THE PRODUCT/PROCESS MATRIX: AN EMPIRICAL TEST ON THE FRENCH INDUSTRIAL MANUFACTURING INDUSTRIES

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Abstract

This paper tests the validity of the Product/Process matrix, introduced by Hayes and Wheelwright, through a sample of approximately 1700 French manufacturing companies.

The results indicate that industries tend to have a natural position on the diagonal of the Product/Process matrix, as a consequence of the life cycle phase the industry is in.

However, the data also shows that the individual company in an industry can reposition itself, and as such differentiate from the other players in its industry. This indicates that a company's position in the Product/Process matrix is an important element of the manufacturing strategy of the company, rather than just a consequence of a natural evolution in the industry. Companies positioned "off the diagonal" can be successful, but success requires an adapted business strategy, oriented towards quality, lead time, responsiveness and price for the companies below the diagonal, and oriented towards reputation, service and innovation for the companies above the diagonal.

This research has been conducted within the convention signed by the Banque de France and INSEAD. It is based on the database 'SESAME', which has been developed by the Banque de France. The research was supported by the I.C.M. (Brussels).

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1. Introduction

The literature on manufacturing strategy has stressed the need for consistency between the manufacturing strategy and the competitive strategy of the company. One particular aspect is the need for consistency between the variety of products offered by the company, and the choice of production processes used to manufacture these products. This problem has been analyzed by Hayes and Wheelwright in the 1970s. In a series of two HBR-papers they introduced a theoretical model that describes this relationship between the products and the production processes (Hayes and Wheelwright, 1979a and 1979b). This model, which is referred to as the "Product/Process matrix" has since been used widely. The purpose of this paper is to test the validity of the Product/Process matrix on a large database of French industrial companies.

2. The Product/Process matrix

Hayes and Wheelwright proposed with the Product/Process matrix a simplified model to link two life cycles, i.e. the product and the process life cycle.

The product life cycle model describes the evolution over time of a product, from its introduction, over growth and maturation, to the phase of commodity or decline. Typically a high variety of products is offered in the early phases, and the product variety declines in the later phases. Similarly, the product volume per model increases over time as the product evolves through the subsequent life cycle phases. Another interesting evolution lies in the form of competition. Typically, in the introduction phase, competition focuses on the product characteristics. It shifts to quality and availability in the growth phase. The maturation phase is characterized by a competition on price and dependability. In the final phase companies appear to compete on price.

The process life cycle model suggests that a production process evolves from a fluid, uncoordinated process (a job shop process), towards increasing standardization, mechanization and automation (a batch process or assembly line), until it eventually becomes very efficient, capital-intensive, interrelated and less flexible (a continuous flow line).

It has been argued in the work of Abernathy and Utterback (1978) that typically there is a strong interaction between the evolution of the product through its life cycle, and the evolution of the manufacturing process used to produce the product. The combination of the two can be represented in a matrix in which each company (or business unit within a diversified company) can be positioned on the basis of the phase of the life cycle of its products and its choice of the production process (See Figure 1).

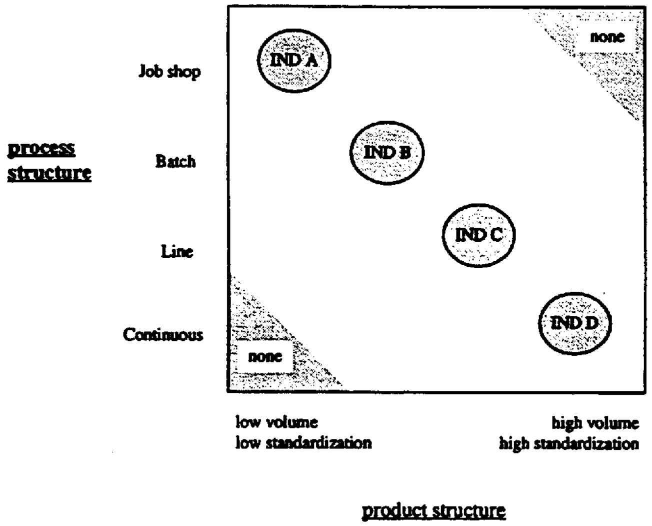

Figure 1
The Product/Process matrix
(Hayes and Wheelwright, 1979a)

The concept of the product/process matrix has been illustrated in the work of Hayes and Wheelwright through examples from the watch industry, the electric motor industry, and the color television industry. The model has been used by a variety of authors to make assertions about the optimal position within the matrix, the costs of deviation from this critical position, and the link between profitability and position in the matrix. Ward and

Miller for example have identified the industry characteristics that explain the predominant production process in an industry, thereby predicting the position of an industry on the process dimension of the matrix, on the basis of some characteristics of its product dimension. Their research was based on a sample of 115 industries (Ward and Miller, 1991). However, in most other cases these assertions lack empirical validation beyond case material.

It is the purpose of this paper to test the validity of the model on a large sample of industrial manufacturing companies in France.

3. Hypotheses

The first set of hypotheses that will be tested relates to the *position of the companies* in this Product/Process matrix. Firstly, Hayes and Wheelwright argued that on the diagonal of this matrix there is a natural match between product and process structure. As companies move away from the diagonal they become increasingly atypical, and dissimilar from their competitors.

Secondly, when we use the industry as the unit of analysis, we see in Figure 1 that typically the companies within an industry tend not only to position along the diagonal, but also to be limited to a relatively small range of that diagonal. That is, industries tend to focus on a particular position on the diagonal in the Product/Process matrix.

We therefore hypothesize that

- H1a There is a tendency for companies to move to a position on the diagonal in the Product/Process matrix.
- H1b Industries tend to be positioned on the diagonal in the Product/Process matrix.
- H1c Companies within the same industry tend to cluster on a limited range of the diagonal in the Product/Process matrix.

However, more recent literature indicates that world class manufacturers gain competitive advantage by differentiating themselves from their competitors. In terms of the Product/Process matrix this may suggest that positions off the diagonal may be very successful if they are in line with the company's competitive strategy. This is for example what many Japanese manufacturers have accomplished, who produce a variety of products with a flexible, yet efficient production process (Hayes and Pisano, 1994). This trend in manufacturing implies that, although we still expect a general tendency for companies to move to a position on the diagonal, we are particularly interested in examining the sample of companies that have moved to a position below or above this diagonal.

The second set of hypotheses relates to the competitive *implications of such a position off the diagonal.* A company positioned below the diagonal apparently manages to produce a certain variety of products through a production process that is more efficient than the process of most of its competitors. This company may therefore exploit a cost advantage. However, this company may find greater difficulties to adapt to changing market needs, since it has a rather capital intensive process. The company that is positioned above the diagonal on the contrary, maintains the possibility of changing products, volumes and processes quickly, if market demands are changing. However its unit cost is likely to be higher than the unit cost of most of its competitors.

We expect that the competitive advantage of companies below the diagonal is typically related to its manufacturing system, whereas the competitive advantage of companies above the diagonal is more typically related to customer orientedness.

Since the database that is used for testing the hypotheses is cross-sectional, it does not provide the data required to test the potential of the company to adapt to changing market needs. It does, however, provide data that describes the competitive advantage of the company.

We hypothesize that

H2a Companies that are positioned below the diagonal tend to compete on cost, whereas companies positioned above the diagonal tend to compete on other, more customer oriented competitive factors.

Hayes and Wheelwright claim that companies that move too far away from the diagonal become increasingly dissimilar from their competitors, which may make them vulnerable to attack. Positions in the upper right and lower left corner of the matrix are therefore to be avoided.

We hypothesize that

H2b Companies in the upper right hand corner (producing a commodity product in a job shop process) or companies in the lower left hand corner (producing a one-of-a-kind product in a continuous process) are less profitable than companies positioned close to the diagonal.

4. Empirical test

The empirical data that will be used is part of the database "Sesame". Sesame is a qualitative database on the strategic behavior of small and medium-sized French industrial companies. The database has been constructed by the Banque de France.
The data, which is mainly of a qualitative nature, has been collected in a national survey, in 1993, through face-to-face interviews with business leaders. In total, self-reported data has been collected on 2098 French companies, spread over 28 industries (at the 3 digit industry code level). The industry coding system which is used in the Sesame database is the French "APE"-coding system. Appendix 2 lists the industry codes and the corresponding industry descriptions at the 3 digit classification level.
The total number of respondents after the adjustment for the type of process (as explained in the next section), and after elimination of the observations with missing values, is 1703.

5. The variables

5.1. Product variety

The horizontal axis of the Product/Process matrix represents companies in four different life cycle phases, with products that vary in their degree of standardization and in volume. Underlying is the assumption that their is a linear relationship between the variety of the product, the product volume, and the product life cycle phase.

The *degree of standardization* of the products has been calculated on the basis of the responses on questions in the questionnaire that ask what proportion of the products is weakly, medium or strongly standardized. A detailed explanation of how this variable has been constructed is found in Appendix 1. A score of 1 for the degree of standardization indicates a high variety of products; a score of 5 indicates a highly standardized product line.

The *stage of the product life cycle* has been measured by asking the respondents to indicate whether their market is in the introduction phase, the growth phase, the maturity phase or the decline phase.

The database provides no reliable data on the *volume* of the products (which is defined as quantity * work content)

The correlation between the life cycle phase and the degree of standardization is only 0.04 (not significant)[1]. This may be due to the fact that companies may offer products with a degree of standardization that doesn't correspond with the life cycle phase of the industry it is in. It may also be due to poor data quality for the life cycle phase variable. It is striking for example that the mode of the life cycle phase is "maturity" in all industries, except for industry 171 (where it is "decline") and for industry 330, which has two modes ("growth" and "maturity"). This is not surprising, since it is a lot more difficult for a

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[1] Since the life cycle phase has been measured for each of the product classes in the company separately, whereas the degree of standardization is an aggregate measure for the product lines as a group, we have limited the correlation analysis to monoproduct companies (which constitute 57% of the database).

respondent to estimate an industry characteristic such as the life cycle of the products, than to describe the products produced in his or her own company.

These considerations have convinced us that the degree of standardization of the products offered by the company is the most appropriate operationalization for the horizontal axis of the matrix in our analyses; its measurement is explained in Appendix 1. It is important to note that this implies that product variety is defined here as a managerial choice, rather than an industry characteristic as was suggested in the papers by Hayes and Wheelwright. This will provide us with more richness in the data, since it will allow us to test the fit between the process type and the product variety, not only for the average company in the industry, but also for companies that, deliberately or unconsciously, offer a standardized product in a market characterized by high variety, or vice versa.

5.2. Type of the production process

The vertical axis of the Product/Process matrix represents the type of production process in the company.

In the questionnaire, it was asked what proportion of the products are produced in a unit production process, in small, medium or large batches, and in a continuous flow process. This data was used to determine the dominant production process in the company. In Appendix 1 we explain in detail how the type of production process has been determined for each of the respondents.

The scale for the type of production process is interpreted as follows:

- 5 all or most of the products are produced in a unit production process (job shop)
- 4 all or most of the products are produced in lot for lot or in small batches
- 3 all or most of the products are produced in medium sized batches
- 2 all or most of the products are produced in large sized batches
- 1 all or most of the products are produced in large sized batches in a continuous flow process.

Intermediate scores indicate that the process is a mixture of 2 or more types, dominated however by the type of process that corresponds with the nearest digit.

We have tried to improve the robustness of the scale by omitting those companies that have two sets of production processes of a different type. We refer to Appendix 1 for more details.

5.3. Competitive advantage

The respondents were asked to indicate, on a list of eight items, their two main competitive advantages. The competitive advantages listed in the questionnaire are price, quality, innovation & technical performance, brand image & reputation, lead time & responsiveness, service, geographical proximity, and an eighth class for any other competitive advantage.

5.4. Performance

The performance of the company has been measured as Return on Sales and Return on Investment.

6. Results

6.1. Test of Hypothesis 1a

In order to test Hypothesis 1a we analyze the linear regression model of the type of production process as a function of the degree of standardization. As shown in Section I of Table 1, we find indeed a linear relationship in the expected direction. However, the relationship is rather weak (Adj R^2 0.23, indicating that only 23% of the variance in the type of production process is explained by the degree of standardization of the products). This weak relationship is also clear from the scatter plot of all the companies in the Product/Process matrix, which is shown in Figure 2.

These results suggest that there is indeed a "natural diagonal", around which companies tend to position. The direction and position of the diagonal correspond with the theoretical model (see Figure 1). We conclude that H1a is supported.

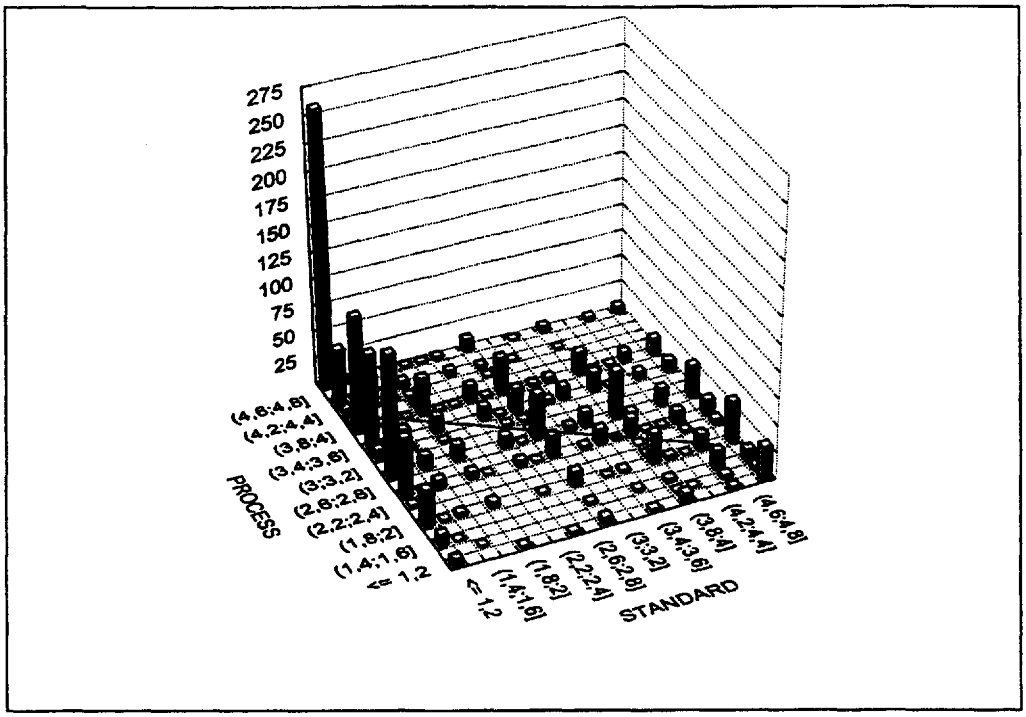

Figure 2
Plot of the Product/Process matrix
for the French industrial manufacturing companies (1703 companies)

The "natural" match between the product and process characteristics appears to be stronger in some industries. Repeating the regression analysis on an industry basis (three digit level industry code) reveals that three groups of industries can be distinguished (See Table 1[2]):

- industries with a strong and significant product/process relationship. The results for these industries are shown in section II of Table 1. The plot in Figure 3 illustrates this relationship for one of these industries, namely the industry with code 151 (See Appendix 2 for a description of the industries).
- industries with a weak, but still significant relationship (at the 5% level minimum), as predicted by the Product/Process matrix. These results are shown in section III of Table 1.
- industries which show no significant relationship (at the 5% level).

[2]Six industries have been omitted from this list as they consist of only five respondents or less (ie the industries with code 100, 130, 140, 260, 270 and 320).

These results seem to suggest that even within an industry, companies tend to move to a position along some kind of a "natural" diagonal. This casts some doubt already on Hypothesis 1c, which suggests that within an industry, companies tend to cluster on a limited range of the diagonal.

	Sample		Linear regression model				Descriptive statistics	
		N obs	intercept	slope	Adj R^2	F prob	% below	% d<|1σ|
I	whole dataset	1703	4.29	-0.36	0.23	0.0001	48.6	
II	industry 241	12	5.54	-0.55	0.71	0.0004	0	33.3
	industry 282	14	5.17	-0.74	0.66	0.0003	64.3	35.7
	industry 131	11	4.71	-0.54	0.64	0.002	45.5	18.2
	industry 151	41	4.73	-0.62	0.61	0.0001	63.4	26.8
III	industry 150	89	4.74	-0.59	0.49	0.0001	52.8	25.8
	industry 240	243	5.18	-0.43	0.44	0.0001	16.0	20.6
	industry 291	71	4.24	-0.35	0.39	0.0001	53.5	25.4
	industry 220	36	4.65	-0.39	0.35	0.0001	33.3	41.7
	industry 160	31	4.08	-0.34	0.25	0.002	54.8	12.9
	industry 230	57	4.77	-0.38	0.25	0.0001	26.3	22.8
	industry 340	57	4.35	-0.34	0.20	0.0002	43.9	31.6
	industry 500	114	3.18	-0.24	0.20	0.0001	86.0	14.0
	industry 281	91	4.55	-0.30	0.20	0.0001	34.1	11.0
	industry 250	68	4.85	-0.30	0.17	0.0002	20.6	14.7
	industry 210	314	4.32	-0.31	0.14	0.0001	48.4	30.6
	industry 530	166	3.37	-0.25	0.13	0.0001	75.3	12.7
	industry 520	30	3.62	-0.28	0.11	0.04	73.3	16.7
IV	industry 171	13	3.91	-0.36	0.22	0.06	69.2	30.8
	industry 172	21	3.93	-0.33	0.13	0.06	66.7	14.3
	industry 110	21	3.97	-0.29	0.13	0.06	57.1	14.3
	industry 211	109	3.04	-0.10	0.02	0.07	56.0	14.7
	industry 330	18	4.06	-0.06	-0.03	0.49	61.1	0
	industry 200	56	3.54	-0.12	-0.005	0.39	66.1	39.3

Table 1
Regression results
The type of the production process as a function of the degree of standardization of the product

industry number : industry code (three-digit level) according to the French APE-coding system; see Appendix 2 for a description of the industries
Nobs: number of observations in the sample;
intercept, slope, ADJ R^2 F prob: estimates, adjusted R square and F-statistic of the linear regression model (type of production process as a function of degree of standardization);
% below: percentage of companies positioned below the diagonal calculated on the basis of average industry data
% d < | 1σ |: percentage of companies within a distance of 1 standard deviation (0.89) to the industry's average position in the Product/Process matrix

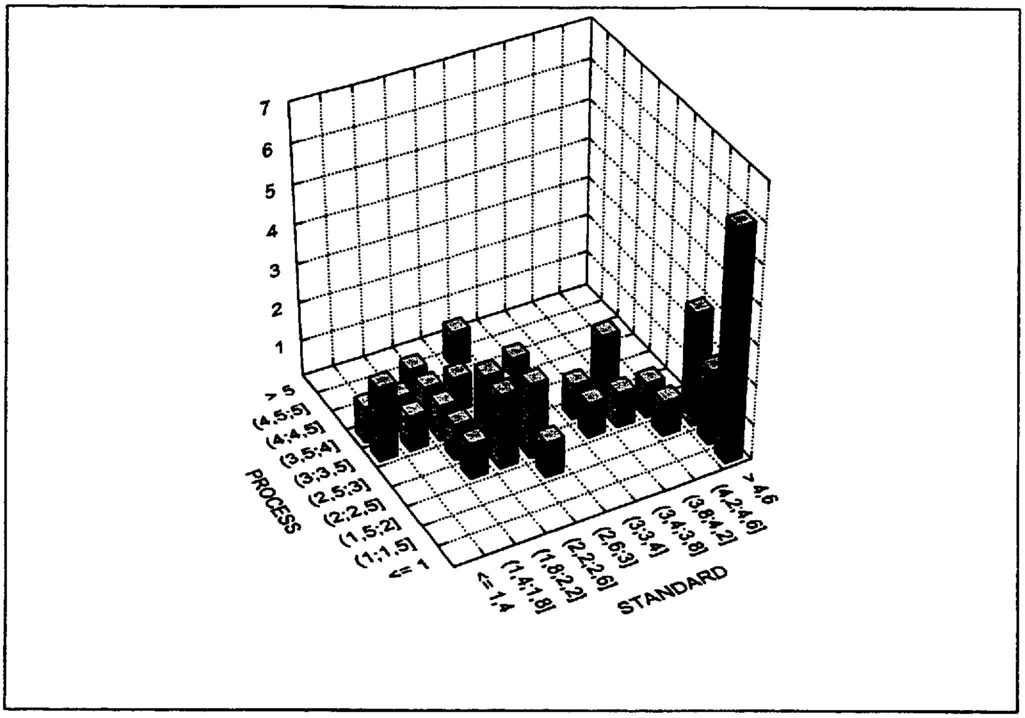

Figure 3
Plot of the Product/Process matrix for industry 151
(tiles, bricks, ceramics)

6.2. Test of Hypothesis 1b

If we shift the unit of analysis from the company level to the industry level, we can draw a chart of the Product/Process matrix, similar to Figure 1, based on the empirical data from the sample of French manufacturing companies. This plot is provided in Figure 4. Each industry is represented by an oval; the center of the ovals has the average degree of standardization and the average process type in the industry as its coordinates; width and height of the ovals are set equal to one standard deviation[3] of the degree of standardization and process type respectively.

[3]Under assumptions of normality this would imply that 38% of all observations fall within the range drawn in Figure 4, for each of the 2 dimensions. That is, only approximately 14% of all observations per industry fall within the ovals.

At this level of analysis we calculate the position of the diagonal. Given the scaling used, the regression line of the average process type in an industry as a function of the average degree of standardization in that industry is[4]

PROCESS = 4.93 - 0.60 STANDARD (adj $R^2 = 0.44$; $p<0.0001$)

The relatively high level of R^2 supports hypothesis 1b that industries tend to position along this diagonal.

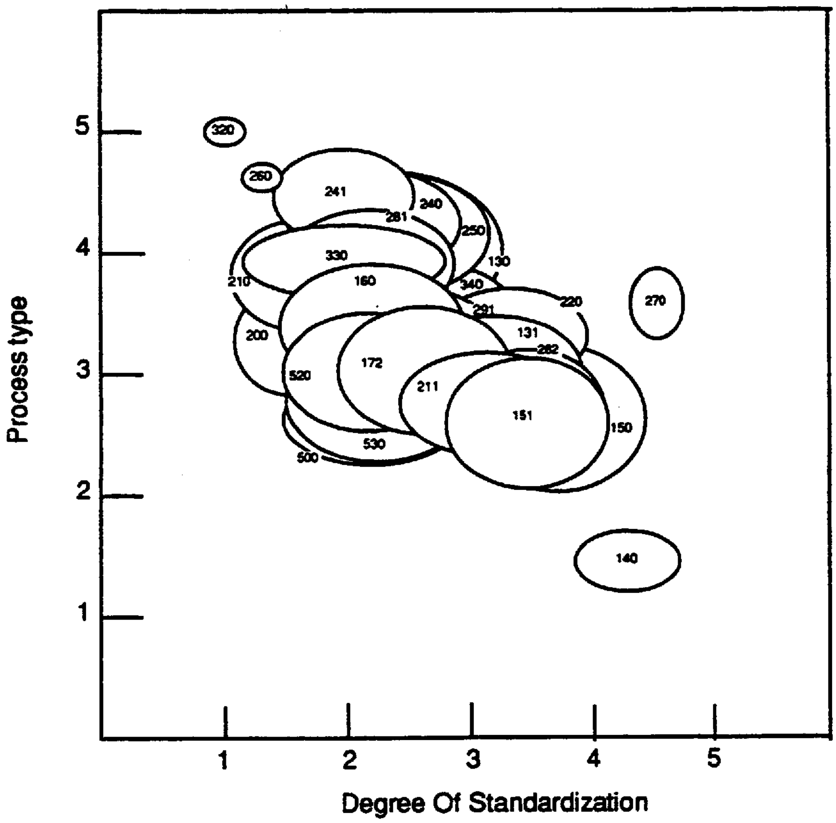

Figure 4

Position of (three-digit level) industries in the Product/Process matrix[5]

This regression line is superimposed on the data in Figure 2 to give an impression of the overall fit of the data with the diagonal. Tests of hypotheses 2 will be based on this linear

[4] The type of process is treated as an interval scale in this analysis. In Appendix 1 we discuss why this is a valid assumption.

[5] 4 industries are hidden; only 1 observation was available for industries 260 and 320.

function as a description of the diagonal[6]. However, for interpretation purposes, this diagonal should not be thought of as a line, but rather as a bandwidth positioned around this regression line.

If we define "distance from the diagonal" as the metric distance between the position of a company and its orthogonal projection on the diagonal, we find that the companies are spread over a distance of approximately 2.84 below to 2.65 above the diagonal. 72% of all companies are concentrated in a bandwidth of distance +/- 0.89 from the diagonal, which is +/- 1 standard deviation of distance.
Further analysis shows that slightly more companies are positioned above the diagonal than below the diagonal (51.4% above, 48.6% below; not significantly different from 50/50 division). This division of companies above and below the diagonal varies widely however from industry to industry. The percentage of companies below the diagonal for each of the (three digit level) industries is shown in Table 1.

6.3. Test of Hypothesis 1c

H1c suggests that typically industries not only position along the diagonal, but also cluster within a limited range of this diagonal (see Figure 1). However, as we discussed in the previous section, the regression of the type of process against the degree of standardization suggests that the companies within a certain industry tend to spread over relatively large ranges (The plot for industry 151 is represented in Figure 3 as an illustration). To test this hypothesis the percentage of companies positioned within a distance of 0.89 (1 standard deviation) from the industry's average position is calculated, for each of the three-digit level industries. These percentages are shown in the right hand column of Table 1. It is clear from this table that for each of these industries only a small percentage of the companies (between 0 and 42%) is positioned close to the industry average. Hypothesis 1c is therefore not supported.

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[6]These results are not sensitive to the exact position of this diagonal. We have repeated the analyses using a regression line calculated on the basis of the data of the 4 industries with the strongest product/process relationship (industries 241, 282, 131 and 151). The results are not significantly different.

A possible explanation for this observation may be that the level of aggregation used in the analysis was inappropriate. However, this explanation is not supported by the data. We refer to Appendix 3 for the results for a more detailed level of aggregation, namely the 4-digit level industry classification. Approximately 75% of the (four-digit level) industries have fewer than half of their companies positioned within a distance of 1 standard deviation from the industry average.

6.4. Test of Hypothesis 2a

H2 suggests that companies may intentionally position above or below the diagonal to support their strategic position vis-à-vis their competitors. In the dataset Sesame a list of 7 possible types of competitive advantages was provided : (1) price, (2) quality, (3) innovation or technical performance, (4) brand image or reputation, (5) lead time or responsiveness, (6) service, and (7) geographical proximity. An 8th type was included to account for any other possible competitive advantage.

In order to test the hypothesis H2a that there is a different competitive focus for companies below and above the diagonal, we distinguish two groups of companies: companies below the "natural bandwidth" of +/- 1 standard deviation of distance from the diagonal, and companies above this bandwidth. In table 2 we have listed, for each group and for each of the competitive advantages, the percentage of respondents that checked the advantage as being one of their two key advantages[7].

A χ^2 test indicates that the distribution of the competitive advantages in the group of companies below the diagonal is significantly different from the distribution of the competitive advantages in the group of companies above the diagonal (probability of no difference << 0.001).

[7]Theoretically the percentages should add up to 200% as each company was asked to check its two main competitive advantages. However, due to rounding errors, and due to the fact that some companies have checked only 1 competitive advantage, they may not add up exactly to 200%

	below diagonal distance < -0.89	*above diagonal* distance > +0.89
price	***0.26***	0.23
quality	***0.56***	0.43
innovation/technical performance	0.34	***0.38***
brand image/reputation	0.19	***0.32***
lead time/responsiveness	***0.43***	0.32
service	0.11	***0.20***
geographical proximity	0.03	0.03
other	0.01	0.01

Table 2
Competitive advantage versus position in the Product/Process matrix

Companies below the diagonal tend to compete relatively more on quality, lead time and responsiveness, and slightly more on price, whereas companies above the diagonal compete relatively more on brand image and reputation, and service, and slightly more innovation and technical performance[8].

As hypothesized, the companies below the diagonal compete more on price than those above the diagonal, although the difference is small. We should note that the competitive advantage is specified here from the point of view of the customer. Consequently, price was given as a choice in the questionnaire, not cost. However, it is fair to state that a cost advantage is a prerequisite for a price advantage. The companies below the diagonal also focus on lead time and responsiveness, two competitive advantages that are supported to a large extent by the manufacturing system of the company. As hypothesized, the companies above the diagonal focus more on market related advantages, such as image and service, and apparently also on innovativeness.

We conclude that H2a is supported.

[8]These results are not sensitive to the choice of the cutoff value for the distance to the diagonal.

6.5. Test of Hypothesis 2b

In order to test H2b the dataset has been divided into three groups of companies : those close to the diagonal, those far below the diagonal, and those far above the diagonal. Using an ANOVA[9] we compared performance of each of the two extreme groups with the diagonal group. Performance has been measured by Return on Sales and Return on Investment.

The cut-off value for the bandwidth close to the diagonal has been set equal to 0.89, which is one standard deviation of the distance. Companies were said to be far above or below the diagonal if they were on a distance of 1.34 from the diagonal, which is 1.5 times the standard deviation of the distance.[10] The results are summarized in Table 3.

Position relative to the diagonal	Cut-off values	N	**ROS**	signif. level p (H_0:equal ROS)	**ROI**	signif. level p (H_0:equal ROI)
far above diagonal	distance > $1.5\sigma = 1.34$	62	**11.43**		**12.28**	
				] 0.47		] 0.14
close to diagonal	$-\sigma=-0.89<\text{distance}<0.89=\sigma$	1019	**10.64**		**10.21**	
				] 0.04		] 0.01
far below diagonal	distance < $-1.5\sigma = -1.34$	115	**12.10**		**8.38**	

Table 3

Comparison of performance for companies close to / far above / far below the diagonal

We can conclude that - contrary to H2b - no significant difference is found in Return on Sales for the companies close to the diagonal and those far above the diagonal. The Return on Investment of the companies far above the diagonal appears to be even higher than for the companies close to the diagonal. The significance of this result is rather low (14%). However, with other cut-off values, the significance increases.

The companies far below the diagonal show a significantly higher Return on Sales than those close to the diagonal. However, with other cut-off values, the significance disappears.

[9]General Linear Model method was used to account for the unbalance in the number of observations per group. The Cochran ttest was used to account for the unequality of variance in the subgroups.

[10] The test has been repeated for three different cut-off values for determining the comparison groups. Although the significance levels for the mean comparisons differ according to the cut-off value, the overall results are quite stable.

As predicted by H2b, the companies far below the diagonal are rated significantly lower in Return on Investment than those close to the diagonal.
We conclude that H2b is not supported.

7. Discussion

An analysis of the type of production process used, and the degree of standardization of the products offered in approximately 1700 French manufacturing companies has shown that the natural match, as predicted by the Product/Process matrix is present. However, this effect is not as pronounced as was suggested in the original descriptions of this matrix. (Hayes and Wheelwright, 1979a and 1979b). We find that industries, on average, tend to position within a bandwidth around this diagonal, but individual companies in an industry take positions spread "allover the map" in this Product/Process matrix. This indicates that, although industries tend to be characterized by an ideal position on the diagonal, companies within an industry have a strategic choice to differentiate oneself. The position taken by a company in the Product/Process matrix appears to be a manufacturing strategy decision, independent of the life cycle. This observation is very much in line with the more recent manufacturing strategy literature, which states that the company's manufacturing organization is an important locus of capabilities that allow the company to differentiate from competition. (Hayes and Pisano, 1994)

Positions off the diagonal are in general accompanied by a particular competitive focus: Companies below the diagonal tend to compete relatively more on quality, lead time and responsiveness, and price, whereas companies above the diagonal tend to compete relatively more on brand image and reputation, service, and innovation and technical performance.

We did find companies in the upper right hand corner and the lower left hand corner of the Product/Process matrix. Our hypothesis that the rare companies that would be found in these extreme positions would be less profitable than the other companies was not confirmed.

Companies in the lower left hand corner of the matrix, on average, do not have a lower Return on Sales than companies close to the diagonal. They do, however, on average, have a lower Return on Investment. This raises the assumption that these companies, which apparently produce a high variety of products in a batch oriented or continuous process, have invested heavily compared to companies closer to the diagonal. This observation may be an indication that these extreme companies manage to hold this Product/Process position through an investment in flexible manufacturing systems. It has indeed been argued in the literature that FMS would alter the nature of the interaction between product characteristics and process characteristics. See for example Goldhar and Jelinek (1983), Beckman (1990), Noori and Radford (1990), and Pearson et al. (1991). Beckman for instance predicts that FMS systems will cause the "diagonal" to rotate downwards, as is sketched in Figure 5.

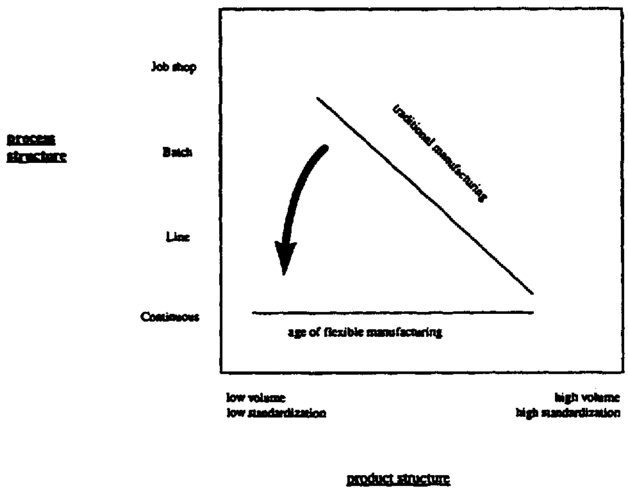

Figure 5
Impact of FMS on the Product/Process matrix
(Source : Beckman, 1990)

It is accepted that flexible automation allows the company to combine cost effectiveness (through economies of scale) with the flexibility of providing a high variety of products, (through economies of scope) (Goldhar and Jelinek, 1983). This can explain the fact that price (and therefore presumably cost) is considered an important competitive advantage for these companies, even though they provide a high degree of variety. The opportunity that these recently developed systems offer to combine economies of scale and scope is referred to by Noori and Radford (1990) as "economies of integration".

Companies in the upper right hand corner of the matrix use job shop type production processes to produce standardized products. Despite of this "mismatch" between the products offered and the production process used, these companies, on average, are not performing less well than the companies close to the diagonal: They have approximately the same Return on Sales, and they even seem to outperform the companies close to the diagonal in Return on Investment. It may be that these companies are not using their production capabilities as the competitive weapon, ie. that production is considered "internally neutral" in these companies (Hayes and Wheelwright, 1984). This possible explanation is supported by the observation that these companies attach relatively more importance to competitive advantages which are not directly production driven, namely innovation, technical performance, service, brand image and reputation.

8. Conclusion

In this paper, we have described a methodology for determining the position of companies and industries in the Product/Process matrix. The empirical sample used for testing the validity of the matrix consisted of approximately 1700 French manufacturing companies.

The results indicate that industries tend to have a natural position on the diagonal of the Product/Process matrix, as a consequence of the life cycle phase the industry is in.
However, the data also shows that the individual company in an industry can reposition itself, and as such differentiate from the other players in its industry. This indicates that a company's position in the Product/Process matrix is an important element of the manufacturing strategy of the company, rather than just a consequence of a natural evolution in the industry. Companies positioned “off the diagonal” can be successful, but

success requires an adapted business strategy, oriented towards manufacturing for the companies below the diagonal, and oriented towards marketing, service and innovation for the companies above the diagonal.

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Appendix 1
Degree of standardization and type of production process: construction of the variables

Degree of standardization

The variable "degree of standardization of the products" has been constructed on the basis of the responses to the following question:

How are your distinct products divided, according to their degree of standardization ?

		none	some	a lot	almost all
S_1	weak standardization		x		
S_2	rather weak standardization			x	
S_3	medium standardization			x	
S_4	rather strong standardization		x		
S_5	strong standardization	x			

Table A1.1

Example of the response for the degree of standardization of the products

We have assigned a value of 0 to the variable S_i in case the score given by the respondent for S_i was "none"; a value of 1 in case the score given by the respondent for S_i was "some"; a value of 2 in case the score given by the respondent was "a lot" and finally a value of 3 in case the score given by the respondent for S_i was "almost all".
We have then calculated the weighted average of the values of the variables S_i (with a weight of 1 for S_1 to 5 for S_5). The resulting score ranges from 1 to 5. This score has then been used in the analyses as the measure for the degree of standardization.
For the example illustrated in table A1.2, the degree of standardization is therefore :

$$\frac{1*1+2*2+2*3+1*4+0*5}{1+2+2+1+0} = 2.5$$

From a managerial point of view however one may argue that, in determining the overall degree of standardization of the products, one should focus on the standardization of a lot, or most of the products, and ignore the "some" responses. Therefore we have opted to assign a value of 0 not only to the "none" class, but also to the "some" class.
The analyses have been performed twice, namely by using the adjusted variables and by using the unadjusted variables. It was shown that the adjustment of the data does not affect the results significantly. The analyses reported in this paper have been conducted using the variables calculated after adjustment.

Type of production process

The variable "type of production process adopted by the company" has been constructed on the basis of the responses to the following question:

For each of the main types of production processes, indicate how many of your products are involved

		none	some	a lot	almost all
P_1	unit production	x			
P_2	lot for lot or in small batches		x		
P_3	in medium batches			x	
P_4	in large batches			x	
P_5	in large batches AND continuous flow	x			

Table A1.2
Example of the response for the type of production process

The construction of the variable follows the same logic as explained above for the standardization variable. Therefore, for the example illustrated in table A1.2, the score for the type of production process is:

$$\frac{1*1+1*2+2*3+2*4+0*5}{0+1+2+2+2+0} = 3.4$$

which indicates that the dominant production process in this company is a batch process, with medium to high batch sizes.
Finally, this scale has been reversed, in order to obtain a scale that is comparable to the scaling used by Hayes and Wheelwright, in their descriptions of the Product/Process matrix.

The same adjustment as described for the degree of standardization has been made to the data used for determining the type of production process: If only "some" products use a distinct type of production process this observation was neglected. Again it should be noted that this adjustment did not influence the results considerably.

A second adjustment needs to be made for the production process variable. It is possible that a factory consists of two (or more) separate entities, with a different type of process. This has been described by Skinner (1974), as the "plant-within-a-plant". The questionnaire does not allow us to identify these situations. We may however reduce the problem by eliminating the obvious cases of this phenomenon, that is those companies that responded they have a lot of products produced in processes that are separated in the interval scale. The example in Table A1.3 illustrates such a case, where part of the production is in small batches, and part is in large batches. This fictitious company would be eliminated from the analyses.

		none	some	a lot	almost all
P_1	unit production	x			
P_2	lot for lot or in small batches			x	
P_3	in medium batches	x			
P_4	in large batches			x	
P_5	in large batches AND continuous flow	x			

Table A1.3

Illustration of a company with two distinct production processes

In order to determine the type of production process used in the companies of the respondents we implicitly assumed that the type of production process can be regarded as an interval scale (1 to 5). There is indeed to a large extent consensus in the literature on POM that these types of processes can be viewed as lying on a continuum, ranging from general purpose to highly specialized. Moreover, since the operationalization of the production process type used in the database 'SESAME' is based on the batch size, the scale can be regarded as an interval scale. However, one could argue that there is a discontinuity between P4 and P5, that is between 'in large batches' and 'in large batches and continuous flow'. To test the severeness of this discontinuity, we have calculated the degree of standardization as a function of the production process type for all observations, and we have compared this function to the same regression function calculated after omission of the companies with a continuous flow process. The hypothesis of equality of the slope and intercepts of these two regression functions could not be rejected ($p \approx 0.40$ for H_0 of equal slope and $p \approx 0.50$. for H_0 of equal intercept). This confirms our assumption that the production process type scale can be used as an interval scale in the analyses.

Appendix 2
description of the (4 digit) industries, grouped in the (3 digit) industry codes

Strong relationship (at the industry level) between the process type and the degree of standardization

ind. 241	manufacture of machinery for the textile industries, industrial sewing machines manufacture of machinery for the paper, cardboard and graphic arts industries
ind. 282	manufacture of electrical installation equipment manufacture of electrical batteries and low-voltage lighting equipment manufacture of accumulators manufacture of electric lamps
ind. 131	semi-manufactured aluminum and other light metal products semi-manufactured lead, zinc and cadmium semi-manufactured copper products
ind. 151	manufacture of tiles and bricks manufacture of sandstone, china and ceramic products manufacture of domestic ceramic ware

Weak relationship (at the industry level) between the process type and the degree of standardization

ind. 150	extraction of sand and alluvium gravel quarrying of crushed stone and slag manufacture of building stonework manufacture of concrete products
ind. 240	manufacture of industrial-type valves, taps and cocks manufacture and installation of ovens manufacture of aeraulic, heating and refrigerating equipment manufacture of internal combustion engines other than for motor vehicles and aircraft manufacture of hydraulic and pneumatic transmissions manufacture of pumps and compressors manufacture of thermal and hydraulic turbines and dam equipment manufacture of boilers manufacture of machinery for the food, chemical, plastics industries, footwear machinery
ind. 291	manufacture of control and regulatory systems for industrial automation, and electric and electronic systems manufacture of professional electronic and radio-electric equipment

ind. 220	manufacture of agricultural tractors manufacture of other agricultural machinery
ind. 160	manufacture, working and cutting of flat glass, manufacture of glass mirrors manufacture of technical glassware
ind. 230	manufacture of metal-working machine tools manufacture of wood-working machine tools manufacture of tools, machine tools manufacture of gears and transmission gears manufacture of welding equipment
ind. 340	clock and watch making manufacture of weighting apparatus and meters, measuring instruments manufacture of corrective and protective eye glasses manufacture of optical and precision instruments manufacture of photographic and cinematographic equipment manufacture of medico-surgical equipment and prostheses manufacture of bearings
ind. 500	manufacture of paper and cardboard paper industry paper processing manufacture of corrugated cardboard and corrugated cardboard products manufacture of cardboard articles
ind. 281	manufacture of electric distribution equipment, low voltage switchboard equipment, electronic power applications manufacture of high-power or high-voltage electric material manufacture of low-voltage industrial relay equipment, signaling equipment manufacture of rotary machines and electric transformers of low and medium power manufacture of insulators and glass and ceramic insulating parts manufacture of automated equipment and of industrial processes repairing of heavy electrical machinery manufacture of electrical lighting material manufacture of insulated electrical wires and cables manufacture and installation of elevators, lifts and escalators
ind. 250	manufacture of public works machinery manufacture of machinery for the steel and iron industry, foundries, preparation of materials, fixed railway equipment manufacture of mechanical handling and lifting equipment manufacture of mining and drilling machinery

ind. 210	forging, stamping, hot pressing treating and coating of metals cutting manufacture of bolts and nuts, screws metal construction metal joinery of buildings general mechanics, molds and patterns manufacture of hand tools, portable power tools, agricultural tools
ind. 530	manufacture of compound, laminated sheets, sheets, films, tubes, pipes and sections manufacture of plastic packaging material manufacture of building fittings manufacture of cellulose film
ind. 520	manufacture of rubber products

No significant relationship (at the industry level) between the process type and the degree of standardization

ind. 171	manufacture of mineral opacifiers, compounds and pigments for enamels manufacture of other mineral-chemical products manufacture of other fertilizers (non-nitrate, non-phosphate)
ind. 172	organic, synthetic chemistry manufacture of synthetic pigments chemical treatment of oils and fats, especially stearine and glycerin, manufacture of basic detergent products manufacture of plastic materials manufacture of synthetic rubber and other rubber goods manufacture of essential oils, natural and artificial flavorings
ind. 110	drawing of steel and manufacture of steel wire derivatives cold rolling of steel sheets
ind. 211	manufacture of hardware tinware, manufacture of household stencils, cutlery manufacture of metal furniture manufacture of metal drums and casks, metal boxes and packaging, manufacture of metal conditionings manufacture of small metalware
ind. 330	aircraft cell construction manufacture of aircraft propellers and propeller parts manufacture of specific aircraft equipment manufacture of spacecraft and space launchers
ind. 200	ferrous metal foundries non-ferrous metal foundries

Appendix 3

Percentage of companies within distance of 1 standard deviation from industry average position in the Product/Process matrix

4-digit industry code	N	% within distance 0.89
1001	15	100.0
1101	10	20.0
1105	5	40.0
1310	6	16.7
1501	7	57.1
1502	9	44.4
1503	9	11.1
1508	48	22.9
1509	7	28.6
1510	13	38.5
1512	10	20.0
1513	14	42.9
1601	15	33.3
1602	7	14.3
1603	7	42.9
1719	10	40.0
1725	6	16.7
2001	32	50.0
2002	24	50.0
2101	22	22.7
2102	53	45.3
2103	26	19.2
2104	17	5.9
2105	15	13.3
2106	44	77.3
2107	21	66.7
2108	109	80.7
2109	7	57.1
2110	9	66.7
2111	21	61.9
2112	18	33.3
2113	28	21.4
2114	15	0.0
2115	14	14.3
2202	32	43.8
2301	16	37.5
2303	13	30.8
2304	15	40.0
2305	9	11.1
2401	25	48.0
2403	53	20.8
2405	10	40.0
2406	12	8.3
2408	81	77.8
2409	55	27.3
2410	7	28.6
2411	5	100.0
2501	11	18.2
2502	8	37.5
2503	44	18.2
2504	5	40.0
2810	14	7.1
2811	5	20.0
2812	12	25.0
2813	16	68.8
2815	18	77.8
2817	12	16.7
2818	10	10.0
2821	7	28.6
2823	5	60.0
2911	6	33.3
2913	16	31.3
2914	22	22.7
2915	23	56.5
3301	6	100.0
3303	9	55.6
3401	13	30.8
3402	6	100.0
3403	7	85.7
3404	5	40.0
3406	20	50.0
3407	5	100.0
5002	21	33.3
5003	12	25.0
5004	19	15.8
5006	22	86.4
5007	39	35.9
5203	26	7.7
5301	29	17.2
5302	51	3.9
5303	45	11.1
5304	18	33.3
5305	23	13.0

industries with less than 5 observations are omitted from this table