MODULARISATION AS A COMPETITIVE CRITERION IN INDUSTRIES MANUFACTURING MACHINERY AND EQUIPMENT IN BRAZIL

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ABSTRACT

This research aimed at identifying the competitive criteria that, together with modularisation, impacted the differentiation strategy in industries manufacturing machinery and equipment in Brazil. This was survey-type research that used structural equation modelling (SEM-PLS) for data analysis. A total of 236 responses were obtained from participants in Brazilian machinery and equipment companies in the area of R&D, including directors, managers, coordinators, and supervisors. From this sample, the results show that applied modularisation positively impacted the competitive criteria related to innovation, quality, and flexibility, whereas, when applied to the delivery costs and performance criteria, it did not contribute to a competitive differential. Since it deals with a non-probabilistic sample by convenience, the present model does not represent the relationship between the constructs in a definitive way, for it concerns a model that address a sample of the machinery and equipment manufacturing industry, referring to ISIC D28, from Brazil.

OPSOMMING

Die doel van hierdie studie is om die mededingendheidskriteria wat, saam met modularisering, die differensiasiestrategie in die masjinerie en toerusting vervaardigingsindustrie in Brasilië beïnvloed het. Hierdie meningspeiling gebaseerde navorsing het gebruikgemaak van strukturele vergelyklingsmodelering om die data te ontleed. 236 reaksies is vanaf deelnemers verkry, met ʼn verskeidenheid van rolle in die bedryf, naamlik direkteure, bestuurders, koördineerders en toesighouers. Die resultate van die steekproef toon dat toegepaste modularisering ʼn positiewe invloed op die mededingendheidskriteria, insluitend innovasie, gehalte, en buigsaamheid, gehad het. Dit het egter nie ʼn noemenswaardige invloed op afleweringskoste of vertoningskriteria gehad nie. Aangesien dit aan die hand van ʼn nie-stogastiese steekproef afgelei is, is die resultate nie veralgemeenbaar nie. Die resultate is beperk tot die masjinerie en toerusting vervaardigingsindustrie in Brailië.

1 INTRODUCTION

With globalisation, entrepreneurial organisations have had to search for strategies that aim to increase their operations' productivity and, consequently, their profitability [1–3]. This entrepreneurial setting faces constant changes that relate to topics such as the development of new technologies [4, 5], the variety of products [6, 7] and processes, and the services offered [8, 9]. These factors challenge the organisations to look for new alternatives with the objective of increasing their competitiveness [10–13]. Historically, companies try to adopt the most diverse strategies in order to increase their level of competitiveness in the market; and these relate to product changes, productive processes, and consumer support [11, 12, 14]. A company's capacity to search for solutions in this context provides these organisations with development and maintains their competitive advantage [15–17]. The increase in the products' life cycles can be a competitive differential, as modularisation has the potential to reduce development time and costs [18–24]. Research into the product's life cycle esaddress the features and the versatilities of the products with modular architecture as the main item of analysis [25–28]. A product's architecture is its main feature [29]. This can impact the life cycle considerably [28, 30–32]. Products with modular architecture show a particular increase in their life cycles [26, 33–35]. Through modularisation, the development of a range of new products in order to meet demand becomes unnecessary [33, 36–38]. However, the number of components to be used decreases in relation to the products with a traditional (integral) architecture, and so do their costs [33, 37, 39, 40]. In addition, modularisation tends to magnify the products' character [29, 39, 41], and so becomes essential to the issue of quality when it is addressed in the project that refers to the products' reliability [42]. Thus modularisation becomes a strategic option for product innovation so that organisations can increase their competitive differential in terms of innovativeness, deliveries, costs, quality, and flexibility [40, 43–47].

Research into the use of a modularisation strategy for products as a competitive differential [48–53] claims that it contributes to the differentiation of products and processes. Among the components of such a strategy are the use of modular architecture as a basis for modularisation [30, 46], and the use of modularisation to optimise the product development process [40, 53–55], to improve the products' manufacture and quality [39, 40, 47, 51, 56, 57], and to speed up their delivery [40, 52, 58].

The machinery and equipment industry manufactures capital goods that serve the facilities, machines, devices, and components that make up a company's fixed assets and that relate to the factors of the production of goods and services. They cover a wide range of industries, such as metalworking, electrical and electronic installations, and transportation (excluding areas focused on the production of supplies and consumer goods) [59]. The Brazilian economic crisis has caused the national GDP to decline. The sharpest reduction was in the machinery and equipment sector (-8.8 per cent), in which the automotive sector and the machinery and equipment sector decreased (-4.7 per cent and -7 per cent respectively) in 2019 [60]. It should be noted that, from a technological point of view, the machinery and equipment industry is characterised as more of a borrower of new technologies than as a disruptive innovator [61].

This article aims to answer the following research question: "What are the competitive criteria with a differentiation emphasis that, along with modularisation, mostly impact the innovation strategy in companies in the Brazilian machinery and equipment industry?". As a general objective, this research aims to identify the competitive criteria combined with modularisation, and how positively they impact the differentiation strategy in companies in the Brazilian machinery and equipment industry. The specific objectives are:

- To apply survey-type research in companies that manufacture machinery and equipment and that already use modularisation as a strategy;
- To design a model from structural equations in order to measure the interviewees' perceptions on the topic.

This article is divided into four sections. Besides this introduction, there is: (ii) a theoretical review of the topic of modularisation and on competitive criteria; (iii) the methodology applied in carrying out this research, and analysis of the results; and (iv) final considerations and suggestions for future research.

2 BACKGROUND

2.1 Modularisation

Modularisation is a strategy used to organise and develop products and processes in a more dynamic and efficient way [53, 62]. The modular approach can be an efficient strategy through which the organisation can retain, develop, and discard different capacities —, for example, a car manufacturer that has a non-modular design and whose production is highly vertical and integrated [63]. Modularisation must include the design definitions that must be designed before working on the independent modules. These include points such as modular architecture, modularity, and modules (systems, configurations, and typology) [30, 45, 46, 64]. The use of modules may make production more efficient, since the product's modular architecture allows the manufacture of a great variety of products with the current resources and at reduced costs [40]. This cost reduction happens both in the product's project development and in the production process. Other benefits that come from the use of modularisation are an increased flexibility in production, a reduced product development time, and improved productivity [65].

By combining different modules, it is possible to obtain several variations of the models and products with a short development lead time [31]. Modularisation is related to the degree of control with which the changes in the processes or the requirements affect the product and through the interchangeability of modules, components, and systems. Modularisation provides the designers with a set of flexible solutions for meeting the changing processes. This flexibility allows postponing the design decisions until more information is available to the product's development process. The development of modular products is beneficial to the production process, for they provide the flow, along with regular suppliers, reduced stocks, a lower number of ongoing projects, a swifter processing time, a lower number of designs (projects), easy reworking in the event of defective assemblies, and flexibility in responding to demand [39].

Besides the three listed modularisation types — design [29, 52, 63, 66], production [67–70], and use [71–74] — modularisation can be applied from two other perspectives: organisational modularisation [29, 52, 72, 75–78] and services [79–83]. Organisations must develop strategies to manage the complexity, and modularisation is one of the most efficient forms [84]. A modular product project enables a decreased development time and manufacture cycle time for the product, providing the designers with the development of simultaneous modules from their perspective. Before executing any modular project, the basic information and the expected functionalities must be collated at the start of the project to establish better productivity [40].

Modular systems are able to adapt to changes in their substitution requirements or individual module expansion, especially because of their flexibility [45, 70, 85]. Thus modularisation becomes a possibility for the flexible adaptation of machinery and appliances in the manufacturing line [86]. Moreover, as a result, modularisation reduces costs [45, 47, 65, 87], speeds up the pace of innovation [67, 88, 89], improves quality [47, 87, 90], decreases the number of parts [52, 67, 88], and increases flexibility [47, 68, 91] in the companies that adopt it as a strategy [29, 45, 62, 68, 70, 92]. The way a company manages the delivery time may represent a competitive advantage, so it is necessary to decrease the production time with the objective of enabling more the frequent manufacture of the product mix and a swifter response to the clients' demands [52, 93].

The modular product design decreases the delivery time through the reuse of existing standardised modules. This process saves time and engineering resources in the development of new products and manufacturing processes. Project modularity enables the designer to have much greater flexibility in changing the product, processes, and requirements. Another important aspect of modularity is the possibility of reducing costs in the product life cycle by improving R&D processes [39, 94].

With product architecture, project modularisation is a strategy for managing product development activities and production systems and issues around the chain of associated supplies. The consequences are many, from project engineering [95] to business strategy [88]. The first difference in the product architecture typology is between a modular architecture and an integral architecture [30, 45]. The product architecture based on the modular concept includes a differentiated mapping of the functional elements in relation to the structure of the product's physical components and the interfaces between them. On the other hand, the integral architecture includes a mapping of functional elements in the physical components and/or interfaces associated with the products' components [30]. Project modularity can become a viable strategy in which it is possible to take advantage of the external sources of knowledge and of innovation, as part of the products' development processes [96]

2.2 Strategy and competitive criteria

There are three different kinds of business strategy that an organisation can adopt: leadership in respect of the total cost, differentiation, and focus [11]. The total cost strategy is related to the gains of scale, whether in production, purchase of raw material, or even client transactions – this type of strategy requires a high capital investment, from modern machinery to aggressive prices with small profit margins, until the brand is consolidated in the market [11]. The risks the organisation takes upon adopting this strategy are: (a) the cancellation of investment due to technological changes; (b) high inflation in the costs, which will reduce the organisation's capacity to maintain the price difference and other forms of differentiation; (c) the appearance of new competitors through low-cost learning; and (d) the capacity to copy or invest in the same technology [97, 98].

Strategy by differentiation focuses on products with exceptional features or exclusive services that the company offers. Quality is also assumed in this strategy [99, 100] This positioning will enable the organisation to be known for the differential in the context in which it operates [97]. Some of the risks in this strategy are: (a) the cost difference in relation to the market and to the differentiated company may become too large for the differentiation to hold the loyalty with consumers, who would sacrifice some differential features in return for cost savings [101, 102]; (b) the need of these differential features to decrease as consumers become more sophisticated; and (c) imitation, which will decrease the differential factor, so the company will lose competitiveness in terms of differentiation, making it a competition for "commodity" [11, 103]. From this research's point of view, the strategy to be discussed will be that of differentiation.

Through three factors of fundamental importance (ruling guidance, the diversification pattern, and the perspective of growth), the operational area is one of the main elements in the company's strategy definition, and is responsible for three important roles within any organisation in line with the company's general strategy: i) the implementation of the strategy adopted; ii) the development of manufacturing resources that are suitable for the strategy; and iii) the supply of all the performance aspects the organisation might need to implement the strategy [11, 103, 104].

The operations involve five factors that are defined as competitive criteria and that coincide with the business strategy. They are related to quality, speed, flexibility, innovativeness, and cost [12, 105]. These five competitive criteria are the basic elements of concern for the operational area, in the sense that they address the company's business strategy. Some of these combinations of criteria contribute to an increased competitiveness in the market in which the company operates and, generally speaking, to its growth [11, 105]. These five competitive criteria are adjusted for and assimilated into the organisation's generic competitive strategies [12]. Thus the decision about which criteria must be prioritised becomes fundamentally important, since combining all of them at the same time could be a dangerous option [98]. In this research, only the five competitive criteria are emphasised.

The importance of prioritising the competitive criteria happens is found in the existence of trade-offs — that is, the distinction between two or more criteria, which reinforces the risk that comes from prioritising all of the criteria simultaneously [98]. A trade-off means an imbalance between two criteria once an improvement in one criterion affects the other, directly and negatively [12].

As one of the competitive criteria in the operational area, quality can be divided into eight different concepts, and combining them to prioritise quality as a strategy of competitiveness is a possibility [12, 14]. Within these eight different concepts, the author highlights performance [12, 14, 15], which is related to the main functioning attributes and product value proposition, and which is normally linked to the features it will present, whether functioning or inherent [103]. Two other concepts are the product's secondary features such as comfort and ergonomics, which will not have any influence on its functioning characteristics but will enable a more personalised user experience through more ergonomic functions, comfort, or even by saving time [97]; and reliability, which is directly related to product use and to the possibilities that it will reveal some flaws or malfunction after some time [105].

Conformity, the fourth concept, refers to the product's degree of adequacy with the features and tolerances established in the project. It can refer either to the conformity of a set of parts or to the conformity of a component within this set.

The fifth concept, as pointed out by the author, is durability [12, 14, 17], which, put simply, is the product's lifespan. This can be divided into two categories: economic and technical [12]. The economic point of view evaluates the extent to which the cost of keeping the product will be less than buying a new one. As for the technical point of view, it is about the product's lifespan until it starts malfunctioning. Added services come with the fifth concept, representing all the services offered by the company in the after-sales phase [106]. It can also be called 'technical support' without the use of third-party companies; it is a personalised service focused on offering a better consumer experience [12, 105].

Besides these concepts, aesthetics (which is part of the competitive criterion of quality) and the quality that is experienced are aspects that are subjective to each individual. Thus it is not possible to please every consumer. The experienced quality, which is related to a collection of attributes to which the client gives importance, meets certain needs and expectations in relation to the product, its name, its brand, and even the company's reputation [12, 105].

In the operational area, time is one of the most important variables, for it has a direct influence on both the operational costs and the benefits offered to clients. The speed of both the internal and the external processes will show whether the company runs a lean and productive operation [103, 105]. Time can be divided into two dimensions in a company: the demand time, which is the period of time the client will have to wait between ordering and receiving the product, also called delivery reliability; and the total time of the operational flow, which is the time needed to complete the internal processes, including the demand time, and is also called the speed of delivery [12, 104].

Two types of benefit are evident in the reliability of delivery: external — perceived by customers, and increasingly a differential for customer loyalty; and internal — which is related to the increase in productive efficiency, increasing the commitment of all the areas involved, which tends to offer several advantages to the operational area, such as reducing inventories and having more assertive plans [97].

Speed is not only related to the operational and delivery processes. It must also be considered in the introduction of new products to the market. The speed with which products are introduced into the market, and the moment when the company performs this insertion, are also a strategy of efficient speed. A company that releases two product innovations while their competitors release only one increases the probability that it will sell its products [105].

Flexibility is the ability of the operational area to adapt to different situations by adopting new processes or, if necessary, by changing them [105]. Flexibility is the capacity of an organisation to respond to external and internal variations, and it addresses them from a more strategic point of view [12]. The internal variables can be the lack of certain raw materials, machinery or facility malfunctions, failures in the production planning processes, a failure tp supply the production line, etc. The external variables are the demands that the market imposes, such as technological advances, different delivery schedules, and types of negotiation [98].

Flexibility includes volume, product mix, and delivery, and is directly connected to a company's competitive positioning [107]. Among the most important are the flexibility of volume and product mix. Volume flexibility is the capacity of productive systems to adapt to changes in demand without major damage or affecting the production's results [14, 107, 108]. The flexibility of mix, on the other hand, deals with the variety and quantity of products that can be manufactured by the production system without having a negative impact on its performance [17, 109, 110]. In a competitive and dynamic setting, the companies that do not appear to be flexible risk losing out to competitors that use this criterion [103]. However, flexibility is not a normal spect to be dealt with generically. It can be initially divided into two general dimensions: the flexibility ofrange, or how significantly an operation can be changed; and the flexibility of response, which is the speed with which this change needs to take place. Besides these two definitions, flexibility can be divided into four other types: flexibility of new products, product mix flexibility, volume flexibility, and delivery flexibility [105].

A company's ability to innovate is one of the most impactful competitive criteria, for innovation is present and extends to the remaining criteria, such as quality, flexibility, cost, and speed. Innovativeness is a changing process, like any other activity that can be developed in an organisation and be managed by focusing on its future competitive advantages [105]. Innovation is the main source of industrial structural change, besides representing an opportunity for the company to expand the market and/or enhance product differentiation [11]. Two different kinds of orientation for the term 'innovation' can be distinguished. One of them is related to the development of new products, while the other is related to innovation in manufacture [12].

In competitive environments, innovation is a critical issue for companies that are committed to the development of new products [111]. The term 'innovation' was largely misunderstood in the managerial literature [112]. The use of this construct in academic research results in several definitions competing to clarify the central question of innovation: their objective was to deliver high-value new products with new technologies to the market [113]. In this sense, four different kinds of orientation for the term 'innovation' can be distinguished in the literature [21]. First, the individual-oriented perspective maintains that individual factors, such as age, gender, and educational level, have an impact on innovation. Second, the structural-oriented perspective focuses on an organisation's ability to perform innovatively. The third perspective, interactive-oriented, investigates how human actions affect structure (or vice versa) in the innovation process. The last perspective, innovation-oriented systems, studies how national or local arrangements influence the innovative activity in organisations [113].

The innovation that is related to the swift development of new products is a way to gain advantage over competitors [12]. The response time for the introduction of these new products into the market is directly linked to the level of interaction and integration among the sectors that take part in the development of new products, with transparency in the conception of projects, besides strong development [97, 98]. The innovation related to the development of new products can come from inside or outside the industry. For example, the company that innovated by launching colour TV sets was the market leader in black-and-white TVs at the time; and the release of electronic calculators was carried out by the manufacturers of slide rules [11].

One of the benefits that innovation and speedy development provide a company is the release of products aheadof their competitors, and the ability to achieve higher profit margins, since it will be alone in the market for some time [12, 104]. The concept of innovation in the operational area is related to the cycle of continuous improvement, since production is always trying to improve its processes, based on the implementation of improvements through statistics and process refinement [12, 98, 103]. This type of innovation can change the structure of a business through innovation in manufacturing methods or processes, influencing variables such as working capital, economies of scale, fixed costs, building up experience, and vertical integration [11]. Innovation in the operational area is the improvement encouraged by benchmarks — that is, the company can improve its processes by comparing results with performance before and after such improvement, or by comparing itself with its competitors that perform better in the aspect that has been improved [12, 97, 104].

The performance of the cost dimension is directly affected by the performance of the other competitive dimensions. Low cost levels represent better margins for negotiating prices with clients. Thus companies that do not treat cost as their main competitive differential are not always able to maintain low cost levels, since cost reduction, in these cases, represents higher profit margins [101, 102, 105, 114–116]. Table 1 summarises the competitive criteria addressed in this role.

Table 1: Competitive criteria

Constructs	Authors
Costs	[14, 45, 47, 52, 70, 105, 114, 117, 118]
Innovativeness	[40, 43, 44, 62, 68, 96]
Delivery performance	[18–20, 45, 62, 94, 119, 120]
Quality	[39, 41, 42, 56][39, 45, 62, 65, 68, 85, 92]
Flexibility	[39, 45, 62, 65, 68, 85, 92] [45, 47, 52, 70, 105, 114, 117, 118] [40, 43, 44, 62, 68, 96]

3 METHODOLOGY AND RESULTS

The focus of this research was limited to the population from companies that manufacture mechanical capital goods in Brazil. The machinery and equipment industry includes companies that are linked to mechanical production, mechanical devices, industrial appliances, machinery and farming supplies, mining machinery, and road machinery [121]. Brazil has around 7.500 machinery and equipment companies. Of these, 1,500 are linked to the Brazilian Association of Machines and Equipment (ABIMAQ). Together they made US$ 16,78 billion in 2017 [122].

From an analysis of the bibliographic references, the constructs to be researched were established and explored on the basis of the theories of modularisation and competitive criteria. Through these constructs, the research hypotheses below were created (Table 1).

After establishing the hypotheses, a formative model for measurement was proposed with the objective of identifying the competitive criteria associated with modularisation, and how they positively impact innovation strategies in the Brazilian machinery and equipment industry (Figure 1). The constructs were analysed as independent variables (endogenous constructs), and a final indicator (□10) was defined as a dependent variable (exogenous construct), aimed at summarising the set of established constructs.

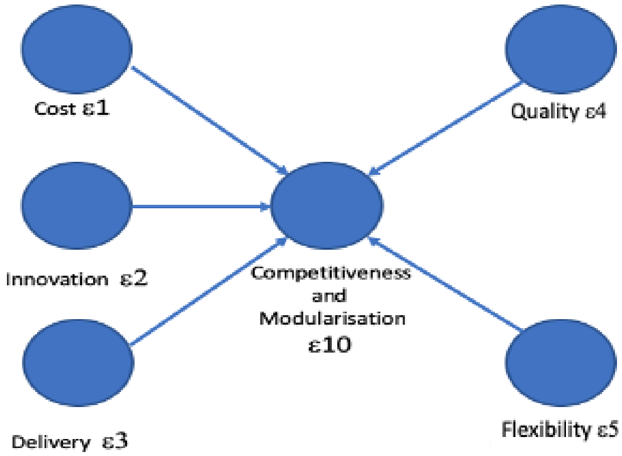

Figure 1: Measurement model

Then the survey-type research questions (indicators) were formulated and sent to the sample of respondents. Table 1 briefly presents the theoretical basis related to the main constructs associated with the indicators in each construct, and the authors related to each. In order to promote further steps, each construct and its indicators were abbreviated.

The companies selected for this research ranked among the thousand largest companies in Brazil in 2017 [123]. Among them, the ones that were selected are part of ABIMAQ [122]. Thus 94 companies manufacturing machinery and equipment were selected. These companies had their industrial, engineering, and innovation directors checked on LinkedIn. Besides these positions, managers, coordinators, and R&D supervisors in these companies were also researched. (LinkedIn is a social network that was founded in 2002, and that is useful for academic research since it responds efficiently to specific searches for the intended community [124, 125]. After the LinkedIn analysis, 627 possible respondents (managers and directors) were found in these companies.

In relation to the research method used, a survey was applied [47, 65, 126–128]. This method is considered a valuable tool in the investigation of industrial segments that operate with innovative strategies, products, and services [129]. After defining the survey, it was decided to apply it using an electronic tool through Google Forms [130], which is a fast, efficient, and low-cost method for creating online questions, and which enables dynamic analysis of results [131, 132]. The survey comprised 18 questions, grouped as three questions related to the five endogenous constructs (modularisation and delivery performance, modularisation and products and services quality, modularisation and flexibility, modularisation and costs, and modularisation and innovativeness), and three questions related to the exogenous construct (modularisation as a competitive differential) [11, 12, 47, 98, 104, 105]. These questions (indicators) were measured on a Likert scale from 1 to 5, in which 1 meant "fully disagree" and 5 meant "fully agree" [47, 130, 133]. The survey was pre-tested with 15 respondents whose characteristics were similar to those of the sample to be explored in the research.

From the pre-test answers, Cronbach's alpha was performed to evaluate the research instrument's reliability. The Cronbach's alpha coefficient, also called the reliability coefficient, performs the internal consistency measurement used to measure the reliability of a Likert scale [129, 134]. Results from 0.1 to 0.6 are considered unsatisfactory, while higher values show a good internal consistency [47, 129]. The data obtained in the pre-test were entered into the IBM-SPSS software. Then the questionnaire's Cronbach's alpha was calculated, yielding a result of 0.785. In relation to each construct, the results were: MDEL 0.785, MQUAL 0.66, MFLEX 0.82, MCOST 0.875 and MINN 0.627, which means that they were considered satisfactory [129, 135].

Table 2: Constructs and hypotheses

Constructs	Hypotheses	Indicators	Authors	Questions
Modularisation and costs (MCOST)	The use of modularisation for cost reduction positively impacts the differentiation strategy of the companies researched (H1)	Modularisation reduces the organisations' operational costs (MCOST1). Modularisation aims at decreasing the factory manufacturing operations and, consequently, reducing the operational cost (MCOST2). Modularisation reduces the inventory costs, and thus the costs decrease (MCOST3).	[45, 47, 52, 70, 105, 114, 117, 118]	Does modularisation reduce the operating costs of the organisation? Does modularisation reduce manufacturing operations and operational costs for the organisation I belong to? Does modularisation reduce inventory costs?
Modularisation and innovativeness (MINN)	The use of modularisation to boost innovation in products and processes positively impacts the differentiation strategy of the companies researched (H2)	Modularisation enables the products' speedy innovation (MINN1). Modularisation allows the innovation to keep pace with client demand (MINN2). Modularisation is a strategically viable option for product innovation (MINN3).	[40, 43, 44, 62, 68, 96]	Does modularisation make product innovation happen faster? Does modularisation make the customer aware of and request greater commitment to innovation? Is modularisation a viable strategic option for product innovation?
Modularisation and delivery performance (MDEL)	The use of modularisation to boost product delivery positively impacts the differentiation strategy of the companies researched (H3)	Modularisation reduces production lead time (MDEL1). Modularisation reduces products' and services' development lead time (MDEL2). Modularisation contributes to products' delivery performance and client support (MDEL3).	[18–20, 45, 62, 94, 119, 120]	Does modularisation reduce the production lead time for products with this architecture? Does modularisation reduce the lead time for product and service development? Does modularisation improve product delivery performance and customer support?
Modularisation and products and processes quality (MQUAL)	The use of modularisation to boost the quality of products and processes positively impacts the differentiation strategy of the companies researched(H4)	Modularisation improves products and services reliability (MQUAL1). Modularisation improves products and services performance (MQUAL2). Modularisation contributes to the quality of products and services offered to clients (MQUAL3).	[39, 41, 42, 56] [39, 45, 62, 65, 68, 85, 92]	Does modularization improve the reliability of products and services? Does modularisation improve products with this architecture and the performance of the services offered? Does modularisation contribute to the quality of products and services offered to customers?
Modularisation and flexibility (MFLEX)	The use of modularisation to increase the flexibility of products and processes positively impacts the differentiation processes of the companies researched (H5)	Modularisation in product projects increases flexibility in relation to product mix (MFLEX1). Modularisation increases processes' flexibility (MFLEX2). Modularisation increases flexibility in relation the level of service of the volumes produced (MFLEX3).	[39, 45, 62, 65, 68, 85, 92] [45, 47, 52, 70, 105, 114, 117, 118] [40, 43, 44, 62, 68, 96]	Does modularisation in design improve flexibility regarding the mix of products offered? Does modularisation improve flexibility in manufacturing processes? Does modularisation improve flexibility in terms of the service level of the volumes produced?

From the pre-test results, the research instrument was sent to the respective respondents, who were chosen randomly; thus the sample was non-probabilistic for convenience. The respondents were previously contacted by e-mail and invited to take part in the research. Those who accepted had the questionnaire sent to them between 01 December 2018 and 05 January 2019, when the research ended. The survey had a global return rate of 37.63 per cent (236 respondents). This return rate is in accordance with what is accepted in the literature for survey-type research — that is, between 25 per cent and 46 per cent [126, 136].

After receiving the completed questionnaires, the collected data were entered into the IBM-SPSS software, and the Cronbach's coefficients for each construct were calculated, as seen in Table 3, which shows that they were satisfactory.

Table 3: Cronbach's coefficients for each construct in the research

Constructs	Cronbach's alpha
Modularisation and costs (MCOST)	0.86
Modularisation and innovativeness (MINN)	0.846
Modularisation and delivery (MDEL)	0.802
Modularisation and quality (MQUAL)	0.839
Modularisation and flexibility (MFLEX)	0.849

The sampling adequacy was also quantified through the Kaiser-Meyer-Olkin (KMO) measurement [137]. The KMO test generates a value between one and zero. A value above 0.60 suggests that a variable analysis factor is suitable [138]. The Bartlett's sphericity test checks if the variables are not correlated [139]. From the SPSS, this test's result was KMO = 0.834. Besides this test, the Bartlett's sphericity test was performed [134]. This test must have a meaningful result that is below 0.05 [129, 134]; in this case the significance result of this research was zero. The exploratory factor analysis (EFA) was performed to group the variables that showed similar behaviours. Table 4 presents the results.

Table 4: EFA factor results

Old anycrom	1	2	3	4	5	New anycrom after EFA
MCOST1	0.243	0.266	**0.804**	0.07	-0.119	COST1
MCOST2	0.365	0.061	**0.782**	0.088	0.228	COST2
MCOST3	0.148	0.232	**0.834**	0.113	0.196	COST3
MINN1	**0.688**	0.05	0.285	0.314	-0.227	INN1
MINN2	**0.798**	0.372	0.093	0.156	0.183	INN2
MINN3	**0.754**	0.22	0.248	0.004	0.424	INN3
MDEL1	**0.725**	0.1	0.327	0.098	0.186	INN4
MDEL2	0.211	0.039	0.184	0.516	**0.701**	DEL1
MDEL3	0.188	0.413	0.104	0.27	**0.683**	DEL2
MQUAL1	0.2	0.18	0.031	**0.82**	0.23	QUAL1
MQUAL2	0.151	0.303	0.295	**0.688**	0.235	QUAL2
MQUAL3	0.047	0.251	0.024	**0.835**	0.055	QUAL3
MFLEX1	0.216	**0.773**	0.042	0.293	0.078	FLEX1
MFLEX2	0.2	**0.783**	0.267	0.236	0.084	FLEX2
MFLEX3	0.107	**0.796**	0.31	0.167	0.196	FLEX3

Then SmartPLS 3.0 software was used [140] to check and measure the model. The partial least squares (PLS) method distinguishes the best causal relationships between the constructs; it is applied to small samples, and makes no presuppositions about data distribution [133, 141, 142]. Afterwards, the data were modelled through structural equation systems, which are regarded as a statistic approach to test hypotheses for linear relationships between the variables [143], and may deal with the complex relationships between the latent variables that are simultaneously observed [144, 145]. Figure 2 shows the structural model and the results generated by the PLS algorithm, after seven iterations.

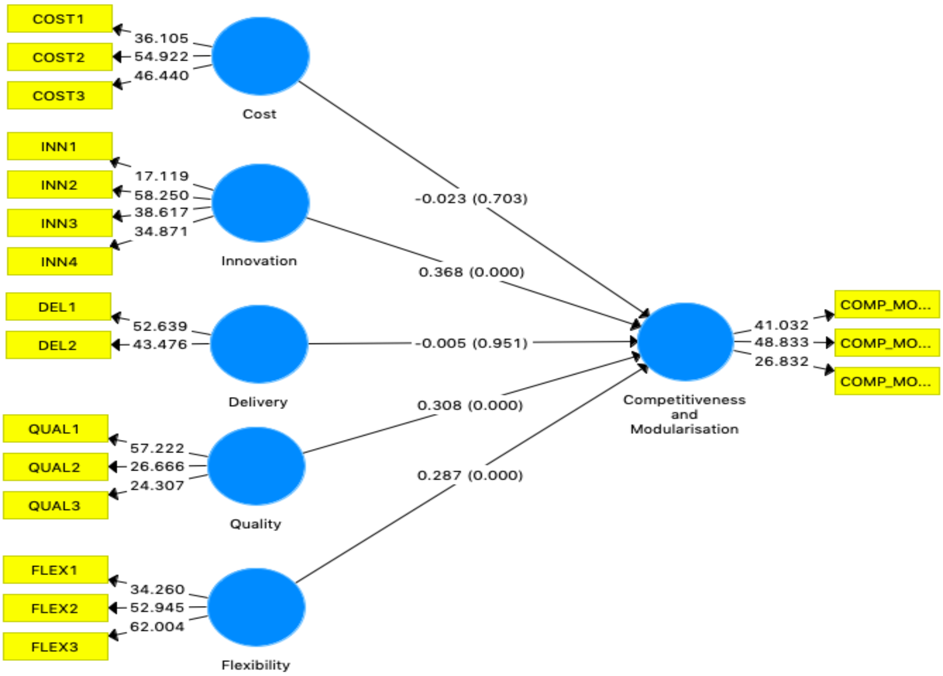

Figure 2: Structural model

After the PLS modelling, it is necessary to certify the measurements that show the model's predictive ability to analyse its quality. The PLS-SEM structural model's evaluation is based on a set of evaluation criteria that must be met: the measurement model's validation involves composite reliability analyses, convergent validity, indicator reliability, and discriminant validity [146].

The answers and the sample are validated in their set through composite reliability, which is an indicator that is associated with a measurement quality and evaluates the structural model's quality [129, 147]. Values above 0.7 are considered acceptable [148], while values between 0.70 and 0.90 are considered satisfactory [149]. From the data analysed by the SmartPLS 3.0 software, the values found for the constructs show that the composite reliability values are: cost 0.914, innovation 0.898, delivery 0.909, quality 0.903, and flexibility 0.909.

The AVE (average variance extracted) is the variables' data that are explained by each respective latent construct — that is, the variables positively correlate with their respective constructs, and are themselves the convergent validity. AVE values higher than 0.50 mean that the model converges to a satisfactory result, which is enough to explain the average number of variables that positively correlate with their respective constructs [149–151]. The respective AVEs presented the following results for the constructs: cost 0.781, innovation 0.688, delivery 0.834, quality 0.757, and flexibility 0.769.

Discriminant validity is the analysis in which the constructs empirically differ from other similar constructs. In this way, the discriminant validity is noticed when one of the constructs or latent variables does not depend on the others by comparing the AVE value square roots [146]. When the AVE square root comparison is higher than the correlation coefficient between the latent variables, one concludes the existence of discriminant validity. The results found in the constructs are: cost innovation, delivery, quality and flexibility. According to Figure 2, the correlation coefficient values certify that there is discriminant validity among the respective constructs [146]. In addition, the heterotrait-monotrait ratio (HTMT) was below 0.9, confirming that the discriminant validity was in line with the assumptions of [152].

Moreover, the constructs that present high loads show that the associated indicators share the occurrence extracted by the latent constructs, which deal with the indicator reliability. For external loads above 0.7, it can be concluded that the loads and the external model's significance are found above the level recommended in the literature [146]. In exploratory studies, the values must be higher than 0.40 [153]. In order to obtain the indicators' reliability, it is necessary to square the loads according to Table 5. The indicators' values presented values higher than 0.4, which confirms their reliability [154].

Table 5: Indicator of reliability

Construct	New acronym	Charge	Reliability
COST	COST1	0.863	0.744
	COST2	0.897	0.804
	COST3	0.891	0.793
INN	INN1	0.710	0.504
	INN2	0.889	0.790
	INN3	0.887	0.786
	INN4	0.822	0.675
DEL	DEL1	0.926	0.857
	DEL2	0.900	0.810
QUAL	QUAL1	0.898	0.806
	QUAL2	0.869	0.755
	QUAL3	0.842	0.708
FLEX	FLEX1	0.837	0.700
	FLEX2	0.894	0.799
	FLEX3	0.899	0.808

In this way, after being modelled in the SmartPLS 3.0 software, this research presented an R^2 determination coefficient for the DEP01 dependent variable. This variable tried to identify whether the organisations in which the interviewees work apply the modularisation strategy as a competitive differential. R^2 means that the independent variables moderately explain 0.596 of the variance in □10 — that is, the proposed model directly impacts this variable by 59.6 per cent. The coefficient correlation values between the constructs must be higher than 0.1 in order to be considered meaningful [146, 155].

The H2 (0.368), H4 (0.308) and H5 (0.287) hypotheses' path relationship, which analyses modularisation as a strategy to improve quality performance, increase flexibility, and expand innovation, is statistically meaningful, since the path coefficient is higher than 0.1 [155]. As for hypotheses H1 and H3, which respectively analysed modularisation as a possible delivery leverage and as a cost reduction factor, they are not meaningful, as their path coefficients (-0.023 and -0.005 respectively) are negative.

From these data, it is found that hypotheses H2, H4, and H5 positively impact the differentiation strategy in the companies researched in the sample presented in this research.

4 CONCLUSIONS

This research aimed to identify the competitive criteria linked to modularisation, and the extent to which they positively impact the differentiation strategy in companies in the machinery and equipment industry in Brazil. From the data analysis, it is possible to state that, in response to H2 (Hypothesis 2), it is seen that, for the respondents, the innovation leverage in products and processes presented the highest positive impact in the differentiation strategy. This variable obtained a load of 0.368. These results support the findings in the literature, which state that innovation is hastened by the application of the modularisation strategy [39, 62, 65, 68, 92].

H4 (Hypothesis 4) examines the use of modularisation to leverage product and process quality and thus become a competitive differential. For the sample researched, this has a positive impact, as this variable presented a load of 0.308. Some authors state that quality is improved by the use of modularisation in products and services [39, 41, 42].

As for H5 (Hypothesis 5), which analysed the use of modularisation to increase product and process flexibility, it also presented a positive impact, with a loading factor of 0.287. These results confirm previous studies that stated that flexibility increases the potential, from the introduction of a modularisation strategy, of product development, product production, and manufacturing processes [26, 28, 39, 62, 65, 86, 94]. Hypotheses H2, H4, and H5 are considered significant, since they have a load for each of the constructs that is higher than 0.1 [146, 155].

On the other hand, hypotheses H1 and H3, which analysed the use of modularisation for cost reduction and the use of modularisation to leverage product delivery, did not produce results that impacted competitiveness (-0.023 and -0.005, respectively). For the respondents, these values mean that these constructs do not have any correlation with differentiation. These results are not in accordance with what has been presented by previous research on the topic, because modularisation reduces costs [33, 37, 39, 40], since a product's modular architecture allows the production of a larger mix of products with the current resources [40]. This cost reduction happens both in the products' project development and in the productive process [65], just as modularisation reduces the projects' cycle times [26, 33, 38, 65, 67], and decreases the manufacturing lead times [45, 52, 87–89] and costs [31, 39, 45, 52, 94].

It should be emphasised that these results come from a non-probabilistic sample by convenience, and cannot be taken as definite, like the model proposed for analysis. In addition, the results should be interpreted with caution. Cronbach's alpha in some constructs was below 0.7. Although Freitas and Rodrigues [135] accept 0.6 as a valid index, this is an important limitation. Some reasons for this result from Cronbach's alpha must be several items in the questionnaire [156], the time of application [157], or a similar sample of respondents [156]. These points must be addressed in future work.

As suggestions for new research, it is important to expand the knowledge about hypotheses H1 and H3 with the objective of going deeper into the reasons, possibly through the completion of case studies, that modularisation does not impact the costs nor the delivery performance in Brazilian companies in the machinery and equipment industry. Another suggestion is that comparisons of this nature should be made between emerging countries and developed countries, as well as completing studies in companies from other industries that make a significant contribution to Brazil's GDP, with the objective of establishing comparisons from areas that tend to explain the technical-economic and cultural distinctions.

In conclusion, it seems pertinent to deepen the analysis of the results obtained from this research from the perspective of mass customisation, considering that the main aspects referred to in this topic — cost reduction and delivery deadlines – were not identified as important by the managers who took part in this research. It is also suggested that confirmatory studies and the use of CB-SEM be carried out in such studies.

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