensures a partnership capable of lasting contributions [79]. Reliability can be analyzed through benchmarks such as financial stability, market reputation, labor issues, geographic location, and past performance [69]. This performance can be measured by evaluating organizational capacity and established practices both in environmental and social management, as well as in risk management [15].

There is always a great expectation about the results that are set beforehand when a contract between companies is signed. The competence to achieve expectations set by the partnerships depends on the technical and managerial capacity of the supplier, as well as its reputation, past performance, communication infrastructure [17], LIMA [21], and culture of collaboration [16]. Continually meeting expectations requires resilience on three levels: efficiency (keeping what has been agreed,adaptation (local, specific adjustment; and renewal, not just adaptive behavior but transformation [45].

The risks of supply failures (caused by supplier instability), information leakage, opportunism, and dependence-associated uncertainties also precede the supplier selection process [6, 69, 92, 97]. An inconsistent supplier that occasionally falls short of the frequency, deadline, and quality requirements established by the OEM can also be considered high risk [69]. The risk of information leakage and opportunism occurs at the points of knowledge

Table 4 Moderating factors for selecting suppliers to participate in the sourcing of serialized components

Moderating factors	Authors
4.1 Image of the OEM towards suppliers: capacity of the OEM to create value for the supplier	Mortensen and Arlbjorn [19]; Lima Junior et al. [21]
4.2 OEM's market competition	Eltantawy et al. [80], Mortensen and Arlbjorn [19]
4.3 Supplier's market competition: competitive pressure generated by the presence of multiple sources of supply	Govindan et al. [60]
4.4 Uncertainty level in the business environment (probability of failure): market turbulence and opportunistic behavior (leading to increased transaction costs)	Prasannavenkatesan and Go [72], Wu et al. [73], Lee et al. [16], Chen [74], Li and Zabinsky [70], Williamson [44], Wuyts and Geyskens [55], Demil and Lecocq [33], Lui and Ngo [52]
4.5 Specificity of the partner's assets	Williamson [44]
4.6 Administrative philosophy that assigns a strategic role to supply management: requires support from senior management to recognize the strategic role of the purchasing function	Mortensen and Arlbjorn [19]
4.7 Reliability of suppliers: financial stability, market reputation, the existence of labor issues, geographic location, political/economic stability, specificity of the assets that the supplier has, and past performance (this performance can be scaled by evaluating organizational capacity, established environmental/social/risk management practices, and systems to ensure the desired level for both quality and delivery performance)	Hosseininasab and Ahmadi [69], Dey and Bhattacharya [15], Venkatesan and Goh [79]
4.8 Competence to achieve the expectations defined upon the partnership: evaluate technical and managerial capacity, supplier reputation, past performance, communication infrastructure, collaboration culture, resilience (efficiency, adaptation, growth and renewal)	Talluri et al. [17], Lima Junior et al. [21], Lee et al. [16], Adobor and Mcmullen [45]
4.9 Risk assessment: risk of supply failures (caused by the instability of suppliers), risk of information leakage, risk of opportunism, risk of uncertainties associated with power and dependency and power asymmetry	Hosseininasab and Ahmadi [69], Rosell et al. [6], Li et al. [97], Lo et al. [92], Day et al. [32], Chen [75]

integration, and it is brought by one of the partners possibly obtaining an undue advantage from the information and results produced by the joint effort [6]. Finally, the power asymmetry between partner companies has a direct influence on their dependence. What contributes to this asymmetry are the market conditions of the OEM and the supplier, the capabilities and vulnerabilities of both, the difficulty of finding competing supply sources, and the characteristics of the product/service such as criticality, value, complexity, and uncertainty of the demand [32, 75].

Table 4 presents all the moderating factors pointed out in this section as necessary for the supplier selection participating in the delivery of serialized components for the OEM.

3.2.2 Connecting factors—serialized components

Supplying serialized items presents its own challenges in terms of volume, frequency, lead time, quality, and even in terms of fluctuating demand. These challenges can be managed through the connecting factors directly linked to the supplier, such as the cost–benefit ratio, the supplier's commitment to the quality of items delivered, the willingness to flex customer service, commitment to service level, willingness to invest and share technologies, and commitment to punctuality [10, 21, 41, 53, 62, 68]. These factors can be monitored through performance indicators such as rejected item rate, late delivery rate, and delivery compliance, which can be monitored by comparing the requested quantity and the quantity that is actually delivered [73]. However, the OEM also has a share of responsibility for the success of this type of partnership in the form of willingness for inter-organizational communication and joint action [60].

Due to the degree of uncertainty associated with the provision of serialized items, a set of formal and informal rules is also relevant due to the potential to restrict and relax a partner's behavior [16]. Establishing rules is a way to guide the partner behavior and impose practical restrictions on the work process, in addition to structuring an environment with more precise procedures and criteria for more predictable and controllable performance. Thus, a partner connection platform works as a formal means to connect the resources and capacities of the parties involved, contributing to successful relationships [16]. Through a survey, Caldarelli et al. [43] suggest the adoption of the Blockchain platform in fashioning a sustainable supply chain.

The review of formal/informal rules and the implementation of a connection platform allows continual alignment between partners. This occurs through an up-to-date and reliable information flow which helps reduce relationship complexity within the supply chain and its different types of risks: delivery, cost, quality, flexibility, and trust in general (information leakage, opportunistic behavior) [76, 80].

For the OEM, supplier trust can be materialized into delivery reliability (fulfillment on the planned date, delivery time, contractual commitment, flexibility to deal with unforeseen changes, and correct service frequency), maintenance of the agreed quality level (rejection rate in quality control, customer rejection rate), adequate cost (purchase price, logistical cost) of the items transacted, and communication efficiency [24, 37, 57, 59, 65, 67, 68, 79, 98].

To meet OEM-imposed trust requirements, the supplier must be committed to relationship improvement, and this can be observed through four variables. The first is the will to improve performance: commitment to continuous product and process improvement, supplier's effort to eliminate waste, promote Just-in-Time principles, and willingness to help manage the partnership (definition of goals and penalties). The second is the willingness to share information: honest and frequent communication, and making the necessary means available. The third is the willingness to trust each other: mutual respect, honesty, and ethical standards. The fourth is the willingness to engage in a long-term relationship: adjustments in process compliance, adequacy of physical infrastructure [15, 46, 71].

The probability of supply failures or interruptions is another factor that needs to be considered [72] and can be related to the strength of the connection that enables an interdependence between partners [76]. The supplier must take an active role with the OEM in defining quality and delivery goals (including penalties) in order to reduce delivery failures, as well as in choosing any forms of recognition and rewards by the maintained level of commitment [41].

Finally, another important point is that the supplier's development process can be improved if the contract scheme between parties is dynamic. This means that contracts should not be established for long fixed periods of time, because this will reduce opportunism caused by the self-indulgence of a static and long relationship [31, 61]. This logic finds support in the Real Options Theory [99], which considers the need to incorporate managerial flexibilities (uncertainties and opportunities) in order to change a company's behavior. Therefore, the short-term contract allows uncertainties and flexibilities associated to changes in business scenarios to be incorporated into the company's future cash flow projection.

Table 5 presents all the connecting factors pointed out in this section as necessary for the supplier selection required in the delivery of serialized products to the OEM.

Table 5 Connecting factors for selecting suppliers sourcing serialized components

Connecting factors	Authors
5.1 Cost–benefit ratio: financial viability 5.2 Supplier commitment to the quality of items delivered 5.3 Supplier willingness to be flexible in customer servisse 5.4 Supplier commitment to the level of service 5.5 Supplier willingness to invest and share technologies 5.6 Supplier commitment to punctuality: performance indicators: rejected item rate, late delivery rate, and delivery compliance	Arabsheybani et al. [10], Lima Junior et al. [21], Singh et al. [62], Rezaei and Ortt [68], Omurca [66], Wu et al. [73], Su and Gargeya [53]
5.7 OEM willingness for inter-organizational communication 5.8 OEM capacity and disposition for joint action	Govindan et al. [60]
5.9 Formal and informal rules 5.10 Connection platform	Lee et al. [16], Caldarelli et al. [43]
5.11 Alignment of partners: flow of updated and reliable information through the allocation of necessary resources	Noorizadeh et al. [76], Eltantawy et al. [80]
5.12 OEM trust on the supplier: reliability in delivery, quality, cost of the transacted items, and in the efficiency of the communication	Venkatesan and Goh [79], Ordoobadi [67], Mirmousa and Dehnavi [65], Rezaei and Ortt [68], Bai and Sarkis [59], Akrout [24], Wagner et al. [98], Handfield and Bechtel [57], Handfield et al. [37]
5.13 Mutual commitment to improving the relationship: Willingness to performance improvement: commitment to continuous product and process improvement, supplier's effort to eliminate waste, supplier's effort to promote Just-in-Time principles, willingness to help manage the partnership (definition of goals and penalties) Willingness to share information: honest and frequent communication, and making the necessary means available Willingness to trust each other: mutual respect, honesty, and ethical standards Willingness to engage in a long-term relationship: adjustments to process compliance, adequacy of physical infrastructure	Dey and Bhattacharya [15], Rezaei et al. [71], Whitehead et al. [46]
5.14 Probability of failures or interruption in supply: depends on the strength of connection that characterizes the interdependence between the parties; 5.15 Supplier needs to take an active role with the OEM in defining quality and delivery goals (including penalties), and in choosing forms of recognition and rewards	Prasannavenkatesan and Go [72], Noorizadeh et al. [76], Noshad and Awasthi [41]
5.16 Dynamic change of the contract between the parties over time	Worthmann et al. [61], Myers [99]

4 The reference model

The reference model was divided into two parts. In part A there are critical factors for supplier selection aiming to participate in the OEM's PDP. Part B refers to factors on serialized component supply. Factors were segmented into three groups: moderating factors, supplier-associated connecting factors, and OEM-associated connecting factors. Each moderating factor can influence one or more supplier connecting factors, just as each supplier connection factor can support one or more OEM connecting factors. Neither the factor weights, their relationships, nor the intensity between them are pre-defined in the model. The definition of this information is part of the reference model setup for its application in different business environments (Fig. 1).

Relationships can be established between factors when analyzing the model. For example, we can assume that the factor "2.1 Supplier company size" tends to confirm the importance of "3.2 Development capacity provided by supplier". This happens because the larger the supplier, the greater the certainty that it actually has the necessary resources to meet "3.2". Following this same logic, we have that "2.2 Supplier is innovation oriented" also tends to confirm the factor "3.2", because innovation has a positive correlation with development capacity.

On the other hand, the factor "2.3 Management philosophy" based on top managerial support to the establishment of collaborative ties, openness, and encouragement for continuous learning" tends to support factors such as "3.6 Willingness to communicate and share information" and "3.7 Willingness to participate from the project specification". In other words, the more the supplier is willing to exchange information and integrate the development team from the early stages of the project, the greater the importance of it being managed from a philosophy focused on establishing collaborative ties and learning.

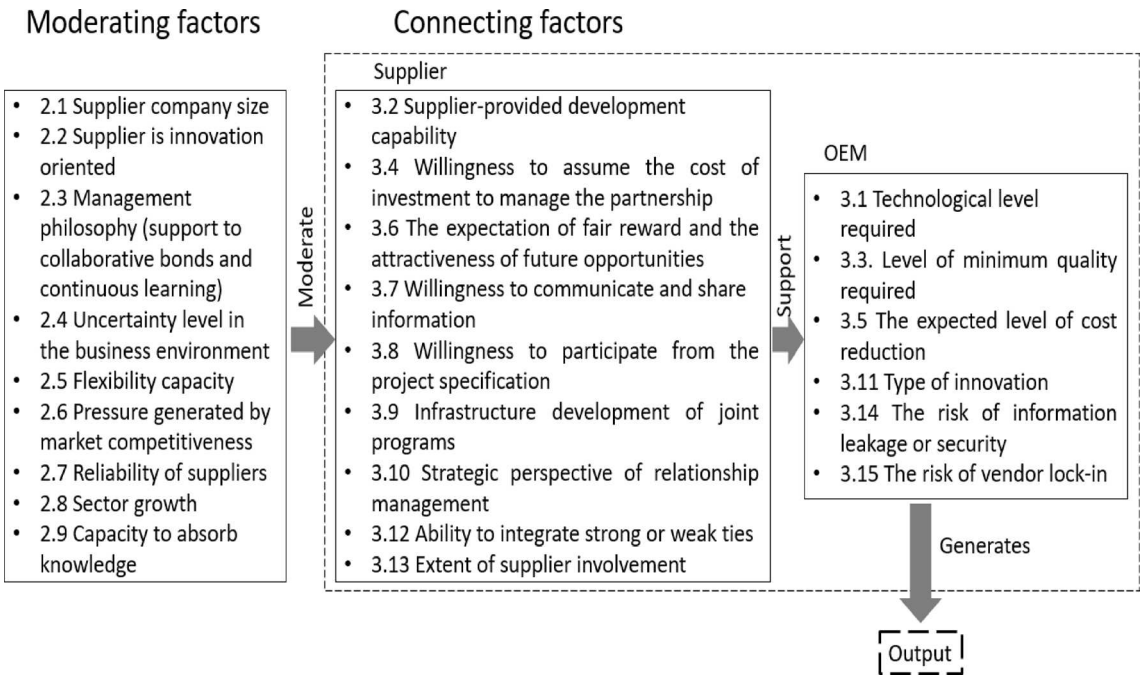

Fig. 1 Part A—Reference model for supplier selection process when participating specifically in the OEM's PDP

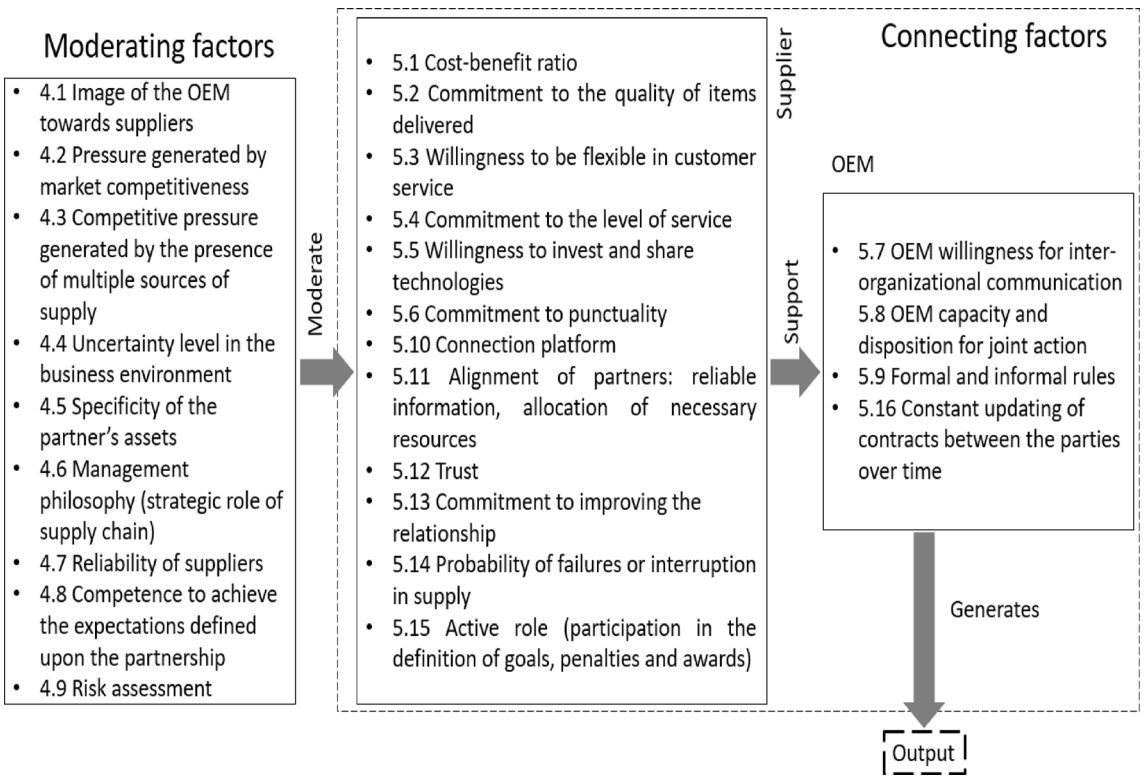

Fig. 2 Part B—Reference model for supplier selection process in order to provide serialized components for the OEM

The factor "2.4 Uncertainty level in the business environment" tends to reinforce the importance, for example, of factor "3.6 Willingness to communicate and share information" because the greater the level of uncertainty and risk, the greater the importance of a good performance in communication and in sharing information to overcome problems. This analysis can be extended to all other factors. The same supporting logic is established between supplier connection and OEM connecting factors.

Another point that needs to be noted is that factors "3.1", "3.3", "3.5" and "3.11" are of the "more-better" type. It is reasonable to accept that the higher the "3.1 Technological level required" the better for the OEM because the greater the possibility of producing technological innovations. The same applies to the other factors because their higher levels increase the possibility of the OEM having a strong competitive advantage. On the other hand, factors "3.14" and "3.15" represent situations such as "less-better", because it is reasonable to assume that the greater "3.14 The risk of information leakage or security" and "3.15 The risk of vendor lock-in" penalize the OEM since it is forced to take unwanted risks. Therefore, it is to be expected that the OEM will set higher scores for the first four factors (maximizing gains) and lower scores for the last two (minimizing losses).

The next figure illustrates the part of the model related to the supplier selection that will integrate the serialized component supply chain (Fig. 2).

In parts A and B of the reference model, each moderating factor is linked to each of the supplier's connecting factors through a binding force set in a score ranging from 0 to 3, where 0, 1, 2 and 3 represent no impact, weak impact, medium impact, and strong impact, respectively. Binding strength is important because even if a moderating factor is very strong, it can have a low influence on a specific factor. For the weight of the factors, a scale ranging from 0 to 5 was chosen, meaning no importance, very little importance, little importance, medium importance, high importance, and very high importance, respectively. Scales with higher scores (for example, from 0 to 10) reinforce the problem of subjectivity when assigning weights and are more difficult to maintain consistent throughout the entire evaluation.

The product between moderating factor (A), binding force of the moderating factor over the supplier's connection factor (B), supplier connection factor (C), binding force (D), and

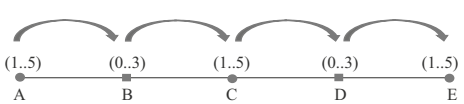

Fig. 3 **A** moderating factor; **B** binding force of the moderating factor over the supplier's connection factor; **C** supplier connection factor; **D** binding force of supplier connection factor over OEM connection factor; **E** OEM connection factor

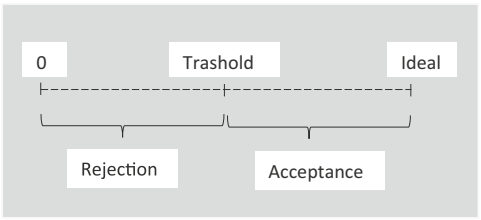

Fig. 4 Supplier acceptance/rejection interval

OEM connection factor (E) works as the final output. If there is no relationship between factors, the grade assigned in part (B) or part (D) will be zero. In this case, the moderating factor is ignored and only the score of the supplier's own connection factor is considered.

As there are several moderating factors and several connecting factors (both OEM and supplier), their combination will generate two vectors: the first is the Supplier connection factor weights vector, and the second is the OEM connection factor weights vector. The sum of the elements of the last vector provides the total points obtained by a given supplier (Fig. 3).

One can adopt the strategy of running the model for two hypothetical situations, the acceptable worst case and the best possible case. From these two scores obtained, it is possible to establish an interval for acceptance/rejection of suppliers. Within the acceptance range, one can select a supplier with the highest score, or if tied, one can select the one with the lowest contractual cost or some other chosen criterion (Fig. 4).

Below is an example of a worksheet, according to the 10 steps described above. The colored columns are those in which the scores for the moderating factors, connecting factors and binding forces will be recorded. The other columns result from the automatic multiplication of these notes. It will be necessary to run this model once for each supplier, and the result obtained must be evaluated and compared with the acceptance/rejection interval of the suppliers (Table 6).

The spreadsheet is divided into two interconnected parts. The upper half refers to the relationship between moderating factors and supplier connecting factors. The lower half refers to the relationship between the vendor and OEM connecting factors. The top half of the spreadsheet can be filled in by assigning grades (0..5) to each moderating factor (MF_Grade_Supplier column) and each connecting factor (CF_Grade_Supplier line). Grades (0..3) also need to be assigned to the strength of influence of each moderating factor on each connecting factor (column A). Next, columns B (multiplying each value of column MF_Grade by each value of column A) and C (multiplying each value in the CF_Grade_Supplier row by the corresponding value in

Table 6 Example of the reference model application. CF_Grade_Supplier, MF_Grade, CF_Grade_OEM: 1, 2, 3, 4, 5; **A**: Binding force (0, 1, 2, 3); **B**: MF*I; **C**: (Se B = 0; CF; MF*I*CF)

	Supplier connecting factor	3.2 Development capacity provided by the supplier			3.4 Willingness to assume the cost of investment to manage the partnership			3.6 The expectation of fair reward and the attractiveness of future opportunities			3.7 Willingness to communicate and share information			3.8 Willingness to participate from the project specification			3.9 Infrastructure development of joint programs			3.10 Strategic management perspective of relationships			3.12 Ability to integrate strong or weak ties			3.13 Extent of supplier involvement				
CF_Grade_Supplier ==>		5			5			2			1			1			1			1			1			1					
Moderating Factors (MF)	MF_Grade	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C			
2.1 Supplier company size	4	3	12	60	1	4	20	1	4	8	2	8	8	1	4	4	1	4	4	1	4	4	1	4	4	1	4	4			
2.2 Supplier is innovation oriented	2	2	4	20	0	0	5	1	2	4	2	4	4	1	2	2	1	2	2	1	2	2	1	2	2	1	2	2			
2.3 Management philosophy	4	1	4	20	3	12	60	3	12	24	1	4	4	1	4	4	1	4	4	1	4	4	1	4	4	1	4	4			
2.4 Uncertainty level in the business environment	2	1	2	10	1	2	10	3	6	12	2	4	4	1	2	2	1	2	2	1	2	2	1	2	2	1	2	2			
2.5 Flexibility capacity	5	3	15	75	2	10	50	1	5	10	1	5	5	1	5	5	1	5	5	1	5	5	1	5	5	1	5	5			
2.6 Pressure generated by market competitiveness	2	2	4	20	2	4	20	1	2	4	0	0	1	1	2	2	1	2	2	1	2	2	1	2	2	1	2	2			
2.7 Reliability of suppliers	1	0	0	5	3	3	15	1	1	2	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
2.8 Sector growth	1	0	0	5	0	0	5	1	1	2	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
2.9 Capacity to absorb knowledge	2	3	6	30	3	6	30	1	2	4	0	0	1	1	2	2	1	2	2	1	2	2	1	2	2	1	2	2			
Supplier connection factor weights vector				245			215			70			29			23			23			23			23			23			
Weights_vector_Supplier ==>		245			215			70			29			23			23			23			23			23					
Conecting Factors - OEM	CF_Grade_OEM	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C			
3.1 Technological level required	5	3	15	3675	1	5	1075	2	10	700	1	5	145	1	5	115	1	5	115	1	5	115	1	5	115	1	5	115	6170		
3.3. Level of minimum quality required	4	2	8	1960	2	8	1720	3	12	840	1	4	116	1	4	92	1	4	92	1	4	92	1	4	92	1	4	92	5096		
3.5 The expected level of cost reduction	3	1	3	735	1	3	645	1	3	210	1	3	87	1	3	69	1	3	69	1	3	69	1	3	69	1	3	69	2022		
3.11 Type of innovation	2	2	4	980	1	2	430	2	4	280	1	2	58	1	2	46	1	2	46	1	2	46	1	2	46	1	2	46	1978		
3.14 Risk of information leakage or security	1	0	0	245	0	0	215	2	2	140	2	2	58	1	1	23	1	1	23	1	1	23	1	1	23	1	1	23	773		
3.15 Risk of vendor lock-in	1	2	2	490	1	1	215	1	1	70	2	2	58	1	1	23	1	1	23	1	1	23	1	1	23	1	1	23	948		
Total score	16.987																														

OEM connection factor weights vector

column B) are calculated. Finally, for each column C, all the values are added up, generating the Supplier connection factor weights vector.

The lower half of the spreadsheet can be filled in by assigning grades (0..5) to each connecting factor-OEM (CF_Grade_OEM column) and grades (0..3) to the strength of influence of each factor associated with the supplier (Weights vector supplier) on each OEM connection factor (column A). Then, column B is calculated by multiplying each value of column CF_Grade_OEM by each value of column A and calculating column C by multiplying each value in the Weights_vector_Supplier row by the corresponding value in column B. For each row under the connecting factors-OEM column, the values of the C columns need to be added, thus producing the OEM connection factor weights vector. Finally, the values in the OEM connection factor weights vector need to be added, and the result obtained will be the supplier's performance score.

5 Conclusion

Supplier selection is a multicriteria decision-making problem that OEMs are still attempting to overcome. In order to help overcome these challenges, a longitudinal study was carried out in the form of a broad literature review in indexed databases of relevant journals in the field. The final results answer the research questions concerning the most important factors for supplier selection to participate in the PDP and also for serialized component supply, separating the moderating factors from the connecting factors and structuring the forces between them.

The first contribution to the literature on supplier selection is the survey of critical factors for selecting partners. This compilation allows a more complete view of the supplier selection process while reducing the risk of neglecting important variables. The second contribution is the classification of factors according to their nature, that is, moderating factors and connecting factors. Without this consideration – a very frequent gap in the literature – supplier selection models may end up

disregarding the type/intensity of relationships between forces capable of positively or negatively influencing the collaboration process between OEM and its suppliers. This classification made a third contribution: it shows evidence that there are moderating and connecting factors specific to the PDP, as well as moderating and connecting factors specific to the delivery of serialized components. This highlights the risk of proposing models that mix these factors without due care. The fourth contribution is in the proposition of a reference model from which new supplier selection models can be derived for specific situations.

As managerial implications of this research, the first contribution is the guarantee that managers will be using all critical factors to select suppliers, which contributes to a more effective supplier selection. The second contribution lies in the fact that the model takes the business scenario (through moderating factors) and the elements that can be negotiated at the time of signing a collaboration contract (through connecting factors) into account. The third contribution refers to the flexibility to instantiate this model according to the strategy of each company by prioritizing the factors that are strategically most relevant by assigning grades or weights. The fourth contribution is that the model allows for establishing a supplier acceptance interval, and once within this range, criteria such as lower cost or shorter delivery time can be adopted. The fifth contribution of the proposed model is the case where a selected partner must develop a component for the PDP and also deliver it in a serialized way. This set of contributions cannot be found in other model proposals.

As suggestions for future research, one can use experimental analyses to identify the effect of changing the moderating factor weight on the connecting factors. This can be done by conducting a survey with a significant sample of companies. Another research opportunity is that, although the moderating factor weight over the connecting factors depends on the specificities of the type of business of the companies, it is reasonable to assume that within the same business sector, this relationship of influence is relatively the same. This requires an investigation that can identify these relationships and also point out their intensity.

It is important to highlight that, although the model does not explicitly address global events such as the pandemic and armed conflicts, nor does it specifically address sustainability requirements, adapting the model to the specific reality of each OEM can deal with these new factors. For example, global events such as the pandemic and armed conflicts impose the need for more resilient and strong supply chains. Thus, some factors in the model and directly related to resilience are risk assessment (Factor 4.9) and the probability of failures or interruption (Factor 5.14); Likewise, supply chain strength is fueled by flexibility (Factor 5.3) and communication (Factor 5.11), as well as the commitment effort between parties (Factors 5.2, 5.4, 5.6, and 5.13). The same reasoning can be applied to environmental requirements because factors such as "2.1 Supplier driven by innovation", "2.7 Supplier's financial reliability" and "3.2 Development capacity provided by the supplier" can be directed towards meeting sustainable requirements. Regarding outsourcing components, factors such as "4.7 Reliability of suppliers" and "4.8 Commitment to meeting expectations defined in the partnership" can also be directed towards meeting sustainable requirements.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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