Titre: Title:	Exploring the relationship between productivity problems and technology adoption in small manufacturing firms
Auteurs: Authors:	Jean Harvey, Élisabeth Lefebvre, & Louis André Lefebvre
Date:	1991
Type:	Rapport / Report
Référence: Citation:	Harvey, J., Lefebvre, É., & Lefebvre, L. A. (1991). Exploring the relationship between productivity problems and technology adoption in small manufacturing firms. (Rapport technique n° EPM-RT-91-14). https://publications.polymtl.ca/9831/

18 OCT. 1991

EXPLORING THE RELATIONSHIP BETWEEN PRODUCTIVITY PROBLEMS AND TECHNOLOGY ADOPTION IN SMALL MANUFACTURING FIRMS

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EXPLORING THE RELATIONSHIP BETWEEN PRODUCTIVITY PROBLEMS AND TECHNOLOGY ADOPTION IN SMALL MANUFACTURING FIRMS[1]

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ABSTRACT

Small manufacturing companies are generally less sophisticated than large companies. Their decisions to adopt new manufacturing technologies are often based more on short-term operating realities than on long-term strategic plans. This research study conducted on 100 smaller manufacturing firms investigates how the process innovators in that group differ from the other firms in terms of the operating problems they face. The global picture of a process innovator which emerges from this study is that of a company with tighter capacity management, better process design, more qualified and better trained employees, a more flexible and more responsive manufacturing system, better quality and a more harmonious labor relations climate than other companies.

INTRODUCTION

Technology adoption has generally been studied from the point of view of large companies. The need for a strategic perspective has been largely dominant in the literature [1], even though it is not clear that all, or even most large companies are as articulate and forward-looking in their manufacturing and technology strategies as would be required [2, 3]. Small manufacturers, however, are generally much less sophisticated than large companies [4] and their strategic outlook is generally limited to short-term time horizons [5]. Thus, we may surmise that their decisions to adopt new manufacturing technologies are based more on short-term operating realities than on long-term strategic plans. This research study investigates the linkage between productivity problems involving both quantity and quality of output [6] and technology adoption.

Technology is indeed a critical component of any manufacturing process. New

1 This research was partly funded by a grant from the Canadian Labour Market and Productivity Center to the Groupe de Recherche et d'Intervention en Productivité, and by SSHRC grants number 494-89-0053 and 494-89-0036. The authors are also indebted to three anonymous referees for their constructive comments.

manufacturing technologies (NMTs) can contribute in many ways to the improvement of productivity: improving quality and reducing the cost of reworks [7, 8, 9], reducing the cost of direct manpower [8], increasing capacity and production efficiency [9, 10] and reducing the duration of the manufacturing cycle [8, 10, 11]. Although the strategic potential of NMT's seems enormous, introducing and implementing these technologies can be a costly and risky venture, especially for smaller manufacturing firms [12]. It may involve the "creative destruction" [13] of existing skills, at both the individual and company levels. It can also create operating problems and have repercussions on human resources, quality of work life, labor relations, materials management, reject rates, and equipment downtime. NMTs thus have a dual potential: for improving productivity and for creating productivity problems. The premise of this paper is that technology adoption in smaller firms is often justified on the basis of trying to solve productivity problems. This problem diagnostic approach could lead us to a better understanding of NMT adoption in smaller manufacturing firms.

CAUSES OF PRODUCTIVITY PROBLEMS

Productivity, which is usually defined as the ratio of output to input, nonetheless carries many different and often ambiguous meanings [14]. For firms in the manufacturing sector, productivity cannot merely be viewed as the lowering of production costs; increasingly it has come to mean improvements in product and service quality, flexibility, and dependability [8]. This enlarged definition may particularly apply to the smaller firms since they have traditionally placed more emphasis on achieving economies of scope as opposed to economies of scale.

The manufacturing process should be able to produce output with a combination of cost, quality, flexibility and dependability [15] which allows a firm to compete in the market. In this paper, we define a productive company as one which achieves its goal with respect to these key process characteristics. Any actual or anticipated shortcoming therein constitutes a productivity problem.

Such problems may have numerous causes. A joint study by the Columbia University Center for Operations and Coopers & Lybrand [16] found some of these to be the negative attitude of workers and middle managers towards productivity improvements, obsolete equipment and facilities, and lack of skills on the part of employees. Betcherman and McMullen [17] also found employees' lack of skills, coupled with inadequate yields, to be a substantial causal factor of low productivity. Miller and Roth, in their annual Manufacturing Futures Survey [18], identified production to high quality standards, poor forecasting, yields and rejects, material costs, lead times, indirect labor productivity and high inventories as top manufacturing concerns.

From these and other studies, we identified 24 distinct potential causes of productivity problems. Without implying that this list is exhaustive, we feel that it constitutes a good representation of the types of productivity problems found in smaller firms (see Table 1).

Causes of productivity problems can be grouped into five categories: human resources, machinery and installations, materials, products and management. This typology is adapted from Sumanth's classification of productivity improvement programs [19]. We have grouped Sumanth's "employee-based" and "task-based" categories into one and have added management-based productivity problems as a distinct category. This last category encompasses to some extent the preceding four, since it supports and directs all organizational activities and practices. A great deal of research has been done on various aspects of this issue: authors such as Hayes and Abernathy [20] have stressed top managers' lack of experience with manufacturing operations and their short-term planning horizon; Judson [21] has indicated that the lack of consensus on priorities between different organizational groups may impinge on the successful implementation of productivity improvement programs. Hayes, Wheelwright and Clark [22] for their part have argued in favor of interactive top-down / bottom-up decision processes instead of overly centralized decisional structures.

Figure 1 illustrates the relation between dimensions of the manufacturing strategy content

[15] and the causes of productivity problems. Although the causes listed in Table 1 are common to all firms, their relative importance may vary considerably with firm size. For example, unreliable suppliers [23] and the lack of qualified workers [24], have long been identified as two of the major problems plaguing smaller firms, in particular.

METHODOLOGY

Data collection procedures

During the summer of 1988, a study was conducted to assess the causes of productivity problems encountered by 100 small manufacturing companies and their corresponding technology strategies. Although this study also investigated perceptual gaps between management and employees concerning productivity improvement programs, the data used in this paper is based solely on interviews with the general manager or chief executive officer. They were retained here as the key respondents because they possess the most comprehensive knowledge of all aspects of the firm's operation [25]. Furthermore, they also have a strong influence on the selection of the company's strategic direction [26] and play a key role in the technology adoption decision [3].

A stratified random sample of small and medium-sized firms was drawn from an up-to-date government list. All firms selected had between 50 and 500 workers[2]. Four industrial sectors were represented: garment, metal products, electrical and electronic products and transportation products.

It was decided to end the data collection phase when the number of responding firms reached 100 since it was felt that this would represent a large enough number of respondents to provide statistically valid results. All 100 firms were visited. Trained

2 The lower limit was set quite arbitrarily in order to allow the presence of productivity improvement programs. The upper limit corresponds to the accepted definition of small or medium-sized firms.

graduate students acted as interviewers and spent half a day or more on site.

Information was gathered with a pre-tested questionnaire. In this paper, we present data pertaining to the firm's experience with NMTs and management's perception of the causes of productivity problems faced by the firm, using the list shown in Table 1. Henceforth, we will refer to the causes of productivity problems within a company as its "productivity profile". New technologies considered include computer-assisted design, computer numerical control, robots, computer-assisted manufacturing and computer-assisted production planning and control.

Statistical analysis

A principal component factor analysis was first performed on the 24 causes of productivity problems in order to uncover the structure within this set of observed variables and to identify the key underlying dimensions of the productivity profiles of the companies in the sample. The varimax rotation method was used in order to ensure that the derived factors were orthogonal.

The sample was then split into two groups of firms: the first group (n_1 = 24) consists of firms which have adopted at least one of the technologies in question and thus are considered to be "process innovators"; the firms in the second group (n_2 = 64) are not considered innovative and are called "other firms". An iterative discriminant analysis was conducted to identify those factors which best discriminated between process innovators and other firms. This would allow us to determine hierarchically the dimensions of the productivity profile on which the two groups differ the most. However, since the existence of statistically significant differences is a necessary but not a sufficient condition to establish a causality relationship between these differences and technology adoption patterns, this paper does not set out to prove the existence of such a relationship but merely to establish its likelihood.

RESULTS AND DISCUSSION

The varimax rotated factor analysis yielded 10 factors which collectively explain 74% of the variance in the 24 original variables. The 10 factors, presented in Table 2 in order of decreasing percentage of variance explained, are retained based on the widely accepted criterion that only factors whose eigen value is greater than 1 should be considered [27]. All the loadings which are greater than .50 are judged significant [27]: they have been highlighted in Table 1 and are used to derive the interpretation which follows. The set of 24 variables provided a combined MSA (Kaiser's Measure of Sampling adequacy) of .57, indicating that the variables are well suited for factor analysis.

The first factor has to do with **lack of flexibility and timeliness.** Inadequate production planning systems, excessively long manufacturing cycles and inefficient administrative and clerical workers render the firm incapable of meeting rush orders. The second factor deals with **low quality.** It is characterized by inadequate quality control, excessively high reject rates and an excessive number of engineering changes, an important cause of quality problems.

Factor 3 is related to the **excessive distance between management and employees.** It is characterized by excessive centralization and by management's perceiving itself as too far removed from the shop floor, i.e. management makes too many decisions with too little information. Factor 4 involves **unreliable suppliers,** with respect to both timeliness of delivery and product quality.

The fifth factor is concerned with **poor labor relations** as a cause of productivity problems. Low productivity of direct manpower as well as employee absenteeism are clearly associated with this phenomenon. The sixth factor is related to **lack of skills** and lack of qualified manpower. Inadequate training programs represent one possible culprit in this situation.

Factor 7 reflects **poor process design.** It is characterized by obsolete machinery and poor floor layout. Factor 8 is strictly related to **insufficient capacity,** whereas factor 9 is **loose capacity management.** The variables associated with the latter factor are excessive capacity and inadequate equipment maintenance. In many factories, the latter is a consequence of the former, as there is little immediate incentive to "run a tight ship" when a large proportion of your capacity is not being utilized. However, such a shortsighted approach may lead to the development of bad habits among management and employees, which may be carried over into other activities and which may be hard to correct when business picks up. The tenth and last factor deals with the **dispersion and confusion** which result when the company is spread too thinly along too many product lines. The lack of focus caused by this dispersion inhibits good communications between departments and may be an important cause of productivity problems.

The ten factors are listed in Table 2 along with their contributing variables and the cumulative percentage of explained variance. The reliability of underlying dimensions revealed by the factor analysis is quite acceptable overall as shown by the corresponding Cronbach Coefficient Alpha (Table 2). In fact, the average reliability of these factors (α = .59) meets the guidelines set by Van de Ven and Ferry [28] and is more than acceptable for new instruments measuring organizational attributes [29].

The productivity profile factors which best discriminate between process innovators and other firms were assessed through a stepwise discriminant analysis (Table 3). This analysis yielded a discriminant function containing six factors, expressed here in decreasing order of importance.

The factor which differentiates most between process innovators and other companies is factor 9, that is, loose capacity management. Small companies are very cost conscious and they need an immediate and tangible motive to invest in new technology. A company which is operating at or near its peak capacity will often consider the acquisition of NMTs as a means to increase its capacity. The need is concrete and immediate. Additional capacity translates into tangible benefits for the company in the short term. It appears to be easier for small companies to justify the substantial cash outlays required by new technology on this basis rather than on less tangible benefits such as quality improvement and increased flexibility. The discriminating power of this factor may also reflect the cost structure of NMTs: in order to generate profit, the equipment must by used as close to maximum capacity as possible. Indeed, this technology involves a much larger fixed cost and a lower variable cost than traditional processes. Once the process is installed and operational, the labor cost associated with the production of one additional unit is much lower, since a large part of the process is automated and pre-programmed and the manual work which remains generally requires less qualified and thus less costly manpower. Thus, technology attenuates the usual barriers to the introduction of a second or a third shift, i.e. scarcity of qualified manpower and quality problems, among others.

The second most important factor in the discriminant function is factor 7, i.e. poor process design. Generally, companies which invest in new technology also take better care of their machinery in general and of the shop-floor layout. Technology is but one element - albeit a crucial one - in process design. Process innovators appear to pay close attention to all aspects of process design and not just to technology.

The third factor in the discriminant function is the lack of qualified employees (factor 6). Process innovators are less likely than other companies to have production problems that they attribute to a lack of qualified employees or inadequate training. While the questionnaire used in the study did not ask which specific skills and qualifications were missing, the presence of this factor in the discriminant function led us to surmise that process innovators suffer less than others from the lack of skilled machinists, engineers and technicians. Conceivably, the acquisition of NMTs alleviates the problems caused by a shortage of qualified machinists, while a shortage of engineers and/or qualified technicians makes a company more hesitant to acquire new technology. As discussed earlier, the causal relationship between productivity and technology adoption goes both ways.

The fourth factor to enter the discriminant function is factor 1, which deals with flexibility and timeliness. This factor alone captured almost 17% of the variance in the original set of variables. Process innovators experience significantly fewer problems with meeting deadlines, with rescheduling to meet rush orders and with their production planning systems in general. One of the distinguishing characteristics of NMTs vis-à-vis earlier automation technology is their flexibility. Apparently, process innovators outperform other companies in this regard. For small firms, particularly those acting as sub-contractors to larger firms, the ability to meet deadlines - even unrealistic and frequently rescheduled ones - may be an important source of competitive advantage.

The fifth factor in the discriminant function is factor 2, low quality. Process innovators experience fewer problems with rejects and quality control. Closely associated with this factor are the quality problems caused by an excessive number of engineering changes. With a largely manual process, or with a process automated using the traditional inflexible technologies, last minute engineering changes may be quite disruptive and constitute an important cause of quality problems. NMTs improve process flexibility and allow for rapid and efficient changes in the manufacturing sequence and program. Some elements of quality are also built into the process, in a foolproof fashion - or "poka yoke" as the Japanese would call it [30].

The last factor in the discriminant function is factor 5, which deals with poor labor relations. Process innovators indicated labor relations to be less of a problem than other firms did. While again this could either be a cause or a consequence of technological change, we believe that the existence of a minimal level of labor harmony is a prerequisite for the successful adoption and implementation of NMTs [31]. It could of course be argued that companies experiencing chronic problems in labor relations may be tempted to invest more in NMTs in order to replace manpower by technology, but the results of such a course of action are very doubtful. It is likely that process innovators experience better labor relations because these relations were better to begin with.

The global picture of a process innovator which emerges from this study, as shown in Table 3, is one of a company with tighter capacity management, better process design, more qualified and better trained employees, a more flexible and more responsive manufacturing system, better quality and a more harmonious labor relations climate than other companies. In short, process innovators appear to be better managed and more competitive companies.

A close look at the factors which best discriminate between process innovators and non-innovators reveals that the most important factors appear to be very tangible and short-term considerations. Small companies must often be more attentive and responsive to short-term results than larger companies. Thus, the introduction of NMTs will be facilitated in small manufacturing firms if it meets compelling short-term needs such as the need to increase capacity. This is confirmed by the fact that process innovators are first and foremost characterized by tight capacity management.

It is interesting to note that, while innovators also differ from non-innovators because they are more flexible and experience fewer quality problems, this difference is not as marked as it is in the case of capacity management. The necessities of survival with only limited resources compel small companies to be very choosy about their capital investments. They must clearly distinguish the "nice to have" from the "must have". There is often a direct relationship between the latter and the immediate problems experienced on the shop floor. The financial situation of many a small firm is such that the acquisition of an NMT which offers exciting prospects for quality improvement and increased process flexibility may in fact trigger the failure of the company unless these properties translate into hard cash in the short term.

CONCLUSION

Small manufacturing companies that adopt NMTs exhibit different "productivity profiles" from other firms. They appear to have fewer problems in a number of critical areas. They appear to be better managed and better equipped to face competitors. This is the central result coming out of a study on the perception of the causes of productivity problems in a sample of small companies.

Process innovators face different realities than do non-innovators. In these differences lies part of the answer to the question: why do some small companies adopt NMTs while others do not? Our methodology does not allow us to be more specific, however, since the causal relationship between productivity and technology goes both ways. Are the observed differences part of the context which led to the adoption decision in the first place or are they instead a consequence of the adoption of NMTs? This problem is illustrated by the earlier discussion of the differences in labor relations and in employee qualifications observed between process innovators and other companies.

In fact, both causal relationships are probably valid. They reinforce each other in a dynamic feedback loop. The small manufacturer experiences productivity problems, as defined in this paper. In an effort to address the causes of these problems, he adopts his first NMT. If he is successful, the productivity situation improves and management learns something new about what NMTs can do for the company [32]. Criteria used to decide on adopting NMTs are modified [33], resulting in further adoption of NMTs. In this way, the gap between adopters and non-adopters of NMTs grows.

These results do not in any way disprove the so-called "strategic model" of technology adoption. However, Ettlie and Penner-Hawn have indicated that about 10% of North American companies have a manufacturing strategy [34]. Thus, we believe it likely that, when it comes to small companies, we are more likely to find this kind of adaptive hands-on approach to new technology adoption than a more cerebral strategic analysis.

Many confounding factors stand in the way of formally demonstrating this result, not the least of which is the dynamic interaction between technology adoption and productivity. A longitudinal study would probably be the best way to isolate the changes in productivity profiles brought about by NMTs from the impact of such profiles on the technology adoption decision. However, controlling for differences in competitive environments as well as for the simultaneous and cumulative effects of different technologies being adopted at various points in time will undoubtedly prove to be a daunting task.

Investing in NMTs is but one way for a company to address the causes of productivity problems. A host of other programs are available to companies seeking to solve these problems, including human-resource-based programs and programs dealing with layout and work design, with materials and supplier management, and with quality improvement and value analysis. Depending on the firm's specific circumstances, programs other than the investment in NMTs may be more suitable. A more detailed study of these circumstances and of the programs and actions taken to address specific situations could allow us to situate our understanding of the decision process with respect to the adoption of NMTs in the broader framework of the constant search for process improvement and competitive advantage.

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FIGURE 1

Causes of Productivity Problems and Manufacturing Strategy Content

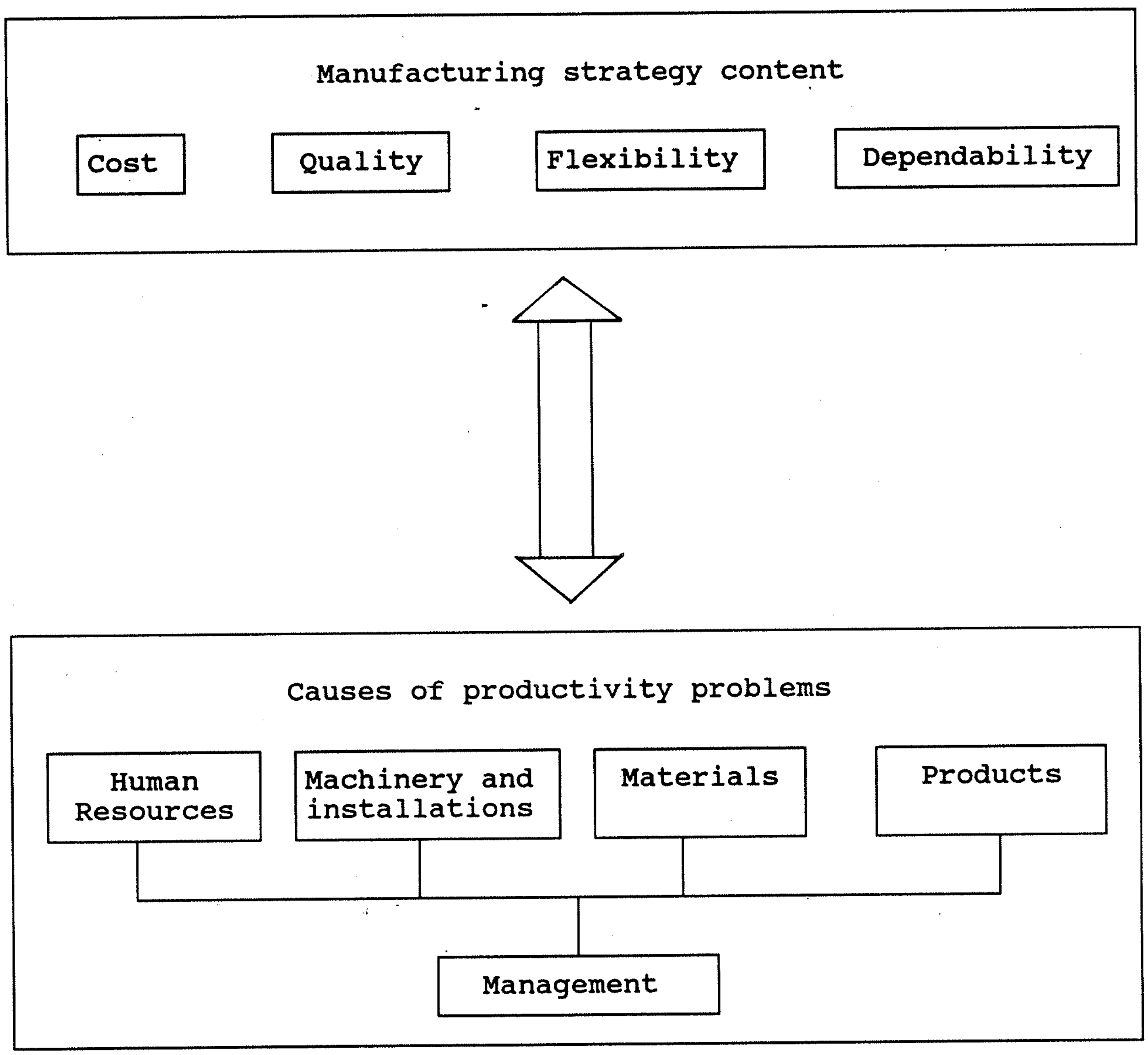

TABLE 1 (1)
VARIMAX ROTATED FACTOR ANALYSIS

CAUSES OF PRODUCTIVITY PROBLEMS	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7	FACTOR 8	FACTOR 9	FACTOR 10
1) HUMAN RESOURCES										
LOW PRODUCTIVITY OF DIRECT LABOR	.00866	.16774	-.07290	.22381	**.55481**	.29984	.18901	-.46941	-.04280	.05972
LOW PRODUCTIVITY OF INDIRECT LABOR	**.51991**	.26907	.31465	.06295	.33216	.15540	.04317	-.04486	-.16452	-.09826
LACK OF QUALIFIED WORKERS	.10213	-.10597	-.13759	-.02800	.05662	**.83170**	-.15981	.10894	.14905	-.05853
INADEQUATE TRAINING	.11458	.19572	.15051	.08506	-.07973	**.80575**	.20951	-.00048	-.13849	.07494
POOR LABOR RELATIONS	.10774	.06464	-.00497	-.06519	**.82757**	-.08481	-.02176	.10357	-.00995	.00523
WORKER ABSENTEEISM	-.35834	.03236	.17048	.31393	**.55044**	-.01349	-.10799	.20619	.23024	-.09265
EXCESSIVE EMPLOYEE TURNOVER	-.10205	.13477	-.10948	.42625	.29064	.18344	-.26733	.37976	.33634	.04770
2) MACHINERY AND INSTALLATIONS										
OBSOLETE MACHINERY AND PROCESS	-.09084	.39948	.15429	-.09387	.05165	-.19595	**.69453**	-.10283	.20229	.01633
POOR LAYOUT	.27809	.04105	-.06886	.16488	-.06121	.18331	**.73084**	.17522	.05686	.06256
INADEQUATE MAINTENANCE	.08386	.17894	.03264	.02409	.04576	-.04859	.19164	-.01609	**.82169**	-.01188
LACK OF FLEXIBILITY FOR RUSH ORDERS	**.69919**	-.37978	-.11078	.09036	.02291	-.06324	.13230	.14259	.26370	.10841
INSUFFICIENT CAPACITY	-.03371	.02650	.06764	.03524	.10928	.14752	.16320	**.82902**	-.10801	.06511
EXCESSIVE CAPACITY	-.10238	-.17452	.16795	-.17815	-.06739	.14816	-.05906	-.49262	**.62540**	.16930
3) MATERIALS										
INADEQUATE PRODUCTION PLANNING SYSTEM	**.75636**	.20834	.16766	.06318	.01742	.03909	.25386	-.06067	-.00365	.10960
INADEQUATE QUALITY CONTROL	.11326	**.73419**	.09220	-.17354	.21720	.05077	.14605	.12552	-.08344	.25618
EXCESSIVELY HIGH REJECT RATE	-.02636	**.67461**	.14139	.13923	.06912	.11814	.27109	-.06241	.25309	.01251
EXCESSIVELY LONG MANUFACTURING CYCLE	**.71296**	.08774	.29743	.16523	-.06888	-.06164	-.15759	-.02925	-.04231	-.08161
UNRELIABLE SUPPLIERS - CF: QUALITY	.08505	-.12451	.16539	**.61485**	.12465	-.09251	.26182	-.01103	-.04683	.40351
UNRELIABLE SUPPLIERS - CF: DELIVERY DATES	.16803	.04477	-.08249	**.83320**	.00973	.09614	.02712	.02955	-.04885	-.03556
4) PRODUCTS										
TOO WIDE A RANGE OF PRODUCTS	-.02422	.12028	.01563	.11413	-.08979	.01035	.05111	-.02232	.05938	**.86119**
TOO MANY ENGINEERING CHANGES	.28137	**.57205**	.11565	.46464	-.13514	-.13618	-.13876	-.03099	.06706	.16905
5) MANAGEMENT										
POOR COMMUNICATIONS BETWEEN DEPARTMENTS	.22052	.36407	.42490	-.06442	.24642	.03674	-.07494	.19303	-.00139	**.56440**
MANAGEMENT TOO FAR REMOVED FROM OPERATIONS	.16134	.12455	**.84604**	.12148	-.08572	.01697	.03620	.19505	.04040	.04429
EXCESSIVE CENTRALIZATION	.15391	-.04393	**.83860**	-.11783	.09374	-.03786	.03670	-.15347	.07373	.07959

(1) Based on 100 firms. All variables are measured on Likert scales and are standardized for the factor analysis. Kaiser-Meyer-Olkin measure = 0.57 (Sample adequacy test).

TABLE 2
INTERPRETATION OF FACTOR ANALYSIS

Factor	Identification	Contributing variables	Cumulative % of explained variance	Cronbach Coefficient Alpha
1	Lack of flexibility and timeliness	Inadequate production planning system Excessively long manufacturing cycle Lack of flexibility for rush orders Low productivity of indirect labor	16.9%	.70
2	Low quality	Inadequate quality control Excessively high reject rate Too many engineering changes	26.4 %	.60
3	Excessive distance between management and employees	Management too far removed from operations Excessive centralization	34.6 %	.71
4	Unreliability of suppliers	Unreliable suppliers - delivery dates Unreliable suppliers - quality	41.5 %	.54
5	Poor labor relations	Poor labor relations Low productivity of direct labor Worker absenteeism	48.2 %	.60
6	Lack of skill	Lack of qualified workers Inadequate training	54.6 %	.51
7	Poor process design	Poor layout Obsolete machinery and process	60.2 %	N/A
8	Insufficient capacity	Insufficient capacity	65.5% %	.54
9	Loose capacity management Excessive capacity	Inadequate maintenance	69.9 %	
10	Dispersion/confusion Poor communications between departments	Too wide a range of products	74.1 %	.57

TABLE 3

RESULT OF THE DISCRIMINANT ANALYSIS PERFORMED ON THE TWO GROUPS OF FIRMS: PROCESS INNOVATORS AND OTHER FIRMS

Factors entered by the stepwise method

Factor 9:	Loose capacity management
Factor 7:	Poor process design
Factor 6:	Lack of qualified employees
Factor 1:	Lack of flexibility and timeliness
Factor 2:	Low quality
Factor 5:	Poor labor relations

Classification results obtained by the six factors retained in the stepwise method: 68.18%

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* All basic assumptions are met for the discriminant analysis: factors are independent, so the assumption of non-multicollinearity is respected; the assumption of multinormality is not rejected because of the large sample size (n=100); the test of equality of group co-variance (Box's M=30,4 with a significance level of 0,16) allows us to accept the null hypothesis that the covariance matrices are equal.