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Manufacturing flexibility selection: an analogy to the stock portfolio for the minimization of risks and problems in the industry environment

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Abstract

For manufacturing companies, several authors recommend the use of manufacturing flexibility to minimize the adverse impacts that the risks represent to organizations. However, the multidimensional character of manufacturing flexibility and trade-offs between the various types make the task of selecting and adjusting the flexibility degree to be adopted difficult. Furthermore, the inappropriate selection of the types of flexibility to the solution of problems can create unnecessary and inappropriate investments, causing loss of capital and inefficiencies in the use of flexible resources for the anticipation of risks. Thus, to make the results available for operation management, which enable the selection of different types of flexibility, according to the needs and availability of resources of each company becomes crucial. For that purpose, an empirical research that included five companies from different industrial segments was conducted, where, through an analogy to the diversification of risks in the stock portfolio, the composition of different types of flexibility portfolios has been proposed.

Keywords: risk, selection of types of flexibility, manufacturing flexible, industry, stock portfolio.

1 Introduction

Market demand used to be stable, with low product variety and long life cycles (BEACH et al., 2000). However, over the past two decades, industrial companies faced unprecedented market changes (SCALA et al., 2006). Remaining competitive in this environment requires organizations to deal with small production batches, customized products, increased levels of abroad competition, fast changes in the market and in the regulatory (CORREA, 1994).

According to Bengtsson & Olhager (2002) and Slack (2005), flexibility became an important source of manufacturing competitive advantage, making possible to react to increasing changes in global market and product life cycle reduction. Serrão (2001) argues that the manufacturing flexibility has become a key element in the competition, above and beyond cost, time, and quality. Slack (2005) warns that manufacturing must be flexible so that it can manage operations under conditions of variety, risks and uncertainties, allowing the production process to go on.

Slack (1983) mentions that the growing consumer demand for quick responses and great product variety, together with a scenario of fierce competition,, makes flexibility the solution for many problems, contributing to manufacturing performance, reliability, cost, and speed. For those involved on tight schedules, consumer preference constant changes, and high uncertainty, manufacturing flexibility is not only desirable, but also a requirement for organizational survival (GUSTAVSSON, 1984, GUPTA & GOYAL, 1989; NORDAHL & NILSSON, 1996; KOSTE & MALHOTRA, 1999; BEACH et al., 2000; D'SOUZA & WILLIAMS, 2000; KARA & KAYIS, 2004; BOYLE, 2006, CHANG et al., 2007; BAYKASOGLU & OZBAKIR, 2008; WAHAB et al., 2008).

Despite the existence of important advances in flexible manufacturing along the last two decades, there is much work to be done to raise the understanding of this complex phenomenon (KARA & KAYIS, 2004). Corrêa (1994) highlights that more research is necessary to understand the mechanisms involved into the relationship between flexibility and uncertainty, i.e. would flexibility practices help companies and managers to better handle business uncertainties and risks? How? Which kind of flexibilities would worthwhile be used? Would it be advantageous to have some of them combined? Suarez et al. (1996) and Parker and Wirth (1999) advanced some steps toward answering some of those questions.

The present article aims to explore such gap, identifying through an empirical study, the influence of the flexibility dimensions on the risks and problems that occur in manufacturing, consequently enabling industrial organizations to deal with a variety of risks and current uncertainties. An empirical research in five companies has been performed with the objective of identifying which types of flexibility would be most helpful in preventing manufacturing problems. The research expected contribution is to establish a process to select different types of manufacturing flexibility to reduce companies' overall exposure to risk

The work is structured as follows: Section 2, segmented into manufacturing flexibility and stock portfolio, discusses the theoretical framework that brings sustainability to the article, listing concepts on manufacturing flexibility, types of manufacturing flexibility, stock portfolio, selection of stock portfolio, shares risk and diversification of share risks; section 3 discusses the empirical research in five companies in five different industrial segments, organizing, interpreting and analyzing the results and, finally, section 4 presents the conclusion of the study.

2 Stock Portfolio and Manufacturing Flexibility

This chapter presents a review on the theoretical framework of stock portfolio and manufacturing flexibility. Analogies to risks in the stock market are used: In the stock market, based on Markowitz (1952) and Sharpe (1964), a relationship between risk and return was established, being possible to reduce the risk from the agglutination of different types of shares (stock portfolio). Even though stock analyses deals with variables such as invested amount, prices and returns variability, and correlation among different stocks to define the amount to be invested in a company, manufacturing flexibility selection seems to be more complex, as described ahead.

Stock portfolio management involves decision based on perceived risk and reward expectations, while manufacturing flexibility management is related to many internal and external factors, interactions and dimensions that must be considered to support strategic operation decisions, in order to define the optimal balance between risks and costs for flexibility implementation and maintenance, i.e.: There are many types of manufacturing flexibility, which leads to the need of establishing priorities in the adequate choice of these flexibilities for different types of risks and uncertainties that occur in the productive environment.

This is a major decision-making problem, since the inappropriate choice of types of flexibility for the solution of problems will impact on unnecessary and inappropriate investments, causing loss of capital, and unavailability and inefficiency of the flexible resources selected for the problem solution.

2.1 Stock Portfolio

An individual or company makes investments with the expectation of a future outcome, always expecting a higher level of return and a lower level of risk (ROSS et al., 2002). The risk stems on the odds of effective returns to be lower than the expected return - the greater is the chance of a low or negative return to occur, the more risky the investment will be (BRIGHAM et al., 2001). To minimize risks, Treynor & Black (1973) recommended the diversification of assets through a selection of stock portfolio in order to compose what Markowitz (1952) called a 'stock portfolio'. Markowitz (1952) found that the combination of assets minimally correlated in a stock portfolio would reduce the total risk of the investor, without affecting its expected return. Selection of stock portfolio is the study of how one can invest in stocks with

the highest expected return and lowest risk as possible. It is a process to compensate the risk and the expected return in order to find the best combination of assets (LAKONISHOK et al., 1994).

According to Ross et al. (2002) and Brigham et al. (2001), a portfolio is a combination of assets, where the expected return is simply a weighted average of the expected returns of securities that comprise it. However, unlike the returns, the risk of a portfolio σ_p, generally is not a weighted average of standard deviations of its individual assets, the risk of the portfolio, in principle, can be quite different from the risks of the assets that compose it. This can be seen in Table 1, which illustrates typical average standard deviations of portfolios containing different quantities of securities traded on the New York Stock Exchange (NYSE), randomly selected.

Table 1: How many stocks make a diversified portfolio

Number of stocks in the portfolio	Annual return average standard deviation	Ratio between the portfolio standard deviation and the standard deviation of a single stock
1	49.24%	1.00
2	37.76%	0.76
4	29.69%	0.60
6	26.64%	0.54
8	24.98%	0.51
10	23.93%	0.49
20	21.68%	0.44
30	20.87%	0.42
40	20.46%	0.42
50	20.20%	0.41
100	19.69%	0.40
200	19.42%	0.39
300	19.34%	0.39
400	19.29%	0.39
500	19.27%	0.39
1000	19.21%	0.39

Source: Statman (1987)

It can be observed that the standard deviation of a portfolio of a single stock is about 49%. If two stocks were randomly selected half of the resources available were invested in each, the standard deviation would be about 37%, on average, and so on. The standard deviation of the portfolio decreases as the number of stocks increases. When it has around 100 stocks, the standard deviation of the portfolio decreased about 60%, i.e. from 49% to 20%. With 500 stocks, the deviation is 19.27%.

Therefore, the portfolio risk depends not only on the risk of each element that composes it and / or on their participation in the total investment, but also on the way in which its components relate to each other (ASSAF NETO, 2003).

According to Brigham et al. (2001), the tendency of two variables to move together is called correlation and the coefficient correlation measures this tendency. The correlation degree is measured through the correlation coefficient, which ranges from +1 for perfect positive correlation, to -1 for series with perfect negative correlation. If two series move in the same direction, they are positively correlated, if two series move in opposite directions, they are negatively correlated (TRIOLLA, 2005).

The correlation is essential to develop an efficient portfolio. To reduce the overall risk, it is better to combine - or to add to the portfolio - assets that have a negative correlation (or low positive) (ROSS ET AL., 2002). According to Assaf Neto (2003), combining assets negatively correlated can reduce the overall variability of returns. Even if the assets are not negatively correlated, the lower the positive correlation between them, the lower the resulting risks. Moreover, there are also the not correlated assets - there is no interaction between their returns. To combine non correlated assets may reduce the risk, although not as effectively as combining negatively correlated assets.

2.2 Manufacturing Flexibility

The proper interpretation and understanding of what means manufacturing flexibility is complex, both for professionals seeking for guidance as for academicians that research on the subject (GUPTA & SOMERS, 1992; OKE, 2005, CHANG et al., 2007).

On this article, a definition has been compiled, based on several authors, as follows: manufacturing flexibility is the ability (Slack, 1983; Sethi & Sethi, 1990; Upton, 1997; Zukin & Dalcol, 2000), capacity (Gustavsson, 1984; Gerwin, 2005; Koste & Malhotra, 1999), agility (Cox, 1989), competence (Suarez et al., 1995), and fitness (De Toni & Tonchia, 1998) that an organization has to change or react (Slack, 1983), given the changes in the manufacturing environment (Gupta & Goyal, 1989), considering time, cost and effort involved (UPTON, 1997).

Based on the utility concept, Correa (1994) believes that the flexibility emerges due to the need to deal with inherent uncertainties and variability of processes outputs. The uncertainties and variability lead to changes, which could be whether planned (when occur according to the organization's conscious decision made to change the organization itself or its relationship with the environment) and unplanned (when occur regardless of the organization determination, but to which the organization needs to fit). The author also suggested that environmental uncertainty and variability in the results are the two main reasons (or incentives) to search for flexible manufacturing. On the other hand, the sources of stimuli could be process, suppliers, customers, society, Corporation, competitors, and other functions, while managers seek to maintain control over the situation. According to the author, unplanned changes have five main dimensions: size, novelty, frequency, certainty, and rate.

Kara & Kayis (2004) report the necessity that leads to flexibility, which could be: a) related to the market: Demand variability (seasonal or random); Short life cycle of products and technologies; Great product variety; Increased customization; and Reduced delivery times; and b) Related to the manufacture process: Uncertainties in relation to the stop of machines; Uncertainties in relation to the material in processes; Change in the delivery time of raw materials; and Labour variations.

According to Upton (1994, 1995) and Boyle (2006), flexibility in manufacturing can exist in different levels of the organization (strategic, tactical and operational), being composed of several different types, e.g., machinery, process, product. Each type can have different aspects, known as potential, real, and necessary flexibility, measured in terms of quantity of states that can be achieved (range), mobility (impacts generated by changes such as costs and setup time), and uniformity (how much performance measures such of quality, change with the changes implemented).

Reid & Sanders (2005) segmented the manufacturing flexibility into two types: the customization and the volume flexibility. For Slack (1983), there are four types: New products flexibility - ability to introduce and produce new products or modify existing ones; Mix flexibility - ability to change the variety of products being made by the operations within a given period of time; Volume flexibility - Ability to change the aggregate level of operation outputs; and Delivery flexibility - Ability to change the delivery dates planned.

Gupta & Goyal (1989) listed eight types of flexibility: Machine flexibility - the ability to replace broken and discarded tools, to change tools in a tool magazine, and to meet or assemble the necessary structures without interference or long setup periods. This is how the system easily makes the necessary changes to produce a given set of parts; Process flexibility - ability to vary the necessary steps to complete a task. This allows several different tasks to be completed in the system using a variety of machines; Product flexibility - the ability to switch the production to a new product within a defined range of parts; Routine flexibility - ability to vary the sequences of use of the machine to continue the production of a given set of parts; Volume flexibility - Ability to operate a FMS (Flexibility Manufacturing System) profitably at different production volumes; Expansion flexibility - the ability to build a system and expand it as needed, easily and in a modular way; Process sequence flexibility - ability to change the order of several operations for each type of part; Production flexibility - ability to quickly and economically change the range of parts for any product that a flexible manufacturing system can produce.

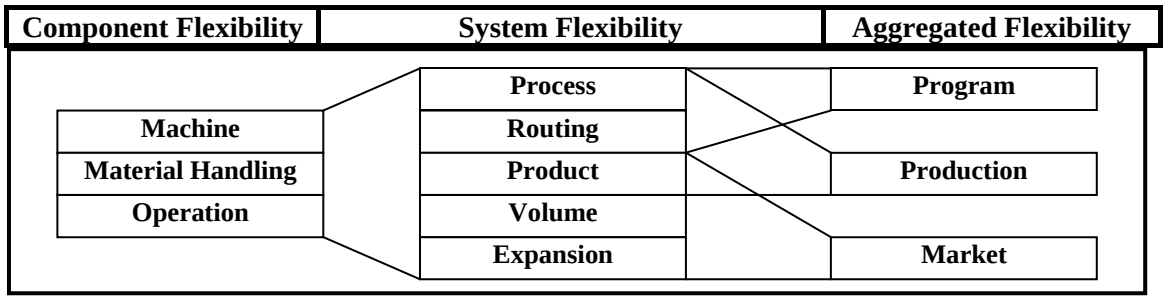
For Koste & Malhotra (1999), there are ten manufacturing flexibility dimensions, which were observed by these authors in numerous studies (Table 2).

Table 2: Manufacturing flexibility dimensions

Dimension	Definition
Machine	Quantity and variety of operations that a machine can perform not incurring in high transition penalties nor large changes in the performance results.
Labour	Quantity and variety of tasks / operations a worker can perform not incurring in high transition penalties nor large changes in the performance results.
Material movement	Quantity of paths between processing centers and heterogeneity (variety) of material that can be transported along these paths not incurring in high transition penalties nor large changes in the performance results.
Routing	Quantity of products with alternate routes and the extent of changes between the routes used not incurring in transition penalties neither in large changes to the performance results.
Operation	Quantity of products with alternate sequencing plans and the variety of plans used not incurring in transition penalties nor large changes in the performance results.
Expansion	Quantity and variety of expansions that can be accommodated not incurring in high transition penalties nor large changes in the performance results.
Volume	The extent of change and fluctuation degree in the aggregate level of outputs that the system can accommodate not incurring in transition penalties neither in large performance changes.
Mix	Quantity and variety (heterogeneity) of products that can be produced not incurring in high transition penalties neither in large changes in the performance results.
New Products	Quantity and variety of new products that are introduced into production not incurring in high transition penalties neither in large changes in the performance results.
Modification	Quantity and variety of changing in the product that are made not incurring in high transition penalties neither large change in the performance results.

Source: Koste & Malhotra (1999)

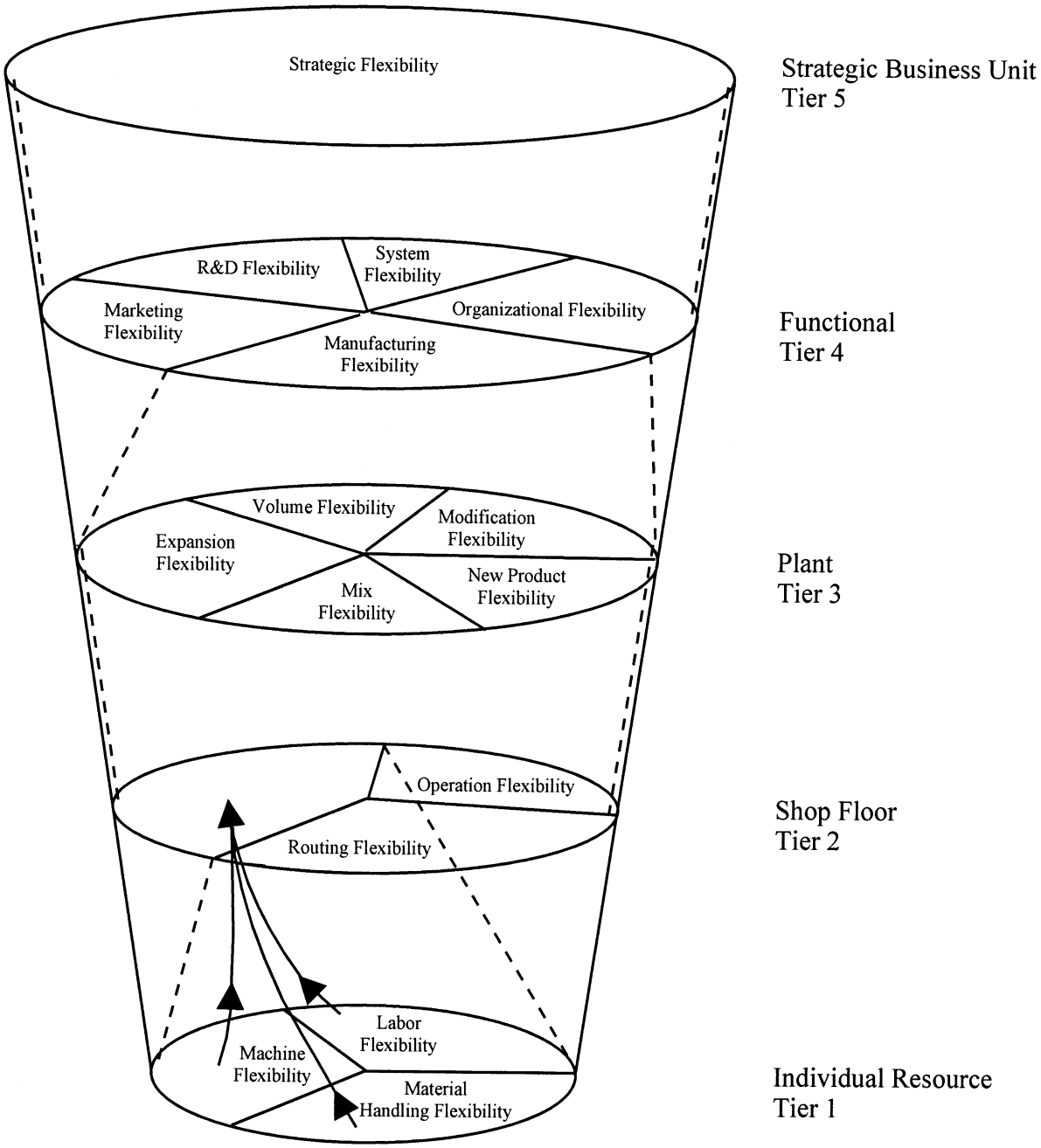
For Vokurka & O'Leary-Kelly (2000), there are twelve flexibility dimensions, adding the flexibility of production (the ability to produce new products without the need for investment in new equipment) and supply (capacity of the plant to adapt to changes in the delivery requirements) to those already proposed by Koste & Malhotra (1999). Sethi & Sethi (1990) organized the types of flexibility in a hierarchical structure that reflects the different operation levels of the production systems, and their connections, as seen in Figure 1.



Source: Sethi & Sethi (1990)

Figure 1: Links between the various types of flexibility

Suarez et al. (1995, 1996) presented the concept that the various types of flexibility express their effects on so-called basic or first-order flexibilities, namely: mix, volume, new products and delivery time, which are directly perceived by the consumer, directly affecting the strategic positioning in the market. Similarly, Koste & Malhotra (1999) established a hierarchical scale for flexibilities that shows potential relationships among them, such as individual resources, production techniques and materials, product, plant, functional and strategic business units, as shown in Figure 2.



Source: Koste & Malhotra (1999)

Figure 2: Hierarchy of the flexibility dimensions

Similarly to the correlation that exists in the stock portfolio, the manufacturing flexibility has trade-offs among its different types. Gupta & Goyal (1989) argue that understanding these trade-offs can increase the internal organization of a structured flexible system. Suarez et al. (1996) analyzed 31 plants for the production of printed circuit boards in Europe, Japan and the United States, and found the existence of positive and negative relationships between the variables involved in the process. Parker & Wirth (1999) also studied the relationship between the flexibility dimensions of and its elements and identified the existence of complex relationships and trade-offs. Koste and Malhotra (2000) searched eighteen papers on the subject and found a relationship between machine flexibility and mix flexibility, quoted in ten researches as a requirement of the product flexibility and a relationship between machine flexibility and routing flexibility. They also found that five dimensions (expansion, volume, mix, new products and change of products) are not related to other dimensions, indicating that these dimensions do not support the development of other dimensions, but are developed by them.

3 Empirical Research on Manufacturing Flexibility

The research, performed along a three-month period on companies located in southern Rio de Janeiro state, Brazil, from five different industrial segments (see Table 3), was based on a survey of tactical-level staff (production environment related), aimed at investigating the manufacturing flexibility demands from different industries, and also verifying heterogeneities in the perception of respondents about the effect of each type of flexibility on the solution of manufacturing problems. The study sample had five respondents from each of the companies surveyed, totalling twenty-five respondents.

Table 3: Classification of companies surveyed

Company	Product
Automotive industry	Commercial vehicles
Chemical industry	Agrochemicals, fertilizers, and pesticides
Glass Industry	Flat glass
Equipments industry	Electronic equipments
Tires Industry	Tires

Source: Research data

The research purported to find out which types of flexibility help the most on preventing manufacturing problems and what would be the optimum flexibility composition (different types of flexibility selected and agglutinated), based on management perception, i.e. an 'ideal flexibility portfolio', similar to stock portfolios, having as development base the studies from Swamidass & Newell (1987), Beach et al. (2000), Kayis & Kara (2005), Slack (2005) and Gerwin (2005), who argue that different manufacturing situations are subject to different types of uncertainty and variations, requiring different types of flexibility, which often conflict and overlap (D'SOUZA & WILLIAMS, 2000; UPTON, 1995; SAWHNEY, 2005). Twelve different types of flexibility have been selected to compose the data collection instrument, based on Slack (1983), Gupta & Goyal (1989), Koste & Malhotra (1999) and Vokurka & O'Leary-Kelly (2000), as seen on Table 4. Results are shown, explained, and discussed ahead.

Table 4: Summary of analysis of flexible manufacturing in five companies surveyed

Types of Flexibility	AFF	Chemical			Glasses			Equipment			Tires			Vehicle		
		A	CTF	FF	A	CTF	FF	A	CTF	FF	A	CTF	FF	A	CTF	FF
Labor	16.80	4.0	■■■■	16.0	3.4	■■	6.8	5.0	■■■■■	25.0	4.6	■■■■■	23.0	4.4	■■■	13.2
Volume	16.28	4.6	■■■■	18.4	4.6	■■■■	18.4	4.4	■■■	13.2	4.4	■■■■	17.6	4.6	■■■	13.8
Mix	13.48	4.6	■■■■	18.4	2.4		0.0	5.0	■■■■■	25.0	3.2		0.0	4.8	■■■■■	24.0
Machine	11.32	2.6		0.0	2.4		0.0	5.0	■■■■■	25.0	4.6	■■■■	18.4	4.4	■■■	13.2
Expansion	10.80	3.4	■	3.4	5.0	■■■■■	25.0	3.4	■	3.4	4.2	■■	8.4	4.6	■■■	13.8
Delivery	8.00	2.0		0.9	5.0	■■■■■	25.0	4.2	■■	8.4	3.0	■	3.0	3.6	■	3.6
Production	5.04	4.6	■■■■	18.4	2.6		0.0	3.2		0.0	3.4	■	3.4	3.4	■	3.4
New Products	5.00	3.6		0.0	2.4		0.0	5.0	■■■■■	25.0	2.2		0.0	2.2		0.0
Modification	3.52	2.2		0.0	3.8	■	3.8	4.6	■■■	13.8	2.4		0.0	3.2		0.0
Operation	3.36	2.0		0.0	2.6		0.0	3.4		0.0	2.4		0.0	4.2	■■■■	16.8
Routing	1,44	1.4		0.0	1.6		0.0	3.4		0.0	2.4		0.0	3.6	■■	7.2
Movement of material	0.72	1.8		0.0	2.0		0.0	3.6	■	3.6	2.4		0.0	1.8		0.0

"A" stands for Average ratings of respondents on the help that a certain kind of flexibility provides the manufacture problem solutions, with a score ranging from a minimum of 1 (not helpful) to a maximum of 5 (essential); "CTF" indicates the Compositions of Types of Flexibility essential for manufacturing investment: each respondent selected the types of flexibility required for the company operations. Each mark (black square) indicates how many respondents (out of five) selected that kind of flexibility to compose the "portfolio" of flexibility for the company. The column "FF" represents the flexibility factor, obtained by multiplying “A” by “CTF”, as proposed by Oliveira (2009).

“AFF” is the average of the flexibility factors (FF) among the five companies surveyed. The twelve types of flexibility at Table 4 are arranged in “AFF” descending order, i.e., the overall respondent priority choice. Result analyses are commented, as follows:

As it can be seen at Table 4, the vehicle assembly plant composes flexibility mainly with machine, volume, and expansion. The chemical industry establishes 'flexibility portfolios' with volume, mix, production, and labour. The glass industry adheres to the selection of the flexibility of delivery, volume, and expansion. The equipment industry prefers the flexibility of machine, labour, new products, and product mix. The tire industry brings together the flexibility of labour, machine, and volume, based on the respondents' perception it would minimize the required flexibility investments.

With the exception of volume and labour, whose average in all five companies ranged between 3.4 and 5.0, the priority flexibilities are quite different. In the chemical industry, for example, three types of flexibility got the highest scores: volume, production mix, and production (tied at 4.6); at the glass industry, there is a tie between expansion and delivery (tied at 5.0). In the manufacturing equipment, labour, mix, machine, and product mix have scores of 5.0. In the tire industry, the top flexibilities are machine and labour (average of 4.6 for both). In the auto manufacturer, the flexibility with higher score, as perceived by the respondents, is the production mix;

The equipment industry, out of the five studied companies, is the heavier manufacturing flexibility user, indicating machine (5.0), labour (5.0), mix (5.0), product (5.0), modification (4.6), volume (4.4), and delivery (4.2) to solve problems; The glass industry, by the other side, is the least used of manufacturing flexibility, evaluating the most flexibility a general statement,

Even though demands for flexibility are particular to each industry segment, a common preference for flexibility of manpower, volume, mix, and machine has been detected. These four types of flexibilities have been cited with emphasis on the score, separately and in different combinations, in at least three of the five industries analyzed.

4 Conclusions

Similarly to what occurs in the stock market, portfolios of flexibility can be used against risks and uncertainties in manufacturing organizations. Although, the research was not aimed at finding an efficient manufacturing flexibility frontier (if it does exist), as occurs in the stock market. However, the literature review showed that there are trade-offs in the flexibility and that these trade-offs indicate negative and positive relationships between different types of manufacturing flexibility. This means that, investing in types of flexibilities which have a high positive correlation, less investments in flexibility will be needed, while, when one invests in flexibility with negative correlation, more investments will be required (exactly the opposite of what occurs in the stock market).

For this reason, here are deemed feasible portfolios of manufacturing flexibility, according to the perceptions of those involved with the daily production process industries. The reason is to make possible an optimal balance between its different types, to provide reducing the impact of operational risks, without requiring the need for unnecessary investments for solving problem on industrial organizations.

Although the results found here are empirical, it is recommended that further studies of flexibility, compiling results from companies related to the same type of industry (for example, four equipment manufacturers, five chemical plants, etc.), so that more robust findings can help companies to define which types of flexibility to adopt. Continuity to this research can lead to development of flexibility decision arrays, useful in managing companies' risks.

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