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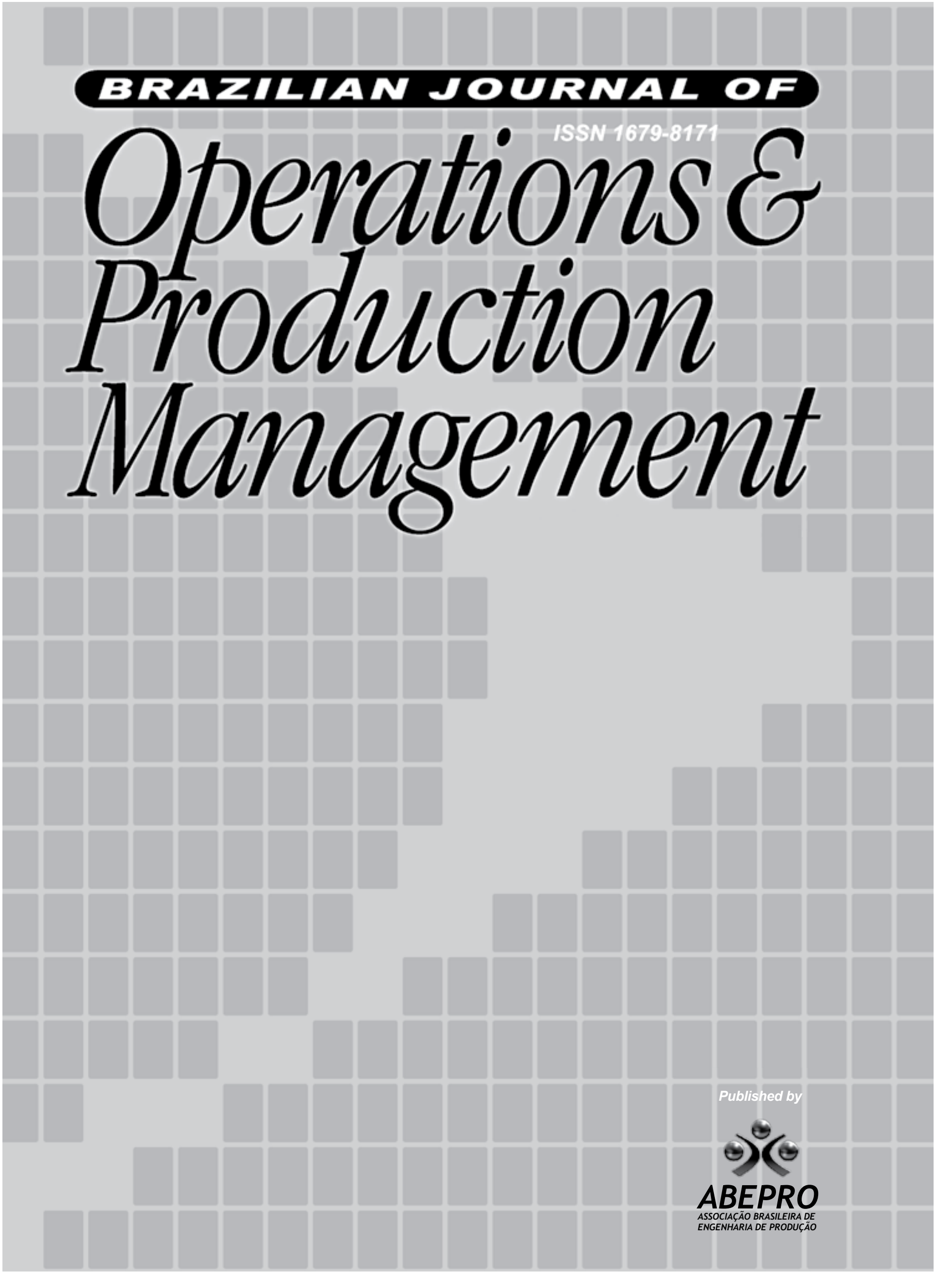

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Editorial Introduction
Paulo A. Cauchick Miguel, Marcelo Márcio Soares, Sérgio E. Gouvêa da Costa . 03

A Study on Just-in-Time Implementation in Portugal: Some Empirical Evidence
Maria Rosário Mota Oliveira Alves Moreira and Rui Alberto Ferreira dos Santos Alves 05

Framing Operations and Performance Strategic Management System Design Process
Edson Pinheiro de Lima, Sergio Eduardo Gouvêa da Costa and Jannis Jan Angelis 23

Monitoring the Mean Vector and the Covariance Matrix of Bivariate Processes
Marcela Aparecida Guerreiro Machado and Antônio Fernando Branco Costa .. 47

Sensorial Analysis of Wines from *Malpighia glabra* L. Pulp
Sheyla dos Santos Almeida, Roberto Rodrigues de Souza, José Carlos Curvelo Santana and Elias Basile Tambourgi............................ 63

The Effect of the Workload on Due Date Performance in Job Shop Scheduling
Miguel Cezar Santoro and Marco Aurélio de Mesquita 75

ABEPRO Executive Board.. 89

About ABEPRO – Brazilian Association of Production Engineering.. 89

ABEPRO Editorial Board.. 89

Manuscript Guidelines... 90

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Editorial Introduction

On behalf of the Editorial Board, we are happy to deliver the first issue of volume 5 (2008) of the Brazilian Journal of Operations & Production Management. We appreciate all the academicians who support and contribute to the editorship. The accomplishment of this issue would not be possible without the work of our editorial review board. We would like to take this opportunity to acknowledge their contribution to the journal referral process.

In this issue we have the pleasure of announcing that Barbara Flynn of Indiana University and Robert Young of North Carolina State University, both from the USA, are now part of the editorial advisory board. Sérgio Gouvêa da Costa and I have formally invited them and we are honoured they kindly accepted.

We hope the readers find the articles in this issue a useful source within the scope of production engineering and operations management.

In this Issue

The present issue has five competitive and up-to-date papers from some researchers from Brazil and abroad. The articles consider qualitative and quantitative methods as the methodological research approach.

The first paper is from Portugal by Maria do Rosário Moreira and Rui Alves. It surveys Just-in-Time (JIT) implementation in Portuguese manufacturing firms. An important contribution is the identification of most common difficulties for JIT implementation, so that Portuguese firms that can be prepared to overcome those difficulties. In addition, a significant empirical implication of the study is that Portuguese firms should use Just-in-Time as a philosophy rather than as a solution for operations-related problems.

The Portuguese paper is followed by a joint research by Edson Pinheiro de Lima and Sergio Gouvêa da Costa, from Brazil and Jannis Angelis, from Warwick Business School in the UK. The authors propose a framework that represents reconciliation between research and practice in the field of operations strategic management system design, implementation and management. The main result is a synthesis of three frameworks that each addresses the design process in different levels: the performance management system life cycle model; the process approach for guiding design and implementation issues; and recommendations that synthesizes the design task.

The third article is a study by Marcela Machado and Antônio Branco Costa, who propose the joint use of two charts based on the non-central chi-square statistic (NCS statistic) for monitoring the mean vector and the covariance matrix of bivariate processes, named as the joint NCS charts. The joint NCS charts are recommended for those who aim to identify the out-of-control variable instead of the parameter that was affected by the assignable cause: if only the mean vector or only the covariance matrix or both.

Sheyla Almeida, Roberto de Souza, José Curvelo Santana and Edias Tambourgi explores the sensorial analysis of Barbados cherry wines. The authors conduct an assessment by using a questionnaire to evaluate the effect of soluble solids and the concentration of fruit pulp on sensorial quality attributes (colour, flavour and aroma) of wines. Results showed that Barbados cherry wines were suave, and sweet and with moderate alcohol concentration. Flavour and colour of wines were characteristic of ***acerola*** fresh fruit. In addition, a statistical analysis was also undertaken to assess the sensorial attributes.

Finally, the fifth article, by Miguel Santoro e Marco de Mesquita, offers a simulation model to investigate the effect of the work-in-process control on due date performance in a job shop environment. The paper demonstrates that the simulation runs include different shop floor configurations, workloads and sequencing rules. The results reveal that due date performance is highly dependent on the work-in-process, particularly after the system reaches saturation. Additionally, the simulation model is useful to show job shop managers the effect of the work-in-process control in the due date meeting performance.

Once again, thank you everybody that contributes to the BJOPM. The journal expects to count on the research community by considering the journal as the outlet for publication of their research work mostly related but not limited to the research areas defined by ABEPRO.[1]

This issue closes with ABEPRO's executive and ABEPRO's Editorial Board (NEA).

Paulo A. Cauchick Miguel and Sergio E. Gouvêa da Costa

[1] Production Management; Quality Operations; Economic Management; Ergonomics and Work Safety; Product Development; Operational Research; Strategy and Organizations; Technology Management; Information Systems; Environmental Management; Education issues in Operations Management.

Volume 5, Number 1, 2008, pp. 05-22

A Study on Just-in-Time Implementation in Portugal: Some Empirical Evidence

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Abstract
The objective of this paper is to find how far the Just-in-Time system is being implemented by Portuguese manufacturing firms, as well as assessing its perception and its potential benefits by managers. First, several studies about the implementation of the Just-in-Time system in various countries over the past 25 years are reviewed, and then the descriptive survey research is reported. Data were collected from a mail questionnaire sent to a few hundred firms in Portugal. The findings show that the surveyed firms view the Just-in-Time system as a way to reduce inventories, to increase quality, and to eliminate waste. Despite this good perception, less than 6% of the surveyed firms have the necessary conditions to successfully implement a Just-in-Time system. A significant practical implication of this study is that Portuguese firms should use Just-in-Time as a philosophy rather than as a solution for operations-related problems. Another contribution is to point out the most common difficulties for its implementation, so that Portuguese firms that want to do it can be prepared to overcome those difficulties.

Keywords: just-in-time, descriptive survey

Introduction

Just-in-Time is a philosophy of operation that seeks to utilize all resources in the most efficient way. This is accomplished by eliminating waste, i.e., anything that does not add value to the product. The Just-in-Time system was developed in Japan by Toyota (Monden, 1998), and was also adopted by other automobile and electronic manufacturers in Japan. In the late 1970s U.S. manufacturers became more and more interested in this manufacturing management philosophy, and since the 1980s many non-Japanese firms began adopting it. Indeed, as regional and global competition increases, efficient operations are paramount.

As early as 1982, Schonberger (1982a), identified higher quality, lower inventory levels, improved throughput times and shortened response times as some of the benefits of Just-in-Time. According to Inman and Mehra (1993), the main advantages of the Just-in-Time philosophy are lower costs, better quality, and higher competitive advantage. But the most consistent benefit found in empirical studies is a reduction in inventory levels and/or an increase in inventory turnover (Toni and Nassimbeni, 2000; Cua et al., 2001; Kaynak and Pagán, 2003).

There are, however, some conditions or pre-requisites to successfully implement this management philosophy, such as quick and economic setups (to allow small lot sizes) and a uniform production rate (to ensure schedule stability). These conditions are presented by several authors (e.g., Golhar and Stamm, 1991; Zhu et al., 1994; Ahmad et al., 2004; Schonberger, 2007), adding other elements such as a pull control system, flexible employees, preventive maintenance, supplier long-term relationships, and quality circles. Golhar and Stamm (1991), conducted an extensive literature review and identified four basic principles of the Just-in-Time management philosophy: (i) elimination of waste, (ii) employee involvement, (iii) supplier long-term relationships, and (iv) total quality control. These principles, and the implementation conditions, provided the foundation for the survey research design presented in Section 3.

Several studies on Just-in-Time practices and its implementation have been conducted, first in developed countries (e.g., United States, United Kingdom, Japan, Australia, Canada) and later in developing countries (e.g., Mexico, Egypt, Ghana, India, Malaysia, Saudi Arabia). This paper presents a field study of Just-in-Time in Portugal. Its objectives are to report the results of a descriptive survey research (Forza, 2002) conducted in Portugal to assess local implementation of Just-in-Time practices.

An important contribution of this paper is that it adds to the empirical database of Just-in-Time practices and its implementation in Portuguese firms, allowing one to know how manufacturing managers are aware of this management philosophy and its potential benefits. Another contribution is to find the most common difficulties for Just-in-Time implementation, so that Portuguese firms can be prepared to overcome them. As this study is exploratory in nature, no hypotheses are presented for rigorous statistical testing. Instead, some preliminary findings with regard to the above issues are highlighted.

The paper is divided as follows. Section 2 presents a short review of empirical studies of Just-in-Time practices in several countries. In Section 3, a description of the research methodology (sample, method, questionnaire design, etc.) is presented. The analysis of the results of the survey, using descriptive statistics, are presented in Section 4, and Section 5 contains the main conclusions and some recommendations for practitioners considering the use of Just-in-Time in Portugal.

Literature Review

As previously mentioned, in the late 1970s, early 1980s many non-Japanese firms began adopting the Just-in-Time philosophy. Subsequently, many studies dealing with Just-in-Time implementation in several countries have been conducted and reported.

Table 1 presents a non-exhaustive list of such empirical studies, with the countries sorted in alphabetical order. These studies were collected searching international bibliographic databases (such as Academic Search Complete and Business Source Complete - EBSCO, EconLit, Economia y Negocios, Regional Business News, Science Direct, Emerald, Ingenta Select, and Scopus) using the search capabilities of those databases (by word in the subject, abstract or title fields). A search on the World Wide Web using Google Scholar complemented the previous list of references.

As can be seen in Table 1, the first studies date back to 1982 and 1983, and were conducted in the United States and the United Kingdom by Schonberger (1982b), and White (1983), respectively. These two countries deserved a lot of attention over the years, especially the United States, and other studies followed.

Table 1 - Studies relating to Just-in-Time implementation in several countries.

Country	References
Australia	Buxey and Petzall (1991); Clarke and Mia (1993); Power and Sohal (2000)
Canada	Handfield et al. (1993); Deshpande and Golhar (1995)
China	Pheng and Min (2005)
Egypt	Salaheldin (2005)
Ghana	Gyampah and Gargeya (2001)
Hong Kong	Cheng (1988)
India	Chandra and Kodali (1998); Kumar et al. (2004); Laosirihongthong and Dangayach (2005); Wakchaure et al. (2006)
Italy	Bartezzaghi et al. (1992)
Japan	Matsui (2007)
Korea	Lee (1992)
Malaysia	Ahmed et al. (2004)
Mexico	Lawrence and Hottenstein (1995); Lawrence and Lewis (1996)
Saudi Arabia	Andijani and Selim (1996)
Singapore	Hum and Ng (1995); Min and Pheng (2005)
Spain	Zantinga (1993); Gonzalez-Benito and Spring (2000)
Sweden	Engstrom et al. (1996)
Turkey	Oral et al. (2003); Polat and Arditi (2005)
United Kingdom	White (1983); Voss (1984); Voss and Robinson (1987); Mould and King (1995); Oliver et al. (1996); Waterson et al. (1999)
United States	Schonberger (1982b); Plenert (1985); Celley et al. (1986); Crawford et al. (1988); Im and Lee (1989); Gilbert (1990); Ahmed et al. (1991); Billesbach et al. (1991); Freeland (1991); Young (1992); White (1993); Huson and Nanda (1995); Sriparavastu and Gupta (1997) Wafa and Yasin (1998); White et al. (1999); Lau (2000); Kaynak and Pagán (2003); Yasin et al. (2003)
US and Japan	Womack et al. (1990); Cusumano and Takeishi (1991); Daniel and Reitsperger (1991); Nakamura et al. (1998); Aghazadeh (2003)
West Germany	Wildemann (1988)

Volume 5, Number 1, 2008, pp. 05-22

In the 1980s, besides the several studies on the U.S. and the U.K., there were also papers about the implementation of Just-in-Time in West Germany and Hong Kong in 1988. Most of the studies reported in the 1990s were conducted in developed countries, such as Australia, Canada, Italy, Korea, Spain, Sweden, etc. Similar studies in developing countries (China, Egypt, India, Mexico, Turkey, etc) are more recent, most of them already in the 21st century. Most of the reported studies provide empirical evidence about Just-in-Time implementation and practices.

Research Methodology

A survey questionnaire was used to obtain the data used in this research. This methodology has been used by several researchers in global manufacturing planning and control (e.g., Handfield and Withers, 1993).

Convenience sampling (Forza, 2002) was selected, and the electronic, metal parts, and paint manufacturers (ISIC codes 3210, 3813, 2891, 2422, 3521) were chosen due to the availability of data that allowed us to send them a postal questionnaire.

The questionnaire was sent to the manufacturing or general manager of the selected firms. The criteria to select the firms were the number of workers and annual sales. The mean number of employees in each industry and the mean sales value were first computed, and any firm that had simultaneously more than a half of those values was selected with the purpose of avoiding small and non-representative firms. Thus, the questionnaire was mailed to 384 companies (293 from the metal parts industry, 53 from the electronic materials industry and 38 from the paint manufacturers).

The questionnaire was developed to collect three types of information: (1) general information about the firm, including its characteristics and the industry it belongs to; (2) information that would allow an assessment of the extent to which the responding firm is using Just-in-Time; (3) information that would allow an assessment of the extent to which the respondent is familiar with the Just-in-Time system.

The design and administration of the questionnaire followed Salant and Dillman's total design method as closely as possible (Salant and Dillman, 1994). The initial questionnaire was pre-tested on operations management professors and questionnaire survey builders and, after incorporating their comments and suggestions, an intermediate version was tested on a small group of firms in order to eliminate any ambiguous and/or misleading questions. Thus, five firms were randomly chosen and the questionnaire was tested with the top manufacturing managers through personal interviews.

Comments from these managers were incorporated into the final version of the questionnaire, which consisted of 26 questions. The first six questions were about the firm's characteristics. It also contained questions about the quality system (questions 12 to 16), suppliers (questions 17 to 19), seasonality/production rate (questions 7 and 8), employee flexibility (questions 9 and 10) and preventive maintenance (questions 22 to 23); finally, it contained one question about the production control system (question 11), the production lot size (question 20), the set-up times (question 21) and the knowledge and use or not use of Just-in-Time (question 25 and 26). Detailed information about each question is presented in the Appendix, together with the answers' codification.

In total, 142 questionnaires were received (103 from the metal parts industry, 20 from the electronic materials industry, and 14 from the paint manufacturers; 5 questionnaires did not answer questions 1 and 2). The response rate was 37%, which is better than in similar studies reported in the literature (e.g., Cheng, 1988; Bartezzaghi et al., 1992; Lee, 1992; Clarke and Mia, 1993; Lawrence and Hottenstein, 1995 and Lawrence and Lewis, 1996). However, 11 questionnaires had to be discarded because many answers were left blank, and so only 131 questionnaires could be used. Returns mirrored the composition of the original sample, indicating no systematic response bias.

The answers to eight questions (questions 9, 11, 12, 13, 16, 18, 20 and 22) had to be codified because they were categorical. Eleven of them were binomial (yes/no) and were entered into the analysis through the use of a 0-1 code. Five were continuous (the answers of questions 3, 4, 5, 6 and 17), and their values were considered. The answers to questions 1 and 2 indicate the firm's main activities and were used to distinguish the questionnaires among industries.

Main Results

Being a descriptive survey, the questionnaires were analyzed using descriptive statistics and no attempt was made to test any hypotheses. The results are based mainly on the aggregate data obtained from the 131 sets of responses.

The answers to the binomial and the dichotomic questions are presented in Figures 1 and 2. It can be seen in Figure 1 that most firms (87.5%) experience no seasonality, 74.6% of them don't need extra work, and 85.7% have flexible workers, thus having some of the necessary conditions for a Just-in-Time system. However, most firms (71.8%) still use a push method to control production (Figure 2).

Quality is a major concern; in spite of the fact that less than half of the firms have a product and/or process certification, quality is considered more important than price (Figure 2), and almost all the firms surveyed had some kind of inspection mechanism to detect defectives (Table 2). In most cases (around 85%) suppliers deliver in time and there are efforts to reduce setup times. Although used by less than one third of the firms, the Just-in-Time system is quite well known by 86.5% of them.

From the answers to question 26 it is possible to conclude that when a firm says it is using a Just-in-Time system (31.5% of them answered "yes"), that does not necessarily mean that it has consistent practices. The questionnaires with an affirmative answer to question 26 were further analysed to see if the answers to the Just-in-Time implementation conditions were consistent, and Table 2 shows the number of firms that, although

Volume 5, Number 1, 2008, pp. 05-22

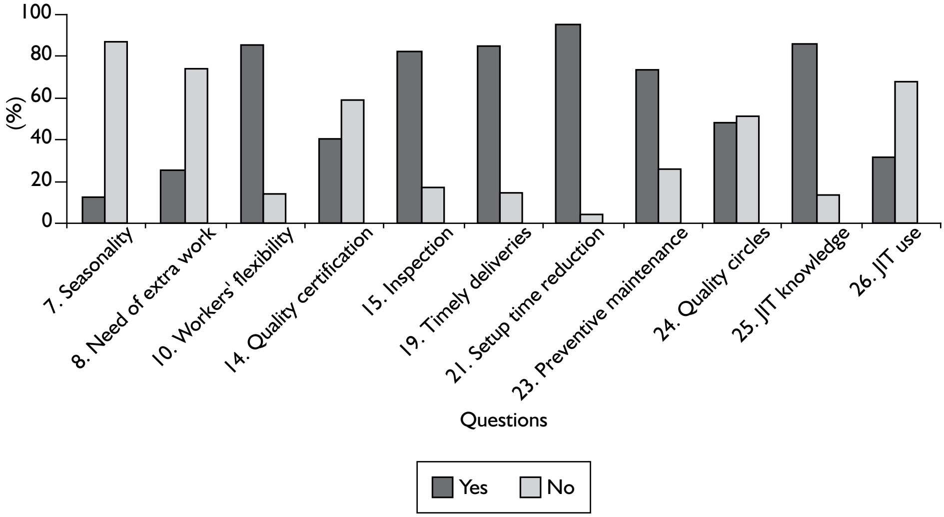

Figure 1 - Answers to yes-no questions.

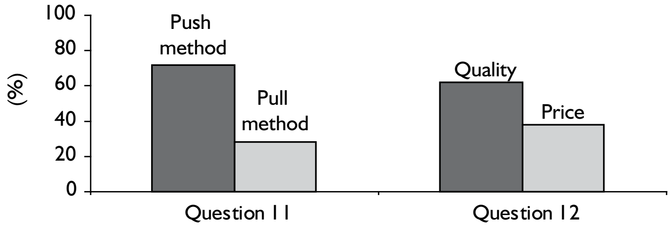

Figure 2 - Answers to dichotomic questions.

Table 2 - Answers to some questions from firms that say they use JIT.

Question	Answer	Frequency	Percentage
7	Seasonal products	5	13.8
9	Low employee flexibility	8	22.2
11	Use push control system	22	61.1
15	Any quality control system	6	16.7
20	Large lot size	12	33.3

saying they have a Just-in-Time system to control their operations, have a non-uniform production rate, are using the *push* control system, have employees with low flexibility, do not have any quality control system, or have large production lots.

Table 3 presents statistical data regarding the number of workers, sales and inventory values, and the number of suppliers of the responding companies. The number of workers ranged from 17 to 3,686, with a mean of 190. Annual sales ranged from 8,000 euros to 312,500 million euros, with a mean of 4,750 million euros. In both work-in-process and final products inventory the mean was high for companies that were trying to implement the Just-in-Time system. Even though the average number of suppliers across all firms was high (85 suppliers for the main raw material), there was a significant proportion (40%) that had 10 or fewer suppliers.

Table 4 records data concerning the responding firms' manufacturing system profile. It can be seen that few firms (less than 25%) purchased raw materials in periods longer than

Table 3 - Statistical data of the responding firms.

Question	Mean	Mode	Std. Dev.	Min	Max
Number of employees	190	40	375	17	3,686
Sales value (10^6 euros)	4,750	50,000	32,755	8,000	312,500
Final products inventory value (10^6 euros)	5,745	0	37,335	0	350,000
Work-in-process inventory value (10^6 euros)	4,400	500	30,640	0	275,000
Number of suppliers	85	10	321	1	3,000

Table 4 - Manufacturing system profile of the responding firms.

	Answers	Code	Frequency	Percentage
Workers' specialization	Low	1	26	20
	Medium	2	89	69
	High	3	14	11
	Total		129	100
Firm position in terms of quality	Inferior	1	0	0
	In the mean	2	59	45
	Superior	3	72	55
	Total		131	100
Where control is made	At beginning	1	10	10
	Several phases	2	81	78
	At end	3	12	12
	Total		104	100
Raw material purchases frequency	<1 week	1	15	12
	[1,2] weeks	1.5	33	27
	]2,4] weeks	3	45	37
	[1,3] months	9	26	21
	>3 months	30	4	3
	Total		123	100
Production lot	<1 day	1	18	18
	[1,10] days	5	34	35
	]10,20] days	15	18	18
	]20,30] days	25	18	18
	>40 days	40	10	11
	Total		98	100
Machine breakdown frequency	Every day	1	8	7
	[2,5] days	3	9	8
	]5,10] days	8	8	7
	]10,30] days	20	22	20
	[1,3] months	60	21	19
	]3,6] months	150	20	18
	> 6 months	270	23	21
	Total		111	100

Volume 5, Number 1, 2008, pp. 05-22

4 weeks; of the remaining firms, roughly half purchased every 2 to 4 weeks and the other half every 2 weeks or less. In some cases the production lot was large enough to last for 20 or more days; however, more than half of the firms used lots that lasted only for 10 days or less. The time between machine breakdowns is also an important issue; some firms experienced frequent failures, but for the majority the time between machine breakdowns exceeded one month.

Question 25 asked firms about their knowledge about the Just-in-Time system. If the answer were affirmative, they were asked about its most important characteristic. Table 5 presents the most important characteristics mentioned by managers, sorted by their relative importance. It can be seen that 47 firms (about 42%) pointed out inventory reduction (in general, finished goods, and work-in-process) as the most important characteristic. For 15 firms (about 13%) good relationships with suppliers and/or timely deliveries are important issues, while 19 firms (about 17%) mentioned high quality standards and/or zero defectives as a major concern.

Table 5 - Most important characteristics of the Just-in-Time system.

JIT characteristics	Frequency
Low finished goods inventory	25
Inventory reduction	16
High quality standards	13
No delivery delays	13
Zero defects	6
Raw materials arrive as soon as needed	6
Low work-in-process inventory	6
Good relationships with suppliers	5
Suppliers deliver in time	4
Flexible production system	3
JIT production	3
Kanban	3
Continuous production flow	2
Feasible equipment	2
Production flexibility	1
Good planning	1
Set-up reduction	1
Small lot sizing	1
Good information system	1

Conclusions

Most of the surveyed firms either have only some of the conditions for a successful implementation of a Just-in-Time system or there is a significant trend towards it (like no seasonality, flexible workers, quality concern, efforts to reduce setup times, etc).

Among all the respondents only 7 firms, less than 6%, fulfill all the previously mentioned conditions.

Concerning the managers' awareness about the Just-in-Time system, the data showed that most of the sample companies were concerned primarily with its operational elements, such as reduction of inventories, quality improvement, and relationships with suppliers. So, managers do not view the Just-in-Time system as a global management philosophy nor do they recognize strategic motivations for its implementation.

It has also provided empirical data which indicate that managers are aware of the importance of quality, since almost all of the firms have an inspection system to detect defectives. However, very few of them are certified and quality circles practically do not exist. Further, most Portuguese firms do not have all the necessary conditions to successfully implement a Just-in-Time system.

This study has also shown that Portuguese firms have the following basic perspectives about the Just-in-Time system: it is perceived as a tool to reduce inventories, to increase quality and to eliminate waste, it highly depends on suppliers' performance, it helps improve quality and thus reduce scrap and defectives, and it is a tool for production planning and control.

From the analysis of the aggregate data obtained from the 131 sets of responses, the most common difficulties for the implementation of the Just-in-Time system in Portugal are: (i) most firms (more than 70%) still use a push method to control production; (ii) some firms purchase raw materials in periods longer than 4 weeks (one possible explanation is that suppliers are not considered as partners and a safety stock is kept to face poor supplier delivery performance); (iii) in both work-in-process and final products inventories the mean value was high for companies that were trying to implement Just-in-Time.

This study has some limitations. The main goal of the questionnaire survey was to find out whether Portuguese firms that have, apparently, operational conditions to adopt a Just-in-Time system, do use it. No information is available to assess what is specific about Portuguese firms, and what its impact is on the success of Just-in-Time implementation, and to compare Portuguese practices with other countries.

These limitations provide clues for future research: to find what is particular about Portugal and other recently developed countries, and what can be learned from those settings, and to establish a link between this study and the studies presented about other countries.

Acknowledgements

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Volume 5, Number 1, 2008, pp. 05-22

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Volume 5, Number 1, 2008, pp. 05-22

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Biography

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Volume 5, Number 1, 2008, pp. 05-22

Appendix: Questionnaire and Answers' Codification.

	Question	Description
1	Firm's activity	Firm's main activity
2	Other activities	Firm's other activities
3	Employees	Number of employees
4	Sales value	Sales value in thousands of euros (at the end of the year)
5	Final products inventory	Final products inventory value in thousands of euros (at the end of the year)
6	Work-in-process inventory	Work-in-process inventory value in thousands of euros (at the end of the year)
7	Seasonality	1, if the firm has seasonal products; 0, otherwise
8	Work over time	1, if the firm needs employees to work over time; 0, otherwise
9	Workers' specialization	1, if workers have low specialization; 2, if they have medium specialization; 3, if they have high specialization
10	Workers' adaptation	1, if workers can easily perform other tasks; 0, otherwise
11	Push-Pull method	1, if production control is made from the beginning to the end (push); 2, if production control is made from the end to the beginning (pull)
12	Quality vs Price	1, if quality (conformance) is more important than price in the specific firm's market; 2, if price is more important than quality (conformance) in the specific firm's market
13	Position of quality	1, if the firm has relative "less quality" than its competitors; 2, if the firm has the same quality as its competitors; 3, if the firm has relative "more quality" than its competitors
14	Quality certification	1, if the firm has a product or process certification; 0, otherwise
15	Quality control mechanism	1, if the firm has a mechanism to control the quality of the process; 0, otherwise
16	Control phase	1, if the control is made at the beginning of the production process; 2, if the control is made after more than one phase of the production process; 3, if the control is made at the end of the production process
17	Suppliers of raw materials	Number of raw materials suppliers
18	Purchases frequency (for the most important raw materials suppliers)	1, if the purchase frequency is less than 1 week; 1.5, if the purchase frequency is between 1 and 2 weeks; 3, if the purchase frequency is between 2 and 4 weeks; 9, if the purchase frequency is between 1 and 3 months; 30, if the purchase frequency is more than 3 months
19	Timely deliveries	1, if the most important suppliers deliver materials on or before the due date; 0, otherwise
20	Production lot size	1, if the production lot corresponds to less than 1 day of sales; 5, if the production lot is between 1 and 10 days of sales; 15, if the production lot is between 10 and 20 days of sales; 25, if the production lot is between 20 and 30 days of sales; 40, if the production lot is more than 30 days of sales
21	Set up reduction	1, if the firm has made efforts to reduce set-up times (by training the workers); 0, otherwise

Appendix: Continued...

	Question	Description
22	Equipment break-down frequency (average of all machines)	1, if breakdowns occur every day; 3, if breakdowns occur between 2 and 5 days; 8, if breakdowns occur between 5 and 10 days; 20, if breakdowns occur between 10 and 30 days; 60, if breakdowns occur between 1 and 3 months; 150, if breakdowns occur between 3 and 6 months; 270, if breakdowns occur in more than 6 months
23	Preventive maintenance	1, if the firm has a preventive maintenance system; 0, otherwise
24	Quality circles (teams)	1, if workers have periodic meetings with the operations/production manager to discuss subjects about the process quality; 0, otherwise
25	JIT knowledge	1, if the firm knows what JIT production system is → open answer: which are the JIT most important characteristics 0, otherwise
26	JIT use	1, if the firm has implemented the JIT system; 0, otherwise

Volume 5, Number 1, 2008, pp. 23-46

Framing Operations and Performance Strategic Management System Design Process

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Abstract

The increasing competitive pressure resulting from operations activities and market globalization are forcing enterprises to reorient their strategies, operations systems and processes. Specifically, organizations are paying closer attention to the changing nature of operations systems performance, to the point where operations strategic management system used in enterprise performance evaluation becomes the main focus of redesign projects. This study explores the process rationality behind operations strategy management systems design, taking into account a content definition established by a structural specification of the management system and the integration of life cycle and implementation models. This research proposes a framework that represents reconciliation between research and practice, contributing to the development and test of practical solutions for operations strategic management system design, implementation and management. The main result is a synthesis of three frameworks that each addresses the design process in different levels: the performance management system life cycle model; the process approach for guiding design and implementation issues; and recommendations that synthesizes the design task. The study also discusses methodological choices in approaching the design, implementation and use of an operations strategic management system. Doing so, the study develops the discussion on structural and process aspects of strategic performance measurement system design.

Keywords: operations strategy, performance measurement, strategic management, system design

Volume 5, Number 1, 2008, pp. 23-46

Introduction

The complexity and dynamics of the business environment is challenging strategic management models, particularly at the operational level where companies are directly connected with their suppliers and customers (Melnyk et al., 2004). The associated redesign of the operations systems covers organizational and management processes. Specifically, organizations are paying closer attention to the changing nature of the performance of operations systems, to the point where the operations strategic management system (OSMS) used in enterprise performance evaluations often is the main focus of redesign projects (Gomes et al., 2004). Managers look for a more 'balanced', 'integrated', 'flexible', 'multifaceted' and 'multidimensional' management system (Gomes et al., 2004). Such properties should reflect the performance specifications when describing the operations strategic management system. However, as noted by Slack (2000) and Platts (1995), the employed systems are not well developed and integrated and do not offer the opportunity for firms to better understand their operations systems environment and to increase their performance level.

The strategic management of performance measurement systems should enable an organization to develop continuous improvement and organizational learning capabilities through continuous reviews of the measurement system (Kennerley and Neely, 2003). For improved performance, the OSMS should also be conceived to deploy enterprise strategic performance management instead of performance measurement systems; develop dynamic rather than static strategic management systems; enhance the flexibility of performance measurement systems, improving its capability to cope with organizational changes (Neely, 2005).

This study investigates performance rationality as it is perceived by operations management practitioners and its use for managing operations systems. The causal relationships between the planning and measurement systems must be set in a management framework to explain the strategies, structures and processes used to solve performance problems. The study presents a theoretical development and proposes a process based rationality for designing of a strategic management system. This is defined at the operations functional level. The strategic management system is investigated, and its boundaries identified to conceive the process rationality of operations strategic management system design. The methodological approach is founded in a theoretical construction that inter-relates structural and procedural frameworks. Specifically, the process or Cambridge approach represents a link between structural and procedural frameworks, and it is used for this purpose. Methodological implementation issues are also discussed when presenting the approach.

The main result is a synthesis of three frameworks that address the design process in three different levels: the performance management system life cycle model; the process approach for guiding design and implementation issues; and recommendations that synthesizes the design task.

Operations Strategic Management System

In order to define the strategic management system, it is necessary to conceptualize the operations function and the operations strategy content. These elements define the 'content' or 'object' the system manages. The operations function is responsible for translating and running the business strategy at the functional level (Hofer and Schendel, 1978). The operations strategy content may be organized by setting the competitive objectives and relating them to the performance dimensions. These dimensions establish references for the decision processes that take place in respective area. Performance dimensions and decision areas define the content of the operations strategy (Hayes and Wheelwright, 1984). Table 1 (a) and (b) shows the performance dimensions that may be used in manufacturing and service production processes.

The decision areas define the operations function domain, as represented in Table 2 (a) and (b), customized for manufacturing and service production processes.

Table 1 - Performance dimensions.
a) Manufacturing

Orientation	Description	Performance dimension
Doing the activities right	Do not commit mistakes; the products should be in conformity with their design specifications. When the manufacturing provides this capability to the production process, it gives to the process a quality competitive advantage.	Quality
Doing the activities faster	Lead time, defined as the total amount of time between the placing of an order and the receipt of the goods ordered, should be lower than the competitors. When the manufacturing provides this capability to the operations system, it gives to the system a speed competitive advantage.	Speed
Doing the activities on time	Keep delivery promises. Developing that manufacturing capability implies in correctly estimates the delivery dates (or alternatively being able to accept the client required deadlines); clearly communicating that dates to the client; and finally, to deliver the products on time. When the manufacturing provides this capability to the operations system, it gives to the system a dependability competitive advantage.	Dependability
Able to change the activities	Adapt or reconfigure the production system; being able to attend the client changing demands or to reconfigure the operations due changes in the production process or in the supply chain. This capability means that the manufacturing system is able to change in the right pace. When the manufacturing provides this capability to the production process, it gives to the process a flexibility competitive advantage.	Flexibility
Able to produce unique products	Design new products; being able to launch a more diversified collection of products in reduced product developing times, than the competitors. When the manufacturing provides this capability to the operations system, it gives to the system an innovation competitive advantage.	Innovativeness
Doing the activities with low costs	Manufacture the products at low cost; being more efficient than the competitors. In the long term, the only way to achieve this advantage is through the negotiation of low cost resources and efficiently running the production process When the manufacturing provides this capability to the production process, it gives to the process a cost competitive advantage.	Cost

Source: Slack and Lewis (2008) and Slack (1991).

Table 1 - Continued...

b) Service

Orientation	Description	Performance Dimension
Rendering credibility through the service processes	Reliability or uniformity of successive results; absence of variability in the service operations results or processes.	Consistency
Provide high quality services	Ability and knowledge (competence) for executing the service. It is related to the technical customers needs (technical requirements).	Competence
On time delivery	Enterprise and employees promptness to service delivery. It is related to waiting time, in real terms or in the way it is perceived by the customers/clients.	Delivery speed
Fidelity relationship development	Customized attention to the customers; well developed communication channels; courtesy; pleasant relationship environment.	Service 'environment'
Able to change the activities	Being able to adapt and change the way the services are being executed and delivered, in order to attend the changing customers' demands or to adjust the operations processes for new situations in the supply chain.	Flexibility
Credibility image creation	Customer low risk perception; enterprise's ability to communicate trustiness.	Credibility/ Trustiness
Service promptness	Enterprise access readiness; properly localization; opening times.	Access
Quality perception	Tangible perceived quality obtained from physical artefacts, as equipments, facilities, personnel etc.	Tangibility
Doing the activities with low costs	To deliver low cost services.	Cost

Source: Slack and Lewis (2008), Johnston (2005), Johnston (1994) and Correa and Gianesi (1994).

Table 2 - Decision areas.
a) Manufacturing

Structural Decision Areas	
Product Design	Design for manufacturing; design for assembly; design and manufacturing processes specifications.
Capacity	Capacity flexibility, shift work management, temporary labour subcontracting policies.
Facilities	Size, localization and manufacturing resource 'focus'.
Manufacturing process technology	Automation level, technology selection, layout, maintenance policy, internal process development capability.
Vertical integration	Make-versus-buy strategic decisions, suppliers and procurement policies, suppliers' dependence level.
Capabilities	Manufacturing vision, development paths, and best practices.
Infra-structural Decision Areas	
Organisation	Structure, organisational and management processes, levels of centralization/ decentralization; planning and control systems; roles-responsibilities-autonomy; communication and learning processes.
Quality policy	Quality policies, Quality models, systems and processes, Quality techniques, procedures and tools.
Production planning and control	Materials and production planning and control systems.

Table 2 - Continued...

Human resources	Recruitment, training and development policies. Organisational culture, leadership and management styles. Reward policies. Competencies management model.
New products introduction	Manufacturing and assembly design directives. Product development cycles and matrix. Organisational issues.
Performance measurement and rewards	Performance indicators structure and use. Financial and non-financial measures. Relationships between manufacturing performance and the rewards systems and processes.
Information systems	Data and information acquisition, analysis and use processes and systems.
Continuous improvement systems	Manufacturing operations processes continuous improvement system, processes and procedures development.

Source: Slack and Lewis (2008), Mills et al. (2002) and Hayes and Wheelwright (1984).

b) Service

Structural Decision Areas	
Service design	Rendered service packages contents; 'focus'; responsiveness; value leverage (cost benefit analysis versus value creation assessment).
Capacity and demand	Volume; capacity flexibility; demand behaviour; demand and capacity adjustment.
Facilities	Localization; decentralization; layout; architecture; interior design, maintenance policies.
Service process technology	Front office and back office definition; customer interface; working process technologies: equipments, automation, capacity, flexibility.
Capabilities	Service vision, development paths, and best practices.
Infra-structural Decision Areas	
Customers/Client relationship management	Customer service process participation level; customer expectations management; customer communication and information processes; customer development and training.
Organisation	Structure, organisational and management processes, levels of centralization/decentralization; planning and control systems; roles-responsibilities-autonomy; communication and learning processes.
Human resources	Recruitment, training and development policies. Organisational culture, leadership and management styles. Reward policies. Competencies management model.
Quality policy	Quality policies, models, systems and processes; Quality techniques, procedures and tools. Faults prevention and treatment processes; service warranty policies; service standards; customer needs and expectations monitoring.
Operations planning and control	Service planning and control system; service programming; decision rules and processes.
Flux and queuing management	Service queuing policies and management processes; customer waiting time perception management.
Materials management	Materials planning and control system; supply policies; storehouse design; availability levels.
Performance measurement and rewards	Performance indicators structure and use. Financial and non-financial measures. Relationships between service delivery performance and the rewards systems and processes. Evaluation system design. Priorities definition; standards definition; techniques and tools selection.
Information systems	Data and information acquisition, analysis and use processes and systems.
Continuous improvement systems	Service operations processes continuous improvement system, processes and procedures development.

Source: Slack and Lewis (2008), Johnston (2005), Johnston (1994) and Correa and Gianesi (1994).

Volume 5, Number 1, 2008, pp. 23-46

The measurement system is part of a wider system - the strategic management system - which includes goal setting, feedback, and reward functions (Neely et al., 2005). As seen in Figure 1, Frohlich and Dixon (2001) employ a strategic management framework for testing and refining the manufacturing strategy taxonomy proposed by Miller and Roth (1994). The framework is based on the intrinsically closed loop nature of the strategy process.

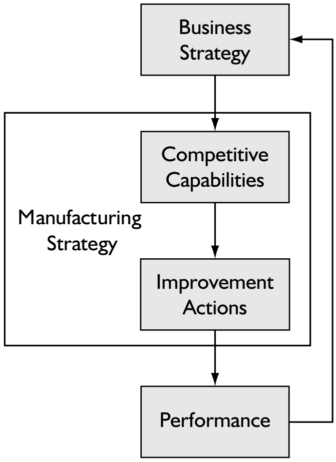

Figure 1 – Strategy process (Frohlich and Dixon, 2001).

The performance measurement subsystem creates the feedback function in the strategic control system. Neely et al. (2005) state that the introduction of a performance measure system as one element of the strategic control system can be used to influence behaviour. In their study of the performance of Japanese manufacturing plants, Daniel and Reitsperger (1991) argue that management controls of these operations are totally integrated with their strategies. Oge and Dickinson (1992) propose the adoption of closed loop performance management systems, which integrate periodic benchmarking with monitoring/measurement. The feedback loops (identified by gray lines in Figure 2) present variance control of processes and organizational system redesign through program implementation.

A well known performance measurement frameworks is Kaplan and Norton's (1992) 'balanced scorecard', which provides a planning technique and performance measurement framework within the same system. It can be classified as a strategic management framework since it integrates strategic map processes to performance dimensions. The system creates customer focused value through the improvement and development of business processes. The balanced scorecard model is based on 'innovation action research' and uses a methodology that integrates design, implementation and operation of a strategic management system (Kaplan, 1998). Through the evolution of performance measurement frameworks, the balanced integrated approach expands to a total integrated approach, with evidence of an evolutionary or co-evolutionary process. Table 3 shows the main characteristics that could be used to define an evolutionary or life cycle model for strategic performance measurement systems (SPMS).

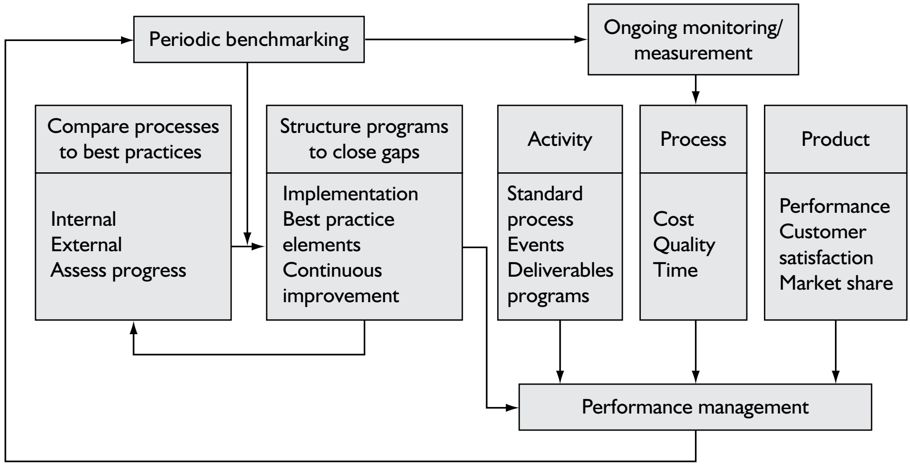

Figure 2 - Closed loop performance management (Oge and Dickinson, 1992).

Table 3 - The strategic performance evolutionary process.

Phase	Description
1	The performance measurement matrix integrates different dimensions of performance, employing the generic terms 'internal', 'external', 'cost' and 'non-cost'. The matrix enhances the perspective to external factors (Keegan et al., 1989).
2	The strategic measurement, analysis, and reporting technique – SMART – developed by Cross and Lynch (1989) uses a hierarchic, performance pyramid structure to represent the integration between organizational vision and operations actions. There is a interplay between external and internal orientations to improve the internal efficiency and the external efficacy.
3	The performance measurement model proposed by Fitzgerald et al. (1991) integrates determinants and results of the operations systems performance, exploring causalities between them. Measures are related to results (competitive position, financial performance) or are focused on the determinants of the results (e.g. cost, quality, flexibility).
4	The Balanced Scorecard (BSC), proposed by Kaplan and Norton (1992) constitute a multidimensional framework, based on financial, customer, internal processes and learning and growth dimensions, which integrates structural and procedural frameworks for designing a strategic management system.
4	The integrated dynamic performance measurement system – IDPMS – conceived by Ghalayini et al. (1997) incorporates the performance the dynamic features and the integrative properties. The integration process involves the management function, process improvement teams and the factory shop floor. The system creates a dynamic behaviour that articulates its specification and the reporting process.
5	The dynamics features are presented in the Neely et al. (2002) performance prism. This is a scorecard based system for measuring and managing stakeholder relationships. The framework is conceived to cover stakeholder satisfaction, strategies, processes, capabilities, stakeholder contribution dimensions. The main objective of the strategic management system is to deliver stakeholder value.

Empirical studies coordinated by Henry (2006), Chenhall (2005), Chenhall (2003) and Simons (1991) on the use of strategic control of measurement systems investigates the levers used in organizations to measure and manage performance. They found two patterns in managing a measurement system: diagnostic simple feedback control and interactive control. Bourne et al. (2005) use their frameworks to compare the results of average-performing and high-performing business units. In the former, the logic of the strategic management system is adherent to simple feedback control. In the latter, strategic management systems are based on both the interactive and simple feedback control approaches.

The literature indicates that the intensity of engagement and interaction with the performance measurement processes may have a great impact on the overall business performance if complementary roles are managed. This is suggested by Simons (1991) and here applied to the strategic management system in the manner suggested by Bourne et al. (2005).

Henry (2006) develops the understanding of performance measurement system based on a diagnostic and interactive use of management control systems. He identified two roles that work simultaneously but with different purposes: the diagnostic use represents a mechanistic control approach and the interactive use an organic control system one. The diagnostic use defines the role of performance measurements system as a measurement tool and the interactive use defines the role of performance measurements system as a strategic management tool. For the development of dynamic properties, several observations can be made:

- The diagnostic control system represents a single-loop learning process proposed by Argyris and Schön (1978), who state that the development of such process is a prerequisite for the development of a double-loop learning process. Thus, the strategic management process needs to combine both types of learning processes.
- The strategic management control system creates a dynamic tension when jointly using both approaches to manage performance. Dynamic tension is defined by a 'competitive' and 'cooperative' behaviour stated between interrelated elements (English, 2001; Lewis, 2000).
- Control systems should develop a strategic capability so as to contribute to the emergence of strategies and not be reduced to an implementation role (Simons, 1991).
- SPMS may focus their organizational attention on strategic priorities, thereby creating a knowledge company (Nonaka and Takeuchi, 1995).
- Market orientation, entrepreneurship, innovativeness, and learning capabilities are closely related to the strategic management approach used to manage the performance management system. Thus, the use of the measurement system could specifically contribute for a capability development (Henry, 2006).

The line of causality between organizational capabilities and performance is important for understanding the role of operations and performance strategic management systems as this complements market based models with a resource based view. Strategic control features of long term operations strategy and a predictive control system may be realized through the development of organizational capabilities. Such in-depth comprehension about the relationship between operations capabilities, performance and competitiveness has been developed by Hayes et al. (1988). Their claim is that the main role of competence development is to sustain customer value creation better than competitors do. Concepts like dynamic capabilities (Teece et al., 1997), cumulative capabilities (Flynn and Flynn, 2004) and manufacturing vision (Maslen and Platts, 2000) have been developed to support the operations strategy resource-based approach.

The notion of manufacturing vision, describing manufacturing capabilities a company intends to develop, helps the organizations to develop a strategic thinking orientation for their strategy-making processes. The managers are stimulated to engage in a strategic learning process that produces a vision that orients the business development (Maslen and Platts, 2000; Mintzberg, 1994).

Figure 3 organizes and frames the underlying logic of operations strategic management systems. A real world system may be represented by a set of 'capabilities', strategically managed by the operations strategy subsystem, planning subsystem and its measured performance. Meanwhile, the double feedback loops represent the monitoring (operational feedback loop) and the refreshing or redesign (strategic feedback loop) functions.

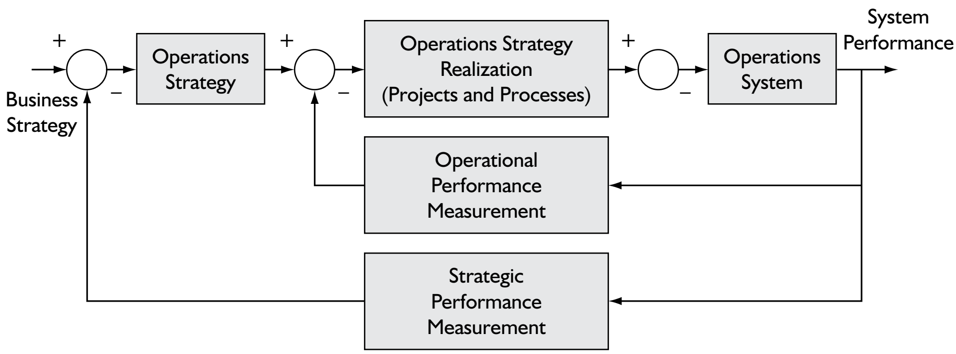

Figure 3 - The operations strategic management system (Pinheiro de Lima et al., 2008).

Two key questions emerge at this point: "Why rely on feedback control systems to strategically manage the operations system?" Does this not recede to the mechanistic view of organizational systems, deny the continuous changing nature of strategy scenery and consider the operations systems as a closed system? This section explores the causality links of main elements of a strategic management system that could help the operations system to attend its 'organic' role, through the development of the refreshing process. The operations system and the organization as a whole would develop design and subsequent operations organically, dynamically integrating in the same system a short and long term perspective of operations strategy. Having defined the object of the design project, rationalities for its development are established next.

Structural Rationality

The study assumes that theoretical constructs may be based on frameworks that inform design, implementation and management processes. This assumption help define system boundaries, performance dimensions and their relationships (Rouse and Putterill, 2003). The constructs, a set of interrelated recommendations based on the system content, which can be seen as a structural framework, and processes that develop the procedural framework (Folan and Browne, 2005). The integration of both structural and procedural perspectives is realized through the operations strategic management system specification.

For structural rationality, we propose the use of an organizational design framework adapted and applied to OSMS design (Pinheiro de Lima and Lezana, 2005). The framework is formed by structural, processes and spaces dimensions interfaced by a hypertext organizational model (Nonaka and Takeuchi, 1995). The structural dimension is used to explain OSMS content. The processes dimension is related to different processes that represent the material and informational fluxes and their management, and the context is developed through a space definition that establishes the locus of strategic management realization. Figure 4 shows the employed structural framework.

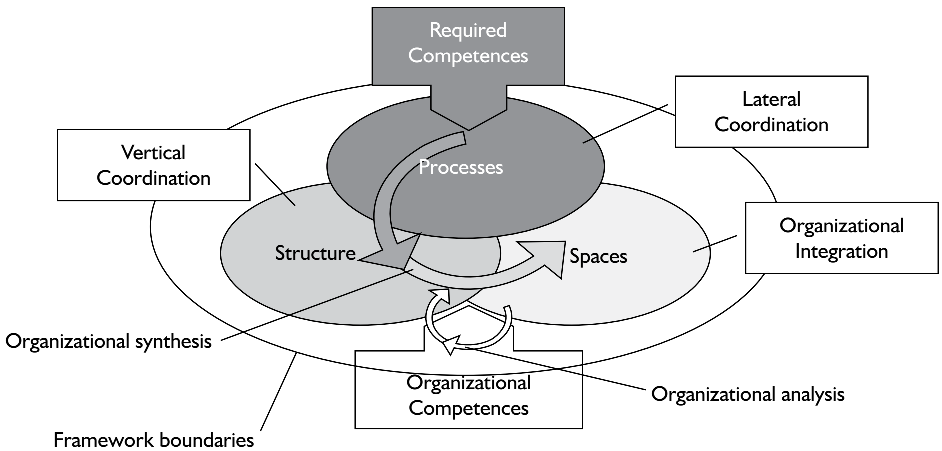

Figure 4 - The organizational design framework (Pinheiro de Lima and Lezana, 2005).

Defining the organizational design framework elements, we revisit the strategy-structure model (Chandler, 1962) to establish a connection with the competence-based model proposed by Sanchez et al. (1996). The resulting relationships define the framework inputs. The strategy defines a set of required competences, which represent the input reference set for the organizational design development. Moreover, the organizational competences influence the strategy definition, through the combination of the organization resources and abilities, developing a capability to accomplish such strategy (Hayes and Wheelwright, 1984). The required and organizational competences could be related to the operations strategic management system.

Three main organizational design areas define the design domain: processes (strategic management processes) represent the horizontal flows; structure (operations strategy structure/content) realize the vertical coordination; and spaces (strategic management system) are the locus of strategic and control actions. These three levels are defined by the hypertext organizational model, providing specific contexts for the organizational studies (Nonaka and Takeuchi, 1995). The organizational model integration is obtained by their structural definition (processes, structure and spaces) and by their strategic orientation that are represented by a set of required and stated competences.

The reference framework shown in Figure 4 incorporates dynamics features to the organizational model. These features define the normative and participative modes of 'operation'. The management of the conceptual framework could be done by navigating through their three contexts: vertically, in the participation or normative structure; and horizontally, through the material and information flows perspective (Pinheiro de Lima and Lezana, 2005). Note, however, that the operations strategy and the reference framework relationship are obtained through the organizational competences. The competences represent the operations strategy content as well as the normative reference for the OSMS design. The presented design dimensions delimit the aspects to be managed. Figure 5 represents the interfaces developed by the management and production system.

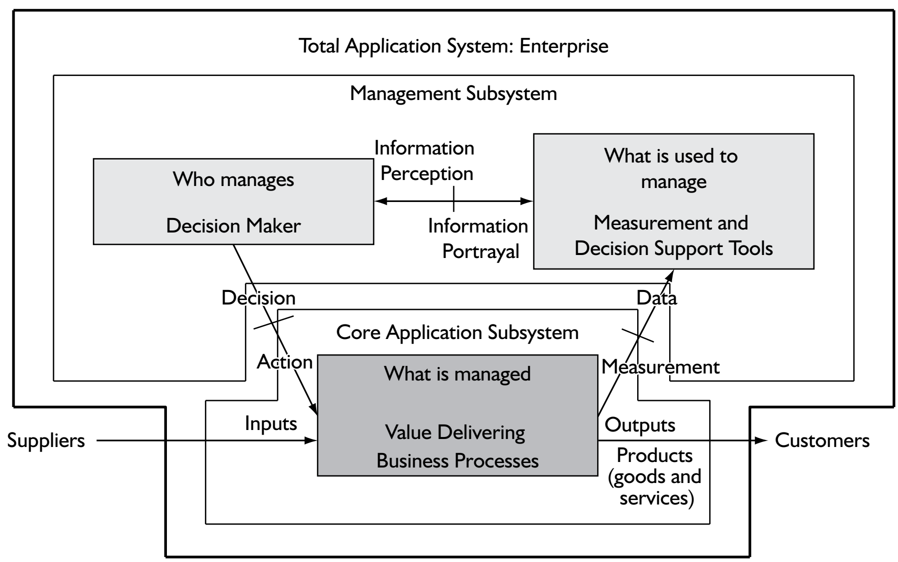

Figure 5 - The enterprise system (Sousa et al., 2005).

Figure 4 defines the systemic dimensions for designing the management system that is presented in Figure 5. Figure 5 could be used as a structural framework for the SPMS and this system should be conceived in its structural, processes and spaces dimensions.

Having identified the design dimensions and OSMS boundaries, the design process rationality is explored next.

Process-Based Rationality

This section presents the process rationality underlying OSMS design. Frohlich and Dixon (2001) comment that Operations Management field, particularly in strategic related themes, has brought forward new ideas, but that it has been less effective in validating concepts after their introduction. Hence, the underlying OSMS processes must be related to its knowledge life cycle. Our study does this by employing propositions in three different perspectives incorporating system design, implementation and realization processes, and the role that findings play relating theory and practice.

The three perspectives are related to the design of a strategic management system, implemented at the operations function level. The design approach is based on the practice versus theory reconciliation logic (Slack et al., 2004), using a process that continuously interplay empirical and theoretical assumptions (Neely, 2005). The practical application is set by the operational and management processes developed by Slack (2000) and Platts (1993) respectively.

The first perspective asks the question: "How does the Operations Management (OM) field build and refresh its knowledge basis?" To address this question, rationalities used in OM for producing knowledge that are consolidated in theories, models, frameworks and processes are presented. For this purpose, theoretical constructions developed by Neely (2005) and Slack et al. (2004) are used to illustrate process rationality of the knowledge creating cycle.

Slack et al. (2004) propose that selected OM orientation should continually look for a point of reconciliation between research and practice. They acknowledge that this is not a trivial task, but it is logical if OM's principal academic role is to 'conceptualise' practice and 'operationalise' theory. Therefore, OM would be better recognized not as a 'normal' functional management discipline but rather as a knowledge broker in the whole knowledge producing process (Nonaka and Takeuchi, 1995). OM methods provide an important contribution in improving the enterprises operational and strategic activities. The results or 'design solutions' contribute to the development and test of practical solutions for the operations strategic management system design, implementation and management.

The theoretical construction of Neely (2005), represented in Figure 6, may be used as a meta-framework to position the presented discussion in the evolutionary life cycle process that founds the discipline of Performance Management (PM).

In the early stages of PM, effort was on identifying problems, followed by a structuring activity based on theoretical frameworks proposition that organize and address the knowledge body to solve problems. Based on the proposed frameworks, processes were developed to test them and to verify their robustness and correctness through empirical investigation. This interplay between analysis and synthesis allowed an evolution and consolidation of the theoretical body of the PM discipline. The cycle process developed by Neely (2005) identifies a specific context used to explain the approach used in this

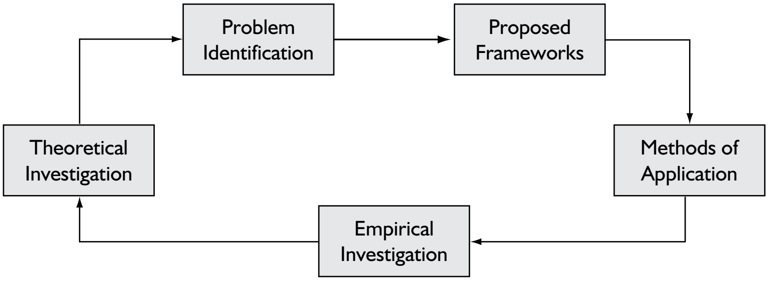

Figure 6 - The evolutionary life cycle process (Neely, 2005).

study for producing and testing models and methodologies for designing the operations strategic management system. Simplified, the main logic that governs OSMS may be explained by the design and engineering of a general management system, as presented in Figure 7 (Sousa and Groesbeck, 2004). The OSMS (re)design process should be linked to real operations systems and all the theoretical constructions formulated based on previous work and experiences related to the knowledge production continuous flow in the OM field. Therefore, it should be recognized that the OM field is in a continuous, complex and dynamic evolution. Operations managers and professionals are facing in their day-to-day decision process situations that are questioning their mental models and this characterizes events that are continually restarting the redesign process (Slack et al., 2004; Zilbovicius, 1997).

The second perspective employed in this study explains how practical issues may be addressed in designing, implementing and managing OSMS. The process approach may be used to found all implementing activities, integrating in a participative way the design and management processes (Platts et al., 1996; Platts, 1994; Platts, 1993). The Cambridge approach, developed by Platts (1993), presents a prescriptive process, 'operationalising' a set of concepts through a structured process provided with the data collection instruments, a dynamic management process and evaluation criteria. The approach entails various advantages for OSMS development. Table 4 synthesizes the main characteristics of the Process approach implementation (Gouvêa da Costa, 2003; Platts, 1994).

The underpinning rationality of the design process addresses the implementation and managing processes, creating the conditions for a double loop learning process development.

Slack (2000) identifies three main activity phases in the process of redesigning a manufacturing system: structuring, suppositional and assimilation activities. The structuring activity is used to construct, in social terms, a common sense of the design objectives and options. The design options may be defined in terms of the performance trade-offs within the systems' strategic context. The suppositional activity extends the common language developed to approach the performance issues in the structuring activity, to a process of creating the scenarios for the design choices. This phase stimulates

Volume 5, Number 1, 2008, pp. 23-46

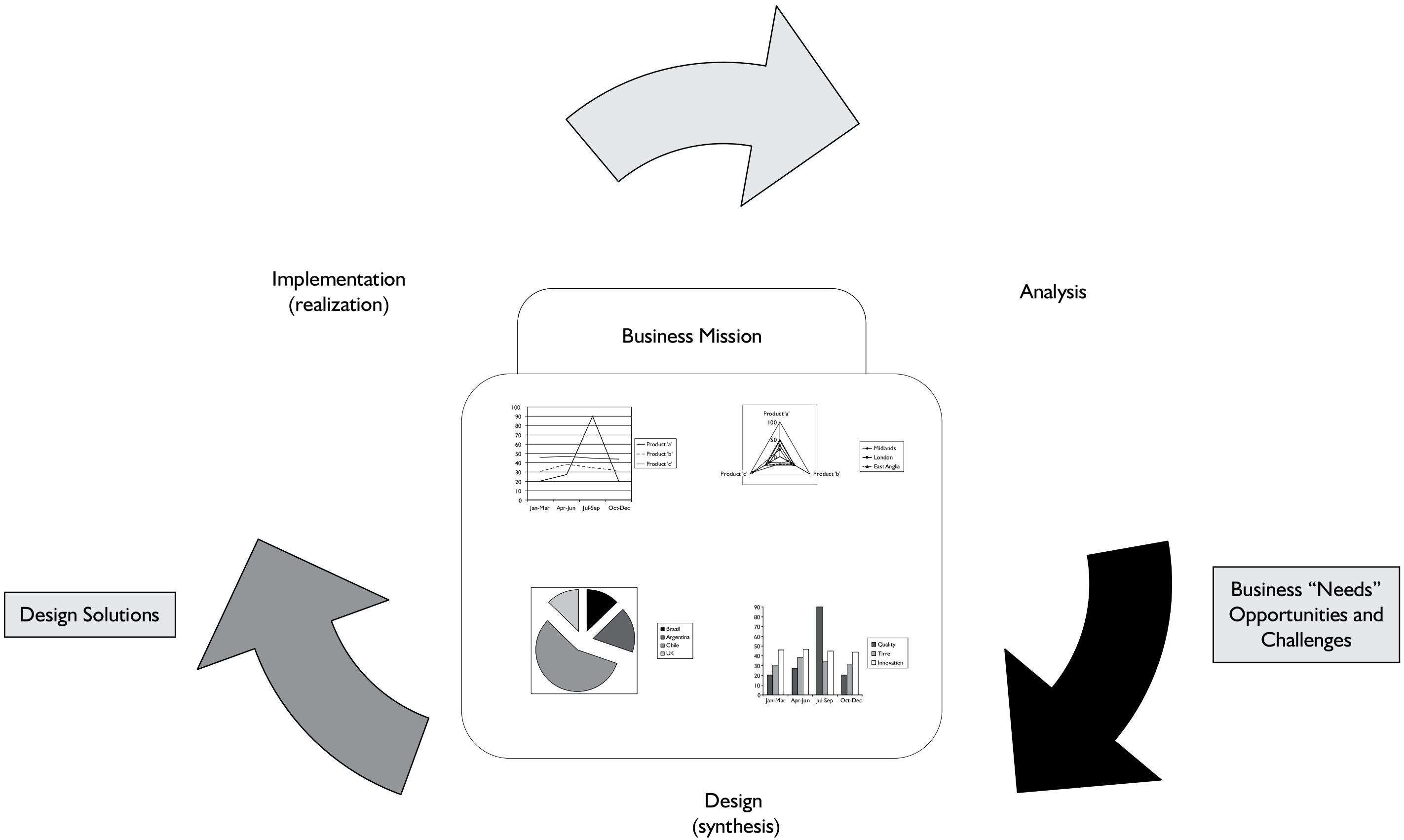

Figure 7 - The system design and engineering logic (Sousa and Groesbeck, 2004).

Table 4 - The main characteristics of the Process Approach.

Procedure	Participation	Project Management	Point of Entry
The process is properly defined in terms of organization and operational procedures.	Individual and team based activities interrelates all the involved actors.	It is important to check if all the required resources are addressed and available.	It is important to clearly define the scope, content and pretended results of the project.
Phases: • information searching and scanning; • information analysis; • change and/or improvement opportunities identification.	The participative characteristics increases: • the enthusiasm; • the comprehension; and • the involvement.	It is important to define: • coordinator group; • support group; and • operational or executive group.	The start and development of the project should have the acknowledgement and concordance of the coordinator group.
The applied techniques and tools should be simple enough to attend the requirements of the operational processes. Their use must be easily understood.	The participation 'spaces' could be run through workshop to: • achieve the concordance around the objectives of the project; • identify and to formally declare the main problems; • propose and develop improvement actions; and • create a locus for involvement and participation.	Project planning and chronogram should be produced by a participative and consensual process.	It is a necessary condition for the project starting activities that the groups are fully involved and identified with their roles. The coordinator group, especially their leader must receive all the required support from the involved actors.
The results of each phase of the project should be documented and reported.	The participative process creates a decision making forum that guides the actions.		

Source: Gouvêa da Costa (2003) and Platts (1994).

the debate around the resource capabilities needed and the trade-offs of the design process. The externalization process developed in the suppositional activity creates the right conditions for identifying the knowledge gaps. At this point, an assimilation activity is running as a result of a learning process, which was emerging in the suppositional phase and was consolidated in the assimilation phase, with the identified knowledge gaps. The three interrelated activities may play a special role in integrating design, implementation and management of an operations strategic management system.

Figure 8 shows the interrelated design activities proposed by Slack (2000). They follow the interactive process of knowledge creation proposed by Nonaka and Takeuchi (1995) as they apply the different modes of knowledge creation. The structuring phase socializes and externalizes knowledge, the suppositional activity combines knowledge and the assimilation phase internalizes the produced knowledge. The importance of knowledge creation in producing sustainable and reinforced learning processes is noteworthy.

A key objective of the research is to conceive a methodology for designing the operations strategy management system. The method rationality follows the Slack (2000) framework in the initial prescription and then employs management and implementation using the process approach developed by Platts (1993).

Volume 5, Number 1, 2008, pp. 23-46

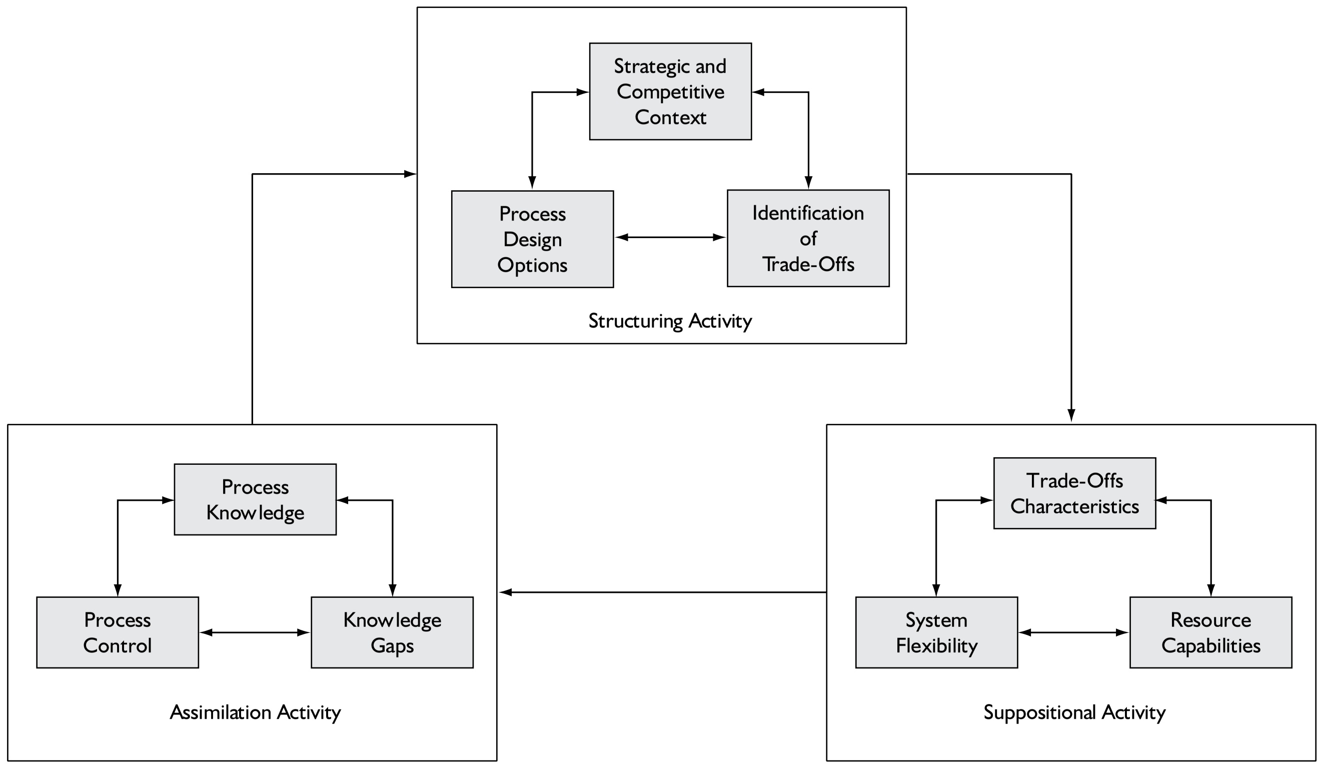

Figure 8 - A model of the underlying design activity (Slack, 2000).

The presented OSMS implementation and use is summarized in Table 5, which was developed by the authors.

Table 5 - The strategic performance framed by process approach.

Dimension	Main characteristic	Description
Design, implementation and management (use)	Organisational learning	The system structurally establishes organisational learning as an important outcome of the design (Slack, 2000) implementation (Platts, 1993) and management processes (Slack, 2000).
Implementation and management (use)	Dynamic behaviour	It develops an understanding of company operations process dynamics, helping firms develop a strategic vision based on dynamic capabilities (Slack, 2000; Teece et al., 1997).
Management (use)	Continuous improvement	The learning processes and the enhancing knowledge basis may lead to an improvement of the perception of having the strategic management system under control. This confidence may in turn reinforce a continuous and virtuous cycle of learning and improvement (Slack, 2000).

The study's third perspective is that may be formally declared, defining initial design choices in the context of OSMS, for the strategic performance measurement system design (Henry, 2006; Folan and Browne, 2005). This can be seen in Table 6 that was developed by the authors.

The discussed structural and procedural models suggest the following propositions:

- The strategic management of the operations functions leads to a better management of organizational actions' efficiency and effectiveness.
- Operations and performance strategic management systems should develop a balanced approach in designing and running their monitor and control functions and their continuous improvement capability development.
- Operations and performance strategic management systems should be designed, implemented and managed as dynamic systems.
- Operations and performance strategic management systems system boundaries definition, structure and causal relationships could be used as a guide for implementation; i.e. in producing processes, techniques and procedures for the effective implementations of OSMS and SPMS design.
- The methodological approach is based on research and practice reconciliation, contributing to the development and test of practical solutions for OSMS and SPMS design, implementation and management.

The three perspectives form a complete view of system design, inter-relating a methodological approach, a development research life cycle and an implementation process. This systemic view gives to the research a strong methodological basis that guides a sequence of research projects over time, creating consistency.

Table 6 - Strategic performance measurement system design recommendations.

Recommendation	Description	Use
Action leads to performance	According to Neely et al. (2005) a performance measurement system is the set of metrics used to quantify both efficiency and effectiveness of actions. Central to these definitions is that action leads to performance and that there are internal and external factors that affect the efficiency and effectiveness of this relationship.	Quantify efficiency and effectiveness of actions.
Strategy as a pattern of actions	Mintzberg (1978) argues that a strategy only can be identified through a consistent pattern of actions. The strategy only exists if it is realized. It is assumed that there is interplay between actions' results and the consistency that is established over time; an OSMS should mediate that interaction.	The strategy only exists if it is realized. OSMS mediates strategy and performance.
Operations strategic management system context	The performance measurement systems should be designed, implemented and managed as part of a strategic management system. The measures should be derived from strategy and should provide consistency for decision making and action. In particular, the production function should be managed in terms of its own strategic management system (Neely et al., 2005; Skinner, 1969).	Measures are derived from strategy and provide consistency for decision making and action.
Strategic management properties	The strategic management control systems should be used as a means to provide surveillance, motivation, monitoring performance, stimulating learning, sending 'signals', anticipating events, introducing constraints and managing scenarios to the operations system. It is important to realize that the control function is defined exploring the complementary features of mechanic and organic behaviour, reacting and tracking the strategy but also reviewing the system design (Henry, 2006; Neely et al. 2005).	Strategic performance management systems are used to provide surveillance, motivation, monitoring performance, stimulating learning, sending 'signals', anticipating events, introducing constraints and managing scenarios to the operations strategic management system.
Causalities comprehension and predictive behaviour	The performance measurement systems should be able to manage the determinants and results of the operations systems outputs, exploring the causalities between them and developing a predictive approach for the whole operations strategic management system (Kaplan and Norton, 1992; Fitzgerald et al., 1991; Keegan et al., 1989).	Management of determinant and results of operations system's performance

Conclusions

This study explores the process rationality behind OSMS design. It has presented and framed structural and procedural rationalities and founded the process design development and its implementation. The design process rationality proposed makes several contributions:

- Theoretical production, whereby the process framework developed contributes to OM theory by testing concepts and establishes relationships between theory and practice.
- Solution construction, whereby the proposed process rationality contributes to the process framework test. The use and application of the developed tools challenges the established structures and processes, restarting the redesign process.

The study employs a set of methodological choices in approaching the design, implementation and use of an operations and performance strategic management system. It is important to point out the fact that these choices represent the first set of design recommendations. All the choices are based on structural and life cycle models, representing respectively content and process decisions.

The discussion indicates that a set of design recommendations may lead to the development of system capabilities that enable the system to play and desired role. The presented discussion is positioned in the research life cycle and its evolution, defined by the refinement and validation process, will depend of the practice and theory reconciliation of its implementing activities. The evolution of the presented theoretical discussion is related to its implementation and test, in order to understand some characteristics of research project management in the field of operations management.

The reconciliation between theory and practice is studied and framed in the process rationality. The life cycle, the Cambridge approach and the recommendations realized (in practical terms) the design and implementation of SPMS. This rationality could be used for guiding the implementation process assisting companies in reviewing their strategic performance measurement system.

The main contribution of this paper could be stated in terms of framing the design and implementation issues related to operations and performance strategic management systems. Life cycle models and procedural frameworks are powerful concepts to explain and describe operations strategy issues.

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Monitoring the Mean Vector and the Covariance Matrix of Bivariate Processes

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Abstract
This paper proposes the joint use of two charts based on the non-central chi-square statistic (NCS statistic) for monitoring the mean vector and the covariance matrix of bivariate processes, named as the joint NCS charts. The expression to compute the *ARL*, which is defined as the average number of samples the joint charts need to signal an out-of-control condition, is derived. The joint NCS charts might be more sensitive to changes in the mean vector or, alternatively, more sensitive to changes in the covariance matrix, accordingly to the values of their design parameters. In general, the joint NCS charts are faster than the combined T^2 and $|S|$ charts in signaling out-of-control conditions. Once the proposed scheme signals, the user can immediately identify the out-of-control variable. The risk of misidentifying the out-of-control variable is small (less than 5.0%).

Keywords: non-central chi-square statistic, covariance matrix, mean vector, bivariate processes

Introduction
Control charts are often used to observe whether a process is in control or not. When there is only one quality characteristic Shewhart control charts are usually applied to detect process shifts. The power of the Shewhart control charts lies in their ability to separate the assignable causes of variation from the uncontrollable or inherent causes of variation. Shewhart control charts are relatively easy to construct and to interpret. As a result, they are readily implemented in manufacturing environments.

However, there are many situations in which it is necessary to control two or more related quality characteristics simultaneously. Hotelling (1947) provided the first solution to this problem by suggesting the use of the T^2 statistic for monitoring the mean vector of multivariate processes. If compared with the use of simultaneous $\bar{X}$ charts, the T^2 chart is not always faster in signaling process disturbances, see Machado and Costa (2008a). Many innovations have been proposed to improve the performance of the T^2 charts. Recently, Costa and Machado (2007) studied the properties of the synthetic T^2 chart with two-stage sampling. Costa and Machado (2008a) considered the use of the double sampling procedure with the chart proposed by Hotelling.

The first multivariate control chart for monitoring the covariance matrix Σ was based on the charting statistic obtained from the generalized likelihood ratio test. For the case of two variables, Alt (1985) proposed the generalized variance statistic $|S|$ to control the covariance matrix Σ.

Control charts more efficient than the $|S|$ chart have been proposed. Recently, Costa and Machado (2008b, 2008c), Machado and Costa (2008b) and Machado et al. (2008) considered the VMAX statistic to control the covariance matrix of multivariate processes. The points plotted on the VMAX chart correspond to the maximum of the sample variances of the p quality characteristics.

There are a few recent papers dealing with the joint control of the mean vector and the covariance matrix of multivariate processes. Khoo (2005) proposed a control chart based on the T^2 and $|S|$ statistics for monitoring bivariate processes. The speed with which the chart signals changes in the mean vector and/or in the covariance matrix was obtained by simulation. The results are not compelling, once the proposed chart is slow in signaling out-of-control conditions. Chen et al. (2005) proposed a single EWMA chart to control both, the mean vector and the covariance matrix. Their chart is more efficient than the joint T^2 and $|S|$ in signaling small changes in the process. Zhang and Chang (2008) proposed two EWMA charts based on individual observations that are not only fast in signaling but also very efficient in informing which parameter was affected by the assignable cause; if only the mean vector or only the covariance matrix or both.

In practice, the speed with which the control charts detects process changes seems to be more important than their ability in identifying the kind of change. For the univariate case, the use of the non-central chi-square statistic (NCS statistic) for monitoring the mean and the variance of processes simultaneously has been more effective than the joint use of the $\bar{X}$ and R statistics in detecting process changes, see Costa and Rahim (2004, 2006); Costa and De Magalhães (2005, 2007) and Costa et al. (2005).

In this article, we consider the joint use of two charts based on the NCS statistic for monitoring the mean vector and the covariance matrix of bivariate processes. The proposed scheme, named as the joint NCS charts, is an alternative to the joint use of the T^2 and $|S|$ charts. The NCS charts are recommended for those who aim to identify the out-of-control variable and the T^2 and $|S|$ charts are recommended for those who aim to identify the nature of the disturbance, that is, if the assignable cause changes the process mean vector or the covariance matrix.

The success of the recently proposed charts for monitoring the covariance matrix (see Costa and Machado (2008b, 2008c), Machado and Costa (2008b) and Machado et al. (2008)) was the motivation to design new charts to control both the mean vector and the covariance matrix.

The paper is organized as follows. In the second and third sections we present the joint NCS charts and the T^2 and |S| charts, respectively. The joint charts are compared in the fourth section. The mathematical development to obtain the power of the joint NCS charts is in the Appendix. An example is also presented to illustrate the application of the proposed scheme. Finally, the last section concludes the paper, presenting an analysis of the main results.

The Joint NCS Charts

The process is considered to start with the mean vector and the covariance matrix on target ($\mu = \mu_0$ and $\Sigma = \Sigma_0$), where $\mu'_0 = (\mu_x; \mu_y)$ and $\Sigma_0 = \begin{pmatrix} \sigma_x^2 & \sigma_{xy} \\ \sigma_{xy} & \sigma_y^2 \end{pmatrix}$. The occurrence of the assignable cause changes the mean vector from μ_0 to $\mu'_1 = (\mu_x + c\sigma_x; \mu_y + d\sigma_y)$ and/or the covariance matrix from Σ_0 to $\Sigma_1 = \begin{pmatrix} a^2\sigma_x^2 & ab\sigma_{xy} \\ ab\sigma_{xy} & b^2\sigma_y^2 \end{pmatrix}$. The correlation $\rho = \dfrac{\sigma_{xy}}{\sigma_x \sigma_y}$ is not affected by the assignable cause.

When the joint NCS charts are in use, samples of size n are taken from the process at regular time intervals. Let X_i and Y_i, $i = 1, 2, 3,..., n$ be the measurements of the variables X and Y. Let $\bar{X} = (X_1 + ... + X_n)/n$ and $\bar{Y} = (Y_1 + ... + Y_n)/n$ be the sample means of the variables X and Y, and let $e(x) = \bar{X} - \mu_x$ and $e(y) = \bar{Y} - \mu_y$ be the difference between the sample means and the target values of the process means. The NCS statistics are given by:

$$T(x) = \sum_{i=1}^{n} (X_i - \mu_x + \xi(x)\sigma_x)^2,$$

$$T(y) = \sum_{i=1}^{n} (Y_i - \mu_y + \xi(y)\sigma_y)^2, \tag{1}$$

for $\rho \geq 0$, we define:

$$\text{If } \begin{cases} e(x) \geq 0 \text{ and } \begin{cases} e(y) < 0 & \xi(x) = \delta \text{ and } \xi(y) = -\delta \\ e(y) \geq 0 & \xi(x) = \xi(y) = \delta \times \delta_1 \end{cases} \\ \qquad\qquad\qquad \text{than} \\ e(x) < 0 \text{ and } \begin{cases} e(y) < 0 & \xi(x) = \xi(y) = -\delta \times \delta_1 \\ e(y) \geq 0 & \xi(x) = -\delta \text{ and } \xi(y) = \delta \end{cases} \end{cases} \tag{2}$$

and for $\rho < 0$, we define:

$$\text{If } \begin{cases} e(x) \geq 0 \text{ and } \begin{cases} e(y) < 0 & \xi(x) = \delta \times \delta_1 \text{ and } \xi(y) = -\delta \times \delta_1 \\ e(y) \geq 0 & \xi(x) = \xi(y) = \delta \end{cases} \\ \qquad\qquad\qquad\qquad \text{than} \\ e(x) < 0 \text{ and } \begin{cases} e(y) < 0 & \xi(x) = \xi(y) = -\delta \\ e(y) \geq 0 & \xi(x) = -\delta \times \delta_1 \text{ and } \xi(y) = \delta \times \delta_1 \end{cases} \end{cases} \quad (3)$$

where the parameters δ and δ_1 are positive constants.

When the variables are correlated ($\rho \neq 0$) and $\delta_1 = 1$ (that is, $\xi(x)$ and $\xi(y)$ are discrete variables assuming only two values, $\pm\ \delta$), the joint NCS charts signal changes in the covariance matrix very fast; however, they are slow in signaling changes in the mean vector. The overall performance of the NCS charts improves when $\xi(x)$ and $\xi(y)$ assumes more than two values, for instance $\pm\ a_1$ and $\pm\ a_2$, with $a_2 < a_1$.

Based on that and following Costa et al. (2005), we propose the use of two design parameters, δ and δ_1, with $\delta = a_1$ and $\delta \times \delta_1 = a_2$. If the variables are positively correlated, the best overall performance is reached with $|\xi(x)| = |\xi(y)| = a_2$ (or a_1 if $\rho < 0$), for the cases in which $e(x)$ and $e(y)$ are both positive or both negative. Otherwise, $|\xi(x)| = |\xi(y)| = a_1$ (or a_2 if $\rho < 0$).

If $T(x)$ and/or $T(y)$ falls beyond the control limit CL, the joint NCS charts signal an out-of-control condition, reminding that two NCS charts are used, one for monitoring the X variable and another for monitoring the Y variable. In the Appendix we obtained the expression (A2), which gives the probability of signaling for the joint NCS charts.

The T^2 and |S| Charts

In the next section we compare the joint NCS charts with the joint T^2 and |S| charts. The T^2 chart was introduced by Hotelling (1947) and it is the most common chart used to control the mean vector of multivariate processes.

Consider that two correlated characteristics are being measured simultaneously and, when a sample of size n is taken, we have n values of each characteristic and the $\overline{X}$ vector, which represents the sample average vector for the two characteristics.

The charting statistic

$$T^2 = n\left(\overline{\mathbf{X}} - \mu_0\right)' \Sigma_0^{-1} \left(\overline{\mathbf{X}} - \mu_0\right) \quad (4)$$

is called Hotelling´s T^2 statistic. When the process is in-control, T^2 is distributed as a chi-square variate with two degrees of freedom, that is, $T^2 \sim \chi^2_{p=2}$. Consequently, the control limit for the T^2 chart is $CL = \chi^2_{p=2,\alpha}$, where α is the type I error. When the process is out-of-control, T^2 is distributed as a non-central chi-squared distribution with two degrees of freedom and with non-centrality parameter $\lambda = n(\mu - \mu_0)' \Sigma_0^{-1}(\mu - \mu_0)$, that is, $T^2 \sim \chi^2_{p=2}(\lambda)$.

The first multivariate control chart for monitoring the covariance matrix Σ was based on the charting statistic obtained from the generalized likelihood ratio test (ALT, 1985). For the case of two variables, Alt (1985) proposed the generalized variance |S| statistic to control the covariance matrix Σ. S is the sample covariance matrix

$$\mathbf{S}=\begin{bmatrix} s_x^2 & s_{xy} \\ s_{xy} & s_y^2 \end{bmatrix}.$$

When the process is in-control $\frac{2\cdot(n-1)\cdot|\mathbf{S}|^{1/2}}{|\Sigma_0|^{1/2}}$ is distributed as a chi-square variable with $2n-4$ degrees of freedom.

Consequently, the control limit for the |S| chart is:

$$CL=\frac{\left(\chi^2_{2n-4,\alpha}\right)^2\cdot|\Sigma_0|}{4\cdot(n-1)^2} \quad (5)$$

Comparing the Joint Charts

The average run length (*ARL*), which is defined as the average number of samples before a sample point outside the control limits, has been the one of the most important properties associated with the statistical process control charts. Knowledge of the *ARL* for a particular assignable cause (that changes the mean vector and/or the covariance matrix of multivariate processes) allows us to design more effective control charts. When the process is in-control, the *ARL* measures the rate of false alarms. A chart with a larger in-control *ARL* (ARL_0) indicates lower false alarm rate than other charts. A chart with a smaller out-of-control *ARL* indicates a better ability of detecting process shifts than other charts.

The correlation coefficient has a minor influence on the NCS charts performance, see Table 1. For example, considering a and b = 1.25 and c and d = 0.0, if ρ changes from 0.0 to 0.7, the *ARL* increases from 15.9 to 17.5. Tables 2 through 6 provide the *ARL* for the joint NCS charts and for the joint T^2 and |S| charts, where ρ = 0.0; ± 0.5; ± 0.7, a and b = 1.0; 1.25; 1.5 and c and d = 0.0; 0.5; 0.75; 1.0. A type I risk of 0.5% is adopted. One can see from these tables that the joint NCS charts compete in performance with the joint T^2 and |S| charts. We selected the values of δ and δ_1 in Tables 2 through 6 based on the overall performance of the NCS charts.

Tables 2 through 6 were built considering three different values of a and b and four different values of c and d. The orthogonal array is, in this case, made up of 144 combinations; however, these tables present only one half of the orthogonal array. The explanation is that the symmetric cases ($a = w_1$, $b = w_2$, $c = w_3$ and $d = w_4$) and ($a = w_2$, $b = w_1$, $c = w_4$ and $d = w_3$), with $w_1, w_2 \in \{1,\ 1.25,\ 1.5\}$ and $w_3, w_4 \in \{0,\ 0.5,\ 0.75,\ 1.0\}$, lead to the same *ARL*.

Table 7 shows the effect of δ on the ARL value of the joint NCS charts. Larger values of δ are better for detecting changes in the mean vector with $a = b = 1.0$, and worse for detecting changes in the covariance matrix with $c = d = 0.0$. For example, when $a = b = 1.0$ and $c = d = 0.5$, the *ARL* value decreases from 50.3 to 20.3 as δ increases from 0 to 2.0.

Volume 5, Number 1, 2008, pp. 47-62

Table 1 - Influence of ρ on the *ARL* values for the NCS charts ($\delta = 0.8$; $\delta_1 = 1.0$).

								n = 5							
			c	0	0	0.5	0.5	0	0.75	0.5	0.75	0.75	0	1.0	1.0
			d	0	0.5	0	0.5	0.75	0	0.75	0.5	0.75	1.0	0	1.0
ρ	*a*	*b*													
0.0[1]	1.0	1.0		200.0	41.1	41.1	22.6	14.4	14.4	11.3	11.3	7.7	6.0	6.0	3.3
0.5[2]				200.0	40.8	40.8	24.5	14.3	14.3	12.1	12.1	8.4	5.8	5.8	3.7
0.7[3]				200.0	40.2	40.2	25.7	14.1	14.1	12.7	12.7	8.9	5.7	5.7	4.0
0.0	1.25	1.0		29.5	18.8	11.5	9.6	10.5	6.0	6.9	6.9	4.5	5.2	5.2	2.5
0.5				29.6	19.5	11.2	10.0	10.7	6.0	7.5	5.8	4.9	5.2	3.5	2.8
0.7				29.8	20.1	11.4	10.3	10.7	5.9	7.9	5.9	5.2	5.3	3.5	3.0
0.0	1.5	1.0		8.1	7.3	5.2	4.8	5.6	3.5	4.0	3.4	3.1	3.8	2.5	2.0
0.5				8.2	7.3	5.2	4.9	5.8	3.6	4.5	3.5	3.3	3.9	2.5	2.3
0.7				8.2	7.4	5.2	5.0	5.9	3.6	4.6	3.5	3.4	3.9	2.5	2.3
0.0	1.25	1.25		15.9	8.8	8.8	6.1	5.3	5.3	4.3	4.3	3.4	3.3	3.3	2.1
0.5				16.5	8.9	8.9	6.7	5.4	5.4	4.7	4.7	3.8	3.3	3.3	2.4
0.7				17.5	9.2	9.2	7.1	5.4	5.4	4.9	4.9	4.0	3.3	3.3	2.5
0.0	1.25	1.5		6.8	4.7	5.2	3.9	3.4	3.8	3.0	3.1	2.5	2.4	2.7	1.8
0.5				7.0	4.7	5.4	4.1	3.4	4.0	3.2	3.4	2.8	2.5	2.8	2.0
0.7				7.3	4.8	5.5	4.4	3.4	4.1	3.3	4.1	3.0	2.4	2.8	2.1
0.0	1.5	1.5		4.4	3.5	3.5	2.9	2.7	2.7	2.4	2.4	2.1	2.2	2.2	1.6
0.5				4.7	3.6	3.6	3.2	2.8	2.8	2.7	2.7	2.4	2.2	2.2	1.8
0.7				5.1	3.8	3.8	3.4	2.9	2.9	2.8	2.8	2.5	2.2	2.2	1.9

[1] *CL*=29.4; [2] *CL*=29.3; and [3] *CL*=29.2.

Table 2 - *ARL* values for the joint T^2 and $|S|$ charts and NCS charts ($\rho = 0.0$; $\delta = 0.8$; $\delta_1 = 1.0$; $CL = 29.4$).

							n = 5							
		c	0	0	0.5	0.5	0	0.75	0.5	0.75	0.75	0	1.0	1.0
		d	0	0.5	0	0.5	0.75	0	0.75	0.5	0.75	1.0	0	1.0
a	*b*													
1.0	1.0		200.0	48.9*	49.2	19.9	16.7	16.8	9.5	9.5	5.4	6.8	6.6	2.3
			200.0	41.1**	41.1	22.6	14.4	14.4	11.3	11.3	7.7	6.0	6.0	3.3
1.25	1.0		42.6	22.2	17.5	11.0	11.2	8.9	6.7	6.3	4.4	5.2	4.7	2.1
			29.5	18.8	11.5	9.6	10.5	6.0	6.9	6.9	4.5	5.2	5.2	2.5
1.5	1.0		15.3	10.7	9.0	6.7	6.9	5.8	4.8	4.6	3.5	4.0	3.7	2.0
			8.1	7.3	5.2	4.8	5.6	3.5	4.0	3.4	3.1	3.8	2.5	2.0
1.25	1.25		15.6	9.9	9.8	6.8	6.2	6.3	4.7	4.7	3.5	3.9	3.9	2.0
			15.9	8.8	8.8	6.1	5.3	5.3	4.3	4.3	3.4	3.3	3.3	2.1
1.25	1.5		15.3	5.5	5.8	4.4	4.1	4.3	3.4	3.4	2.8	3.0	3.0	1.8
			6.8	4.7	5.2	3.9	3.4	3.8	3.0	3.1	2.5	2.4	2.7	1.8
1.5	1.5		4.4	3.6	3.6	3.1	3.0	3.0	2.6	2.6	2.3	2.4	2.4	1.7
			4.4	3.5	3.5	2.9	2.7	2.7	2.4	2.4	2.1	2.2	2.2	1.6

*T^2 and $|S|$ charts; **NCS charts.

Table 3 - *ARL* values for the joint T^2 and $|S|$ charts and NCS charts ($\rho = 0.5$; $\delta = 1.2$; $\delta_1 = 0.75$; $CL = 32.6$).

							n = 5							
		c	0	0	0.5	0.5	0	0.75	0.5	0.75	0.75	0	1.0	1.0
		d	0	0.5	0	0.5	0.75	0	0.75	0.5	0.75	1.0	0	1.0
a	*b*													
1.0	1.0		200.0	38.4*	38.5	34.8	10.8	10.8	15.9	15.9	10.6	4.1	4.2	4.1
			200.0	33.0**	33.0	29.5	11.0	11.0	13.8	13.8	9.9	4.6	4.6	4.2
1.25	1.0		41.6	17.7	14.1	15.8	7.6	6.6	10.1	8.7	7.1	3.5	3.5	3.5
			29.6	15.8	10.2	11.3	8.1	5.1	8.3	6.3	5.6	4.0	3.0	3.0
1.5	1.0		14.6	8.9	7.7	8.4	5.2	4.6	6.4	5.7	5.0	3.0	2.9	3.0
			8.0	6.5	4.9	5.3	4.7	3.3	4.6	3.8	3.5	3.0	2.3	2.4
1.25	1.25		15.9	8.7	8.6	8.6	4.9	4.8	6.1	6.1	4.9	2.9	2.9	2.9
			16.7	8.0	8.0	7.3	4.5	4.5	5.0	5.0	4.1	2.8	2.8	2.5
1.25	1.5		7.3	5.1	5.2	5.1	3.5	3.6	4.1	4.2	3.6	2.5	2.4	2.4
			6.9	4.4	4.8	4.4	3.0	3.4	3.3	3.6	3.0	2.2	2.4	2.1
1.5	1.5		4.3	3.5	3.5	3.4	2.7	2.7	2.9	2.9	2.7	2.1	2.1	2.1
			4.6	3.4	3.4	3.3	2.6	2.6	2.7	2.7	2.4	2.0	2.0	1.8

*T^2 and $|S|$ charts; **NCS charts.

Table 4 - *ARL* values for the joint T^2 and $|S|$ charts and NCS charts ($\rho = 0.7$; $\delta = 2.0$; $\delta_1 = 0.7$; $CL = 45.75$).

							n = 5							
		c	0	0	0.5	0.5	0	0.75	0.5	0.75	0.75	0	1.0	1.0
		d	0	0.5	0	0.5	0.75	0	0.75	0.5	0.75	1.0	0	1.0
a	*b*													
1.0	1.0		200.0	20.6*	20.2	39.7	5.7	5.6	16.5	16.5	12.9	2.3	2.3	5.0
			200.0	21.2**	21.2	34.1	6.9	6.9	15.2	15.2	11.1	3.0	3.0	4.7
1.25	1.0		39.1	11.9	9.8	17.1	4.6	4.2	10.6	8.7	8.2	2.2	2.2	4.1
			33.6	11.5	8.7	13.3	5.2	4.1	9.1	6.9	6.3	2.7	2.4	3.4
1.5	1.0		13.1	6.9	5.8	8.3	3.6	3.4	6.4	5.6	5.3	2.0	2.1	3.3
			9.4	5.6	4.6	6.0	3.6	2.9	5.1	4.1	3.9	2.2	2.0	2.6
1.25	1.25		15.7	6.9	6.8	9.2	3.5	3.5	6.2	6.2	5.4	2.0	2.0	3.3
			19.3	6.9	6.9	8.7	3.6	3.6	5.7	5.7	4.8	2.1	2.1	2.9
1.25	1.5		7.2	4.4	4.5	5.3	2.8	2.8	4.0	4.2	3.8	1.9	1.8	2.7
			8.1	4.2	4.6	5.2	2.7	2.9	3.8	2.9	3.5	1.9	1.9	2.4
1.5	1.5		4.3	3.1	3.1	3.6	2.3	2.3	3.0	3.0	2.9	1.7	1.7	2.2
			5.5	3.4	3.4	3.9	2.3	2.3	3.1	3.1	2.9	1.7	1.7	2.1

*T^2 and $|\mathbf{S}|$ charts; **NCS charts.

On the other hand, when $c = d = 0.0$ and $a = b = 1.25$, the *ARL* value increases from 13.8 to 22.3 as δ increases from 0 to 2.0.

Table 8 shows the effect of δ_1 on the *ARL* value of the joint NCS charts. In general, larger values of δ_1 are better for detecting changes in the mean vector when both variables are affected by the assignable cause and smaller values of δ_1 are better for detecting changes in the mean vector when only one variable is affected by the assignable cause.

Volume 5, Number 1, 2008, pp. 47-62

Table 5 - *ARL* values for the joint T^2 and |S| charts and NCS charts ($\rho = -0.5$; $\delta = 1.2$; $\delta_1 = 0.75$; $CL = 32.6$).

							***n* = 5**							
		c	0	0	0.5	0.5	0	0.75	0.5	0.75	0.75	0	1.0	1.0
		d	0	0.5	0	0.5	0.75	0	0.75	0.5	0.75	1.0	0	1.0
a	*b*													
1.0	1.0		200.0	34.9*	34.9	6.7	10.6	10.6	3.2	3.2	1.9	4.1	4.1	1.1
			200.0	33.0**	33.0	10.1	11.0	11.0	5.0	5.0	3.2	4.6	4.6	1.6
1.25	1.0		41.6	17.7	14.1	5.0	7.6	6.6	2.8	2.8	1.9	3.5	3.5	1.2
			29.6	15.8	10.2	5.5	8.1	5.1	3.7	3.4	2.5	4.0	3.0	1.5
1.5	1.0		14.6	8.9	7.7	3.9	5.2	4.6	2.5	2.5	1.8	3.0	2.9	1.2
			8.0	6.5	4.9	3.5	4.7	3.3	2.7	2.5	2.0	3.0	2.3	1.4
1.25	1.25		15.9	8.7	8.6	3.8	4.9	4.8	2.5	2.5	1.8	2.9	2.9	1.2
			16.7	8.0	8.0	4.0	4.5	4.5	2.7	2.7	2.0	2.8	2.8	1.4
1.25	1.5		7.2	5.0	5.3	3.0	3.5	3.6	2.2	2.2	1.7	2.5	2.5	1.2
			6.9	4.4	4.8	2.9	3.1	3.4	2.2	2.2	1.8	2.2	2.4	1.3
1.5	1.5		4.3	3.5	3.5	2.4	2.7	2.7	1.9	1.9	1.6	2.1	2.1	1.2
			4.6	3.4	3.4	2.4	2.6	2.6	1.9	1.9	1.6	2.0	2.0	1.2

* T^2 and |S| charts; **NCS charts.

Table 6 - *ARL* values for the joint T^2 and |S| charts and NCS charts ($\rho = -0.7$; $\delta = 2.0$; $\delta_1 = 0.7$; $CL = 45.75$).

							***n* = 5**							
		c	0	0	0.5	0.5	0	0.75	0.5	0.75	0.75	0	1.0	1.0
		d	0	0.5	0	0.5	0.75	0	0.75	0.5	0.75	1.0	0	1.0
a	*b*													
1.0	1.0		200.0	20.6*	20.2	2.9	5.7	5.6	1.6	1.6	1.2	2.3	2.3	1.0
			200.0	21.2**	21.2	3.9	6.9	6.9	2.2	2.2	1.5	3.0	3.0	1.1
1.25	1.0		39.1	11.9	9.8	2.6	4.6	4.2	1.6	1.6	1.2	2.2	2.2	1.0
			33.6	11.5	8.7	3.0	5.2	4.1	2.0	1.9	1.4	2.7	2.4	1.1
1.5	1.0		13.1	6.9	5.8	2.4	3.6	3.4	1.6	1.7	1.3	2.0	2.1	1.0
			9.4	5.6	4.6	2.4	3.6	2.9	1.8	1.7	1.4	2.2	2.0	1.1
1.25	1.25		15.7	6.9	6.8	2.3	3.5	3.5	1.6	1.6	1.2	2.0	2.0	1.0
			19.3	6.9	6.9	2.5	3.6	3.6	1.7	1.7	1.4	2.1	2.1	1.1
1.25	1.5		7.4	4.3	4.5	2.1	2.8	2.8	1.5	1.5	1.2	1.9	1.8	1.0
			8.2	4.2	4.6	2.1	2.7	2.9	1.6	1.6	1.3	1.9	1.9	1.1
1.5	1.5		4.3	3.1	3.1	1.9	2.3	2.3	1.4	1.4	1.2	1.7	1.7	1.0
			5.5	3.4	3.4	1.9	2.3	2.3	1.5	1.5	1.3	1.7	1.7	1.1

* T^2 and |S| charts; **NCS charts.

Table 9 presents the values of *Pv*, which corresponds to the probability of the control chart signaling that the assignable cause affects the mean and/or the variance of the *X* variable (given by $T(x) > CL$) when in reality it affects the mean and/or the variance of the *Y* variable. From this table we can observe that the probability of the chart erroneously signaling is small (less than 5.0 %). The *Pv* values are obtained by the expression (A3) in the Appendix.

Table 7 - The influence of δ on the *ARL* of the joint NCS charts ($\rho = 0.5$).

					$\delta_1 =$ **1.0**			
			δ	0	0.5	0.7	1.0	2.0
			CL	18.33	24.10	27.50	33.50	61.12
a	*b*	c	d					
1.0	1.0	0	0	200.0	200.0	200.0	200.0	200.0
		0	0.5	76.7	47.8	42.6	38.7	34.9
		0.5	0.5	50.3	28.5	25.5	23.1	20.3
		0	1.0	12.0	6.8	6.1	5.6	4.9
		1.0	1.0	7.2	4.2	3.9	3.5	3.1
1.25	1.0	0	0	24.5	26.5	29.0	31.1	38.2
		0	0.5	21.3	19.5	19.4	19.6	20.7
		0.5	0	13.7	11.7	11.6	11.3	12.1
		0.5	0.5	12.8	10.5	10.3	9.8	10.3
		0	1.0	8.8	5.9	5.5	5.0	4.6
		1.0	0	4.9	3.8	3.6	3.5	3.4
		1.0	1.0	4.1	3.0	2.8	2.7	2.6
1.25	1.25	0	0	13.8	15.2	16.8	18.1	22.3
		0	0.5	9.7	8.8	9.1	9.2	9.9
		0.5	0.5	7.8	6.9	6.7	6.7	7.2
		0	1.0	4.3	3.5	3.4	3.3	3.3
		1.0	1.0	3.0	2.4	2.4	2.3	2.3

Table 8 - The influence of δ_1 on the *ARL* of the joint NCS charts ($\rho = 0.5$).

				$\delta =$ **1.0**			
			δ_1	0.5	0.75	1.0	2.0
			CL	26.85	29.15	33.50	61.00
a	*b*	c	d				
1.0	1.0	0	0	200.0	200.0	200.0	200.0
		0	0.5	34.8	35.7	38.7	38.1
		0.5	0.5	50.6	28.6	23.1	20.5
		0	1.0	5.1	4.9	5.6	6.3
		1.0	1.0	6.6	4.2	3.5	3.1
1.25	1.0	0	0	28.5	27.4	31.1	42.1
		0	0.5	15.5	16.2	19.6	24.4
		0.5	0	10.5	10.4	11.3	14.2
		0.5	0.5	14.6	10.8	9.8	10.1
		0	1.0	4.2	4.3	5.0	6.1
		1.0	0	3.2	3.1	3.5	4.6
		1.0	1.0	4.1	3.0	2.7	2.6
1.25	1.25	0	0	16.2	15.5	18.1	23.6
		0	0.5	8.2	7.9	9.2	11.9
		0.5	0.5	8.8	7.0	6.7	7.5
		0	1.0	2.9	2.8	3.3	4.4
		1.0	1.0	3.1	2.5	2.3	2.3

Volume 5, Number 1, 2008, pp. 47-62

Table 9 - *Pv* values for the joint NCS charts (%) (ρ = 0.5; δ = 1.2; δ_1 = 0.75; *CL* = 32.6).

				***n* = 5**			
		c	0	0	0	0	0
		d	0.5	0.75	1.0	1.5	2.0
a	*b*						
1.0	1.25		5.0	3.0	1.9	1.2	1.0
1.0	1.5		2.0	1.6	1.4	1.0	0.9
1.0	1.75		1.2	1.1	0.9	0.8	0.7
1.0	2.0		0.9	0.9	0.8	0.7	0.6

Example

In this section we provide an example to illustrate the use of the joint NCS charts. When the process is in-control, the mean vector and the covariance matrix are given by $\mu_0' = (0,0)$ and $\Sigma_0 = \begin{pmatrix} 1 & 0.5 \\ 0.5 & 1 \end{pmatrix}$, respectively.

We initially generate 5 samples of size $n = 5$ with the process in control. The remaining 5 samples were simulated considering that the assignable cause changed the mean and the variability of X, that is, $c = 1.0$ and $a = 1.25$.

Table 10 presents the data of X, Y, $T(x)$, $T(y)$, T^2 and $|S|$. Figure 1 shows the joint NCS charts with design parameters $\delta = 1.2$, $\delta_1 = 0.75$ and $CL = 32.6$ (according to Table 2, $\alpha = 0.5\%$). Figure 2 shows the joint T^2 and $|S|$ charts. The joint NCS charts signal an

Table 10 - Values of X, Y, $T(x)$, $T(y)$, T^2 and $|S|$.

Sample		**Observations**									
		1	2	3	4	5		*T*(*x*)	*T*(*y*)	T^2	|S|
1	*X*	0.53	–1.83	0.20	0.89	–0.80		10.96	20.06	5.45	0.51
	Y	–0.27	–1.71	–0.10	–1.30	–1.55					
2		–1.63	–0.86	–0.25	0.78	–1.30		15.70	11.31	2.47	0.13
		–0.54	–0.51	–0.93	0.14	–0.93					
3		–0.27	0.12	–0.10	–0.73	–1.05		9.41	5.90	0.93	0.06
		–0.66	0.71	–0.18	0.22	–0.43					
4		–0.27	–0.68	–0.59	–1.60	–0.23		13.66	11.97	2.55	0.09
		–1.01	–0.31	–0.17	–1.38	0.18					
5		–0.07	0.77	2.02	–0.56	0.15		17.75	14.66	3.34	0.54
		0.48	–0.27	0.07	–1.66	–0.39					
6		2.20	0.05	1.07	–0.22	0.38		21.72	10.27	3.38	0.39
		0.52	–0.85	1.07	–0.73	–0.17					
7		0.83	0.82	0.76	1.93	–1.15		21.87	9.68	3.10	0.47
		0.97	–0.11	–0.44	–0.60	–0.20					
8		1.25	3.63	1.68	–0.10	–2.12		39.68	9.94	5.27	1.17
		0.14	0.53	0.54	–0.12	–1.29					
9		2.59	1.90	0.80	0.68	–1.87		32.00	27.93	16.89	1.39
		–0.77	–0.51	–0.81	–0.34	–2.64					
10		–0.14	1.01	1.13	1.52	2.33		31.27	13.30	10.95	0.58
		–0.71	–1.61	0.59	0.37	0.35					

Volume 5, Number 1, 2008, pp. 47-62

out-of-control condition at sample 8. We can observe from Figure 1 that the variable X was the responsible for the out-of-control signal. The joint T^2 and |S| charts signal an out-of-control condition at sample 9. According to Figure 2, the T^2 chart was the responsible for the signal; however, it is not possible to identify the variable that had the parameter(s) affected by the assignable cause.

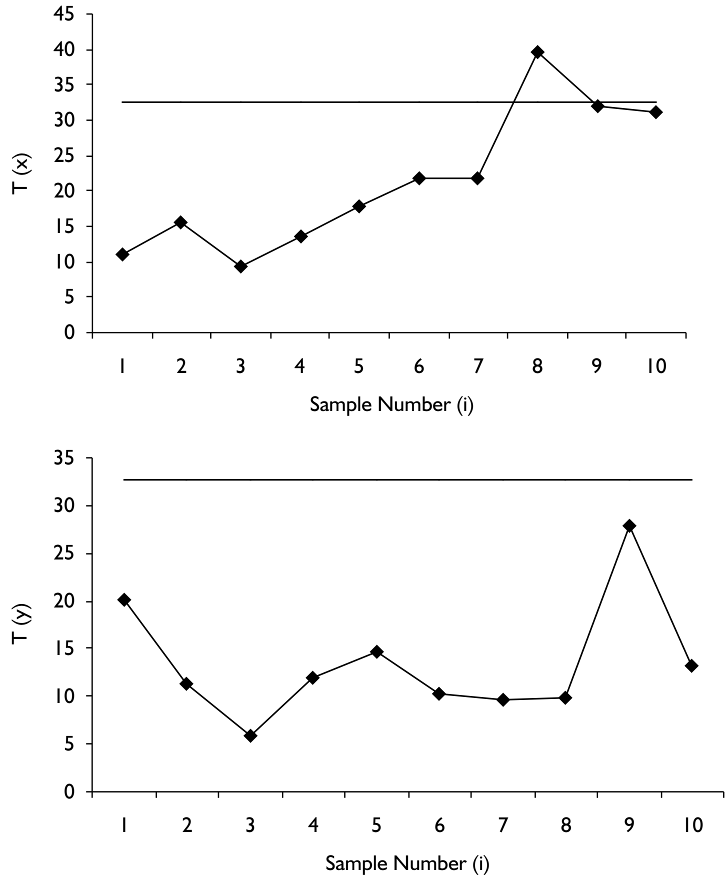

Figure 1 - Joint NCS charts – example.

Conclusions

In this article it is proposed the joint use of two charts based on the non-central chi-square statistic (NCS statistic) for monitoring the mean vector and the covariance matrix of bivariate processes. The way the NCS statistics were defined allowed to obtain the expression to compute *ARL*, which is defined as the average number of samples the joint charts need to signal an out-of-control condition. The joint NCS charts might be more sensitive to changes in the mean vector or, alternatively, more sensitive to changes in the covariance matrix, accordingly to the values of their design parameters. The proposed scheme is an alternative to the joint use of the T^2 and |S| charts which, in general, is faster

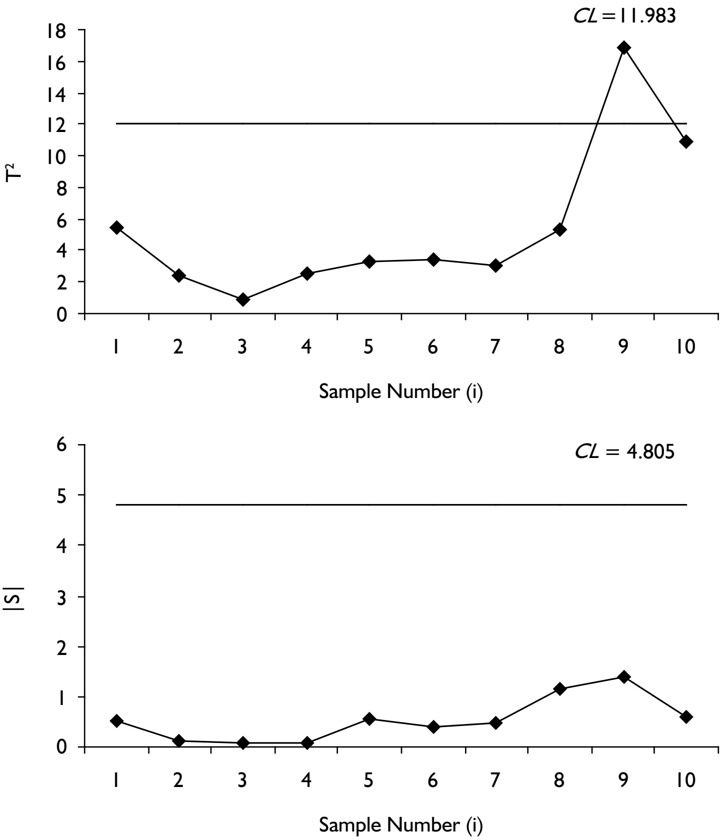

Figure 2 - Joint T^2 and |S| charts – example.

in signaling out-of-control conditions. The joint NCS charts are recommended for those who aim to identify the out-of-control variable instead of the parameter that was affected by the assignable cause: if only the mean vector or only the covariance matrix or both. The risk of the joint NCS charts misidentify the out-of-control variable is small (less than 5.0%).

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Biography

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Appendix: the Probability of *T* (*x*) and/or *T* (*y*) Exceeding the Control Limit.

When the process is in-control the covariance matrix is given by $\Sigma_0 = \begin{pmatrix} \sigma_x^2 & \sigma_{xy} \\ \sigma_{yx} & \sigma_y^2 \end{pmatrix}$. The assignable cause changes the mean vector from μ_0 to $\mu_1' = \mu_x + c\sigma_x; \mu_y + d\sigma_y$ and/or changes the covariance matrix from Σ_0 to $\Sigma_1 = \begin{pmatrix} a^2\sigma_x^2 & ab\sigma_{xy} \\ ab\sigma_{xy} & b^2\sigma_y^2 \end{pmatrix}$. We consider that the assignable cause does not affect the correlation between *X* and *Y*, given by $\rho = \dfrac{\sigma_{xy}}{\sigma_x\sigma_y}$.

Let X_i and Y_i, $i = 1, 2, 3, \ldots, n$, be the measurements of the variables *X* and *Y* arranged in groups of size $n > 1$. Let $\bar{X} = (X_1 + \ldots + X_n)/n$ and $\bar{Y} = (Y_1 + \ldots + Y_n)/n$ be the sample means of the variables *X* and *Y*, and let $e(x) = \bar{X} - \mu_x$ and $e(y) = \bar{Y} - \mu_y$ be the difference between the sample means and the target values of the process means. The two-non central statistics are given by:

$$T(x) = \sum_{i=1}^{n} (X_i - \mu_x + \xi(x)\sigma_x)^2,$$

$$T(y) = \sum_{i=1}^{n} (Y_i - \mu_y + \xi(y)\sigma_y)^2,$$

after some manipulation, we have that:

$$\frac{T(x)}{a^2\sigma_x^2} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{a^2\sigma_x^2} + \left(Z_{\bar{x}} + \frac{c + \xi(x)}{a}\sqrt{n} \right)^2$$

$$\frac{T(y)}{b^2\sigma_y^2} = \frac{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}{b^2\sigma_y^2} + \left(Z_{\bar{y}} + \frac{d + \xi(y)}{b}\sqrt{n} \right)^2$$

where $Z_{\bar{x}} = \sqrt{n}\left(\dfrac{\bar{X} - \mu_x - c\sigma_x}{a\sigma_x} \right)$ and $Z_{\bar{y}} = \sqrt{n}\left(\dfrac{\bar{Y} - \mu_y - d\sigma_y}{b\sigma_y} \right)$.

Consequently:

$$Ps\left(Z_{\bar{x}}, Z_{\bar{y}}\right) = \Pr\left[\left(T(x) < CL\sigma_x^2\right) \cap \left(T(y) < CL\sigma_y^2\right) \middle| Z_{\bar{x}}, Z_{\bar{y}} \right] =$$

$$= \Pr\left[\left(\frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2}{a^2\sigma_x^2} < CL_x \right) \cap \left(\frac{\sum_{i=1}^{n}\left(Y_i - \bar{Y}\right)^2}{b^2\sigma_y^2} < CL_y \right) \middle| Z_{\bar{x}}, Z_{\bar{y}} \right]$$

where $CL_x = \dfrac{CL}{a^2} - \left(Z_{\bar{x}} + \dfrac{c + \xi(x)}{a}\sqrt{n} \right)^2$ and $CL_y = \dfrac{CL}{b^2} - \left(Z_{\bar{y}} + \dfrac{d + \xi(y)}{b}\sqrt{n} \right)^2$.

If *X* and *Y* are normally distributed we have,

$$[y_i - (\mu_y + d\sigma_y)] | x_1, x_2, \ldots, x_n \sim N\left(\rho\frac{b\sigma_y}{a\sigma_x}[x_i - (\mu_x + c\sigma_x)]; b^2\sigma_y^2(1 - \rho^2) \right)$$

or

$$\frac{[y_i-(\mu_y+d\sigma_y)]+\rho\frac{b\sigma_y}{a\sigma_x}[(\mu_x+c\sigma_x)-\overline{X}]}{b\sigma_y\sqrt{1-\rho^2}}\Big|x_1,x_2,\ldots,x_n\sim N\left(\frac{\rho}{\sqrt{1-\rho^2}}(\frac{x_i-\overline{X}}{a\sigma_x}),1\right)$$

As $\rho\frac{b\sigma_y}{a\sigma_x}[(\mu_x+c\sigma_x)-\overline{X}]=(\mu_y+d\sigma_y)-\overline{Y}$, we have (see Mood et al. (1974), page 168):

$$(\frac{y_i-\overline{Y}}{b\sigma_y})\frac{1}{\sqrt{1-\rho^2}}\Big|x_1,x_2,\ldots,x_n\sim N\left(\frac{\rho}{\sqrt{1-\rho^2}}(\frac{x_i-\overline{X}}{a\sigma_x}),1\right)$$

consequently,

$$\frac{\sum_{i=1}^{n}(Y_i-\overline{Y})^2}{b^2\sigma_y^2\sqrt{1-\rho^2}}\Big|x_1,x_2,\ldots,x_n=\sum_{i=1}^{n}\left(\frac{y_i-\overline{Y}}{b\sigma_y\sqrt{1-\rho^2}}\right)^2\Big|x_1,x_2,\ldots,x_n\sim\chi^2_{n,(\rho^2/1-\rho^2)\chi^2_{n-1}}$$

as

$$\frac{\sum_{i=1}^{n}\left(X_i-\overline{X}\right)^2}{a^2\sigma_x^2}=\sum_{i=1}^{n}\left(\frac{x_i-\overline{X}}{a\sigma_x}\right)^2\sim\chi^2_{n-1}$$

then

$$P_S(Z_{\bar{x}},Z_{\bar{y}})=\int_0^{CL_x}g(t)dt=\int_0^{CL_x}\Pr\left[\chi^2_{n,(t\rho^2/1-\rho^2)}<\frac{CL_y}{(1-\rho^2)}\right]\frac{1}{2^{(n-1)/2}\,\Gamma[(n-1)/2]}e^{-t/2}t^{[(n-1)/2]-1}dt \quad \text{(A1)}$$

recalling that the notation $\chi^2_{n,(\rho^2/1-\rho^2)\chi^2_n}$ represents a non-central chi-square distribution with n degrees of freedom and non-centrality parameter given by $(\rho^2/1-\rho^2)\chi^2_n$. The subroutine CSNDF available on the IMSL Fortran library (1995) was used to compute the non-central chi-squared distribution function in expression (A1).

Finally, we have that the probability of $T(x)$ and/or $T(y)$ exceeding the control limit is given by:

$$p=1-\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}Ps\left(Z_{\bar{x}},Z_{\bar{y}}\right)f\left(Z_{\bar{x}},Z_{\bar{y}}\right)dz_{\bar{x}}dz_{\bar{y}} \quad \text{(A2)}$$

where $f\left(Z_{\bar{x}},Z_{\bar{y}}\right)$ is a standardized bivariate normal distribution function with correlation ρ.

During the in-control period $a = b = 1$, $c = d = 0$. As the false alarm risk of the control chart is a continuous decreasing function of CL, a grid search using (A2) allow us to obtain the value of CL that equates p to a specified false alarm risk (α), reminding that $ARL_0=1/\alpha$.

According to the expressions (A1) and (A2), the control limits depend on the correlation; however, the correlation has minor influence on the performance of the NCS charts.

The Pv values are given by:

$$P_v=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\left[\int_{CL_x}^{\infty}g(t)dt\right]f\left(Z_{\bar{x}},Z_{\bar{y}}\right)dz_{\bar{x}}dz_{\bar{y}} \quad \text{(A3)}$$

with $b > 1$ and/or $d > 0$ and $a = 1$ and $c = 0$.

Volume 5, Number 1, 2008, pp. 63-74

Sensorial Analysis of Wines from *Malpighia glabra* L. Pulp

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Abstract
This work aimed to make the sensorial analysis of Barbados cherry (*Malpighia glabra* L.) wines. A standardized questionnaire was used to evaluate the effect of soluble solids (°Brix) and the concentration of fruit pulp on sensorial quality attributes (color, flavor and aroma) of wines; which were measured on hedonic scale, to obtain the best condition for manufacturing wine from Barbados cherry. *Saccharomyces cerevisiae* yeast was used for fermentation. Results showed that Barbados cherry wines were suave, sweet and with 11°GL of alcohol concentration. Flavor and color of wines were characteristic of *acerola* fresh fruit. The t Student test showed that did not present any significant difference among the wines in both these sensorial attributes. Increasing the initial °Brix of must, the wine obtained had better acceptance and there was no effect of pulp mass on sensorial attributes studied. Sensorial analysis revealed that the best Barbados cherry wine was obtained for a must with composition of 22 g/L of sugar and 1 kg of Barbados cherry pulp for each 6 liter of wine. This work supports the usage of *acerola* for obtaining high quality wines which possess pleasing aroma and shiny red color.

Keywords: sensorial analysis, quality control, barbados cherry, wine, color, flavor, aroma

Volume 5, Number 1, 2008, pp. 63-74

Introduction

The Barbados cherry (*Malpighia glabra* L.) fruit, as any other minor non-conventional fruit plants, leaves doubt on its origin. It was introduced in Brazil about 50 years back, in the state of São Paulo, brought from Puerto Rico (Dinizi et al., 2003). The fruit is known for its very high ascorbic acid (vitamin C) content. About 100 g of juice possesses 50 to 100 times more of this vitamin than that of an equal quantity of lemon or orange juice (Gomes et al., 2002). Other vitamins of relevant importance for health and human food purposes such as A, B1 and B2 also favor the consumption of this fruit. The daily consumption of 2 to 4 fruits is sufficient to meet the normal necessities of human being. The Barbados cherry is also important from social and economic aspects as it offers to the poor population as an easy and accessible source of vitamins and mineral salts at low cost.

The wine commercialization undergoes long and traditional trajectories until it arrives at the table for consumption. However, the product undergoes stabilization treatments and packaging that transforms it into a quality product although at many times, turns it to be quite original and personalized. Thus being, the wines should constant improvements in its characteristics and these must be perfectly stabilized and submitted to severe rules which assure product protection against frauds, whereby guarantee the consumer (Delanoe et al., 1989).

Although the wines better appreciated are made from grapes yet other fruits could be utilized as raw material for the manufacture of wines. These fruits could be orange, pineapple, strawberry, Barbados cherry, cashew apple, *cajá* and other exotic fruits such as *cupuaçu* (Costa et al., 2003 and 2006; Freitas et al., 2001; Garrutti, 2001; Santos et al., 2005a and 2005b; Severo Júnior et al., 2007). Generally, the wines made from these fruits result in flavor and aroma characteristics of the original fruit utilized and if proper care is taken, could last for long time storage.

An alcohol drink ("*Aguardente*" or spirit) obtained of starch from root manioc was compared to two sugar-cane alcohol drink by sensorial analysis. Results showed that color, aroma and flavor from manioc spirit these were not significantly differences to the commercial sugarcane spirits (Ferreira et al., 2005).

The *Saccharomyces cerevisae* yeast was reused in human feeding as beer yeast drags. They were obtained of wines from cashew (*Anacardium occidentales* L.), Malay apple (*Eugenia malaccensis*) and mangaba (*Hancornia speciosa* Gomes) pulps, the musts dregs were separated of the wines, placed into capsule former and they were dried at 55 °C into dryer with air circulation. The beer yeast capsules obtained were compared sensorial to the beer yeast drags commercialized in Brazil. The beer yeast drags had aroma, color and flavor characteristics of these fruits sources. The sensorial analysis showed that all beer yeast drags from tropical fruits wines had good acceptance of tasters and its values were more than beer yeast drags commercialized (Almeida et al., 2005).

The sensorial analysis was used to choose the best *Saccharomicys cerevisiae* yeast between FLASHMAN® and FERMIX® to manufacturing the maize beer (Severo Júnior et al., 2005). The sensorial acceptances of 30 consumers on beer sensorial qualities were evaluated by use of a hedonic scale, in a standardized questioner. The sensorial analysis showed that the beer obtained by FLASHMAN yeast was the best in all sensorial quality and its acceptance was very good, introducing that this beer may be commercialized.

A sensorial analysis with 30 consumers had done, to compare the wine from cashew apple (*Anacardium occidentale* L.) with the peach and grape wines. Results showed that cashew wine was a good accepted quality and it was the best wine than others fruit wines (Costa et al., 2003 and 2006).

Severo Júnior et al. (2007) produced a wine from *cajá* (*Spondias mombin L.*) pulp. Of this wine, three new wines were obtained, a non-clarified one and two clarifieds, one by sedimentation and other by membrane separation process. After sensorial analysis with 50 consumers, authors perceived that clarified wines showed a good acceptance by the consumers and that anyone of clarification process did not change the quality of the wine.

Santos et al. (2005a and 2005b) to manufacture a wine from Barbados cherry fruit, but the process had been not starting. Composition of must was of 240 g/L of sugar and 1 kg of pulp from 8 liter of wine. The significant data had shown that the Barbados cherry wine was well accepted for consumers and not had difference with relation to the commercialized wine, being able to be a new source of investments for small producers or new option of market.

Recently, the use of neural network based on Kohonen algorithms was applied in the sensorial analysis of Barbados wine samples. Kohonen network results were similar or better than statistical classification, this shows that the use of Kohonen algorithm in the sensorial analysis of wines is valid. Kohonen algorithm is very good in clustering of wine samples and it uses in sensorial analyses of beverages is promises (Curvelo-Santana et al., 2008; Dias et al., 2008).

With this objective in mind, this work was undertaken to obtain a wine of good and acceptable quality prepared from the usage of Barbados cherry fruit, which may consequently aggregate further values to this fruit culture.

Materials and Methods

The Barbados cherry fruits at stage of maturity were selected, cleaned with chlorine (2 ppm of active Cl_2) water and triturated in a blender, thus obtaining the pulp which was stored in a refrigerator. For the preparation of must, the pulp quantity of Barbados cherry fruits and total soluble solids (°Brix) content were varied according to the experimental planning design of 2^2, presented in Table 1. The inorganic nutrients were added in the concentrations of 1 g/L of $NH_4H_2PO_4$ and 0.1 g/L of $MgSO_4$. The pH of the medium was later corrected in the range of 4 to 5 with Na_2CO_3. Fractions of total volume of these were separated in different flasks, from the principal vat as being to approximately 4 L, 500 ml and 10 ml, which were denominated as vessels. These were pasteurized by heating in an

Volume 5, Number 1, 2008, pp. 63-74

Table 1 - Experimental conditions of manufacture of *acerola* wines.

Wine samples	Factors	
	°Brix (g sugar/100 mL)	% Mass (kg Barbados cherry pulp/liter of must)
A	22	1/6
B	26	1/6
C	22	1/3
D	26	1/3
E	24	¼
F	24	¼
G	24	¼

autoclave and cooling rapidly in running water having the sole objective of sterilization of medium (Delanoe et al., 1989; Garruti, 2001; Lima et al., 2001).

In order to better evaluate the effect of total solids (°Brix, g sugar/100 mL of must) and fruit pulp mass (*%Mass*, kg Barbados cherry pulp/ liter of must) on the wines acceptability in relation to flavor, color and aroma.

Preparation of wines

Fermentation: the *Saccharomyces cerevisiae* was inoculated in the lowest volume of vessel at a concentration of 70 to 80 g/L, where it remained between 20 - 24 hours for adaptation of the medium. It was later transferred to the next vessel and maintained for 48 hours, after which it was transferred to the principal vat, in which it remained for the final days of its fermentation. After fermentation, the wines were clarified by added of bentonit clay at 1% solution. Later filtration for complete separation of the two phases (liquid and solid) was achieved, resulting in a clear wine (Delanoe et al., 1989; Garruti, 2001; Lima et al., 2001). The wines were packed in amber-colored bottles of 1.0 Liter capacity which were sealed with cork. The closed wine bottles were sterilized by heating in an autoclave at 115 °C and 1.5 kg/cm^2 for 15 minutes, cooled later in running water and stored in refrigerator at 5 °C for a period of 6 months for posterior evaluation of its quality (Gava, 1986).

Physical-chemical analysis of wines

The characteristics determined were: total acidity by titrating with NaOH solution 0.1 M and volatile acidity according to the method of Casenave-Ferré, reducing sugars by Fehling method, percent alcohol by distillation and later measurement of density with alcoholmeter, density measurement by weighing the mass in analytical balance of a determined volume, dry matter by drying at 100-105 °C and pH by potentiometer method (Ascar, 1985; Delanoe et al., 1989; Garruti, 2001).

Sensorial analyses

The acceptability of samples of fermented musts was evaluated using sensorial affective tests, comparing with the aroma of sparkling wine. The samples were served to the 50 consumers in codified tulip-shaped glasses covered with watch glasses, using a monadic presentation and a 9-cm non-structured hedonic scale. The consumers also registered their purchasing intentions for each sample on the same score sheet, using a five-point attitude scale (Mamede et al., 2005; Teixeira et al., 1987). Sensorial characteristics such as flavor, color and aroma of wines were evaluated. The experimental research on quantitative basis was undertaken wherein a standard form for sensorial analysis was used and random sampling was applied for each of the above attributes using a hedonic scale (1-9), as is shown in Table 2. Based on frequency of responses, the sensorial data were compared by T Student test of significance and plotted in Figure 1 (Almeida et al., 2005; Ferreira et al., 2005; Teixeira et al., 1987). The Appendix 1 shows the model of questionnaire used to obtain the sensorial data.

Table 2 - Form of translation of the sensorial responses of consumer to numerical valor in hedonic scale, for anyone sensorial qualities.

Sensorial response of consumer (Portuguese)	Sensorial response of consumer	Similar valor in hedonic scale
"Não gostei muitíssimo"	I liked not very extremely	1
"Não gostei muito"	I liked not extremely	2
"Não gostei regularmente"	I liked not regularly	3
"Não gostei ligeiramente"	I liked not	4
"Indiferente"	I perceived not diference	5
"Gostei ligeiramente"	I liked slightly	6
"Gostei regularmente"	I liked regularly	7
"Gostei muito"	I liked extremely	8
"Gostei muitíssimo"	I liked very extremely	9

Results and Discussion

Sensorial qualities from wines

The wines obtained possessed clean appearance having the color and aroma characteristics pertaining Barbados cherry fruit, light and sweet flavor, showing that these characteristics of the fruit were retained to a great extent. According to Freitas et al. (2001) and Garrutti (2001), the wines made from fresh fruit pulps had color, flavor and aroma characteristics of these sources and if due care is taken, could last for long time storage.

The detailed observation for the data in Table 3 shows that majority of wines presented satisfactory results in their sensorial analysis, being close to six, it introduces that Barbados cherry wines had been well appreciated for consumers. Figure 1 presents in the visual form the presentation of mean values of analysis sensorial of wines. This shows that in color practically there was no difference between the diluted or more concentrated wines leading to conclude that the weight of fruit mass did not alter significantly the wine color. It was also observed that there was a little visual difference among the samples in relation to wine aroma and to a little higher extent to flavor.

However, according to Teixeira et al. (1987) to exist significant differences between wines, the valor calculated to t Student must be higher than tabled t Student. Tables 4, 5 and 6

Volume 5, Number 1, 2008, pp. 63-74

Table 3 - Experimental conditions of manufacture of Barbados cherry wines and yours responses to the sensorial qualities.

Wine samples	Responses*		
	Color	**Aroma**	**Flavor**
A	5.740	5.428	4.860
B	6.460	6.340	7.261
C	5.653	5.160	4.027
D	6.380	6.220	6.913
E	6.200	5.907	6.324
F	6.189	5.950	6.176
G	6.020	5.660	5.759

*Average of the sensorial analysis of 50 consumers.

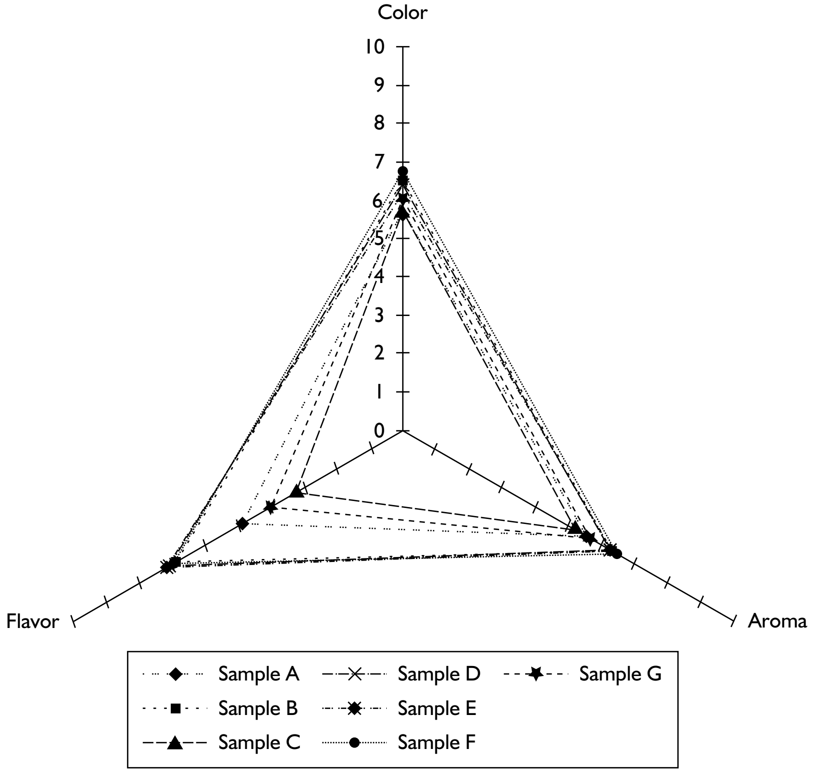

Figure 1 - Sensorial attributes for Barbados cherry wine.

show the t Student test for the sensorial attributes from Barbados cherry wines. From tables, it notes that the valor calculated to t Student varied from 0.005 to 0.36, which is much lower than tabled t Student (2.86), of this way, the value of calculated t Student were be at least four times lower than tabled t Student. Thus, the t Student test showed that did not present any significant difference among the wines in both these sensorial attributes.

Table 4 - Statistic comparison based in t Student analysis at 95% of level confidence, for the wine appearance.

Wines	Calculated t Student					
	B	C	D	E	F	G
A	0.089	0.005	0.079	0.057	0.119	0.032
B	-	0.094	0.010	0.032	0.030	0.057
C	-	-	0.084	0.062	0.124	0.037
D	-	-	-	0.022	0.040	0.047
E	-	-	-	-	0.062	0.025
F	-	-	-	-	-	0.087

Tabled t Student for 50 analyses = 2.864, source: Teixeira et al. (1997).

Table 5 - Statistic comparison based in t Student analysis at 95% of level confidence, for the wine aroma.

Wines	Calculated t Student					
	B	C	D	E	F	G
A	0.108	0.044	0.093	0.103	0.126	0.020
B	-	0.152	0.015	0.005	0.018	0.088
C	-	-	0.136	0.147	0.170	0.064
D	-	-	-	0.010	0.033	0.072
E	-	-	-	-	0.023	0.082
F	-	-	-	-	-	0.106

Tabled t Student for 50 analyses = 2.864, source: Teixeira et al. (1997).

Table 6 - Statistic comparison based in t Student analysis at 95% of level confidence, for the wine flavor.

Amostras	Calculated t Student					
	B	C	D	E	F	G
A	0.185	0.146	0.206	0.209	0.196	0.080
B	-	0.331	0.020	0.024	0.011	0.265
C	-	-	0.3518	0.356	0.342	0.067
D	-	-	-	0.004	0.009	0.285
E	-	-	-	-	0.013	0.289
F	-	-	-	-	-	0.276

Tabled t Student for 50 analyses = 2.864, source: Teixeira et al. (1997).

A general analysis of these wines shows that with the increase in initial °Brix of must, the wine obtained was characterized better acceptance in all sensorial attributes studied. It is also perceived that practically there is no effect of pulp mass on sensorial attributes studied, which indicates that its influence is smaller in the final product quality. However, of this Table 3, it concludes that: the best Barbados cherry wine was "B". This wine was obtained of a must with composition of 22 g/L of sugar and 1 kg of Barbados cherry pulp for each 6 liter of wine.

In Brazil, the Barbados cherry fruit buy for U$ 0.50/kg (same to the sugar price) and as 1 kg of fruit gives approximately 6 L of Barbados cherry wine; the wine cost is approximately U$ 0.16. Thus, the Barbados cherry fruit can be used to obtain a wine of good quality, product suitable for human consumption and low production cost, as will as; the wine manufacture may be a value-added product of Barbados cherry cultivation.

Verify of adjusting of wines to Brazilian laws

For fitting the Brazilian Laws the wine composition must be determined and compared to physical-chemical composition showed in this Norms. Table 7 shows the data obtained after the analysis of Barbados cherry wine samples. From this table, it could be observed that total acidity was within the range established as Brazilian standard (lower than 130 mEq/L) and practically all fermented samples did not characterize for any undesirable acidity which could be volatile, indicating presence of acetic acid or its derivatives. Such substances denature wine, modifying the aroma (pungent) and flavor of the same (bitter).

Table 7 - Physical-chemical analysis of Barbados cherry wines.

Characteristics	Mean value	Standard deviation (±)	Brazilian law standards
Reducing sugars (g/L)	6.670	0.780	-
Total acid (mEq/L)	5.798	0.780	130
Volatile acid (mEq/L)	0.139	0.121	< 55
Density	0.985	0.008	-
pH	3.0	0.5	3.1-3.9
Total solids (%)	4.123	0.126	-
Alcohol content at 20 °C (°GL)	11.0	0.5	9-15

The reducing sugars content in wines varied from 5-20 g/L, which indicates relative stability that a small quantity of sugar could reduce or inhibit any perturbation which may occur in the physical-chemical properties of wines due to microbial action. The dry matter content also was lower and hence it presented a clear appearance and low density due to the presence of non-volatile acids, superior alcohols, carbohydrates, inorganic minerals, tannins, etc. The wine pH was in the range of 3.1 to 3.9 which is very much desired and it results in avoiding microbial contaminations or alterations in color, flavor and in oxi-reduction potential (Delanoe et al., 1989; Garruti, 2001).

Conclusions

The wines obtained in this work had color, aroma and flavor characteristics of *acerola* and it was classified as suave. Its alcoholic gradation was approximately 11 °GL and had all other physico-chemical characteristics within the norms specified by Brazilian Laws.

The sensorial analysis demonstrated that there was no significant difference between the various wines manufactured and their mean acceptance was about 6 point in hedonic scale. The t Student test showed that did not present any significant difference among the wines in both these sensorial attributes. The analysis of the sensorial data showed that the wines which were produced with the must of higher °Brix and lower quantity of pulp mass were more acceptable by panel members. The best Barbados cherry wine was obtained for a must with composition of 22 g/L of sugar and 1 kg of Barbados cherry pulp for each 6 liter of wine. This work demonstrated that it is possible to obtain good and commercially acceptable, which may serve as another form of aggregating value to the Barbados cherry culture.

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Volume 5, Number 1, 2008, pp. 63-74

Appendix 1: Model of Questioner Used to Obtain the Sensorial Data.

Name: ____Date: ____/____/____
Instructions: You will go to receive a series from samples that will be served individually. You prove each one carefully and he evaluates, before the next one is served. You mark with a X in the position that better identifies the intensity of the evaluated characteristic.

Sensorial Characteristic: Appearance

Criterions	Samples						
	A	B	C	D	E	F	G
I liked not very extremely							
I liked not extremely							
I liked not regularly							
I liked not							
I perceived not difference							
I liked slightly							
I liked regularly							
I liked extremely							
I liked very extremely							

Sensorial Characteristic: Aroma

Criterions	Samples						
	A	B	C	D	E	F	G
I liked not very extremely							
I liked not extremely							
I liked not regularly							
I liked not							
I perceived not difference							
I liked slightly							
I liked regularly							
I liked extremely							
I liked very extremely							

Sensorial Characteristic: Flavor

Criterions	Samples						
	A	B	C	D	E	F	G
I liked not very extremely							
I liked not extremely							
I liked not regularly							
I liked not							
I perceived not difference							
I liked slightly							
I liked regularly							
I liked extremely							
I liked very extremely							

OBS:____

____

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Volume 5, Number 1, 2008, pp. 75-88

The Effect of the Workload on Due Date Performance in Job Shop Scheduling

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Abstract

This paper provides a simulation model to study the effect of the work-in-process control on due date performance in job shop environment. The due date performance is measured by both the number of tardy jobs and the total tardiness. The simulation runs include different shop configurations (flow shop and general job shop), workloads and sequencing rules. As expected, the results reveal that due date performance is highly dependent on the work-in-process, particularly after the system reaches saturation. Nevertheless, the model is very useful to show job shop managers the effect of the work-in-process control in the due date meeting performance.

Keywords: scheduling, job shop, CONWIP, dispatching rules, simulation

Introduction

Since the emergence of The Japanese Production System, a massive inventory reduction effort is underway. Manufacturing companies worldwide have workout the competitive priorities of Cost, Quality and Speed.

These priorities are somehow conflicting. To achieve low unit cost, the factory should produce high volume of low mix products, but high volume would increase lead times and inventory cost. Meanwhile, high mix and low volume orders are the current demand pattern in the manufacturing environment.

The Toyota Production System was successful in proving that an automotive company can be profitable producing in small lots. The well known practice of Just-in-Time (JIT) supports production processes with lower inventory. The JIT systems are called pull production, in contrast to the traditional push production. In push systems, job orders are

Volume 5, Number 1, 2008, pp. 75-88

released to shop floor to meet due dates. The Material Requirements Planning (MRP) and its successors operate according to this logic. Pushing orders to shop may increase factory congestion and causes efficiency loss.

In a pull system, orders are released according to the factory workload. New orders are authorized to enter the shop once the total shop workload is below the predetermined maximum level. As a consequence, the maximum work-in-process (WIP) is held constant.

The mechanism to control the WIP in JIT manufacturing systems is the Kanban. Basically, the Kanban cards limit the stock between to subsequent work stations in a repetitive low mix, high volume production line.

Spearman et al. (1990) formulated another pull mechanism that seams to be more adequate to intermittent manufacturing (high mix, low volume production). The mechanism ensures that just after an open order is completely finished, a new order can be released to the shop floor. This method was called constant work-in-process (CONWIP).

In fact, the CONWIP is a hybrid strategy since the job flows in a push fashion inside the plant (usually under the FIFO rule), although new orders are pulled only when the WIP drops the predetermined WIP limit. Framinan et al. (2003) present a complete review of CONWIP production control system. Figure 1 provides a visual comparison of the three basic mechanisms discussed above.

In general, the decisions to be taken when implementing CONWIP control mechanism are to determine: (i) the production quota; (ii) the maximum amount of workload; (iii) the

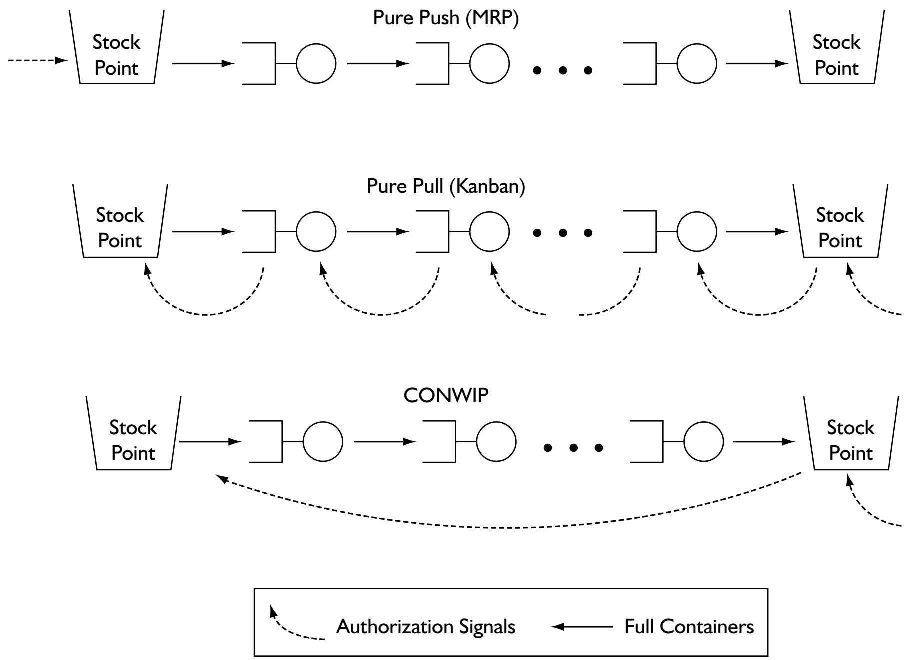

Figure 1 - Push and Pull Production Systems.

capacity shortage trigger; (iv) how to forecast the backlog list; (v) the number of cards into the system; and (vi) how to sequence the orders in the system (Spearman et al., 1990).

This paper provides a simulation model to evaluate the effect of the work-in-process control on due date performance in both flow and general job shop environments. The following section discusses the simulation-based approach for job shop scheduling. Section 3 presents the simulation model used for the evaluation purposes. The scenarios considered are presented in section 4 and the results achieved follow in section 5. The section 6 concludes the paper with an overall analysis and the concluding remarks.

Simulation-Based Scheduling

The classical scheduling theory considers three main groups of goals: (i) on-time delivery; (ii) high throughput; and (iii) maximum machine utilization. For each group, there are different performance measures such as: the maximum tardiness, the number of tardy job, the *makespan* (total completion time), the mean flow time etc. These goals are conflicting and most of the results from scheduling theory "optimize" just one given performance measure (Conway, 1965; Morton and Pentico, 1993; Baker, 1995; Pinedo, 2005).

A scheduling problem can be characterized by a set of jobs, each of them with one or more operations which must be performed in a fixed sequence on different machines. The purpose of scheduling is to determine the schedule that optimizes some performance measure.

The problems considered by the traditional scheduling theory are roughly classified into four main classes: (i) single machine; (ii) parallel machines; (iii) flow shop; and (iv) general job shop. Most of these problems are well known by their combinatorial nature. In particular, the general job shop scheduling problems are included into a large class of intractable numerical problems known as NP-hard (Jain and Meeran, 1999).

Tardiness criterion is of great significance in manufacturing systems since this is one of the most important measures of customer service in a high competitive market. However, very little work is reported on the tardiness problem. A specific review on the flow shop problem is presented by Kim (1995) and an extensive review on scheduling problems with tardiness criterion can be found in Koulamas (1994).

On the other hand, an alternative approach to scheduling problems is the simulation-based scheduling. Simulation has become a widely used tool for operations management. There are many simulation software packages available today that can be used to model and evaluate real-scale system under different performance measures and operational conditions (Law and Kelton, 1991).

The main advantage of using simulation is that one can handle larger problems in reasonable computation times. Complex dispatching rules that integrate management policies and technological constraints can be incorporated into the simulation model. Specially, one can include the work-in-process constraints, which is the main concern of this paper.

In the operational level, where the operations scheduling are accomplished, the inventory issue concerns basically to the work-in-process level. Then, two research questions arise:

1. How the work-in-process constraint affects the due date performance?
2. What is the ideal work-in-process level to achieve an efficient operation?

In order to evaluate the CONWIP effect over due date performance, one should, for each WIP constraint and performance measure, solve the corresponding job-shop scheduling problem. As mentioned earlier, the job-shop scheduling problem presents high computational complexity and the optimization algorithms based on mathematical programming (e.g., the branch-and-bound method) would not solve real problems. The alternative approaches would be the search-based meta-heuristics and dispatching rules simulation.

A number of papers have been published over the years dealing with different sequencing rules, using both flow-time and due-date based performance measures (Panwalkar and Iskander, 1977; Vepsalainen and Morton, 1987; Baker, 1995; Chiang and Fu, 2007).

In this paper, we choose the dispatching rules simulation because of the ease of implementation, flexibility, low computational time and satisfactory performance in providing solutions to the job-shop scheduling problem.

The simulation model presented considers four dispatching rules (shortest processing time, earliest due date, least dynamic slack and least work in next queue), two due date related performance measure (total tardiness and number of tardy job) and two shop configurations (flow and job shop).

Simulation Modeling

A simulation model was developed to study the effect of the WIP constraint on due date performance in a job shop environment. The model performs the scheduling of N jobs through a shop of M machines, based on some available sequencing rules. Each job comprises a set of operations to be executed sequentially, each operation in one machine, with a predetermined setup and process times. These jobs are grouped according to their routing into R possible routes, each route corresponds to a particular product and it is characterized by the same sequence of operations with specified setups and processes times.

The shop configuration is determined by the number of machines and the flow pattern. The user should specify how many routes (R) to consider and, for each route, the respective sequence of machine. This may be done by manually or automatically inputting the sequences, using a random route generator. In this case, the user inputs a transition matrix like the one showed in Table 1. In the transition matrix, each entry p_{ij} corresponds to the probability of an order leaving station *i* proceeds to station *j*. Moreover, station 0 is the entrance and the N+1 is the exit corresponding station.

Table 1 - Job Shop Transition Matrix.

	1	2	3	4	5	6	7	8	9
0	50	30	10	10					
1		50	30	10	10				
2	5		50	30	10	5			
3	5	10		40	20	10	10	5	
4		5	10		35	20	20	10	
5			5	10		40	25	15	5
6			5	5	10		40	30	10
7				5	5	10		40	40
8				5	5	5	5		80

In the general job shop problem, orders can move from one station to any other. The flow shop is a particular case of the job shop where there is an implicit machine sequence such that orders can only proceeds forward, that is, p_{ij} will be zero for all pairs (i, j) with $i > j$.

In addition to the routes, the user should specify the due date and the total process time (including setup) for each order. Again, to simplify the data input, the process time of each operation can be randomly generated using some usual probability distribution.

After generating each operation time, a due date is assigned to each order by sum up the process time of all operations and multiplying this total to a factor *k* greater than one. This value plus a random deviation will determine the specific due date. By varying the *k* factor, one can achieve different workloads. Higher values of *k* will produce orders with grater slacks, which mean that orders can wait more time in queue without being late. As *k* gets close to one, the total queuing time should be reduced in order to complete order on time, and the scheduling problem become much harder.

Finally, we assume that all jobs are available for scheduling at time zero, which it is a common assumption in job-shop scheduling research. Since all time parameters are known in advanced to the simulation, the problem just formulated is classified as a static deterministic job shop scheduling problem that is hard to solve optimally even for a low number of machines and jobs (Pinedo, 2005).

In this paper, it is applied the dispatching rule scheduling approach with CONWIP, that is, a maximum number of orders allowed in the shop is fixed. The orders on the backlog list are released to shop according to a selected sequencing rule.

Inside the shop, each machine has also one sequencing rule chosen from a set of sequencing rules available. The simulation model consists of a discrete event continuous time model and works as follow.

The main event is the completion of an operation in one machine. If this operation is the last one in the process routing, the order is considered finished, otherwise it proceeds to the next station. If this station is idle, operation starts immediately, or, if not, the order joins the queue.

The end of an operation in one machine turns it available to another job. If there is any in queue, the next job will be chosen according to the machine sequencing rule, otherwise, the machine becomes idle.

Volume 5, Number 1, 2008, pp. 75-88

If the WIP fall down the limit when an order leave the system (last operation finished), a new order is pick up from the backlog list also obeying a dispatching rule assigned. The simulation process proceeds until all jobs are processed. The model was implemented using Visual Basic for Application and Microsoft Excel™.

Experimental Scenarios

In the simulation were considered two shop configurations (flow and general job shop), with high and medium workloads and four sequencing rules. For both shop configurations, it was considered 8 machines and 10 routes with at most 10 operations each route.

Two transition matrices are used for the random generation of the routes, one for each configuration, as shown in Table 1 and Table 2. In the flow shop transition matrix (Table 2), the lower diagonal cells are null since the jobs can not return to any previous machine.

The job shop and the flow shop routes parameters are presented in Table 3. The operations times were generated from a normal distribution with mean 4 and standard deviation 0.4 for all operations. The columns labeled "time" are equal to the sum of all operations times, that is, the total processing time (not included the queuing time) of the orders in that route.

The amount of 30 orders was generated for each of the 10 routes, all of them with ready times equal to zero. The due dates were also randomly generated from a normal distribution with mean $k \cdot t_0$ and standard deviation $0.1 \cdot k \cdot t_0$, where t_0 is the total route time from Table 3 and k is the factor that determine the scenario workload. In the job shop configuration, k assumes the values 1.25 and 1.30 for high and medium workloads, respectively, and in the flow shop configuration the corresponding values are 1.30 and 1.35.

The sequencing rules considered were:

1. SPT - Shortest Process Time,
2. EDD - Earliest Due Date,
3. SLA - Dynamic Slack,
4. LWQ - Least Work in Next Queue.

Table 2 - Flow Shop Transition Matrix.

	1	2	3	4	5	6	7	8	9
0	70	20	10						
1		70	20	10					
2			70	20	10				
3				60	30	10			
4					60	30	10		
5						60	30	10	
6							70	20	10
7								70	30
8									100

Table 3 - Job Shop and Flow Shop Routes.

Job Shop Routes			**Flow Shop Routes**		
#	**Route**	**Time**	**#**	**Route**	**Time**
1	1, 2, 3, 6	16.9	1	1, 3, 5, 6	15.5
2	1, 3, 7, 8	16.4	2	2, 3, 4, 5, 6, 8	25.6
3	1, 5, 8	11.6	3	1, 3, 4, 7, 8	20.3
4	1, 2, 3, 5, 6, 7, 8	27.3	4	3, 4, 5, 7, 8	20.9
5	3, 4, 6, 7	16.3	5	1, 2, 3, 5, 6, 7, 8	26.5
6	1, 2, 4, 3, 1, 2, 4, 5, 7	36.0	6	1, 2, 3, 5, 7	19.8
7	2, 6, 5, 6, 8	20.7	7	1, 2, 3, 4, 5, 7	24.5
8	1, 2, 4, 5, 7	19.7	8	1, 3, 5, 6, 8	19.8
9	2, 3, 4, 6, 7	21.0	9	2, 4, 6, 7, 8	19.1
10	1, 2, 4, 5, 8	20.6	10	3, 4, 5, 6, 7	20.1

The SPT and EDD are the most usual dispatching rules considered in job shop scheduling simulation. The former is usually associated with higher throughput, since it speeds up the smaller operations and reduces queuing. The second seeks to reduce tardiness by prioritizing the most urgent jobs.

In the third rule, the job with the minimum slack time has higher priority. Slack time is obtained by subtracting the current time and the total processing time of the remaining operations from the due date. Finally, the fourth rule will select the order that has a subsequent operation on the machine with the current minimum work in queue. This rule tends to minimize the chance of machine idleness and to achieve a more continuous flow.

In total, sixteen instances of the problem were considered, each of that corresponding to one configuration, one charge and one sequencing rule. Each instance was initially simulated with no constraint on the work-in-process (WIP) and the highest WIP observed becomes the upper limit for it. (Setting the WIP above that upper limit will not change any performance measure.) Then, the WIP was gradually reduced to verify the effect of this constraint on the performance of the system, which was evaluated by the following performance measures:

TTA = total tardiness,

NTO = number of tardy orders.

In the job shop configuration, each instance comprises 300 orders passing through the shop. Each instance is replicated with 10 different levels of work-in-process, raging from 10 to 100 jobs. For the flow shop case, it was tested 14 upper limits, raging from 10 to 140 jobs.

The number of machines and jobs considered are assumed to be representative of the scheduling problems found in small and medium-sized enterprises.

The software was codified in VBA for Excel and the simulation was run in a microcomputer with Intel Pentium 4 3.0 GHz processor and 512 Mb RAM. The largest computational time did not exceed 90 seconds.

Volume 5, Number 1, 2008, pp. 75-88

Results

This section presents the analysis of the results obtained from the simulation model. These results are graphically shown in the next four subsections, considering the two due-date related performance measures (Total Tardiness and Number of Tardy Orders) and the two shop configurations (job shop and flow shop). Each of the following subsections presents a short analysis of the results achieved.

Total Tardiness - Job Shop

The first scenario considered is the Job Shop with the Total Tardiness measure. For this scenario, the High and Medium load are presented respectively in Figures 2 and 3.

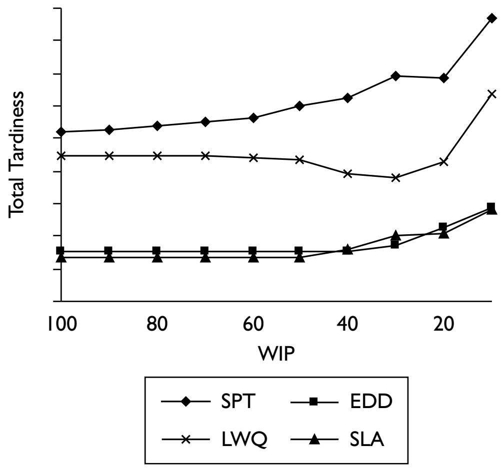

Figure 2 - Total Tardiness for Job Shop – High Load.

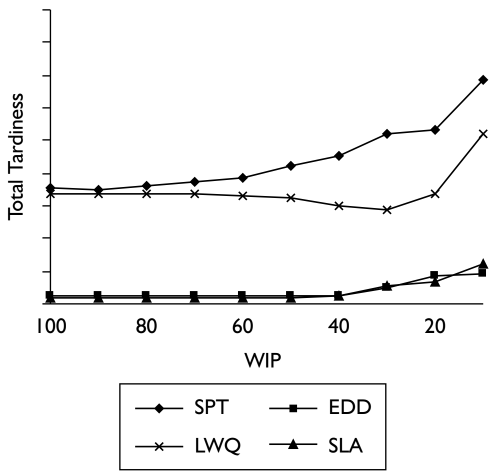

Figure 3 - Total Tardiness for Job Shop – Medium Load.

First of all, one can realize that the workload has changed the values but not the general shape of the plot. By the way, the analysis forward is valid for both loads. From Figures 2 and 3, it is clear that sequencing rules EDD and SLA have an equivalent and better response than the other two rules considered (SPT and LWQ).

Both EDD and SLA present a more regular response, with a uniform increase on Total Tardiness for WIP lower than a turning point of 50 units. For higher values of WIP, there is no change in the total tardiness. Values lower but close to limit level, like 40 units, would promote a less congestion system with almost the same performance on due date criteria. As the WIP decreases to 10 units, the total tardiness increases considerably. The response shape is similar for high and medium workload.

Other results from the simulation reveal that this turning point corresponds to the point beyond that the additional reduction on WIP will cause the increase of the *makespan*, another usual performance measure that correspond to the total time need to complete all operations of all orders in the backlog list. Lower *makespan* is also associated with higher machine utilization.

The rules SPT and LWQ, in comparison to the previous two, always yield higher values of Total Tardiness and a less predictable behavior. The SPT rule had the higher value of the WIP limit (80 units) and below this point, the tardiness performance deteriorates. This fact indicates that SPT rule works better under high congestion, although it is outperformed by the due date related rules (EDD and SLA) in both medium and high workload.

The LWQ rule presents a peculiar pattern if compared to the others. The response curve seems to be not strictly increasing function. It shows a local minimum achieved for a WIP around 30 units. If one continues reducing WIP under this level, the Total Tardiness will increase. It is worth to mention that this pattern was not observed for the *makespan* for the same scenario.

One possible reason to the existence of a local minimum in the total tardiness curve is that, as the system become more relaxed, the rule succeeds in speeding up the flow by choosing stations with shorter queue. This effect stops when the global load continues decreasing. Again, both LWQ and SPT were much worse than due date related rules, named EDD and SLA, in rather medium and high load.

Total Tardiness - Flow Shop

A similar analysis was done for the flow shop configuration. Figures 4 e 5 present the corresponding flow shop results, respectively for the High Load and Medium Load instances.

Like the job shop configuration, the graphics on total tardiness showed the same pattern in the medium and high load case, just changing the values, as expected. Once again, it is possible to group pairwise SPT / LWQ rules and EDD / SLA. The formers were clearly out performed by the others.

In the flow shop, that comprises less subsequent alternative operations, the LWQ lost their advantage in relation to the SPT rule. In addition, the local minimum was not

Volume 5, Number 1, 2008, pp. 75-88

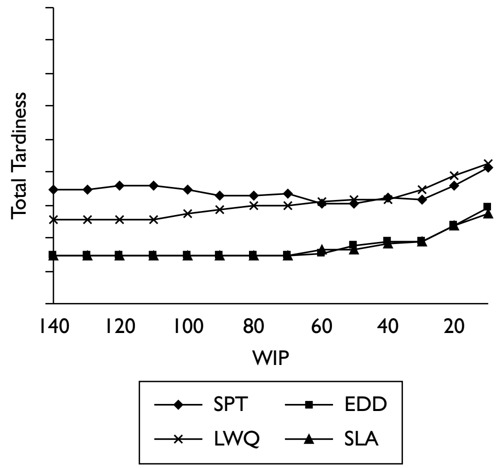

Figure 4 - Total Tardiness for Flow Shop – High Load.

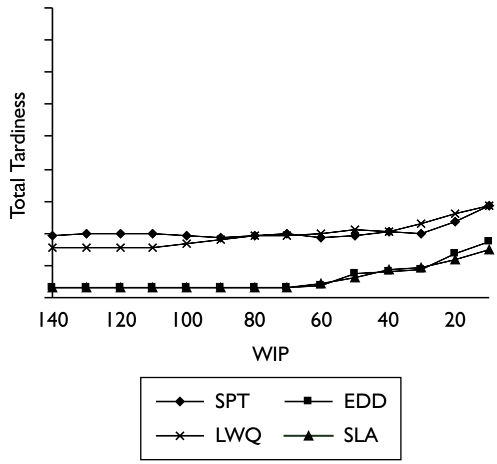

Figure 5 - Total Tardiness for Flow Shop – Medium Load.

detected. In fact, for lower values of WIP, the results for LWQ and SPT become similar. The same happened in the pair EDD / SLA.

The results in Figures 4 and 5 are less regular when compared with those for the job shop case. In spite of the representative sample of jobs simulated, the results do not clearly indicate the existence of an optimum level of WIP in Flow Shop Scheduling with SPT rule and Total Tardiness goal. Additional tests should be conducted in order to get better reasoning on it.

Number of Tardy Orders - Job Shop

What follows is the equivalent analysis replacing the performance measure of Total tardiness by the Number of Tardy Orders. Figures 6 and 7 show the Number of Tardy Orders for the Job Shop, under respectively High and Medium Load.

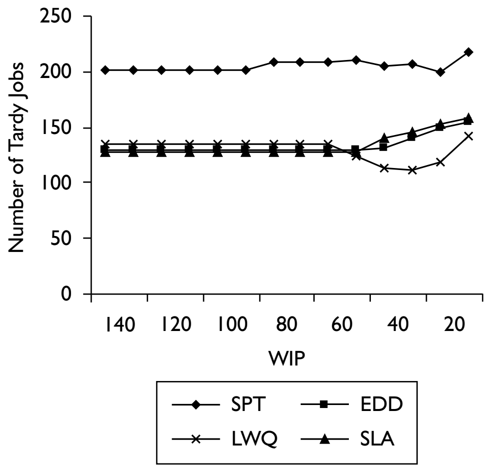

Figure 6 - Number of Tardy Jobs for Job Shop – High Load.

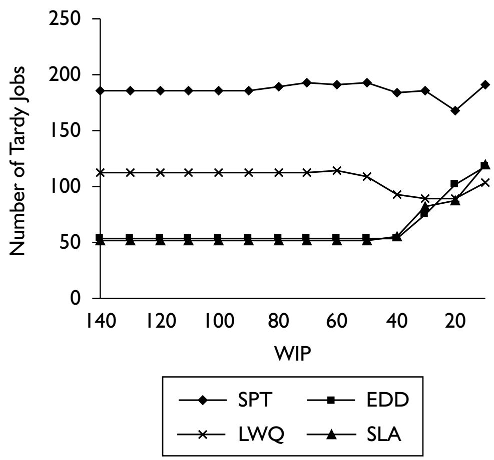

Figure 7 - Number of Tardy Jobs for Job Shop – Medium Load.

Once again, the High and Medium Load are different only in the absolute values, being the response curve of a similar shape for each rule.

The EDD and SLA present results very similar to those for Total Tardiness, that is, the increase in the Number of Tardy Job for WIP under the 50 units limit level. The SPT rule display results with little variation in the WIP range considered. The best performance is reached in the WIP level of 20 units considered.

Considering the LWQ rule, it results in lower Number of Tardy Orders than EDD and SLA for WIP levels below 50 units. In the Medium Load condition, this just happened for values below 20 units. This would be a promising result but the high levels of Total Tardiness achieved before is not. This apparent contradiction suggests that the rule yield a few number of orders late but those late orders with a higher tardiness, that is, a greater variance in orders lateness.

Additional results from simulation indicates that the mean tardiness grow up with reduction on WIP levels for all scheduling rules and that due date relate rules outperformed the other rules considered in that performance measure.

Number of Tardy Jobs - Flow Shop

Concluding the scenarios studied, Figures 8 and 9 present the Number of Tardy Jobs in the Flow Shop configuration.

The rules EDD and SLA provided better and closed results if compared to the Job Shop case. There is an increase in the Number of Tardy Jobs for values of WIP below 30 units and around 50. The LWQ rule, on the other hand, revealed an increase in the Number of Tardy

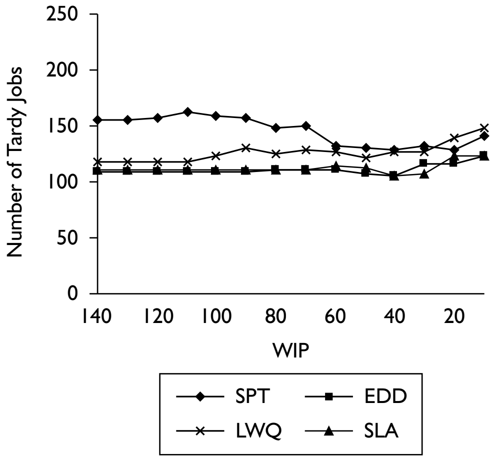

Figure 8 - Number of Tardy Jobs for Flow Shop – High Load.

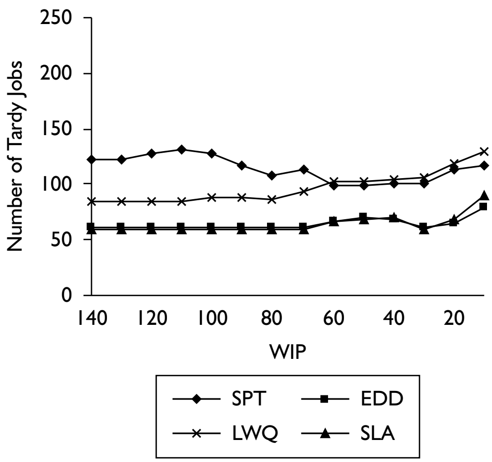

Figure 9 - Number of Tardy Jobs for Flow Shop – Medium Load.

Orders before, when WIP reached 70 units. This probably happened because higher levels of WIP will cause longer queuing time and greater Number of Tardy Jobs. From the above results, it is not possible to make sure inferences about the optimum value of WIP for the flow shop configuration to minimize the Number of Tardy Orders.

Conclusions

Firstly, the Total Tardiness may be considered more important than the Number of Tardy Jobs. In the current manufacturing scene, for example, there is no effect to reduce the Number of Tardy Orders in 50% meanwhile increasing the total tardiness (and consequently the mean tardiness) three or four times.

The analysis considering the Total Tardiness proved that the rules EDD and SLA are consistently better and more regular than the others. Furthermore, in a Job Shop configuration, the results reveal the existence of a WIP limit level that should be evaluated and used for production control purposes. This limit is considerable lower than the limit level obtained with other rules. This suggests that the performance on Total tardiness can be considerably improved in a Job Shop with the use of CONWIP and the sequencing rules like EDD and SLA.

In fact, the level of WIP affect other productivity measures not explicit consider herein, the WIP optimal level could be even lower than that limit, depending on the trade off between inventory reduction and the capacity utilization.

Manufacturing companies with high stock out cost and low inventory cost should operate with WIP near that limit, meanwhile those with low stock out cost and high inventory cost, the WIP should be even lower.

The previous analysis fails in the case of SPT and LWQ since the results reveal a strong correlation between performance measures and both, the shop and load configuration. Although it is possible to evaluate the WIP optimum for a specific case under determined configuration and load, the response curve exhibit a very irregular pattern, it make difficult to find a limit with the same property of that encountered in the last case. This probably happens because both the EDD and SLA rules consider due dates to set the sequencing priorities, in opposite of the other two.

In case one considers the Number of Tardy Orders more important than Total Tardiness, the results suggests a careful analysis of the LWQ rule in the Job Shop with High Load configuration, since it had a superior performance and a clear optimum (minimum level).

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ABEPRO Executive Board

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Manuscript Guidelines

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A file with the manuscript should be submitted to the e-mail: bjopm@abepro.org.br. The article should be prepared using a A4 paper size (ISO 210 x 297 mm) in double line spacing with wide margins, and Times New Roman font 12 points, justified. Articles should be between 4,000 and 8,000 words in length (papers below or exceeding this limit will not be considered for reviewing). The following sequence is suggested (paper structure): title; abstract; keywords; introduction; main text and subject; conclusions; acknowledgements when applicable; and references.

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A title not too long should be provided. The title should precisely represents the subject of the paper in times New Roman font 14 points, all caps and centred.

Authors Affiliation and Biography

All authors not be included whose details must be printed on a separate sheet and the author should not be identified anywhere else in the article.
A brief autobiographical note (about 100 words) should be supplied including full name, affiliation, e-mail address and full international contact details.

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Authors must supply an abstract (100-200 words). Up to 5 keywords should be included which encapsulate the principal subjects covered by the article.

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The introduction should contain information intended for all readers of the journal, not just specialists in its area. It should describe the problem statement, its relevance, significant results and conclusions from prior work and objectives of the present work.

Research Methodology

It should be clearly described under a separate heading.

Headings

Headings must be short, clearly defined and not numbered. Sections headings should be typed bold-face, all in capital letters, flush with left-hand margin. Leave one line before and after headings. Subheadings should be typed bold-faced, flush with left-hand margin and only the first letter should be capital. Notes or Endnotes should not be used.

Main Text and Subject

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Figures and tables must be included in the main text and must be individually numbered and captioned with a brief title They should be provided both electronically and as good quality originals and must be black and white with minimum shading and numbered consecutively using Arabic numerals. Captions should be put below figures and above tables. Leave one line before (tables) or after (figures).

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If there are three or more authors, the expression 'et al.' can be used.

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