Evaluation of the real use of formal methodologies in the product development process in brazilian SMEs

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Abstract: This paper reports on an evaluation of product development methodologies adopted by Brazilian small and medium enterprises (SMEs) operating in a specific region of the state of São Paulo. The companies belong to the metal-mechanical industry. The instrument for collecting data was a questionnaire, which was divided into subjects and developed and applied in on-the-spot interviews by the researchers on a sampling group of 32 companies. The main focus of this paper is to answer the question "Can a Formal Methodology be identified in the Product Development Procedures?" and to verify the possible correlation between the answers to this and other questions regarding product development. The answers to the questions were analyzed and consolidated, providing the results, which were then evaluated directly (through the percentages of the answers to each question) and statistically (through the search for an index indicating a correlation between two questions).
Keywords: design methodology, innovation, product development, small and medium enterprises

1. Introduction

Nowadays small and medium enterprises (SMEs) need competitive advantages in order to survive in their competition with larger-sized companies. Big enterprises have advantages such as renowned brands, earnings in scale of mass-production and a bigger influence on contract development both with customers and suppliers. But even if the current scenario appears to be initially not favorable, there is a tendency to the maintenance, or even growth, in the number of SMEs.

It is known that enterprises must constantly search for new technologies, both in product and in process, in order to obtain higher quality products and compete in the global market (OLIVEIRA, 2000). This is more evident in the metal-mechanic sector, as the competition is very fierce. In the current worldwide scenario, where administrators must learn to act in an environment ruled by the establishment of new regulations and companies must be flexible enough to respond quickly to competition and market changes (PORTER, 2004), SMEs can succeed in some market niches.

The innovative process is defined as a "process in which an idea or invention is transposed to the economy, that is, covers the path that goes from idea generation (using existing or recently developed technologies) to the creation of a new product, process or service and placing it available for consume or use" (VALERIANO, 1998). SMEs tend to mobilize themselves in a shorter time to meet market demands than large companies (BALDWIN, 2000). Also, the innovative process is an important tool for companies to adjust to the competition and to changes in the market (BOMMER & JALAJAS, 2002). It must be noted that the purely scientific discoveries, which broaden the current available worldwide knowledge, do not necessarily bring any innovation that might aggregate value to products and make them more competitive (NICOLSKY, 2002).

Product development is a process in which an organization transforms opportunities and technical possibilities into the manufacturing of a commercial product (CLARK & WHEELWRIGHT, 1993). It is at this stage that scientific discoveries aggregate value to products, through innovations. Also, at this development stage, costs are still relatively small (BAXTER, 1998). And, despite the designer's desires to design for customers (meeting demanded attributes such as appearance, design, durability, etc.), there must also be a concern to design for the manufacturer (manufacture easiness, few resource usage, etc.), for the sales team (transport and stocking easiness, etc.), among others (KAMINSKI, 2000). It must also be said that the adoption of a design methodology is indispensable, for it helps the designer to begin relying on a trustworthy model for their

work accomplishment (OLIVEIRA, 2002). This does not depend on the chosen methodology, as there are many design methodologies available in the existing literature (MAFFIN, 1998). Thus, it can be seen that there is room for countless forms of innovation, in countless stages of a product development.

But what is actually being done, regarding product development, to allow the innovative process to be developed in SMEs? Are these companies aware of the importance of this process, and do they use it? What is, in fact, being done in terms of product development in a Brazilian metal-mechanic SME? This paper tries to observe some of the factors that may answer these questions.

A few similar works have been produced throughout the world. In Italy, 47 SMEs were analyzed in an attempt to identify resemblances among them, in the areas of knowledge management and innovation (CORSO et al., 2003). In North America, 235 Research and Development professionals were interviewed to try to establish the sources of innovation in SMEs (BOMMER & JALAJAS, 2004). And a recent study in Brazil, which will be the initial base of this work, tries to characterize companies of the metal-mechanic sector regarding the product development area (KAMINSKI & OLIVEIRA, 2004a). Therefore, it can be noticed that there is a growing need in understanding the real role of SMEs in the economy. This paper is inserted in this current tendency as it tries to point out a "picture" of what is being done in terms of product development in SMEs nowadays. The researchers are aware that only after the extensive analysis of this "picture", actions can be proposed in order to improve the capacity of Brazilian SMEs to develop products. And, even though the improvement of SMEs is the ultimate goal, it is necessary not to rush ahead, and take some time to observe this "picture".

2. The research

This work demanded an elaborate and extensive questionnaire, which had the main objective of acquiring information from SMEs regarding the use of product and design development methodologies (be them scientific or empiric). The questionnaire provided specific answers that would be obtained with immense difficulty otherwise. To make a posterior formatting easier, the 68 questions (open or multiple-choice) were separated in nine groups, composing specific questionnaires (named A through 1), which had the main targets shown on Table 1.

The first three questionnaires are composed of questions that try to characterize the company and its main products, while the following five questionnaires (D to H) characterize the product development sector. Lastly, questionnaire 1 allowed interviewers to record data that were not approached in the other questionnaires, but enabled a better understanding of the company's processes.

Table 1. Targets of the questionnaires.

A	General data from the company
B	Data about the department in charge of product development
C	Characterization of the company's main product
D	Does the development process generate evolutive or innovative products?
E	Can a methodology be identified in the product development procedures?
F	Does the company possess automatized resources to aid development?
G	Is only the company responsible for the development?
H	Is the development department strategical to the company?
I	General observations

Then, the SMEs needed to be chosen. In literature, there are a few different classifications, depending on which sector is analyzed. The researchers decided to use the number of employees, as defined by GUERRERO (2003), for this is the preferred way to deal with industries.

With the help of the State of São Paulo Enterprise Database (FIESP/CIESP, 2003), SMEs were identified/selected in a 200 Km radius from the city of São Paulo. With this procedure, the researchers were able to make the travels between companies easier, as well as to obtain data from some of the state's main industrial regions (Great São Paulo, and Sorocaba and outskirts). These are some of the most technologically developed regions in Brazil.

With the questionnaire ready and the companies selected, two pilot-tests were conducted to refine the questions, i.e., to find out if there were doubts that could cause the questions not to be answered in the way the researchers desired. After quick changes, the questionnaire was ready to be presented to 30 more SMEs. The researchers visited every one of the companies, having the opportunity to interview the person responsible for the development area. On average, each interview lasted 3 hours.

When the interview phase was finished, the information obtained with the application of the questionnaires was brought together in an immediate analysis, in the form of graphics showing the percentage distribution of the answers to each question. With this first analysis in hand, a statistical approach was initiated, trying to determine if there were evidences that two questions had any relationship with each other. It is important to say that the denial was also desired (that is, if there were evidences that two questions were not correlated). All questionnaires questions that were multiple-choice (that is, allowed one single answer, the greatest example being the questions whose answers are "Yes" or "No") were grouped two-by-two, in search of eventual strong or no correlations.

The results of the research are being published taking as reference the division of the questionnaires. In a first work (KAMINSKI & OLIVEIRA, 2004b), a few first results obtained by the research were presented. After that, the analysis of questionnaire F has shown the computerization tools that aid the product development process in SMEs (KAMINSKI & OLIVEIRA, 2005). This current work has the objective of approaching questionnaire E deeply, to determine the factors that might lead to the answer of its main question. Besides that, it is desired to find out if the listed factors are under the influence of questionnaire E or are influenced by other factors, located in the other questionnaires.

3. Questionnaire E

The general question that questionnaire E tries to answer is "Can a methodology be identified in the product development procedures?". The attempt is to identify if any formal product development methodology exists or is used in the researched company. It is important to point out that both formal and internally developed methodologies are desired, as they represent that the company considers this matter important. This question is pertinent, for the application or not of methodologies is intimately related to the capacity of the company to plan and execute its designs with quality, efficiency and in a short time span.

The questionnaire was designed with 12 main questions, all of them trying to expose points that lead to conclusions about the general question, which is excessively open for the usage of multiple-choice questions, which would make the statistical analysis easier. In this way, questionnaire E possesses both open and multiple-choice questions. Its questions, with their respective answers obtained in the research, are presented in Table 2.

Questions E.1, E.2, E.3, E.4 and E.8 are open questions. Questions E.1, E.2 and E.4 were grouped in categories to allow data interpretation, even though the researchers designed this grouping after the visits were made and the answers were obtained. The other questions (E.5, E.6, E.7, E.9, E.10 e E.12) are closed and multiple-choice.

4. The statistical approach

In order to find out the relationship between questionnaire E's questions with the rest of the questionnaire,

Table 2. Questionnaire E's questions.

Question	Answers
E.1. How does the idea of developing a new product or altering (improving, modifying, correcting) the existing ones arise?	The ideas for product development come, in most cases, from: Commercial Dept. - 27% Clients - 25% Development Dept. - 23% Executive Board - 9% Others - 16%
E.2. How do the ideas get translated in technical specifications?	Action of the Development Dept. - 78% Specifications come from the customers - 11% Others - 11%
E.3. Describe the procedure of product development, citing strong and weak points.	-
E.4. How was this procedure obtained?	Company Experience - 56% Personal Experience - 18% External Procedure - 26%
E.5. Is any national or international product development standard followed?	No - 57% Yes - 43%
E.6. Is an internal development methodology followed? Are there documents to guide the involved employees?	Yes - 61% No - 39%
E.7. Is there any standardized procedure for the filling of drawings, calculus memorials, test results, etc.?	Yes - 89% No - 11%
E.8. How is the final product price obtained?	-
E.9. Is the Design Spiral concept used?	No - 61% Yes - 39%
E.10. Is the Value Analysis concept used in product development?	No - 79% Yes - 21%
E. 11. Is the FMEA tool (Failure Mode Effect Analysis) used in the design?	No - 68% Yes - 32%
E. 12. Is there any design quality program being used?	No - 61% Yes - 39%

a statistical approach was employed. All multiple-choice questions were grouped two-by-two to establish if one question had any correlation with another. For this use, the Chi-Square test was utilized, with the following hypotheses:

H_0: Both questions analyzed are not correlated (are independent); and

H_1: Both questions analyzed are correlated (are not independent).

With the statistical software Minitab (MINITAB INC, 2005), a significance coefficient α can be obtained. α is defined as the probability of making a mistake by rejecting H_0 and adopting H_1 as true. That is: if for the questions A and B $\alpha = 10\%$, that means that, in case an affirmation is made regarding the fact that questions A and B are correlated, there is a 10% chance that this affirmation is wrong and, in fact, A and B are not correlated.

The significance coefficient can provide either an affirmation (i.e. both questions are related) or a denial (i.e. both questions are not related), through the definition of an acceptance level for the affirmations. In this case, the level of 5% was defined: a coefficient between 0 and 5% is accepted as proof of correlation between two questions, while a coefficient between 95% and 100% is accepted as proof of non-correlation between questions.

5. Results

According to the proposal of this work, a study of the correlation of questionnaire E's questions with all other questions in the research was made. It must be noted that only the multiple-choice questions can be evaluated in this way. The results of the obtained α-values were placed in Table 3, in order to easily identify the desired values.

The desired values ($0 < \alpha < 0.050$ and $0.950 < \alpha < 1.000$) are in bold and highlighted in gray. It must be said that, in some cells, it was not possible to obtain an α-value.

From the theory (MONTGOMERY & RUNGER, 2003), it is known that:

$$\chi^2_\nu = \sum_{i=1}^{r} \sum_{j=1}^{s} \frac{(O_{ij} - E_{ij})^2}{E_{ij}} = \sum_{i=1}^{r} \sum_{j=1}^{s} \frac{O_{ij}^2}{E_{ij}} - n \qquad (1)$$

where:

χ^2_ν is the test statistics, with ν degrees of freedom; r is the number of lines in the contingency table (table in which the columns are the possible answers to one of the questions, and the lines are the possible answers to the other, as evidenced in Table 4); s is the number of lines in the contingency table; O_{ij} is the frequency (number of individuals) observed in the intersection of line i and column j; E_{ij} is the frequency (number of individuals) expected in the intersection of line i with column j; and n is the number of elements in the sample.

Table 3. Significance coefficients (α) obtained.

	E.5	E.6	E.7	E.9	E.10	E.11	E.12
A.2	0.071	0.099		0.081	0.478	**0.040**	0.302
A.3	0.165	0.348		0.286	0.880	0.488	0.286
A.5	0.067	0.093		**0.017**	0.360	0.052	0.358
A.6	**0.015**	**0.001**		0.901			**0.003**
A.7	0.349	0.135		0.581		0.739	0.581
D.8	0.538	0.314		0.225	0.583	0.363	0.581
D.9	0.149	0.169	0.053	0.055	0.272	**0.029**	0.234
E.5	**0.000**	**0.026**	0.087	0.314	0.272	**0.007**	0.082
E.6	**0.026**	**0.000**	**0.028**	0.163	0.463	**0.002**	**0.000**
E.7	0.087	**0.028**	**0.000**	0.159			0.159
E.9	0.314	0.163	0.159	**0.000**	**0.036**	0.244	0.706
E.10	0.272	0.463		**0.036**	**0.000**	0.301	0.740
E.11	**0.007**	**0.002**		0.244	0.301	**0.000**	**0.001**
E.12	0.082	**0.000**	0.159	0.706	0.740	**0.001**	**0.000**
F.3							
F.4							
F.5	0.865	0.150		0.242	0.150	**0.950**	0.242
F.6	0.538	0.108		0.740	0.628	0.109	**0.036**
F.7	0.053	0.132		**0.019**			**0.019**
F.8	0.865	0.687		0.483	0.150	**0.950**	0.815
F.9	0.160	0.599		0.612	**0.976**	0.213	0.612
G.1	0.066	0.835		0.092	0.084	0.713	**1.000**
G.2	**0.011**	0.061		0.761	**0.976**	**0.014**	0.054
G.3	0.281	0.604		0.483	0.451	0.147	0.483
G.4	**0.008**	0.299		0.399	0.459	0.109	0.399
G.5	0.513	0.837	0.132	0.926	0.463	0.088	0.515
G.6							
G.7	0.838	0.835		0.399	0.217	0.610	0.399
G.8	0.946	0.348	0.787	**0.020**	0.314	0.919	0.403
H.1	0.349	**0.010**		0.098		0.139	0.098
H.2							
H.3	0.461	0.150		0.815	0.150	0.363	0.242
H.4	0.784	0.163	0.876	0.258	0.740	0.373	0.059
H.5							
H.6	0.316	0.467		0.168	0.863	0.445	0.168
H.7	0.492	0.467	0.621	0.082	0.810	0.690	0.784
H.8	0.946	**0.016**	0.787	0.114	0.892	0.353	0.403
H.9	0.810	0.108		0.581	0.628	0.248	0.740
H.10	0.784	0.515	0.876	0.706	0.581	0.093	0.706

Table 4. Example of contingency table.

	E.5		
G.4		No	Yes
	No	16	8
	Yes	1	7

It is known that $E_{ij} = (f_i \cdot f_j)/n$, where f_i and f_j are the relative frequencies corresponding to line i and column j, respectively. That indicates that, in order to obtain E_{ij}, one

must multiply the values of the line by the values of the column, and divide them by the number of individuals in the sample.

It can be said that there are limits to the product of $(f_i \,.\, f_j)$. It is important to mention that the condition $E_{ij} > 5$ must always be respected. This condition guarantees that the sample is not biased and, therefore, the test results can be used to describe the population. If $(f_i \,.\, f_j) < n$, $E_{ij} < 1$ and the sum that originates Chi-Square tend to high values. So, in the cells filled in black in Table 3, it can be said that the product of the frequencies in some of the calculus matrix cells is too small for the adopted value of *n*. This increases the value of Chi-Square, which denotes that, for these questions, the sample is too small, and the Chi-Square approach cannot be considered valid. With an increase in the sample, $(f_i \,.\, f_j)$ eventually tends to be greater than *n*, and the analysis then becomes valid.

6. Result analysis

According to the data obtained in Table 2, a few correlations whose significance coefficient (α) is within a narrow band of values (from 0 to 5%, and from 95% to 100%) could be determined. These correlations were named "strong correlations", and their values are shown in Table 5.

For a better understanding of the obtained α-values, it is necessary to return to the answers given to each of the questions. With the aid of the database, it is possible to compare the answers given to the two questions analyzed in each of the cells in Table 5. With this method, conclusions can be made regarding the significance coefficients, in order to understand the numbers. One example of this "Answer Table" is given in Table 6, comparing the individual answers to questions E.5 and G4. The obtained α-value for this analysis was $\alpha = 0{,}8\%$. The results are already sorted to allow a quick conclusion.

Thus, evaluating Table 5 and the Answer Tables obtained, some characteristics common to the analyzed SMEs can be observed. But first, a comment must be made: if, in any case, a conclusion is reached, that does not mean that its denial is also true. For instance, if it is said that the companies that do A also do B, that does not necessarily mean that the companies that do not do A also do not do B, unless otherwise stated.

The companies that do not follow product development procedures also do not conduct conjoined works with colleges or research institutes. Also, the companies that follow PD procedures have clients who participate in the development process. Finally, the companies that follow PD procedures also possess an ISO 9001 certificate or are in the process of obtaining one.

The companies that do not adopt any internal development methodology also do not award or promote their successful designs. Moreover, the companies that adopt an internal development methodology have an ISO 9001 certificate. Lastly, the companies that adopt an internal methodology also possess a formal organization chart that includes the PD department.

The companies that do not make use of the design spiral concept also do not certify their products in any external organism. These same companies also do not make use of software for finite element analysis. On this subject it can also be noted that the three companies that make use of finite element analysis software also make use of the design spiral concept.

Companies that do not make use of the value analysis concept in product development also do not utilize the design spiral concept. The participation of clients in the development process, as well as the possession of specific software specially developed for the development department, does not depend on the usage of the value analysis concept.

The companies that utilize the FMEA tool (Failure Mode and Effect Analysis) in designs also employ new manufacturing processes. The companies that utilize the FMEA tool in design also follow an internal development methodology. On this subject, it can be noted that the companies that do not follow an internal development methodology also do not utilize the FMEA tool. The companies that utilize the FMEA tool in designs also have clients who participate in the development process. The usage of software to simulate the manufacturing process, as well as the usage of a centralized database system, does not depend on the usage of the FMEA tool. Finally, the companies that utilize the FMEA tool follow a national or international PD standard.

The companies that do not possess quality guarantee systems in the design phase also do not utilize any design management software, nor the FMEA design tool. But companies with quality guarantee systems possess an ISO 9001 certificate. And companies with quality guarantee systems follow an internal development methodology. On this subject, it can also be noted that the companies that do not follow an internal PD methodology also do not possess a quality guarantee system. Companies that do not possess quality guarantee systems in the design phase also do not make use of finite element analysis software. Lastly, it can be observed that the participation of suppliers in the development process does not depend on having a quality guarantee system.

Thus, it can be said that, regarding Brazilian small and medium-sized enterprises, not much is being done regarding the use of product methodologies. There are processes that appear to be well cited and known – such as the ISO 9001 certification, considered by most companies to be important in business. Also on this matter, SMEs tend to focus more on internally developed methodologies and procedures, which are made especially for the companies'

Table 5. Strong correlations.

		E.5 Is any national or international product development standard followed?	E.6 Is an internal development methodology followed? Are there documents to guide the involved employees?	E.7 Is there any standardized procedure for the filling of drawings, calculus memorials, test results, etc.?	E.9 Is the Design Spiral concept used?	E.10 Is Value Analysis used in the product development?	E.11 Is the FMEA tool used in the design?	E.12 Is there any design quality program being used?	Answers - Percentage	
									Yes	No
A.6 Does the company have ISO 9001 certificate?		1.5%	0.1%	-	-	-	-	0.3%	62%	38%
D.9 Are new manufacturing processes being used?		-	-	-	-	-	2.9%	-	56%	44%
E.5 Is any national or international product development standard followed?		-	2.6%	-	-	-	0.7%	-	43%	57%
E.6 Is an internal development methodology followed? Are there documents to guide the involved employees?		-	-	2.8%	-	-	0.2%	0.0%	61%	39%
E.9 Is the Design Spiral concept used?		-	-	-	-	3.6%	-	-	39%	61%
E.11 Is the FMEA tool used in the design?		-	-	-	-	-	-	0.1%	32%	68%
F.5 Is any centralized database being used?		-	-	-	-	-	95.0%	-	81%	19%
F.6 Is any design management software being used?		-	-	-	-	-	-	3.6%	22%	78%
F.7 Is there any software for simulation of the Finite Elements Method being used?		-	-	-	1.9%	-	-	1.9%	9%	91%
F.8 Is any software for simulation of the manufacturing process being used?		-	-	-	-	-	95.0%	-	19%	81%
F.9 Is there any software specially developed for the department?		-	-	-	-	97.6%	-	-	28%	72%
G.1 Do suppliers participate in the development process?		-	-	-	-	-	-	100.0%	75%	25%
G.2 Do clients participate in the development process?		1.1%	-	-	-	97.6%	1.4%	-	72%	28%
G.4 Are there any works being made with Universities/ Research Institutes?		0.8%	-	-	-	-	-	-	41%	59%
G.8 Are the products developed being certified by any external organism?		-	-	-	2.0%	-	-	-	41%	59%
H.1 Is there any formal organization chart of the company that includes the PD department?		-	1.0%	-	-	-	-	-	87%	13%
H.8 Are successful designs awarded and/or promoted?		-	1.6%	-	-	-	-	-	41%	59%
Answers - Percentage	**Yes**	43%	61%	89%	39%	21%	32%	39%		
	No	57%	39%	11%	61%	79%	68%	61%		

specific needs, mainly by means of the practical experience obtained throughout its years in business. They do not try to evaluate the use of expertise that is known and developed worldwide.

But there is also room for a lot of improvement. Important concepts such as Design Spiral, FMEA and Design Quality Programs are practically unknown in the universe of these companies. Besides, national or international product development standards are mostly not used. SMEs should focus on these points in order to improve their methodologies, gaining an advantage over the average. The use of these methodologies could set them apart from other companies, providing the leverage that is needed for growth.

Table 6A. Example of answer table based on questions E.5 and G4.

Company ID	05	29	26	16	18	31	32	30	10	03	24	25	13	23	11	02	28
E.5 Is any national or international PD standard followed?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
G.4 Are there any works being made with Universities/Research Institutes?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y

Table 6B. Example of answer table based on questions E.5 and G4.

Company ID	09	14	08	20	04	22	01	27	17	12	19	07	06	21	15
E.5 Is any national or international PD standard followed?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
G.4 Are there any works being made with Universities/Research Institutes?	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y

7. Conclusion

The present work consisted, in a first phase, of an intense field research made by the group. The visits to the researched companies allowed the extraction of useful data, which were compiled with the aid of a standard questionnaire. This questionnaire, carefully elaborated by the group, facilitated the interpretation of the data obtained in the visits. In possession of these data, it was possible to begin a statistical work, aiming at the extraction of conclusions from the individual answers obtained.

The analysis of questionnaire E allowed the attainment of interesting data about the methodologies regarding product development in SMEs. These companies employ very few PDM (Product Data Management) and PLM (Product Lifecycle Management) resources, which are restricted to the usage of CAD systems. The use of CAE systems (Finite Element, Manufacturing Process Simulators) is very limited.

The literature makes many scientific methodologies for product development available, but, much to the interviewers' surprise, theoretical concepts (such as international methodologies' standards) are not very much applied in SMEs. Even the use of concepts such as Design Spiral, FMEA and Value Analysis was practically not observed in the research. However, it can be seen that there is a noticeable concern with obtaining external certifications (such as ISO 9001) as to certifying the quality of the company.

The metal-mechanic sector is one of the most important in the industry, originating jobs and revenues throughout the country. Therefore, the reading of this article presents the synthesis of what is seen nowadays in SMEs of this industrial sector in São Paulo regarding product development. The research has produced data that hopefully will allow a better understanding of how product development aids the increase of opportunities for SMEs. It is hoped that this information will be used for the improvement of SMEs, increasing their competitiveness, generating jobs and modernizing the country.

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