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Definition of input and output variables to assess operations strategy efficiency frontier

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Abstract

Purpose – To investigate the relationship between performance frontier and operations strategy. A two-level conceptual framework is proposed based on performance elements that act as output/input variables and delimit the scope of the frontier analysis.

Design/methodology/approach – The framework proposition is based on the fourth round of high-performance manufacturing survey data. A representative set of variables for assessing performance based on operations strategy constructs is defined through multivariate data analysis techniques. The main method used is the principal component analysis.

Findings – The proposed first-level conceptual framework formalizes the relationships between performance frontier analysis techniques and operations strategy, delimiting the scope and the structural definitions. The second-level conceptual framework defines the constructs of the input and output dimensions for frontier analysis studies.

Originality/value – The paper contribution is developed in the gap of market-led orientation to study operations strategy performance frontier since most related literature focuses on capabilities development with a main focus on the resource-based view (RBV) approach. A conceptual framework based on the competitive priorities is therefore proposed to represent the operations strategy in the view of the frontier techniques. The value lies in defining performance measures which are not a straightforward task as the growth of organization competitiveness and complexity require multiple performance measures. A deeper understanding of frontier estimation on the operations strategy context is also provided, contributing to positively influence firms to succeed in the current dynamic competitive environments.

Keywords Multivariate data analysis, Operations strategy, Performance frontier analysis, Performance measures, Competitive priorities

Paper type Research paper

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1. Introduction

Increasingly, organizations must be able to compete in the context of global standards. As commented by Cagliano *et al.* (2005) and Thun (2008), many authors argue that the operations have an important influence on the development of the competitive advantages as the level of competitiveness increases. In this scenario, Abassi and Kaviani (2016) reinforce that operational efficiency is necessary for successful businesses; the superiority organizational performance is not reached unless it achieves excellent levels of operational performance which is provided by effective operations strategy.

Slack *et al.* (2018) observe that operations strategy could be understood in terms of competitiveness development based on the production function, which contributes to the achievement of long-term competitive objectives. Operations strategy addresses what needs to be done to overcome current and future challenges posed by the competitive environment and encompasses the long-term development of operations resources and processes to sustain competitive advantage (Slack and Lewis, 2018). In fact, as indicated by Brown and Blackmon (2005), there are two competing paradigms that managers must deal with, resource-driven versus market-led approaches to strategy. There is a need to reconcile market requirements and operational resources to align manufacturing strategy and business-level competitive strategy.

However, as observed by Slack (2005), the full potential of operations is not properly exploited, which in turn does not contribute to the achievement of a better competitive position. To Anand and Gray (2017) the identification of elements that lead the organization to reach a position of relative maximum performance is still present in operations strategy research, and may represent a differential in the search for a prominent position in the market. This can be accomplished by the concept of performance frontier analysis, originally defined by Farrel (1957). The frontier methods rank the performance through an efficiency score, which is calculated as the distance from the organization to the best practice frontier, through the observation of inputs and outputs of each organization (Chen *et al.*, 2015).

While there is a literature stream that integrates performance frontier methodologies with operations strategy, the connection between operations strategy and firm performance frontier is not exhaustively explored. Most of the works on operations strategy performance frontier are based on the capabilities concept from resource-based view (RBV) theory, as can be seen in the works of Miller and Ross (2003), Maslen (1997), Prahalad and Hamel (1990), Barney (1991) and Wernerfelt (1984) (e.g. Arbelo *et al.*, 2020; Yin *et al.*, 2020; Achillas *et al.*, 2015; Dutta *et al.*, 2005; Ahmed *et al.*, 2014; Akdeniz *et al.*, 2010). The integration of the operations function with business results in performance frontier studies, through the use of competitive priorities, is scarce, even though it has been argued by many authors that competitive priorities connect the operations strategy with the business strategy (e.g. Brown and Blackmon, 2005; Hill and Hill, 2018; Slack and Lewis, 2018). To Brown and Blackmon (2005), it is necessary to intertwine the resource-based and market-led orientation so that it is important to have literature covering both sides. And, to the authors, competitive priorities can be used to understand market requirements and to translate them into manufacturing capabilities; in this sense, exploring the competitive priorities would give a market-led orientation to operations strategy, complementing the existent literature on operations strategy performance frontier.

It is unquestionable that the capabilities approach can help in leading through operations effectiveness. However, it encompasses one research stream of operations strategy, the RBV. The present paper develops its contribution to the gap of the competitive priorities to study the operations strategy through the leans of performance frontier analysis methodologies. The appropriate choice of competitive priorities reflects on the future direction of a firm and has fundamental importance to the achievement of its competitive advantage which may lead to business performance improvement (Okoshi *et al.*, 2019; Phusavat and Kanchana, 2008).

The research paper proposition's importance is enhanced when it is observed that most published works do not provide guidance for the specification of the input and output variables. According to Smith (1997), a weakness of the data envelopment analysis (DEA), a performance frontier method, is that there is no support to choose the input and output variables and to help the researcher to determine whether or not the chosen model is appropriate. Wagner and Shimshak (2007) state that, in spite of the DEA results deeply depending on the set of input and output variables that are used in the analysis, little attention has been paid to how these input and output variables should be chosen in a real-world context. Some literature has contributed to this end (e.g. Eskelinen, 2017; Nataraja and Johnson, 2011; Ruggiero, 2005; Jenkins and Anderson, 2003; Pastor *et al.*, 2002; Alder and Golany, 2001), and this study aims to contribute to the selection of input and output variables, in the context of operations strategy performance frontier analysis, through the concept of competitive priorities.

This paper develops a conceptual framework to identify representative inputs and output constructs to facilitate performance frontier identification in the context of operations strategy. This intention is accomplished through a statistical analysis of the fourth round of high-performance manufacturing (HPM) survey data with companies in 14 countries. This proposal has significant importance due to most of the frontier methods approached by authors requiring input and output variables. However, defining a representative set of performance measures is not a straightforward task, as the growth of the competitiveness and complexity of the organization requires multiple performance measures. Chen *et al.* (2015) state that identifying companies that have a competitive advantage is an easy exercise if performance can be captured by a single performance indicator, but, in the context of multiple metrics, this is no longer a trivial matter. This approach is reinforced by Slack and Lewis (2018), who argue that performance is not a simple concept since the current complexity of the environment requires multi-faceted metrics, as a single measure could never fully communicate such a complexity.

First, both performance frontier analysis and operations strategy concepts are introduced. Grounded on the literature, a first-level conceptual framework is then presented, covering the relationships between performance frontier analysis techniques and operations strategy, delimiting the scope and the study dimensions. Next, the research methodology is depicted. Such a methodology leads to the second-level conceptual framework proposition, which delimits the constructs for each dimension by means of multivariate data analysis. A discussion is made to analyze the strengths and weaknesses of the conceptual framework constructs.

2. Firm performance frontier

Organizations need to respond to competitors with their own increased performance. This occurs because modern companies typically operate in dynamic and competitive environments, generating the need to position themselves in advance of their competitors, that is, increasing levels of efficiency and effectiveness in the market in which they operate (Abbasi and Kaviani, 2016; Singh *et al.*, 2016). In this way, companies that know the maximum production performance frontier could be in a better competitive position, as they have reasoned decision making based on strategic information about the competition.

According to the original concept proposed by Farrel (1957), the efficiency frontier is a function that indicates the maximum level of the attainable result by a given set of inputs. The frontier is estimated based on the observation population of the company's inputs and outputs or a representative sample. The entities for which the efficiency is calculated are called decision-making units (DMU) (e.g. a firm). DMUs are any group of entities that receive the same inputs and produce the same outputs (Golany and Roll, 1989). In this research, the DMU is settled as a firm with at least 100 employees belonging the automotive chain.

The data envelopment analysis (DEA) is one of the methods for calculating firm performance frontier. The DEA was proposed by Charnes *et al.* (1978), who published the original DEA constant return to scale (CRS) model, later extended by Banker *et al.* (1984) to variable return to scale (VRS). In DEA, the performance frontier is obtained through a mathematical optimization model based on linear programming that provides comparative results to assess the performance of organizations based on multiple metrics, to measure the efficiency of a DMU.

Although DEA has a strong link to production theory in economics, the technique is also used for benchmarking in operations management, where a set of measures is selected to benchmark the performance of manufacturing and service operations (Park *et al.*, 2014; Cook *et al.*, 2014). DEA is a tool for multiple-criteria evaluation problems, where each DMU is represented by its performance in multiple criteria defined by the input and output variables (Cook *et al.*, 2014). The efficiency is established from a ratio between outputs and inputs, and the DMU with the highest index is considered relatively efficient (Chen *et al.*, 2015). Results smaller than one represent inefficient firms (Bulak *et al.*, 2016).When a point is technically inefficient, at least one of its input or output factors can be improved to reach the efficiency frontier (Khezrimotlagh and Chen, 2018; Bulak *et al.*, 2016). DEA envelops the data set with the frontier of the most efficient DMU (Chen *et al.*, 2015), and the efficiency index of the DMUs outside the frontier is established according to their gap to the efficient frontier (Liu *et al.*, 2016).

According to Bulak *et al.* (2016), DEA models are nonparametric techniques further divided into two groups, input-oriented and output-oriented. An input-oriented DEA model identifies technical inefficiency as a proportional reduction in input usage, with output levels held fixed. The output-oriented DEA model measures the technical inefficiency as a proportional increase in output production, with input levels being constant (Coelli *et al.*, 2005).

DEA results depend very much on the set of input and output variables that are used in the analysis. In spite of that, little attention has been paid to how these input and output variables should be chosen in a real-world context, which is even more important in a context of multiple variables (Wagner and Shimshak, 2007).

2.1 Selection of DEA variables

DEA is a mathematical programming technique to measure relative efficiencies of DMUs, when multiple inputs and multiple outputs are present. While the concept of inputs and outputs is of clearly understood, little attention has been devoted to ensuring that the chosen measures appropriately reflect the process under analysis (Cook *et al.*, 2014). According to Smith (1997), the main weakness of DEA is that the choice of input and output variables depends on the judgment of the researcher, as there is no support to help the user determine whether or not the chosen model is appropriate. However, to Wagner and Shimshak (2007) the choice of input and output variables is one of the most important steps in the use of DEA. So, prior to developing a DEA study, the input and output variables have to be defined.

The literature proposes some guidelines to limit the number of variables relative to the number of DMUs, as the greater the number of variables, the more difficult it is to discerning DEA results (Golany and Roll, 1989; Jenkins and Anderson, 2003; Alder and Golany, 2001; Alder and Yazhemsky, 2010). An excessive number of input/output variables in a DEA model results in a large number of efficient DMU, not allowing to differentiate between the superior performing companies (Alder and Golany, 2001; Alder and Yazhemsky, 2010). The greater the number of input and output variables in a DEA, the higher is the dimensionality of the linear programming solution space, and the less discerning is the analysis (Jenkins and Anderson, 2003).

The golden rule of Banker *et al.* (1989) states that the number of DMUs should be at least three times the sum of the number of involved variables (inputs and outputs) or at least equal to the product of the number of input variables and the number of output variables. The challenge in DEA is to find a "parsimonious" model, using no more input and output variables that necessary. The accurate specification of the DEA model is important to not disturb the efficiency estimation (Nataraja and Johnson, 2011; Ruggiero, 2005; Smith, 1997).

One of the first propositions to the selection of the input and output variables was that of Golany and Roll (1989), who included three stages in selecting the most relevant variables for the DEA model. The judgmental process, based on Delphi techniques or the analytic hierarchy process, is to get the contribution of experts to make the decision, prioritize or find a measurable surrogate and the factors that have little impact on the efficiency score may be dropped. Other authors have since proposed new methodologies to define the input and output variables. One of the approaches supports that variables which are highly correlated are redundant and should be omitted from further analysis (Velicler and Jackson, 1990; Nunnally and Bernstein, 1994). Jenkins and Anderson (2003) propose a technique that introduces a systematic statistical procedure to help make decisions for variable selection since the authors describe that omitting variables, even if they are highly correlated, and thereby with little additional information on performance, can have a major influence on the computed efficiency measures, so caution is needed in excluding variables.

In contrast to these methods, which look at the input and output variables before the application of DEA, the approach of Pastor *et al.* (2002) looks at the effect on efficiency scores as input and output DEA variables are changed. Pastor *et al.* (2002) proposed the efficiency contribution measure (ECM) that consists of a statistical test to help in deciding about the incorporation or the exclusion of a variable in a given DEA model. They evaluated a reduced DEA model, which did not include one particular variable, and an extended model, which did include that one variable. Efficiencies were calculated for each DMU under both the reduced and extended forms of the model. A statistical test was presented to determine the significance of the efficiency contribution of the particular variable being evaluated.

Eskelinen (2017) compares the techniques of Jenkins and Anderson (2003) and Pastor *et al.* (2002) in an empirical retail bank context. The author concludes that, although the techniques presented some significant differences in the efficiency evaluations, they led to different managerial interpretations of the performance complementing each other. In this way, the techniques can be utilized to evaluate the units from multiple perspectives. Wagner and Shimshak (2007) advances the work on variable reduction methods in DEA, through the development of a stepwise procedure for selection variables to reduce the changes in the efficiency scores as variables are added or dropped from the analysis.

Nataraja and Johnson (2011) indicate four most used approaches to guide variables specification in DEA, besides the ECM, above mentioned, they mentioned the principal component analysis (PCA), a regression-based test and bootstrapping for variable selection. The authors suggest the use of PCA for a small data set (less than 300 observations) with a high correlated degree (greater than 0.8). For larger data sets or data with low correlation levels (smaller than 0.2), both ECM and regression-based tests are indicated.

The statistical procedure based on a regression-based test to the selection of inputs variables utilizing simulation analysis is proposed by Ruggiero (2005). In Ruggiero's (2005) proposal, an initial measure of efficiency is obtained from a set of known production variables. Efficiency is then regressed against a set of candidate variables; if the coefficients in the regression are statistically significant, the variables are relevant to the production process and should be retained. Bootstrapping aims to allow for heterogeneity in the structure of efficiency, by the estimation of the bias and variance and construction of confidence intervals. The method can be used to assess uncertainty about distance to the true production frontier from a small number of points in the production set (Simar and Wilson, 1998, 2000).

To Eskelinen (2017) as variables in the efficiency evaluation are often highly correlated, this leads to the process of omitting some of the highly correlated variables without a significant loss of information. Ueda and Hoshiai (1997) proposed a way of weighting DEA model variables and summarizing them parsimoniously them instead of simply selecting them. Alder and Golany (2001) apply PCA to overcome the difficulties that DEA faces when there is a huge number of variables. In this paper, we develop a conceptual framework that defines the input and output variables, based on PCA, complementing the research previous mentioned, with a specific end of studying operations strategy performance frontier.

3. Operations strategy

In 1969, Skinner's seminal work disseminated the concept of manufacturing strategy by proposing a framework that emphasizes the need to consider the production function in the development of corporate strategy. Operations strategy is the total pattern of decisions that develop the long-term capabilities of any operation and their contribution to the overall strategy (Slack and Lewis, 2018).

The importance of the operations function is growing, not just because it is large and, but because it gives the ability to compete by providing the capacity to respond to customers and by developing the capabilities that will keep it ahead of its competitors in the future to sustain competitive advantage (Slack and Lewis, 2018). There are two competing paradigms to operations strategy: resource-led versus market-driven approaches to strategy; it is necessary to reconcile both of them through a framework entitled strategic resonance for aligning manufacturing strategy and business-level competitive strategy (Brown and Blackmon, 2005).

Market perspective is where an understanding of the market is developed, and the translation of its needs is used in the development of operations strategy (Slack and Lewis, 2018). In this view a market position that provides a competitive edge is sought, therefore firms gain competitive advantage, therefore, through identifying external opportunities in markets and then aligning the firm with these opportunities (Caves and Porter, 1977; Porter, 1979, 1980; Bain, 1956, 1968). Being market-driven concerns providing the competitive criteria in a market to the required levels, for example meeting the delivery lead times that customers expect or reducing costs to allow price in a market to be matched or bettered. An organization can upgrade on the current required levels of a given driver to increase competitive advantage (Hill and Hill, 2018). Companies with a market orientation are likely to develop and adapt products, services and processes that to continuously meet the market needs (Hult *et al.*, 2004).

Alternately, the resource perspective suggests that new strategic options emerge naturally because of the resources of the organization (Wernerfelt, 1984). So, the firm should develop appropriate resources that provide opportunities for sustainable competitive advantage in its chosen markets to maximize returns (Barney, 1991; Peteraf, 1993; Prahalad and Hamel, 1990; Dierickx and Cool, 1989). In this orientation, competitive advantage is built not by the privileged end-product market position but by distinctive, valuable firm-level resources that competitors are incapable of replicating (Makhija, 2003). The competitive advantage is therefore sustained through the development of capabilities and competencies (Hayes, 1985; Prahalad and Hamel, 1990).

Both approaches are fundamentally intertwined (Hill and Hill, 2018; Makhija, 2003), and clearly what is needed is to integrate market requirements and manufacturing capabilities with competitive strategy in a dynamic and unpredictable competitive environment to sustain competitive performance (Brown and Blackmon, 2005).

4. Efficiency frontier to operations strategy

There is a literature stream of study that has already approached the relationship between operations strategy and performance frontier analysis. Most of these works approach the operations strategy from the view point of its capabilities, characterizing a RBV perspective, as they focuses on identifying to which level the internal resources support competitive advantage. For example, Dutta *et al.*, (2005) measure firm-specific capabilities using an extant conceptualization in the RBV literature. Yin *et al.* (2020) study how the internal resources lead to competitive advantages and market profits, grounded in the RBV theory. Ahmed *et al.* (2014) discuss whether the importance given to the operations and marketing functions leads to capabilities development. Akdeniz *et al.* (2010) and Ho and Huan (2020) also work with marketing capabilities and aims to identify their impact on firm performance. Achillas *et al.* (2015) provide a decision-making framework for the selection of an effective portfolio of production strategies within the concept of the "focused factory", helping to decide between conventional production methods or additive manufacturing.

Brown and Blackmon (2005) emphasize the need for intertwining the resource-based and market-led orientation. Even so, the connection with a market-led orientation, in the view of competitive priorities, is still less explored in the literature on operations strategy performance frontier. It is known that markets provide the agenda for all the functional strategies and should also be considered in the development of the operations strategy (Hill and Hill, 2018) so that the market-led orientation has to be considered. Competitive priorities can be used to understand market requirements and to translate them into manufacturing capabilities, interlacing the resource-based and market-led orientation (Brown and Blackmon, 2005) and establishing the basis for operations strategy (Cai and Yang, 2014). To Hill and Hill (2018) competitive priorities can provide the direction of developing internal resources, as well as establishing a link between operations function and business-level strategy. To Brown and Blackmon (2005) firms that have clearly-defined competitive priorities will achieve closer strategic alignment than firms that do not. Manufacturing competitive dimensions embody the domains of manufacturing operations where excellence in performance is pursued: examples include quality, speed, flexibility, cost, innovation and so on (Talluri *et al.*, 2003).

This research, therefore, takes a market-led orientation to explore the definition of variables to study the operations strategy performance frontier, by means of competitive priorities, complementing the existing literature previously mentioned. The analysis of the competitive position formed by competitive priorities is also important, as there are commonly tradeoffs between performance objectives. In other words, improvement in one performance criterion can be achieved only by sacrificing the performance of another. However, there are two visions of tradeoffs. The first emphasizes "repositioning" performance goals by compensating for improvements in some goals for reducing the performance in others. The other emphasizes increasing the "effectiveness" of the operation by overcoming the trade-offs so that improvements in one or more aspects of performance can be achieved without any reduction in the performance of others. Most companies, at one time or another, will adopt both approaches. Efficiency frontier methodologies can help to understand the most suitable approach to each competitive priority (Slack *et al.*, 2018).

The concepts of operations strategy and performance efficiency frontier are closely related. The operations strategy is deployed from the competitive strategy and aims to achieve excellent performance in the key competitive priorities; this is achieved through acting in the so-called decision areas (Slack and Lewis, 2018; Hill and Hill, 2018). The concept of efficiency frontier is a function that indicates the maximum level of results attainable (outputs) for a corresponding quantity of inputs. The frontier is estimated based on the observation of inputs and outputs of a population of companies or a representative sample, as stated by Coelli *et al.* (2005). The input and output variables should be defined according to the coverage of analysis required. Competitive priorities can play a dual role in input and output, depending on the analysis required. To explore a strategic perspective of the operations strategy, that is, how the operations strategy contributes to business results, the operations strategy competitive priorities should be the input variables, and the business strategy results should be the output variables. To take a tactical view of the operations strategy, the competitive priorities should be settled as outputs and other operations strategy components as inputs (e.g. decision areas). Figure 1 shows the relationship between the concepts of operations strategy and the efficiency frontier, demonstrating the tactical and the strategic frontier analysis delimitation, setting the proposed first-level conceptual framework.

The strategic perspective is highlighted in grey, as it is the approach taken by this research. The proposal is to identify where market advantage could be gained by outperforming current standards on the relevant market drivers to enhance business results and then guiding the resource allocation to this end.

Although there are already works exploring a strategic perspective when studying operations strategy performance frontier (e.g. Abbasi and Kaviani, 2016; Bulak *et al.*, 2016; Ramanathan *et al.*, 2016; Talluri *et al.*, 2003), they are still in the minority. Most studies, explores a tactical perspective in the operations strategy (eg: Achillas *et al.*, 2015; Dutta *et al.*, 2005; Cai and Yang, 2014; Jayanthi *et al.*, 1999). That is, the input and output variables are both components of the operations strategy components (e.g. inputs as decision areas and outputs as competitive priorities or capabilities).

4.1 Research variables

With all the frontier analysis methods there exists a causal relationship between the inputs and outputs. The proposed first-level conceptual framework represents this relationship from the operations strategy perspective. As mentioned, if the analysis regards operations function results (tactical perspective), the inputs (cause) are defined by the decision areas and the outputs as the effect represented by the competitive priorities. Taken at an upper management level, regarding a business results analysis (strategic perspective), the competitive priorities or capabilities are the cause or input, and the business results the effect or output. This study aims to identify the influence of operations strategy's on business results so that the operations strategy constructs are defined as the inputs and the business results as the outputs. The business objectives are typically set in the form of financial and customer targets (Gong *et al.*, 2019; Liu *et al.*, 2018; Abbasi and Kaviani, 2016; Ramanathan

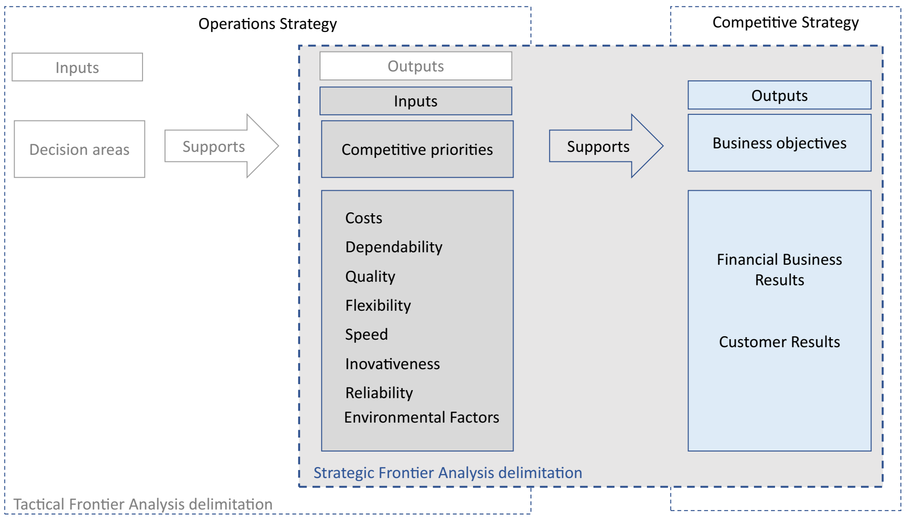

Figure 1.
Proposed first-level conceptual framework

et al., 2016; Kaplan and Norton, 2000), leading to the definition of the output variables. These results are achieved through action in operations, represented by functional strategies. In this way, inputs are defined by the operations strategy competitive priorities.

For competitive priorities, there are several approaches to define the most important competitive dimensions. The five most approached performance objectives are quality, cost, flexibility, dependability and speed. They have meaning for all types of operations and are related to satisfying customer requirements (Slack and Lewis, 2018). Speed and dependability are approached by some authors as delivery (Sansone *et al.*, 2017). The proposed framework suggests including speed and dependability as a separate competitive criterion, as we understand that, in a short time, there will be a tendency to increase the importance attributed to dependability, due to the advent of online businesses and it should be evaluated as complementary to speed. This research deals with the meaning provided by Slack and Lewis (2018), which considers dependability as the fulfillment of delivery promises and speed as the lead time to delivery.

Beyond the traditional competitive priorities, other criteria have been recently approached by the literature due to the current dynamic context. Innovativeness is a competitive priority with the rising importance since it is widely accepted that innovation contributes to the opening of new markets or expanding existing ones (Hult *et al.*, 2004; Pallas *et al.*, 2013), which is of primary importance in the environment of ascending competition. Innovation is also recognized as a new competitive priority to compete in global markets (Laosirihongthong *et al.*, 2014; Hult at al., 2004; Bouranta and Psomas, 2017; Miltenburg, 2008). To Wang *et al.* (2020), manufacturing has an important role on improving innovation so that this competitive priority has to be measured in the context of operations strategy. Reliability is approached as a criterion detached from quality by some authors. For example, Narkhede (2017) indicates that it is an important approach mainly for the USA, Europe, Japan and India, being explored by various authors in relation to manufacturing practices. Wang (2019) and Díaz-Garrido *et al.* (2011) included environmental as a recent concern, bring this priority together with the classical competitive priorities. To Gupta and Gupta (2020) environmental sustainability has a positive impact on firm performance. Vivares-Vergara *et al.* (2016) also bring environmental protection as a competitive priority in their study related to human resources management. Wang (2019) reinforces the impact of green culture on the performance advantage. Environmental performance is part of the sustainability definition which demonstrates it as being an important competitive dimension nowadays (Elkington, 1997; Gavronski, 2012). The definition of the competitive priorities is provided in Table 1.

The delimitation of the constructs on behalf the input and output variables are next explored.

5. Research design

Once the relationship between the concepts of operations strategy and frontier analysis is defined in the first-level framework, delimiting the scope and the study dimensions, the input and output constructs are defined through an in-depth multivariate data analysis based on the fourth round of the HPM Project, leading to the development of the second-level conceptual framework.

According to Slack and Lewis (2018) by grouping competitive factors into clusters, market requirements are translated into a form useful for the development of the operation. The pattern of decisions in these set of performance objectives shapes long-term capabilities and contributes to the overall strategy through the ongoing reconciliation of market requirements and operation resources. The subsequent analysis seeks to define constructs that represent each input and output dimensions. The research methodology steps are presented in Figure 2.

As described in the research steps, the constructs definition is based on the high-performance manufacturing (HPM) project data of the fourth round, realized between 2012 and 2018 (Park and

Input variables	Definition	Authors
Cost	Offer products at lower costs than competitors or be cost-efficient. Costs are about the ability to optimize the utilization of manufacturing resources	Slack and Lewis (2018), Lotfi and Saghiri (2018), Sansone *et al.* (2017)
Dependability	Fulfil the promises of deadline delivery. Besides on-time delivery, this also includes delivery date estimation and communication	Slack and Lewis (2018), Yusuf *et al.* (2014)
Environmental Factors	Items of the production process and product that interfere in the protection of the environment	Vivares-Vergara *et al.* (2016), Díaz-Garrido *et al.* (2011)
Flexibility	Have the capacity to adapt operation whenever needed and with the necessary speed, either due to changes in demand or production process needs. Cope with ever-changing market demands	Slack and Lewis (2018), Slack *et al.* (2018), Asadi *et al.* (2017), Dey *et al.* (2019)
Innovativeness	Capacity in engaging in innovation, which in its turn is related to the introduction of new processes, products or ideas in the organization	Hult *et al.* (2004), Laosirihongthong *et al.* (2014)
Quality	Offer products according to design specifications	Slack and Lewis (2018), Bernroider *et al.* (2014), Chen and Tan (2013)
Reliability	Quality of being trustworthy or of performing consistently well. Reliability is approached as a criterion detached from quality by some authors	Slack *et al.* (2018), Narkhede (2017)
Speed	Deliver to customers faster than competitors	Slack and Lewis (2018), Vázquez-Bustelo *et al.* (2007)

Table 1.
Definition of input and output variables

Paiva, 2018; Phan *et al.*, 2019). The HPM is a solid project, in place since 1998, which has developed a large database to test some of the relationships described as comprising world-class manufacturing. The project seeks to identify the practices adopted by high-performance organizations and applies a survey with companies with at least 100 employees from the machinery manufacturing, vehicle component manufacturing and electronics manufacturing sector. The survey includes 1,597 questions on both practices and performance, based on the work of Hayes and Wheelwright (1985) and Schonberger (1986). The respondents are established as management executives from accounting, downstream and upstream supply chain, environmental affairs, human resources, information systems, process engineering, product development, quality, plant management and supervision. The questionnaires had been widely tested for reliability and validity (Flynn, 1997). Round four captured the behavior of 330 companies across 15 countries (Park and Paiva, 2018; Phan *et al.*, 2019).

This research uses the HPM database by presenting itself as a consolidated database. First, we have selected the HPM questions (called variables) related to the input and output variables mentioned in the first-level conceptual framework. Those dimensions are already discussed in the previous topic. Next, as this study is performed with multiple performance measures, multivariate statistical analysis is required to evaluate them and select valid constructs (Hair *et al.*, 2009). The research is grapples with techniques for sampling and variables selection, principal component analysis, and Cronbach's alpha investigation.

5.1 Sampling definition

Regarding the techniques for sampling selection, most of the recommendations involve determining the sample size based on the number of measured variables included in the analysis, the greater the number of variables the bigger the sample size. However, as

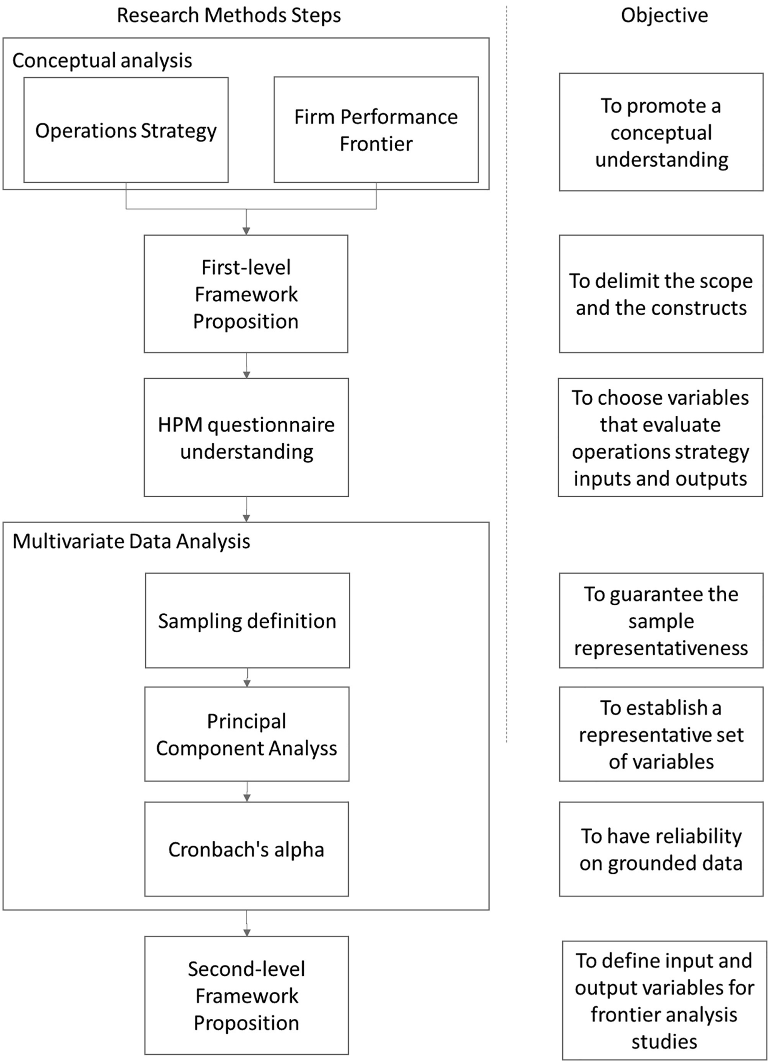

Figure 2.
Research steps

observed by Fabrigar *et al.* (1999), the recommendations given by existing literature vary dramatically. According to Hair *et al.* (2009), it is difficult to carry out an analysis with less than 50 observations; preferably, the sample size should include more than 100 observations. To Nunnally and Bernstein (1994) the number of observations must be at least five times greater than the number of variables; best practice is considered to be a ratio of ten observations per variable. The adopted criterion, therefore, is at least 100 samples and, simultaneously, a minimum of ten observations per variable.

5.2 Principal component analysis

As more variables are added more correlation (or overlapping) occurs between them. Therefore, the researcher needs alternatives to manage variables, grouping highly correlated ones (Hair *et al.*, 2009; Velicler and Jackson, 1990). The principal component analysis (PCA) is a strongly recommended technique for data reduction when the aim is to later perform a DEA model (Nataraja and Johnson, 2011; Alder and Golany, 2001; Ueda and Hoshiai, 1997). PCA is useful for summarizing or describing the variance in a set of variables into fewer dimensions (Denis, 2019).

Filho and Junior (2010) propose a three steps design to run the PCA technique: (1) verify the adequacy of the database, (2) determine the extraction method and the number of factors to be extracted and (3) decide the method of factor rotation. Regarding the database adequacy, Denis (2019) argues that it is recommended to guarantee that the variables are at least partly intercorrelated to produce representative factors. Hair *et al.* (2009) include another method for determining the appropriateness of factor is the Bartlett test of sphericity. It provides the statistical significance that the correlation matrix has significant correlations among at least some of the variables. Another measure to quantify the degree of intercorrelation among variables, approached by Hair *et al.* (2009), is the measure of sampling adequacy, promoted by means of the Kaiser-Meyer-Olkin (KMO) test. Results greater than 0.80 are meritorious, 0.70 or above are middling, 0.60 or above, mediocre, 0.50 or above, miserable and bellow 0.50 is unacceptable.

To define the factor extraction method is important to understand the difference between common factors and PCA. Both techniques aim to generate a linear combination of the variables that capture the maximum variance of observed variables. However, PCA considers the total of variance and derives factors that contain a small proportion of unique variance and, in some cases, error variances. PCA does not discriminate between shared and unique variance, as indicated by Hair *et al.* (2009), and Costello and Osborne (2005). Meanwhile, Hair *et al.* (2009) indicate that the common factors analysis reflects only the shared variance, assuming that both are unique and error variance is not of interest in defining the structure of the variables. PCA is preferred when the objective is to reduce data (Denis, 2019; Costello and Osborne, 2005; Fabrigar *et al.*, 1999).

Another critical decision is the number of factors to be retained. This is an important step since both over-extraction and under extraction of factors retained for rotation can have harmful effects on the results. There are several criteria cited to conduct such an analysis, and no consensus among authors is found (Filho and Júnior, 2010; Hair *et al.*, 2009). To Fabrigar *et al.* (1999), determining the number of factors to be included in the model requires the researcher to balance the need for parsimony (a model with relatively few factors) against the need for plausibility (a model with enough common factors to adequately account for the correlations among measured variables).

Rencher and Christensen (2012) and Hair (2009) indicate the Kaiser Criterion, which considers that only components with eigenvalues greater than one are considered significant, the others should be discarded. However, a number of authors advocate that this is among the least accurate method for selecting the number of factors, even being a default procedure in most statistical software (Rencher and Christensen, 2012; Laros, 2012; Costello and Osborne, 2005; Nunnally and Bernstein, 1994). Laros (2012) and Velicler and Jackson (1990) denote that there is frequently over-extraction when using the Kaiser criterion. Alternate tests for factor retention include the screen test and parallel analysis.

To Rencher and Christensen (2012), the screen test is used to identify the optimum number of factors that can be extracted before the amount of unique variance being to dominate the common variance structure. The screen test is determined by plotting eigenvalues in relation to the number of factors in their extraction order. The parallel analysis proposed by Horn (1965) is based on the generation of random variables for estimating the component that needs to be subtracted. The proposition is that the number of common factors should not be determined using eigenvalues bigger than one. The parallel analysis determines the number of common factors by selecting the number of the eigenvalues of a correlation matrix that was greater than or equal to those provided by data computer-simulated with known characteristics. The idea is to generate random data of similar size and calculate the latent roots and vectors of these random data to provide a criterion tailored to the data set being analyzed. Only factors that correspond to empirical eigenvalues, which exceed the mean values of the eigenvalues obtained randomly, would be extracted (Laros, 2012). An advantage of the parallel tests model, indicated by DeVellis (2003), is that its assumptions make it easy to grasp useful conclusions about how individual items relate to the factors or latent variables, based on our observations of how the items relate to one another.

A third criterion is the percentage of the total variance. Hair *et al.* (2009) consider that 60% is satisfactory in social sciences studies; Rencher and Christensen (2012) recommend 80%. But this value depends heavily upon average correlation; consequently, this rule is basically inapplicable as advice to determinate the number of factors (Nunnally and Bernstein, 1994).

In relation to the factor rotation method, it has the aim of simplifying the structure of factorial loads and often makes the factors more clearly distinguishable and easier to interpret. It can be orthogonal or oblique; the simplest case of rotation is orthogonal. The type of rotation most commonly used is varimax, which has been very successful as an analytical approach to obtain an orthogonal rotation of factors (Hair *et al.*, 2009).

5.3 Cronbach's alpha

To Hair *et al.* (2009), Cronbach's alpha is a reliability measure for data that varies between 0 and 1. Values from 0.6 to 0.7 are considered the inferior limit of acceptance.

6. Results

This section details the results of the main steps presented in the research design. After the first level framework definition, the subsequent step is the HPM questionnaire comprehension, in order to understand and map variables for assessing operations strategy as inputs and outputs dimensions. All the HPM questions are examined and those with relation either with outputs or inputs are selected. Only variables with less than 30% of missing data were considered for this study, respecting the Hair *et al.* (2009) proposition. Even so, a huge quantity of variables was still remaining after this stage; therefore, a PCA analysis is conducted next to consistently reduce the number of variables through the definition of constructs.

6.1 Sampling definition

Table 2 shows the number of variables and sample size (SS). We aimed to have at least ten respondents per variable, respecting the proposition of Nunnally and Bernstein (1994).

Table 2.
Sample characteristic

Category	Number of variables/questions	Sample size	Ratio SS/Variable
Costs	9	117	13.0
Dependability	5	241	48.2
Flexibility	18	212	11.8
Quality	17	210	12.3
Innovativeness	13	202	15.5
Speed	7	181	25.8
Reliability	4	261	65.3
Environmental factors	10	249	24.9
Financial results	1	271	271
Clients results	10	241	24.1

Having selected the variables/questions to be used in the study, the process of reducing them through PCA is performed.

6.2 Principal component analysis

The PCA is promoted to each category. The exceptions are the output category of financial issues and input innovativeness category. The financial category does not require the PCA, as it has only one variable, throughput. In the innovativeness category, the correlation matrix exposed a low correlation between many of the variables. Denis (2019) argues that it does not make sense to perform PCA if the analyzed variables are not correlated at least to some degree. Therefore it is more coherent to classify the variables of this category as formative constructs, as there is a set of exogenous variables. According to Hair *et al.* (2009), in this situation, the indicator causes the construct, whereas, in more conventional latent variables (or reflexive constructs), the indicator is caused by the latent variable. The compression of the innovativeness variables was then promoted through semantic analysis, applying an affinity diagram. In this procedure, three groups of variables were defined related to equipment technologies, process technologies and product innovativeness.

PCA was performed with a varimax rotation method. The KMO as well as the significance level of Bartlett's test of sphericity, for each category are presented in Table 3.

KMO results ranged from mediocre to meritorious, but all categories have enough indication of sampling adequacy for the PCA method. The sphericity test has also determinate conformance. The significance of Pearson correlation values tests was also analyzed, and a few cases where conformance was not presented; the unsuited variable was excluded.

Related to the number of factors to be extracted, for some variables, the total variance and the scree plot recommended a bigger quantity than the parallel analysis. The parallel analysis was promoted using syntax by Brian O'Connor (O'Connor, 2018) and this criterion prevailed. For flexibility variables, the Kaiser criterion recommended six factors and the parallel analysis only three. For quality variables, the Kaiser criterion recommended five factors and the parallel analysis only two. For speed variables, the total variance recommended two factors to be extracted while the parallel analysis indicated only one. Based on the parallel analysis results, PCA was performed again with the fixed number of factors recommended by parallel analysis. For some variables, the parallel analysis confirmed the results given by the Kaiser criterion. The costs, environmental factors and reliability variables had two factors extracted as well as the client results variables. Dependability variables had one factor extracted.

The rotated component matrix was performed to identify the factorial loads of each variable in relation to the extracted components. Based on these results the weight of each variable to compose the component was established, which are proportional to the given

Category	KMO	Bartlett's test of sphericity (sig)
Costs (C)	0.749 (middling)	0.000
Dependability (D)	0.646 (mediocre)	0.000
Environmental factors (E)	0.852 (meritorious)	0.000
Flexibility (F)	0.735 (middling)	0.000
Innovativeness (I)	Not applicable	Not applicable
Quality (Q)	0.844 (meritorious)	0.000
Reliability (R)	0.572 (miserable)	0.000
Speed (S)	0.799 (middling)	0.000
Financial results (FO)	Not applicable	Not applicable
Clients results (CO)	0.775 (middling)	0.000

Table 3. KMO and Bartlett's test of sphericity

component load. Components/Constructs (or new variables) are shown in Table 4, which also displays the previous variable and its weight, the initial eigenvalues (EV), as well as the cumulative percentage of the total variance that the component can explain (TV) through the rotation sums of squared loadings.

All the HPM questions that generated the results of the mentioned previous variables are included in Table A1.Table A2 presents the descriptive statistics of the data gathered in the HPM fourth round for automotive chain companies. Once the framework constructs, or new variables, have been defined, it is expected that the variables inside the same component will have a conceptual consistency between them. The Cronbach's alpha (CA) is therefore performed to confirm such an assumption.

6.3 Cronbach's alpha

The CA is performed to evaluate whether the component has a response standard demonstrating conceptual correlation and therefore, representing formative constructs. The CA is performed for each component generated in the PCA analysis, and they presented an acceptable CA, as expected, confirming the consistency among variables inside the same component. The exception is the innovativeness category that has two components with CA inferior to 0.70, endorsing, therefore, that they are not a reflexive construct (latent variables).

7. Conceptual framework

From the data of the HPM project fourth round, the second-level conceptual framework, developed based on the PCA results, is presented in Figure 3. After all the exclusion process inherent in the PCA procedure, the framework identifies the input and output new variables/constructs that can be used for the purposes of frontier analysis purpose, depicting the first-level conceptual framework previously presented in Figure 2.

The second-level conceptual framework encompasses a representative set of inputting and outputting variables for measuring the effectiveness of operations strategy.

8. Discussion

The former literature on frontier analysis methods requires inputting and outputting variables. However, it is not possible to find a consensus in defining what are the input and output variables that represent the decision areas, capabilities, competitive priorities or business results. Therefore, the establishment of input and output variables to allow the use of operations strategy as a lens for performance frontier analysis is still unclear, which justifies an in-depth study to reveal relationships among variables that define the content of operations strategy. This research work deals with the concept of competitive priorities, as the input variables, and business results as the output variables, promoting a market-led orientation. This delimitation affords a strategic view by the understanding of how the operations strategy contributes to the business results and, from these understandings, supporting the decision of which direction to take in the development of internal resources.

The choice of focusing on the market-led orientation is because most of the existing papers in this area deal with the capabilities concept, characterizing the RBV approach. In this kind of work, inputs and outputs depend on the required capability (e.g. Arbelo *et al.*, 2020; Yin *et al.*, 2020; Ramanathan *et al.*, 2016; Dutta *et al.*, 2005; Ahmed *et al.*, 2014; Yu *et al.*, 2014). However, it is necessary to intertwine the resource-based and market-led orientation. Nevertheless, the connection with a market-led orientation is still less explored in the literature on operations strategy performance frontier. Competitive priorities establish the basis for operations strategy (Cai and Yang, 2014) and can be used to understand market requirements, translating it into manufacturing capabilities (Brown and Blackmon, 2005). That is why the competitive priorities

CAT	Constructs/ new variables	Previous variables (weight)	EV	TV
C1	Manufacturing costs	Product selling price (17.4%)/Unit cost of manufacturing (18.9%)/Labor cost (42.5%)/Operating expense (21.2%)	3.21	45.92
C2	Manufacturing costs–recently launched products	Recently launched products success–Unit manufacturing cost (49.6%) recently launched products success–Unit manufacturing cost (50.4%)	2.06	75.33
D1	Dependability performance	The promises that our plant makes to its customers are reliable (35.6%)/On time delivery performance (29.7%)/Our customers can rely on us for punctual delivery (34.7%)	1.97*	65.62*
E1	Capacity of environmental practices positively influence results	Cost advantages (16.2%)/Cost savings by improving environmental quality (16.8%)/Enter lucrative new markets by adopting environmental strategies (17.6%)/Increase market share by making our current products more environmentally friendly (17.3%)/Quality improvement (14.5%)/Differentiation from competitors (17.5%)	4.00	44.43
E2	Overall environmental performance	Environmental performance (35.8%)/Regulatory performance (34.3%)/Overall environmental performance–compare to competitors (30.0%)	1.98	66.39
F1	Customer vision about flexibility	Our customers select us because we deliver flexible for their needs (32.6%)/Our customers can rely on us for flexibility (31.8%)/We are selected by our customers because of our reputation for flexibility (35.6%)	2.20	27.52
F2	Changing mix/ volume Capacity	Flexibility to change product mix (49.4%)/Flexibility to change volume (50.6%)	1.90	51.27
F3	Product customization	We are highly capable of large-scale product customization (35.2%)/We can easily add significant product variety without increasing cost (27.9%)/We can customize products while maintaining high volume (37.0%)	1.70	71.55
I1	Process technology innovativeness	Quickly adoption of new technologies (14.3%)/We often fail to achieve the potential of new process technology (14.3%)/Modification of production technology as new technologies emerge (14.3%)/There are no substitutes for our production technology (14.3%)/Our plant stays on the leading edge of new technology in our industry (14.3%)/Our current production technology is protected by patents (14.3%)/Posture toward new processes (14.3%)	N.A.	N.A.
I2	Equipment technology innovativeness	We frequently modify equipment to meet our specific needs (25%)/In order to improve equipment performance, we sometimes redesign equipment (25%)/We produce a substantial amount of our equipment in-house (25%)/We actively develop proprietary equipment (25%)	N.A.	N.A.
I3	Product innovativeness	Product innovativeness (50%)/Posture toward new products (50%)	N.A.	N.A.
Q1	Quality performance compared to competitors	Overall product quality perceived by customers (17.8%)/Conformance to established standards (17.6%)/Primary product performance characteristics (17.0%)/Secondary options or features (15.6%)/Aesthetics (15.8%)/ Serviceability; ease of repair (16.2%)	3.72	41.36
Q2	Quality in recently launched products	Conformance quality (29.3%)/Performance–functionality (36.0%)/Features (34.7%)	2.11	64.8
R1	Reliability performance	Durability (life expectancy) (50.3%)/Reliability (time between failures) (49.7%)	1.74	43.55
R2	Recently launched products reliability	Durability (50.2%)/Reliability of the product (49.8%)	1.74	86.96
S1	Speed performance	Fast delivery (24.8%)/Speed of new product introduction into the plant (23.8%)/Agile manufacturing (25.4%)/Cycle time (26.1%)	2.71*	67.63*
FO1	Financial performance	Throughput (100.00%)	N.A.	N.A.
CO1	Market share recently launched products	Market share, compared to competitors (36.2%)/Market share (38.5%)/Customer satisfaction (25.3%)	3.09	44.16
CO2	Customer satisfaction	Satisfaction of requirements and expectations of our customers (25.2%)/Our customers are pleased with the products and services we provide for them (26.4%)/Our customers have been well satisfied with the quality of our products, over the past three years (25.2%)/Responsiveness to customer problems (23.3%)	1.99	72.55

Note(s): *Extraction Sums of Squared Loadings

Table 4. Component composition

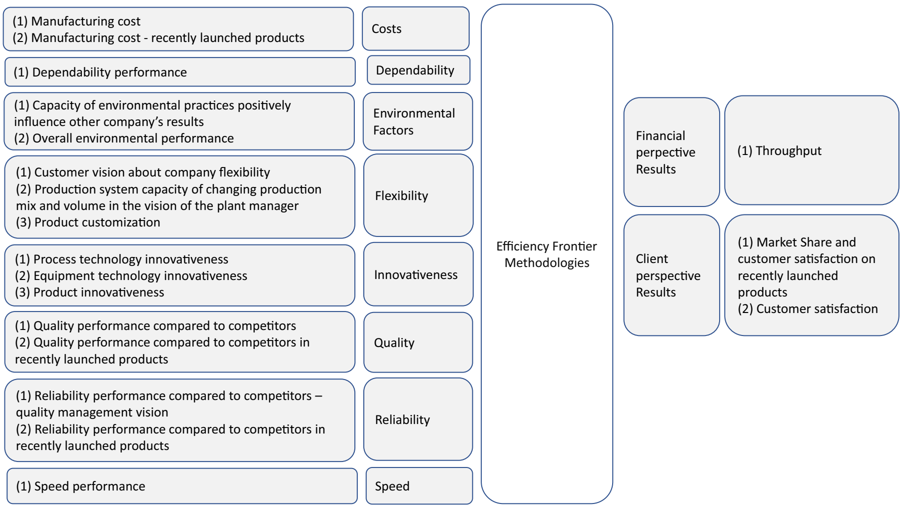

Figure 3.
Second-level conceptual framework

are taken to promote a market-led orientation in the operations strategy performance frontier conceptual framework, promoting a theoretical contribution.

Even though there is some authors have already explored the competitive priorities approach (Abassi and Kaviani, 2016; Bulak *et al.*, 2016; Talluri *et al.*, 2003), they do not demonstrate how the definition of the input and output variables are promoted. In this research, the input and output variables/dimensions were firstly defined, in the first-level conceptual framework, with their constructs defined, in the second-level conceptual framework. The constructs were defined taking into account the HPM database content so that the questions related to the settled input and output variables supported the definition of the constructs. The definition of the constructs was therefore limited to the questions approached by the HPM project. As the HPM is a consolidated project with a wide reputation, results are substantiated.

This paper implies the definition of a representative set of constructs, which are next discussed using existing literature to evaluate whether the variables are a good representation of each category or not. The selected competitive priorities include quality, costs, flexibility, dependability, speed, reliability, innovativeness and environmental affairs. The first five are considered by most authors (e.g. Bulak *et al.*, 2016; Abbasi and Kaviani, 2016; Cai and Yang, 2014; Hallgren *et al.*, 2011) and the interest in these dimensions seems to grow constantly. Innovation, service and environment are also pointed out by some authors. According to Sansone *et al.* (2017), both innovation and service appeared as real interest only in 2001, and innovation was only confirmed as a topic in 2006. Environmental is a new dimension that started to appear in 2008 and its presence is now growing.

From the discussion above, it is accepted that service is an important competitive priority and it is included in the proposed conceptual model on the component "overall quality performance" of quality criteria, with the "serviceability" original variable. The framework results consider the service evaluation inside the quality affairs, which is supported by Sansone *et al.* (2017), that argues that although service can be considered as a competitive priority it is not as important as the classics competitive priorities. Bulak *et al.* (2016) likewise have included service – defined as the quality level of service that a company provides before and after the sale – as a criterion of the quality variable. Slack and Lewis (2018) argue that quality is a multidimensional issue.

To Slack and Lewis (2018) quality is about offering products according to project specifications, and to Sansone *et al.* (2017) the competitive criteria includes performance, conformance and durability. In the proposed conceptual framework, this definition of quality is taken into account, but there is a separate assessment of current products and recently launched ones. The overall quality performance includes aspects of conformance to established standards, primary product performance characteristics, secondary options or features, aesthetics and serviceability. Bulak *et al.* (2016) also include certification in quality evaluation. The proposed framework does not include it, as we understand that certification is a practice to generate quality performance and therefore could not be classified as part of operations strategy results (competitive priorities).

Flexibility is understood as having the capacity to adapt the operation whenever necessary and with sufficient speed, either by changes in demand or by the needs of the production process (Slack *et al.*, 2018). It can be volume, production mix, customization or broad product line flexibility (Sansone *et al.*, 2017). The proposed framework approached volume and production mix as the same component and product customization in a distinctly one. In addition, the customer vision about company flexibility was included.

To Slack and Lewis (2018) costs represent offering competitive costs. To Sansone *et al.* (2017) it can be the total cost and the ability to optimize the utilization of manufacturing resources. The proposed framework is coherent with both definitions. However, the costs are distinguished from current and recently launched products.

To Slack and Lewis (2018) sustainability is an integrative criterion that encompasses the five main competitive priorities (quality, speed, dependability, flexibility and costs). Sustainability is the ability to create an acceptable profit, minimizing the damage to the environment and enhancing the existence of the people with whom it has contact. In this sense, sustainability could be classified as an output variable. Sustainability encompasses three pillars, environmental, social and economic (Elkington, 1997). We considered that the environmental impact is the perspective that can be faced as an input variable. Sansone *et al.* (2017) divide this category into environmentally friendly products and processes. The conceptual framework proposes different segregation including aspects of the ability of environmental practices which positively influence other companies' results and an overall view of environmental performance.

Yet, innovativeness is a topic of current interest, and the variables are then included, even revealing a different behavior that does not allow them to be classified as a latent variable. The innovativeness components are generated through an affinity diagram segregating in three new variables: process technology innovativeness, equipment technology innovativeness and product innovativeness.

Regarding independent variables, the performance is usually assessed using financial and nonfinancial performance measures (e.g. Liu *et al.*, 2018; Bulak *et al.*, 2016; Abbasi and Kaviani, 2016), being consistent with Kaplan and Norton's (2000) Balanced scorecard proposal, which defines the financial and clients as the results perspectives. In addition, the organization may have other strategic objectives, but the customer and financial are the survival goals to most organizations. We proposed the throughput as the financial measure and market share and customer satisfaction as the nonfinancial measures.

According to the above discussion, lessons learned can be summarized as follows.

(1) The definition of the inputs and outputs variables depends on the organizational perspective. From a strategic perspective, a more comprehensive approach is to use competitive priorities as input and some organizational result measure as output. On the other hand, looking at a tactical approach, it is coherent to define the operations strategy competitive priorities as outputs, and the operations resources, in the

decision areas, like the inputs. The first level proposed framework discloses the causal relationship.

(2) A range of authors use financial and nonfinancial performance measures to represent the organizational results measures. Mainly financial performance is measured by indicators such as ROI, ROA, throughput, sales and profitability, while the nonfinancial are related to customer satisfaction and market share. Such an approach is coherent with the balanced scorecard framework, which defines the financial and customer perspective as the results measures and the process and learning as the process measures, bringing out again the causal relationship mentioned above.

(3) The measurement of the competitive priorities with multiple-related variables is increasingly common since competitiveness is growing. The conceptual framework has generated 16 grouped variables to eight competitive dimensions as a representative construct of operations strategy performance.

(4) Sustainability can vary from input and output variables. The triple bottom line concept encompasses the economic, environmental and social dimensions. The economic dimension is mainly an output variable, related to the organization's financial health. Environmental and social variables can be input or output depending on the intended scope.

Finally, we state that traditionally the concept of tradeoff has been imposed among competitive priorities. However, as indicated by Slack *et al.* (2018), in the face of current competitiveness, it is necessary to break the tradeoff barrier to being excellent in seemingly contradictory performance criteria and therefore acquire efficiency in the desired output. The tradeoffs broken have become possible by constant evolution of technology. In this scenario, the maximum performance frontier evaluation model grows into importance, as it can enable the company to identify whether it is still possible to increase its efficiency at the same level of investment. Whereas the concept of tradeoffs is settled, the company can wrongly think that it is on the maximum attainable results, when in fact it can still progress, and more than that, need to progress since some competitors have already reached a superior outcome.

9. Conclusion

By means of the proposed framework, this research work contributes in providing a complete picture of the relationship between operations strategy and performance frontier analysis, which is an important theoretical contribution for research since the concepts of operations strategy and performance frontier analysis simultaneously are not exhaustively explored by the literature when it concerns competitive priorities. Besides that, this paper provides the variables for the conduction of operations strategy performance frontier analysis in new studies.

It is known that operations strategy has to consider how market needs and manufacturing capabilities can be combined by competitive strategy in a dynamic and volatile marketplace to sustain competitive performance. Therefore, due to the unpredictable and complex organizational environment, the set of representative variables might change more frequently which reinforces the need of updating operations strategy measures, bringing out the need for having a process to update variables seeking to continue accurately assessing the effectiveness of the operations strategy. The process of defining operations strategy constructs is fully explored. As a result, the presented constructs are able to significantly represent the input and output performance measures for operations strategy within the HPM context, composing the conceptual framework for performance frontier analysis in this context. Moreover, this study brings more recent perspectives to the main competitive priorities. In this model, those priorities are measured with related multiple variables. The conceptual framework has generated 16 grouped variables to eight competitive dimensions as a representative construct of operations strategy performance. The adopted constructs are frequently used in operations strategy models as well as market-based research. The proposed conceptual framework has its importance grounded in the complexity characteristic of the competitive environment that requires multifaceted measures.

The research design itself objectively circumscribes the HPM project study, which is sufficiently comprehensive for the research proposal (industrial sector and countries participating in the survey). In the HPM, good manufacturing practices are mapped in the largest economies and in developed countries. A limitation of this study is that the constructs were defined using the data of the HPM database, and then the results are representative of this set of data and the conceptual framework can be used to benchmark companies with similar characteristics to the ones listed in the HPM database (firms with at least 100 employees, belonging to the automotive chain). Besides that, the definition of the construct was bounded by the content addressed by the HPM database, thus, it must be considered that some important content, which is not addressed by the HPM, was not eligible to compose the construct. This is a limitation that needs to be considered by the researchers who have the intention of using these results. However, it also needs to consider that the HPM is a solid data base which has been constantly improved since 1998, minimizing such a risk. The HPM is in its fourth round and is evolving to be aligned to manufacturing evolution (best practices and policies as the productive systems evolves from quality management, lean manufacturing, sustainable operations, agile and cyber physical systems) and to be aligned to global market demands (e.g. competitive priorities considered under the sustainable development paradigm).

A future work opportunity can be addressed to replicate this process of selecting representative inputs and outputs variables within other reliable and up to date databases that cover competitive priorities and business results. Besides that, the inherent continuity of this research is to perform DEA using the defined set of input and output variables, to conduct a benchmarking process for a given organization. Indeed, we emphasize that the proposed input and output constructs are defined considering competitive priorities frequently approached by the literature. Even so, the importance of competitive priorities varies according to the competitive scenario, and a priority that might be recognized as important by one company may not be relevant to another company, even belonging to the same sector (Chang *et al.*, 2015; Miller and Ross, 2003), so prior to performing DEA, it is important to identify the operations strategy of the company in which the study will be conducted, in order to select the constructs that will be representative to the target company.

Yet, innovativeness is not presented as a reflexive (latent) construct in this research work, which can represent either a lack of respondent understanding about the concept or a characteristic of the variable. Future studies are recommended to clarify this question.

Still, we hope that this study will contribute to the clarification of the relation between operations strategy and performance frontier methodologies, as well as to the definition of operations strategy input and output constructs, facilitating further empirical study regarding performance frontier identification in the operations strategy context.

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Appendix

Table A1. HPM questions

Factor/original variable	Question	Options					Respondent	Weight (%)
Manufacturing costs	How do your plant's products compare to its leading competitors, on Product selling price?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Plant Management	17.4
Manufacturing costs	How does your plant compare with its competitors in its industry, on a global basis, on Unit cost of manufacturing?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Plant Management	18.9
Manufacturing costs	How does your plant compare with its competitors in its industry, on a global basis, on Labor cost?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Plant Management	42.5

(*continued*)

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Manufacturing costs	How does your plant compare with its competitors in its industry, on a global basis, on Operating expense: funds spent to generate turnover, including direct labor, indirect labor, rent, utility expenses and depreciation?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Plant Management	21.1
Manufacturing costs–recently launched products	How successful have products that were recently launched by your plant been, in terms their goals in of each of the following areas? Unit manufacturing cost	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Product Development	49.6
Manufacturing costs–recently launched products	How do products that were recently launched by your plant compare with similar products that are manufactured and sold by your competitors (Unit cost of manufacturing)?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Product Development	50.4

(*continued*)

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Dependability performance	Indicate the extent to which you agree or disagree with each of the statement: The promises that our plant makes to its customers are reliable	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Downstream SCM	35.6
Dependability performance	How does your plant compare with its competitors in its industry, on a global basis, on On-time delivery performance?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Plant Management	29.7
Dependability performance	Indicate the extent to which you agree or disagree with each of the statement: Our customers can rely on us for punctual delivery	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Downstream SCM	34.7
Capacity of environmental practices positively influence other company's results	Indicate the extent to which you agree or disagree with each of the statement: Being environmentally conscious can lead to substantial cost advantages for our plant	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Plant Management	16.2

(*continued*)

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Capacity of environmental practices positively influence other company's results	Indicate the extent to which you agree or disagree with each of the statement: Our plant can realize significant cost savings by experimenting with ways to improve the environmental quality	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Plant Management	16.8
Capacity of environmental practices positively influence other company's results	Indicate the extent to which you agree or disagree with each of the statement: Our plant can enter lucrative new markets by adopting environmental strategies	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Plant Management	17.6
Capacity of environmental practices positively influence other company's results	Indicate the extent to which you agree or disagree with each of the statement: Our plant can increase market share by making our current products more environmentally friendly	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Plant Management	17.3

(*continued*)

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Capacity of environmental practices positively influence other company's results	Indicate the extent to which you agree or disagree with each of the statement: Reducing the environmental impact of our plant's activities will lead to a quality improvement in our products and processes	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Plant Management	14.5
Capacity of environmental practices positively influence other company's results	Indicate the extent to which you agree or disagree with each of the statement: Better environmental performance can differentiate our plant from our competitors	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Plant Management	17.5
Costumer vision about company flexibility	Indicate the extent to which you agree or disagree with each of the statement: Our customers select us because we deliver flexibly for their needs	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Downstream SCM	32.6

(*continued*)

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Costumer vision about company flexibility	Indicate the extent to which you agree or disagree with each of the statement: Our customers can rely on us for flexibility	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Downstream SCM	31.8
Costumer vision about company flexibility	Indicate the extent to which you agree or disagree with each of the statement: We are selected by our customers because of our reputation for flexibility	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Downstream SCM	35.6
Production system capacity of changing production mix and volume in the vision of the plant manager	How does your plant compare with its competitors in its industry, on a global basis, on Flexibility to change product mix?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Plant Management	49.4
Production system capacity of changing production mix and volume in the vision of the plant manager	How does your plant compare with its competitors in its industry, on a global basis, on Flexibility to change volume?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Plant Management	50.6

(*continued*)

Factor/original variable	Question	Options					Respondent	Weight (%)
Product customization	Indicate the extent to which you agree or disagree with the statement: We are highly capable of large-scale product customization	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Process Engineering	35.2
Product customization	Indicate the extent to which you agree or disagree with the statement: We can easily add significant product variety without increasing cost	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Process Engineering	27.9
Product customization	Indicate the extent to which you agree or disagree with the statement: We can customize products while maintaining high volume	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Process Engineering	37.0

(continued)

Table A1.

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Process technology innovativeness	Indicate the extent to which you agree or disagree with the statement: We quickly adopt new technologies by applying what we learn from our customers	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Downstream SCM	14.3
Process technology innovativeness	Indicate the extent to which you agree or disagree with the statement: We often fail to achieve the potential of new process technology	Strongly agree	Agree somewhat	Neither agree nor disagree	Disagree somewhat	Strongly disagree	Process Engineering	14.3
Process technology innovativeness	Indicate the extent to which you agree or disagree with the statement: As new technologies emerge; we modify our production technology	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Process Engineering	14.3
Process technology innovativeness	Indicate the extent to which you agree or disagree with the statement: There are no substitutes for our production technology	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Process Engineering	14.3

(*continued*)

Factor/original variable	Question	Options					Respondent	Weight (%)
Process technology innovativeness	Indicate the extent to which you agree or disagree with the statement: Our plant stays on the leading edge of new technology in our industry	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Process Engineering	14.3
Process technology innovativeness	Indicate the extent to which you agree or disagree with the statement: Our current production technology is protected by patents	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Process Engineering	14.3
Process technology innovativeness	Which term best describes the plant's posture toward new processes?	Never adopts new processes	Usually among the last to adopt new processes	Adopts new processes when it becomes more or less the general rule	Among the first to adopt new process, but not the leader	Leader in new processes	Process Engineering	14.3
Equipment technology innovativeness	Indicate the extent to which you agree or disagree with the statement: We frequently modify equipment to meet our specific needs	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Process Engineering	25.0

(*continued*)

Table A1.

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Equipment technology innovativeness	Indicate the extent to which you agree or disagree with the statement: We produce a substantial amount of our equipment in-house	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Process Engineering	25.0
Equipment technology innovativeness	Indicate the extent to which you agree or disagree with the statement: In order to improve equipment performance, we sometimes redesign equipment	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Process Engineering	25.0
Equipment technology innovativeness	Indicate the extent to which you agree or disagree with the statement: We actively develop proprietary equipment	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Process Engineering	25.0
Product innovativeness	How does your plant compare with its competitors in its industry, on a global basis, on Product innovativeness?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Plant Management	50.0

(continued)

Factor/original variable	Question	Options					Respondent	Weight (%)
Product innovativeness	Which term best describes the plant's posture toward new products?	Never adopts new products	Among the last to adopt new products	Adopts new products when it becomes more or less the general rule	Among the first to adopt new products, but not the leader	Leader in new products	Product Development	50.0
Quality performance compared to competitors	How does the quality of your plant's products compare to its competitors' products on Overall product quality perceived by customers?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Quality Management	17.8
Quality performance compared to competitors	How does the quality of your plant's products compare to its competitors' products on Conformance to established standards?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Quality Management	17.6
Quality performance compared to competitors	How does the quality of your plant's products compare to its competitors' products on Primary product performance characteristics?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Quality Management	17.0

(continued)

Table A1.

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Quality performance compared to competitors	How does the quality of your plant's products compare to its competitors' products on Secondary options or features; characteristics that supplement the basic functioning of the product?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Quality Management	15.6
Quality performance compared to competitors	How does the quality of your plant's products compare to its competitors' products on Aesthetics; how the product looks, feels, sounds, tastes or smells?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Quality Management	15.8
Quality performance compared to competitors	How does the quality of your plant's products compare to its competitors' products on Serviceability; ease of repair?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Quality Management	16.2

(*continued*)

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Quality performance compared to competitors in recently launched products	How do products that were recently launched by your plant compare with similar products that are manufactured and sold by your competitors on Conformance quality?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Product Development	29.3
Quality performance compared to competitors in recently launched products	How do products that were recently launched by your plant compare with similar products that are manufactured and sold by your competitors on Performance (functionality)?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Product Development	36.0
Quality performance compared to competitors in recently launched products	How do products that were recently launched by your plant compare with similar products that are manufactured and sold by your competitors on Features?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Product Development	34.7

(*continued*)

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Reliability performance compared to competitors in recently launched products	How does the quality of your plant's products compare to its competitors' products on Durability; amount of use before the product deteriorates or needs to be replaced?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Quality Management	50.2
Reliability performance compared to competitors in recently launched products	How does the quality of your plant's products compare to its competitors' products on Reliability of the product; probability of failure in a specified time?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Quality Management	49.8
Reliability performance compared to competitors – quality management vision'	How do products that were recently launched by your plant compare with similar products that are manufactured and sold by your competitors on Durability (life expectancy)?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Product Development	50.3

(continued)

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Reliability performance compared to competitors – quality management vision'	How do products that were recently launched by your plant compare with similar products that are manufactured and sold by your competitors on Reliability (time between failures)?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Product Development	49.7
Speed performance	How do your plant's products compare to its leading competitors, on Fast delivery?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Plant Management	24.8
Speed performance	How do your plant's products compare to its leading competitors, on Speed of new product introduction into the plant (development lead time)?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Plant Management	23.8
Speed performance	How do your plant's products compare to its leading competitors, on Agile manufacturing?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Plant Management	25.4

(continued)

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Speed performance	How do your plant's products compare to its leading competitors, on Cycle time (from raw materials to delivery)?	Much Worse	Somewhat worse	About the same	Somewhat better	Much better	Plant Management	26.1
Overall environmental performance	How have the following outcomes changed for your plant, as a result of undertaking environmental initiatives: Environmental performance?	Much Worse	Somewhat Worse	About the Same	Somewhat Better	Much Better	Environmental Affairs	35.8
Overall environmental performance	How have the following outcomes changed for your plant, as a result of undertaking environmental initiatives: Regulatory performance?	Much Worse	Somewhat Worse	About the Same	Somewhat Better	Much Better	Environmental Affairs	34.3
Overall environmental performance	How does your plant compare to others in your global industry, in Overall environmental performance?	Much Worse	Somewhat Worse	About the Same	Somewhat Better	Much Better	Environmental Affairs	30.0

(*continued*)

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Financial Performance	How does your plant compare with its competitors in its industry, on a global basis, on Throughput: the rate at which the plant generates money through sales?	Much Worse	Somewhat Worse	About the Same	Somewhat Better	Much Better	Plant Management	100.0
Market Share and customer satisfaction on recently launched products	How do products that were recently launched by your plant compare with similar products that are manufactured and sold by your competitors on Market share?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Product Development	36.2
Market Share and customer satisfaction on recently launched products	How successful have products that were recently launched by your plant been, in terms their goals in Market share?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Product Development	38.5
Market Share and customer satisfaction on recently launched products	How successful have products that were recently launched by your plant been, in terms their goals in Customer satisfaction?	Much worse	Somewhat worse	About the same	Somewhat better	Much better	Product Development	25.3

(*continued*)

Table A1.

Factor/original variable	Question	Options					Respondent	Weight (%)
Customer satisfaction	Indicate the extent to which you agree or disagree with the statement: Our plant satisfies or exceeds the requirements and expectations of our customers	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Quality Management	25.2
Customer satisfaction	Indicate the extent to which you agree or disagree with the statement: Our customers are pleased with the products and services we provide for them	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Quality Management	26.4
Customer satisfaction	Indicate the extent to which you agree or disagree with the statement: Our customers have been well satisfied with the quality of our products, over the past three years	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Quality Management	25.2
Customer satisfaction	Indicate the extent to which you agree or disagree with the statement: Our customers seem happy with our responsiveness to their problems	Strongly disagree	Disagree somewhat	Neither agree nor disagree	Agree somewhat	Strongly agree	Quality Management	23.3

Category	Variable	Sample size	Mean	Median	SD
Costs (C)	COS_F1: Manufacturing costs	77	3.22	3.09	0.70
	COS_F2: Customer vision of company costs	77	3.06	3.00	0.72
Dependability (D)	DEP_F1: Dependability Performance	77	4.06	4.05	0.65
Environmental factors (E)	ENV_F1: Capacity of environmental practices to positively influence other company results	77	3.41	3.39	0.79
	ENV_F2: Overall environmental performance	77	4.11	4.04	0.58
Flexibility (F)	FLE_F1: Customer vision of company flexibility	77	3.89	3.85	0.63
	FLE_F2: Production system capacity to change production mix and volumes	77	3.82	3.99	0.71
	FLE_F3: Product customization	77	3.47	3.55	0.78
Innovativeness (I)	INO_F1: Process technology innovativeness	77	3.24	3.21	0.51
	INO_F2: Equipment technology innovativeness	77	3.55	3.70	0.69
	INO_F3: Product innovativeness	77	3.86	3.80	0.66
Quality (Q)	QUA_F1: Quality performance as compared to competitors	77	3.76	3.79	0.51
	QUA_F2: Quality performance as compared to competitors in recently launched products	77	3.89	3.83	0.53
Reliability (R)	RE_F1: Reliability performance as compared to competitors in recently launched products	77	3.80	3.75	0.61
	RE_F2: Reliability performance as compared to competitors	77	3.83	3.82	0.66
Speed (S)	SPE_F1: Speed performance	77	3.65	3.47	0.65
Client output (CO)	CLI_F1: Market Share and customer satisfaction in recently launched products	77	3.61	3.56	0.72
	CLI_F2: Customer satisfaction	77	3.94	3.92	0.63
Financial output (FO)	FIN_F1: Throughput: the rate at which the plant generates money through sales	77	3.60	3.55	0.86

Table A2. Descriptive statistics

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