Configurational methods in operations management contingency research – overview and the introduction of multidimensional scaling as a possible new application[1]

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In this paper we examine different applicable methods for analyzing configurations of manufacturing practices and contingency factors. The paper consists of two main parts. We first review those methods that can be used for investigating configurations based on Venkatraman (1989) and Venkatraman – Prescott (1990): gestalts, profile deviation and covariation, and we introduce another method for configurational analysis, namely the multidimensional scaling (MDS). The second part provides an empirical comparison between some of these methods by using the fifth wave of IMSS database which contains 725 valid observations from 21 countries from the ISIC 28-35 industries. We give an example for the joint use of factor analysis and multidimensional scaling, and also of cluster analysis and multidimensional scaling.

Keywords: contingency factors, configurational models, manufacturing, operations, multidimensional scaling.

JEL code: M11.

Introduction

When one talks about contingency factors, there are many synonymous terms that lack clear definitions. Just to mention some examples:

- contingencies may be intra- and extra-organizational (Donaldson 2001);

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- context as the totality of contingencies (Baranyi 2001);
- situational or contextual factors (Dobák 2006; Dobák and Antal 2010);
- contextual factors (consisting of organizational and contingency factors) (Sila 2007);
- external environmental variables (González-Benito 2002); and
- environmental, organizational and managerial contexts (McKone et al. 1999).

In this paper, all environmental conditions and long-lasting organizational capabilities and factors will be identified as ‘contingency factors’ (according to Dobák and Antal 2010). The research of contingency factors has a long history and dates back to the 1950s. The term “contingency theory” was coined by Lawrence and Lorsch (1967), and played a leading role in the organizational practice of the 1970s. Contingency factors became popular in the field of strategic management in the 1970s and 1980s (see e.g. Mintzberg 1979) and have remained a research target area ever since. This applies to the field of *operations strategy* as well. However, according to Sousa and Voss (2008) there is a lot of space for contingency research in operations management (OM). At this level of research we are interested in the effect of contingency factors on everyday *management practices* (e.g. quality management practices or HRM practices), not on operations strategy. If we compare the quantity of articles with a contingency view to the existing OM knowledge, the ratio is very low indeed. Also, most papers did not investigate contingencies on a system-level, but rather tested relationships between pairs consisting of a contingency variable and an OM variable (see Drazin and Van de Ven 1985 for possible levels of analysis). The system approach refers to the simultaneous examination of the effect of several contingency factors and manufacturing practices on operations performance, and the appearing configurations may be analyzed. This configurational view is the natural extension of the contingency view (Ahmad et al. 2003), and its importance is also noted by Boyer et al. (2000). Bozarth and McDermott (1998) see the distinctive feature of configuration models in the application of multidimensional profiles to describe organizational, strategy and process types. They note that when a theory is described by multidimensional profiles, traditional models (working with mediation and moderation) may be entirely useless because of their linearity constraints and because only few variables may be investigated simultaneously. Configurational models were developed to address these disadvantages. By accepting the fact that there are multiple ways to be successful in any given environment, the configurational approach explicitly supports the notion of equifinality (Meyer et al. 1993). In this paper we examine different applicable methods for analyzing configurations of manufacturing practices and contingency factors, and show practical examples on how to jointly use them.

Literature review

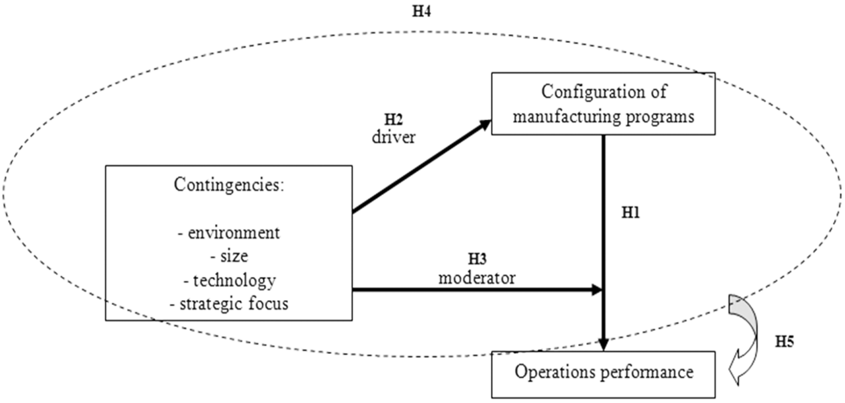
We first reviewed those methods that can be used for investigating configurations based on Venkatraman (1989) and Venkatraman and Prescott (1990). The main problem when writing the articles was that no deeply elaborated method existed to mathematically test fit theories. This gap was caused by the several possible ways to interpret fit. To examine configurations with a system approach in mind, three methods are appropriate: *gestalts, profile deviation* and *covariation* (Sousa and Voss 2008).

In the case of *gestalts*, we examine the degree of internal coherence among a set of theoretical attributes. It is important to examine these theoretical attributes jointly because at the level of single pairwise attributes, we may find internal inconsistencies. Basically, this approach intends to create archetypes. The important analytical issues are the descriptive validity (it is necessary to develop a set of formal criteria to evaluate the descriptive validity of the gestalts) and predictive validity (the performance implications need to be established, and the existence of generic strategy types or multiple configurations of equal success should be demonstrated). For gestalts, we use the cluster analysis, which is a frequently used configuration method in the field of OM, primarily in the field of manufacturing strategy (see, for example, Miller and Roth 1994; Bozarth and McDermott 1998; Cagliano 1998; Jonsson 2000; Kathuria 2000; Sousa and Voss 2001; Christiansen et al. 2003; Sousa 2003; Sum et al. 2004; Cagliano et al. 2005; Oltra et al. 2005; Zhao et al. 2006; Martin-Pena and Diaz-Garrido 2008).

In the case of *profile deviation*, fit is the degree of adherence to an externally specified profile. The approach differs from the gestalts because here the profile is attached to a dependent variable. This approach makes it possible for the researcher to create ideal types, and it is helpful in investigating environment-strategy relationships because the deviation from the profile can be linked to the decrease of performance. The analytical issues of profile deviation are the development of a profile, the equal or different weighting of the dimensions and the creation of a baseline model. This approach was used, for example by Ahmad et al. (2003) and Da Silveira (2005).

In the case of *covariation*, fit is a pattern of covariation or internal consistency among a set of underlying theoretically related variables. The main difference between covariation and gestalts lies in the methodology. As we mentioned, we apply cluster analysis for gestalts, while we use factor analysis for covariation. The analytical issues are the explorative or confirmative approach and testing the impact of performance on fit.

As another useful method, we introduce the *multidimensional scaling (MDS)*, which is an explorative statistical tool. The main assumption behind MDS is the idea that every observation has an exact set of coordinates in space and more similar observations are closer to each other. When we use MDS, we do not have to build a model or assume a causal relationship or test a hypothesis. We use the distances between the observations to create a map of them in a reduced space (usually in two or three dimensions to help visualization) to reveal their hidden structure. The aim is similar to the objective of the principal component analysis (Cox and Cox 1994). Apart from Demeter et al. (2011), we are not aware of any other article that used this method in operations management contingency research. In Demeter et al. (2011) the authors mapped the differences among countries and industries in two dimensions. The objective was to identify which contingency factor causes larger differences in the efficiency of labor productivity drivers.



Source: own research

Figure 1. The elaborated research model

Figure 1 shows the elaborated research model used in this paper, taken from Matyusz (2012). Because of the limitations of the current paper, for the reasoning behind the model and its detailed theoretical foundation and analysis please refer to Matyusz (2012). Here we are only briefly overviewing the model. The model consists of three major blocks. The first block is the configuration of the manufacturing practices, which affects the second block, operations performance (H1). The third block is the block of contingency factors, which have a dual role. On one hand, they are drivers of the use of manufacturing practices (H2), and on the other hand, they moderate the relationship between manufacturing practices and operations performance (H3). Two more hypotheses were stated which dealt with configurations. One assumed that there are different stable contingency-manufacturing practice configurations that coexist simultaneously (H4), while the other proposed that the state of equifinality can be shown, i.e., different and stable contingency-manufacturing practice configurations exist and lead to the same high level of operations performance (H5). Four important contingency factors were analyzed in the model: environment, size, technology and strategic focus. Similar to Mintzberg (1979), we accepted the assumption that the direction of causation is from contingency factors towards manufacturing practices.

Methodology

In this research we use the International Manufacturing Strategy Survey (IMSS) database. IMSS is an international network of researchers who aim to study manufacturing strategy, its implementation, and its results for manufacturing and other adjacent areas (e.g., supply-chain management and new product development). IMSS was launched by Chris Voss (London Business School, UK) and Per Lindberg (Chalmers University of Technology, Sweden) in 1992. Since then, five survey waves have been executed and the sixth is in progress. In our analysis, we will use the data from the fifth survey wave. These data were gathered by the national research teams, whose members asked the respondents to complete a standard questionnaire, which had been assembled by an expert panel, integrating the experience from the previous waves. Where necessary, the questionnaire is translated into the local language by the local OM professors. Although there is a recommended process for the data collection (focusing on better-performing companies, contacting companies via letter and/or phone, mailing a printed questionnaire to a contact person at each company - usually the plant manager or operations manager -, and tracing and assisting the contact person throughout the response phase), the final decision about the process is made by the national research teams. At the same time, the research teams are obliged to inform the global network about the sampling process. The centre coordinating the research executes a preliminary quality check before disseminating the data to the participants.

The fifth wave of the IMSS survey contains 725 valid observations from 21 countries (primarily from Europe, but apart from Africa, all other continents are represented) from the second half of 2009. The survey focuses on the ISIC 28-35 industries. The industry and country distributions are shown in Tables 1 and 2.

Table 1. Number of observations in different industries

Manufacturing activity	Observations
Fabricated metal products, except machinery and equipment	242
Machinery and equipment not elsewhere classified	185
Office, accounting and computing machinery	12
Electrical machinery and apparatus not elsewhere classified	92
Radio, television and communication equipment and apparatus	42
Medical, precision and optical instruments, watches and clocks	42
Motor vehicles, trailers and semi-trailers	52
Other transport equipment	34
Missing	24

Source: own research based on IMSS database

Table 2. Number of observations in different countries

Country	Observations	Country	Observations	Country	Observations
Belgium	36	Hungary	71	Portugal	10
Brazil	37	Ireland	6	Romania	31
Canada	19	Italy	56	Spain	40
China	59	Japan	28	Switzerland	31
Denmark	18	Korea	41	Taiwan	31
Estonia	27	Mexico	17	United Kingdom	30
Germany	38	Netherlands	51	USA	48

Source: own research based on IMSS database

Analysis and discussion

Our goal is to show how MDS is able to support well established methodologies such as factor analysis and cluster analysis. In this paper we use certain examples based on the research model in Figure 1 to do this. This section gives two possible applications of MDS to show its capability to help configurational analysis by giving new insights. These insights clearly show the usefulness of MDS as an exploratory tool, and hence it can save considerable amount of energy and time when one examines the structure of the data and build a research model. The first example uses factor analysis and MDS to construct and interpret the variables of the model, while the second one uses cluster analysis and MDS for the configuration of contingency variables and manufacturing practices. As we mentioned in the previous section we had 725 valid observations to begin with. After cleaning the database, analyzing missing values and examining outliers, a total of 523 companies remained in the final sample. We used SPSS 15.0 for the analyses. For the details, please refer to Matyusz (2012).

Factor analysis and multidimensional scaling

Hypotheses H1-H3 were tested by the SEM-PLS method (Henseler et al. 2009; Tabachnick and Fidell 2007) and it was necessary to create appropriate variables used in the model. In this paper we chose the contingency variable of 'strategic focus' as an example. This variable was based on Question A4 of IMSS about competitive priorities ('Consider the importance of the following attributes to win orders from your major customers.'), whose variables were measured on a 5-point Likert-scale (1 – not important, 5 – very important) (see Appendix 1 for the original question from the survey).

A frequent approach here is to use the traditional four dimensions of operations management (cost, quality, flexibility, dependability). The 12 variables were first divided into 4 factors by factor analysis; then we performed the analysis of unidimensionality based on this grouping. The dimensions consisted of the following variables:

i) *cost focus:* lower selling prices (A4a);

ii) *quality focus:* superior product design and quality (A4b), superior conformance to customer specifications (A4c). Cronbach's alpha for quality focus is only 0.556, which is below the expected 0.6 threshold;

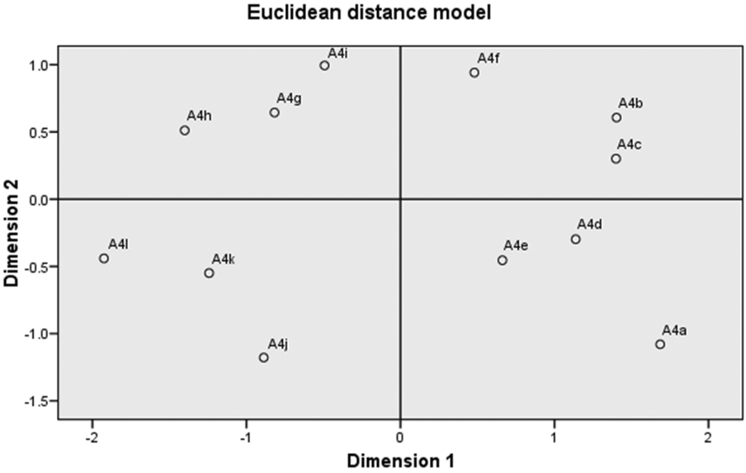
iii) *flexibility focus:* wider product range (A4g), offer new products more frequently (A4h), and offer products that are more innovative (A4i). I.e. this focus is about product and mix flexibility. Cronbach's alpha for flexibility focus is 0.768. By omitting variable A4g (wider product range) Cronbach's alpha's value would increase to 0.799.

iv) *dependability focus:* more dependable deliveries (A4d), faster deliveries (A4e), greater order size flexibility (A4j), environmentally sound products and processes (A4k) and committed social responsibility (A4l). Cronbach's alpha for dependability focus is 0.761. It has to be mentioned that this variable measures not only dependability, because it consists of greater order size flexibility (though this can be related to dependability), but also aspects of social responsibility.

One variable, superior customer service (A4f) was omitted as it did not fit into any of the factors. Appendix 2 contains the details of the factor analysis.

Next, we applied the MDS (ALSCAL method) with the Euclidean distance. Figure 2 shows the 2-dimensional result. The S-stress value is 0.14443, which represents a medium fit (values under 0.2 are acceptable). The RSQ (squared correlation) value is 0.874, which means that the resulting 2D map in Figure 2 explains 87.4% of the initial distances between the variables. By using the map, we can refine the results of the factor analysis. It can be seen that A4a is really a stand-alone variable. A4b and A4c are very close to each other, just as to A4d and A4e, which suggests that the quality and dependability-related variables may fit in one factor. It is an interesting insight, because A4b and A4c together were not too reliable based on the alpha value, while A4d and A4e were reliably grouped together with A4j, A4k and A4l, but according to the map, they are very far from each other and should not be treated jointly. A further analysis by PLS-SEM (partial least square structural equation modeling) indeed showed that these five variables cannot be reliably put within the same factor, hence the result of the factor analysis was misleading and the initial model had to be modified. The flexibility-related variables (A4g, A4h, A4i) are close to each other on the map, while A4f does not belong anywhere, it is equally distanced from the flexibility-, quality- and dependability-related variables. In this example we can see that the MDS was able to give a better assessment of the relationships among the variables.

In general, MDS has one disadvantage though, by not telling us the exact meanings of the dimensions on Figure 2. The researcher has to figure them out by thoroughly investigating the initial data, because the aim of the MDS is to map observations based on their distances from



Source: own research

Figure 2. 2D map of the strategic focus variables

each other, but the method itself does not give any further clues about the content of the dimensions. The researcher has to carefully examine the data and identify the causes that may drive the similarities (i.e. closeness in space) or dissimilarities (i.e. wide distances in space) among the observations. By doing this investigation, it is possible to correctly explain the dimensions. For example, in Demeter et al. (2011) the authors applied the MDS to put certain manufacturing industries on a 2D map based on data related to labor productivity and certain management practices. After analyzing the result and the underlying data they were able to conclude that one of the dimensions which clearly separated one industry from the others can be identified as a technology-improvement axis. In this paper our example just focused on the distribution of the variables in order to group them, so the interpretation of the dimensions was not necessary.

Cluster analysis and multidimensional scaling

Based on several contingency variables (namely: environment complexity, strength of competition, company size, strategic focus, product complexity, technological level, process type and customer order type) and manufacturing program variables, Matyusz (2012) identified four clusters of companies. See Appendix 3 for the original questions from the survey and their operationalization. Appendix 4 shows the mean values of each cluster.

1) ‘Large leaders’ had the highest values in case of all variables, mostly alone, not together with another cluster. Their environment was the most complex, they faced the strongest competition. They represented the largest companies, and with the exception of cost they treated all other foci as the most important to win orders. Their product was also fairly complex, their technology level was high and they were more of a mass producer with more standardized customer orders. They put the greatest emphasis on the use of different manufacturing practices.

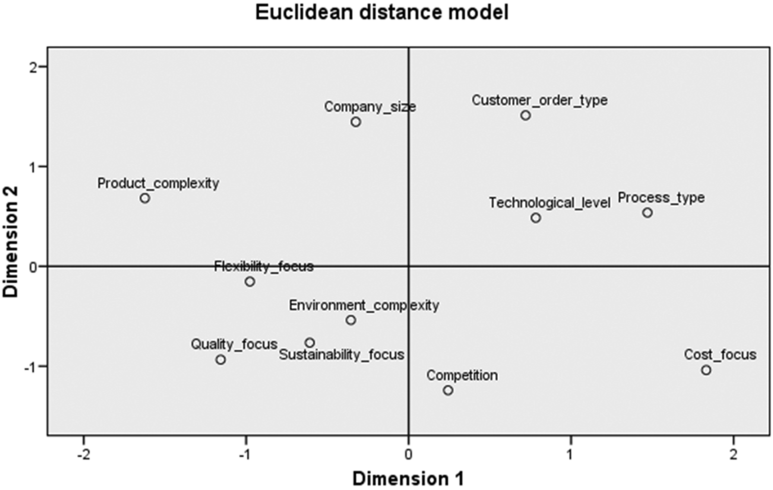
2) ’Small laggards’ were their opposite, whose members used all manufacturing practices the least. In their case the product was also quite complex, but the technology level was low. Basically they focused on quality and cost, the two other priorities were not important to them. Environmental complexity was low, and they faced the least competition. They represented the smallest companies in terms of size. The process type was shifted towards one-off manufacturing with heterogeneous customer orders. The use of manufacturing practices was below average.

3-4) The remaining two clusters (’One-off manufacturers’ and ’Mass producers’) were similar to each other in many aspects. There was no significant difference between them in size, perceived competition (which is above average), technology level (which was medium), and the use of technology and quality management practices (which were slightly below average). The use of the remaining manufacturing practices was a bit more emphasized in the case of ’One-off manufacturers’, just as the focus on quality, flexibility and sustainability. This was the consequence of a bit more complex environment and product. They used HR and process control practices to the greatest extent, at an above average level. There was a decisive difference between the two clusters: ’One-off manufacturers’ got more unique customer orders and applied more one-off production, while ’Mass producers’ were the most standardized mass producers of all clusters.

There was a clear distinction among the clusters along process type and customer order. ‘Large leaders’ and ‘Mass producers’ contained companies doing mass production, while ‘Small laggards’ and ‘One-off manufacturers’ contained companies that manufacture one-off products. Beyond this, however, clusters in the same category did not resemble each other in the other aspects. ‘One-off manufacturers’ and ‘Mass producers’ shared many similarities, while ‘Large leaders’ and ‘Small laggards’ were mirror images of each other.

It could be also concluded that environmental complexity moves together with strategic foci: companies operating in more complex environments found quality, flexibility and sustainability more important to win orders than companies operating in a less complex environment.

These were the results of the cluster analysis. If now we apply the MDS to uncover the structure of the clustering variables we get the following picture as seen in Figure 3. For easier visualization, the 2-dimensional map is shown and we focus on the contingency variables of the model.



Source: own research

Figure 3. 2D map of the clustering contingency variables

The S-stress value of the 2D solution is 0.23641, which indicates a weak fit. The RSQ (squared correlation) value is 0.64148; that is, the resulting 2D-map in Figure 3 explains 64% of the initial distances between the variables. Hence, for research purposes one should use the 3D solution (S-stress value = 0.13993 and RSQ = 0.80015) instead, but it would be difficult to visualize, so we discuss the 2D solution here. According to the map, the main conclusions of the cluster analysis stand. Environmental complexity is close to the three strategic foci mentioned before, and the variable measuring the strength of competition is also nearby. Cost focus is a stand alone variable (this was the only one not showing any significant differences among the clusters). Process type and customer order type are in the same quadrant with technological level. This latter relationship was not shown in the cluster analysis. Product complexity and company size are also separated from the other variables. These results help to refine the relationships of the variables as well as the creation of clusters in the future. For example, in the initial model we did not hypothesize any hierarchies among the contingency variables. Based on the results of the cluster analysis and the MDS, one can argue that maybe the effect of environmental complexity and competition is not direct, but mediated through the strategic foci. The role of technological level may also be reassessed, and the number of clustering variables can be reduced to decrease the complexity of the clustering process.

Conclusions

The paper briefly overviewed the main methods for configurational analysis based on Venkatraman (1989) and Venkatraman and Prescott (1990). A new tool, namely the multidimensional scaling was introduced and used as a supplementary method to factor analysis and cluster analysis through two examples based on IMSS data and the model of Matyusz (2012). The results show that the MDS is indeed a useful tool to uncover the structure among variables. It may help create more robust factors and interpreting clusters, and also simplify and improve the cluster analysis process for further research. By mapping variable structure, it may help in future model development as well as in operations management contingency research. Given to the limitations of the paper, the examples had to be short and we had to refer to Matyusz (2012) for many underlying theoretical and methodological issues. The limitations of the model are also described in detail in his paper. A possible further research direction from a methodological point-of-view is a more thorough investigation of the possible applications of the MDS and its more precise positioning among configurational methods.

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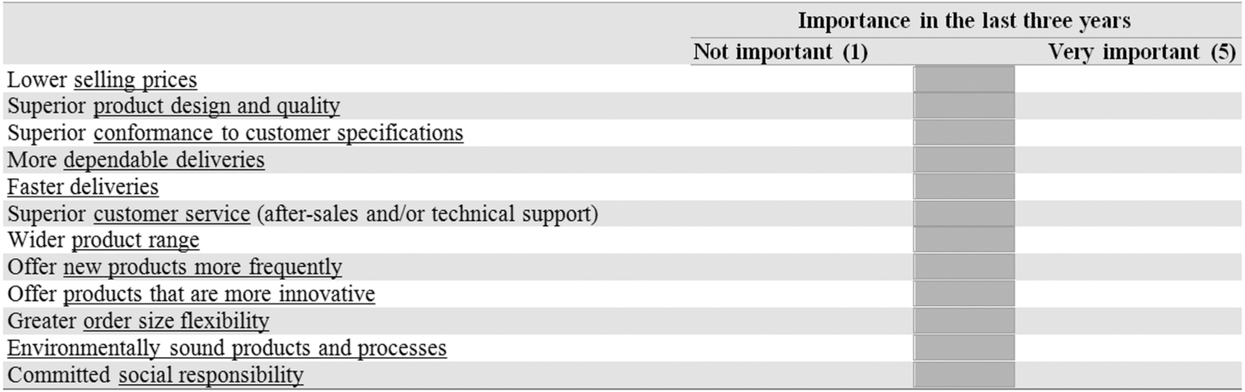
Appendix 1. Original question of the survey used for factor analysis

A4. Consider the importance of the following attributes to win orders from your major customers.



	Importance in the last three years	
	Not important (1)	Very important (5)
Lower selling prices		
Superior product design and quality		
Superior conformance to customer specifications		
More dependable deliveries		
Faster deliveries		
Superior customer service (after-sales and/or technical support)		
Wider product range		
Offer new products more frequently		
Offer products that are more innovative		
Greater order size flexibility		
Environmentally sound products and processes		
Committed social responsibility		

Appendix 2. Details of the factor analysis

KMO and Bartlett's Test

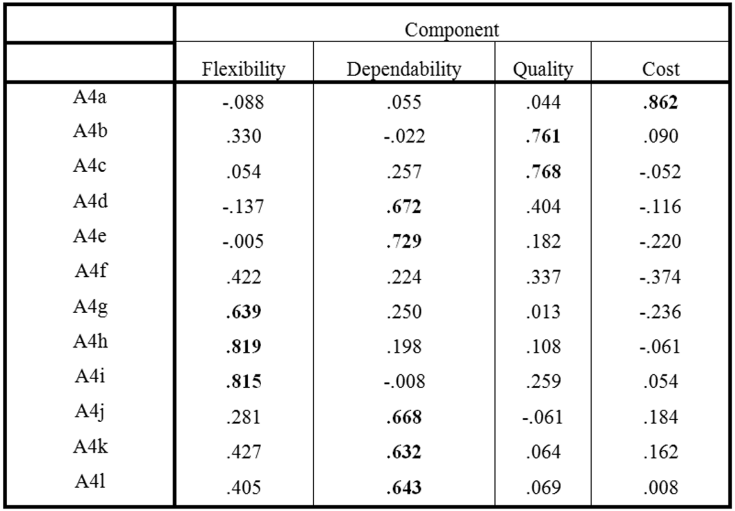
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.787
Bartlett's Test of Sphericity	Approx. Chi-Square	1834.113
	df	66
	Sig.	.000

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.979	33.156	33.156	3.979	33.156	33.156	2.485	20.711	20.711
2	1.450	12.085	45.241	1.450	12.085	45.241	2.465	20.538	41.250
3	1.143	9.522	54.763	1.143	9.522	54.763	1.573	13.107	54.357
4	1.030	8.580	63.343	1.030	8.580	63.343	1.078	8.986	63.343
5	.961	8.004	71.348						
6	.789	6.579	77.927						
7	.576	4.804	82.731						
8	.542	4.514	87.244						
9	.525	4.374	91.619						
10	.459	3.822	95.441						
11	.292	2.433	97.874						
12	.255	2.126	100.000						

Extraction Method: Principal Component Analysis.

Rotated Component Matrix (a)



	Component			
	Flexibility	Dependability	Quality	Cost
A4a	-.088	.055	.044	**.862**
A4b	.330	-.022	**.761**	.090
A4c	.054	.257	**.768**	-.052
A4d	-.137	**.672**	.404	-.116
A4e	-.005	**.729**	.182	-.220
A4f	.422	.224	.337	-.374
A4g	**.639**	.250	.013	-.236
A4h	**.819**	.198	.108	-.061
A4i	**.815**	-.008	.259	.054
A4j	.281	**.668**	-.061	.184
A4k	.427	**.632**	.064	.162
A4l	.405	**.643**	.069	.008

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 8 iterations.

Appendix 3. Original questions of the survey used for operationalizing variables for cluster analysis

A1. What are the name, origin and size of the corporation of which your business unit is a part?

Name Origin (headquarters' country)

Size of the business unit (# of employees): Total sales of the business unit - currency figure

A2. How do you perceive the following characteristics?

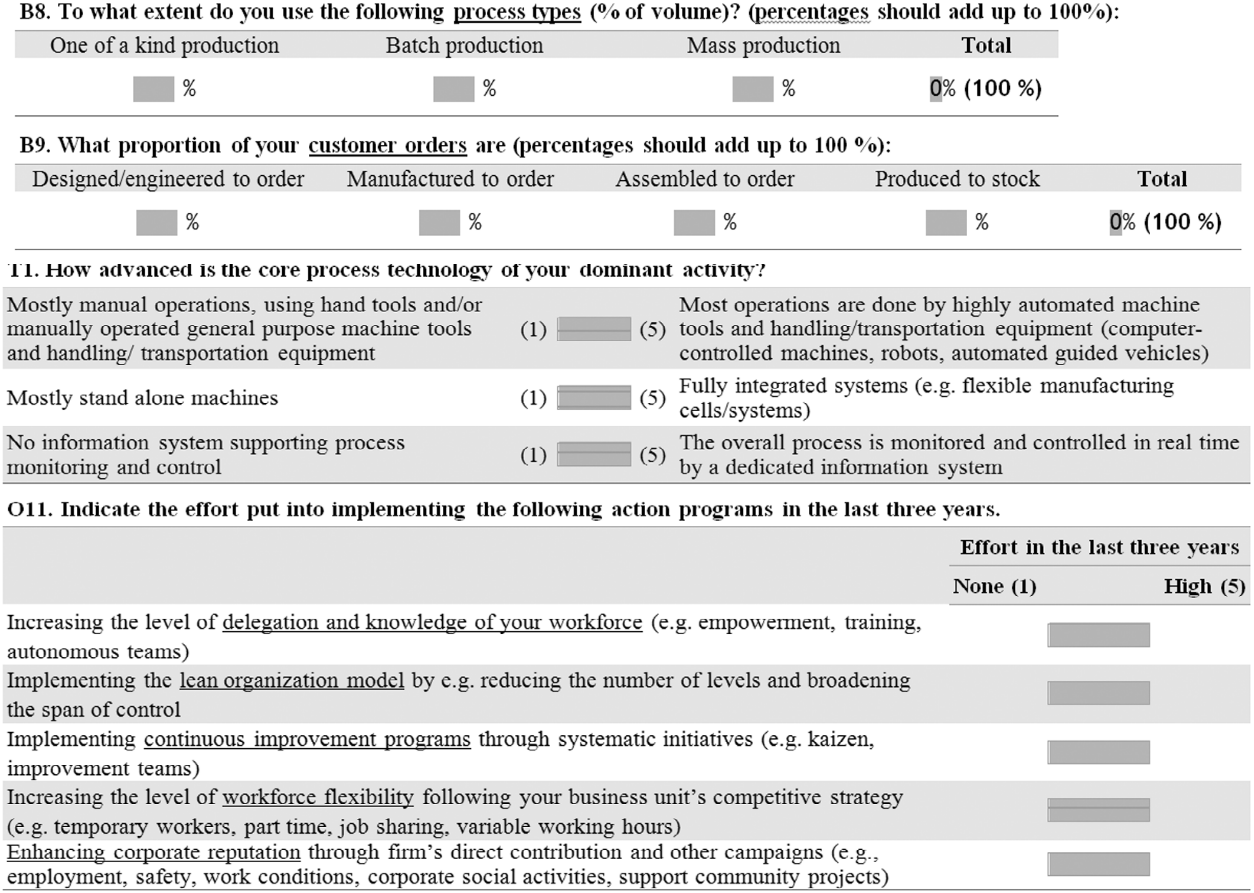
Market dynamics	Declining rapidly (1)		(5) Growing rapidly
Market span	Few segments (1)		(5) Many segments
Product focus	Physical attributes (1)		(5) Service emphasis
Geographical focus	National (1)		(5) International
Competition intensity	Low intensity (1)		(5) High intensity
Market concentration	Few competitors (1)		(5) Many competitors
Market entry	Closed to new players (1)		(5) Open to new players

A3. Please indicate what characterizes technological change in your business:

Logistic processes change	Slowly (1)		(5) Rapidly
Core production processes change	Slowly (1)		(5) Rapidly
Products become obsolete	Hardly ever (1)		(5) Frequently
New product are introduced	Hardly ever (1)		(5) Frequently

B2. How would you describe the complexity of the dominant activity?

Modular product design (1)		(5) Integrated product design
Single manufactured components (1)		(5) Finished assembled products
Very few parts/materials, one-line bill of material (1)		(5) Many parts/materials, complex bill of material
Very few steps/operations required (1)		(5) Many steps/operations required



B8. To what extent do you use the following process types (% of volume)? (percentages should add up to 100%):

One of a kind production	Batch production	Mass production	**Total**
%	%	%	**0% (100 %)**

B9. What proportion of your customer orders are (percentages should add up to 100 %):

Designed/engineered to order	Manufactured to order	Assembled to order	Produced to stock	**Total**
%	%	%	%	**0% (100 %)**

T1. How advanced is the core process technology of your dominant activity?

Mostly manual operations, using hand tools and/or manually operated general purpose machine tools and handling/ transportation equipment	(1)		(5)	Most operations are done by highly automated machine tools and handling/transportation equipment (computer-controlled machines, robots, automated guided vehicles)
Mostly stand alone machines	(1)		(5)	Fully integrated systems (e.g. flexible manufacturing cells/systems)
No information system supporting process monitoring and control	(1)		(5)	The overall process is monitored and controlled in real time by a dedicated information system

O11. Indicate the effort put into implementing the following action programs in the last three years.

	Effort in the last three years	
	None (1)	**High (5)**
Increasing the level of delegation and knowledge of your workforce (e.g. empowerment, training, autonomous teams)		
Implementing the lean organization model by e.g. reducing the number of levels and broadening the span of control		
Implementing continuous improvement programs through systematic initiatives (e.g. kaizen, improvement teams)		
Increasing the level of workforce flexibility following your business unit's competitive strategy (e.g. temporary workers, part time, job sharing, variable working hours)		
Enhancing corporate reputation through firm's direct contribution and other campaigns (e.g., employment, safety, work conditions, corporate social activities, support community projects)		

PC4. Indicate degree of the following action programs undertaken in the last three years.

	Effort in the last three years None (1) High (5)
Expanding manufacturing capacity (e.g. buying new machines; hiring new people; building new facilities)	▭
Restructuring manufacturing processes and layout to obtain process focus and streamlining (e.g. reorganize plant-within -a-plant; cellular layout)	▭
Undertaking actions to implement pull production (e.g. reducing batches, setup time, using kanban systems)	▭

PD3. Indicate the effort put into implementing the following action programs in the last three years.

	Effort in the last three years None (1) High (5)
Increasing design integration between product development and manufacturing through e.g. platform design, standardization and modularization, design for manufacturing, design for assembly	▭
Increasing the organizational integration between product development and manufacturing through e.g. teamwork, job rotation and co-location	▭
Increasing the technological integration between product development and manufacturing through e.g. CAD-CAM, CAPP, CAE, Product Lifecycle Management	▭
Improving the environmental impact of products by appropriate design measures, e.g. design to recycle	▭

Q2. Indicate the effort put into implementing the following action programs in the last three years.

	Effort in the last three years None (1) High (5)
Quality improvement and control (e.g. TQM programs, six sigma projects, quality circles)	▭
Improving equipment productivity (e.g. Total Productive Maintenance programs)	▭
Utilizing better measurement systems for self-assessment and benchmarking purposes	▭

Improving the environmental performance of processes and products (e.g. environmental management system, Life-Cycle Analysis, Design for Environment, environmental certification)	▨
Increasing the control of product quality along the supply chain (raw materials and components certification, supplier audit, product integrity in distribution, etc.)	▨
Monitoring corporate social responsibility of partners along the supply chain (e.g. labor conditions)	▨

T2. Indicate the effort put into implementing the following action programs in the last three years.

	Effort in the last three years None (1) High (5)
Engaging in process automation programs (e.g. automated parts loading/unloading, automated guided vehicles, automated storage systems)	▨
Engaging in flexible manufacturing/assembly systems – cells programs (FMS/FAS/FMC)	▨
Engaging in product/part tracking and tracing programs (bar codes, RFID)	▨
Implementing ICT supporting information sharing and process control in production	▨

Operationalization of the variables

1. Complexity: a total of 11 variables can be related to environment (Questions A2-A3), which were all measured on 5-point Likert-scales, with the higher value of the variable indicating that the environmental effect in question is stronger. For all companies, we counted the values of 4 or 5 of these variables, divided this number by 11 and transformed it into a percentage value. In this way, we obtained a new variable with a value between 0 and 100 (value is 0 if the company gave to all variables a value of 3 or less; value is 100 if the company gave a value of 4 or 5 to all 11 variables). A higher value indicated a more complex environment, as more environmental factors had a stronger effect.

2. Competition: based on variables A2e (competition intensity) and A2f (market concentration). We averaged the single variables and transformed this mean value onto a 1-100 scale to expand variable space and therefore the evaluation can be more subtle.

3. Size: measured by the logarithm of number of employees of the business unit (A1c).

4. Cost focus: based on the single variable A4a.

5. Quality focus: based on variables A4b and A4c. The operationalization is the same as in the case of Competition.

6. Flexibility focus: based on variables A4g, A4h and A4i. The operationalization is the same as in the case of Competition.

7. Sustainability focus: based on variables A4j, A4k and A4l. The operationalization is the same as in the case of Competition.

8. Product complexity: based on question B2. The operationalization is the same as in the case of Competition.

9. Technology level: based on question T1. The operationalization is the same as in the case of Competition.

10. Process type: based on Question B8. We weighted the possibilities (the lowest weight went to one of a kind manufacturing, the highest weight went to mass production), then transformed this value to a percentage scale. The lower the value of the variable, the more dominant one of a kind manufacturing is at the company (at a value of 0 there is only one of a kind manufacturing), the higher the value, the more dominant mass production is (at a value of 100 there is only mass production). If there is only batch production, the variable has a value of 50. In case of mixed processes the value moves in the range according to the ratio of the different processes.

11. Customer order: based on Question B9. We operationalized this variable similarly to process type (weighting and transformation). In case of design/engineer to order only the value of the variable is 0, in case of manufacture to order only it is 33, in case of assemble to order only it is 66, while in case of produce to stock only it is 100. In case of mixed customer orders the actual value reflects the ratio of the different orders and moves between 0-100.

12. HR practices: based on question O11. The operationalization is the same as in the case of Competition.

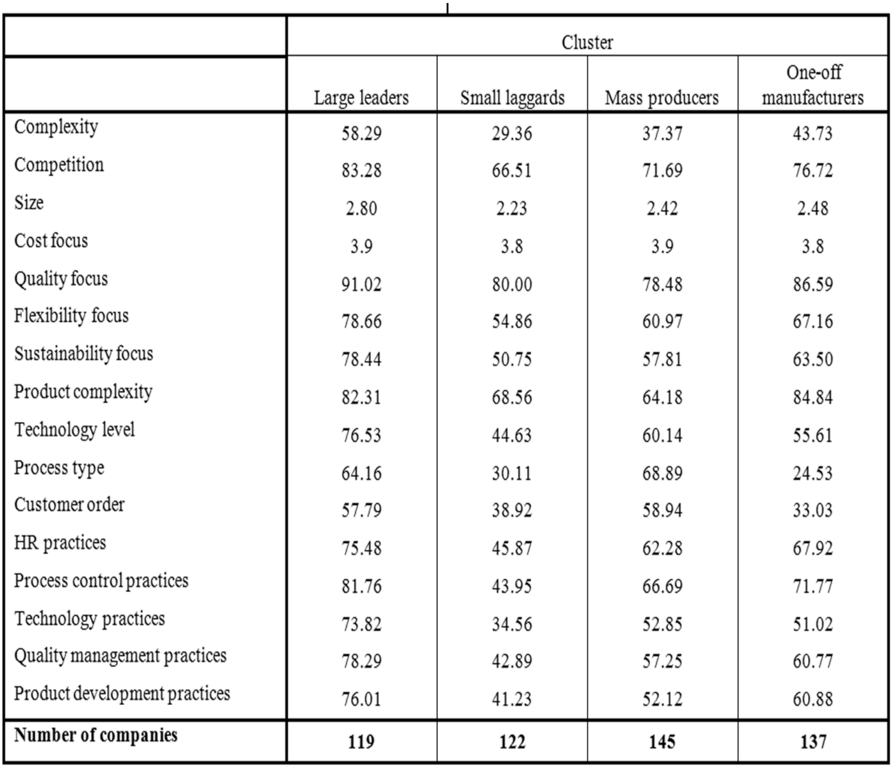
13. Process control practices: based on question PC4. The operationalization is the same as in the case of Competition.

14. Technology practices: based on question T2. The operationalization is the same as in the case of Competition.

15. Quality management practices: based on question Q2. The operationalization is the same as in the case of Competition.

16. Product development practices: based on question PD3. The operationalization is the same as in the case of Competition.

Appendix 4. Final cluster centers



	Cluster			
	Large leaders	Small laggards	Mass producers	One-off manufacturers
Complexity	58.29	29.36	37.37	43.73
Competition	83.28	66.51	71.69	76.72
Size	2.80	2.23	2.42	2.48
Cost focus	3.9	3.8	3.9	3.8
Quality focus	91.02	80.00	78.48	86.59
Flexibility focus	78.66	54.86	60.97	67.16
Sustainability focus	78.44	50.75	57.81	63.50
Product complexity	82.31	68.56	64.18	84.84
Technology level	76.53	44.63	60.14	55.61
Process type	64.16	30.11	68.89	24.53
Customer order	57.79	38.92	58.94	33.03
HR practices	75.48	45.87	62.28	67.92
Process control practices	81.76	43.95	66.69	71.77
Technology practices	73.82	34.56	52.85	51.02
Quality management practices	78.29	42.89	57.25	60.77
Product development practices	76.01	41.23	52.12	60.88
Number of companies	**119**	**122**	**145**	**137**