Linking improvement models to manufacturing strategies—a methodology for SMEs and other enterprises

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Small Manufacturing Enterprises (SMEs) are of major importance to the future economic growth of the European Community. To sustain this role, they need support in defining their specific technological and organizational needs and in finding the right approach to respond to these needs. The main objective of the research described in this article is to develop a supporting methodology for determining the improvement priorities of SMEs through a process similar to the manufacturing strategy formulation. However, the tools and techniques proposed in this paper are of a general nature and need not be restricted to SMEs. The methodology uses Quality Function Deployment (QFD), a product oriented quality technique, to apply a contingency oriented approach to improvement priorities. The essence of the QFD method is to extract the customer needs or desires and then to translate them into technical product quality characteristics. Here, the customers are interviewees from a sample of Small Manufacturing Enterprises. We assume that the manufacturing system improvement needs stem from strategic manufacturing priorities and from concerns that express unsatisfied needs. To propagate the improvement needs from the strategic level to the action level, two QFD oriented matrices were developed. The first matrix was used to define the operating improvement needs of an enterprise while the second was used to determine its improvement priorities. Cluster analysis, a multivariate technique, identified several generic improvement models of the sampled enterprises.

1. Introduction

The role of Small Manufacturing Enterprises (SMEs) has been defined as critical to the future economic growth and job creation within the European Community (Asquith and Weston 1994). These enterprises, commonly defined as employing less than 250 employees, with annual sales of less than US$50 million, represented in 1996 two thirds of all employees in Europe (see European Small Enterprise IT study 1996) and in other countries, as well (e.g. Statistical Abstract of Israel 1996). SMEs have commonly been categorized to be component manufacturers for larger companies where they operate in the ‘make to order’, or rather the engineer to order, approach that imposes rigid constraints on meeting changes in requirements at short notice (Little and Lee 1999). The main barriers to competitive advantages for SMEs are inadequate technologies, as well as inadequate in-house human expertise and poor financial resources (Armstrong and Coyle 1999). Managerial teams in SMEs are usually heavily involved with the short-term operational problems of their business, which leaves them almost no leisure to utilize their driving energy for strategic improvements.

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The factory of the future image is associated with advanced technologies enabling production of a variety of high quality products at low costs, delivered to the customers without delay (Boyer 1999). To achieve such goals, technological innovations are necessary. Technological innovations may involve several orientations such as: design based, manufacturing based and administrative based orientations (Ward et al. 1994). These are intended to improve product quality and process efficiency through a better design, better control, improved logistics, quicker and more effective communication. Technological innovations are typically applied in large enterprises that can afford high investment costs and have well developed R&D departments with highly educated and trained professionals. Small enterprises may feel threatened by technological innovations that are not within their reach. To sustain their economic importance, small enterprises need support for defining their specific technological and organizational needs and then for finding the right approach to respond to these needs. The significance of these needs on a global scale is reflected in the numerous papers that have been recently published on this topic (e.g. Mechling et al. 1995, Cagliano et al. 1998, Little 1998). According to Armstrong and Coyle, current support for manufacturing SMEs tends to be relatively piecemeal and initiatives often have a narrow focus. A much broader approach is in order to address all aspects of SME development in a coherent and integrated manner. In addition, since the SMEs cannot be regarded as a homogeneous group, the form of assistance should be adapted to their varying needs. These should be identified in a methodological way so that they could be used to classify and profile SMEs.

The main objective of the research described in this article is to develop a structured and integrative methodology for supporting the improvement of the manufacturing systems of SMEs. Our approach takes into consideration the two aspects mentioned above. On one hand it draws from the theories and practices of the manufacturing strategy formulation, thus providing a holistic approach for assisting small manufacturing companies in formulating their improvement needs and priorities. On the other hand it considers the variety of the SMEs needs through generic improvement models, that are defined by analysing a sample of small enterprises. The following questions are empirically investigated in this study.

- What are the most urgent needs of SMEs?
- How to ensure that proposed improvement actions are consistent with the urgent improvement needs?
- Do SMEs managers/engineers have the knowledge and capability to select the most critical improvement actions as necessary to respond to the urgent needs? Or is their selection affected by inherent economic constraints, common to all SMEs?
- How to identify generic improvement models of SMEs?

To answer questions such as the above, we utilize Quality Function Deployment (QFD), a product design technique that provided a framework for design as well as for consistency assessment. It enabled us to link the improvement priorities of an enterprise to its manufacturing strategies in an innovative way. This approach may also contribute to improving the structure of the contingency-based manufacturing strategy formulation. Cluster analysis, a multivariate technique, was used to reveal generic improvement models of the sampled enterprises.
This paper is organized as follows. Section 2 briefly reviews the literature on manufacturing strategies and introduces quality function deployment as an appropriate technique for applying the contingency approach to the formulation of improvement priorities. Section 3 describes the research methodology. The data analysis is presented in section 4 while the empirical findings are detailed in section 5. The final section concludes the paper and suggests areas for further research.

2. Background

2.1. Formulation of manufacturing strategies

In early works, manufacturing strategy was described as ‘competing through manufacturing capabilities’ (Skinner 1969). Hill (1993) argued that, in each market in which a company operates, it should identify those criteria, such as price, delivery, product quality and variety, that win orders against the competition. These criteria, also called ‘key success factors’ (Voss 1995) are consistent with Porter’s (1985) notion of ‘competitive priorities’. The competitive priorities represent the main manufacturing objectives of an enterprise (Skinner 1992, Cheng and Mussaphir 1996). To eventually infer the set of strategic operations decisions of an enterprise, these objectives are to be ranked (Slack 1994). The internal and external consistency between the product context and the choices in the content of manufacturing strategy represent a contingency-based approach to manufacturing strategies. According to the contingency approach to manufacturing strategies, the competitive priorities are achieved through a pattern of actions in a set of decision areas such as capacity, control policies, facilities, suppliers, quality and human resources (Mills et al. 1995). Although many writers in the field have developed their own set of manufacturing decision areas, agreement is generally high and the list above expresses the majority view. Among the approaches to the formulation of manufacturing strategies described in the literature, are those of Swamidass (1986), Voss (1992) and Platts (1994). Recently, Quezada et al. (1998) used the Analytic Hierarchy Process (AHP) to connect the various stages of the formulation process. Cluster techniques are important tools for analysing case-based generic manufacturing strategies. Sets of companies following similar or generic strategies are thus identified. Studies dealing with generic manufacturing strategies in the literature were described by, among others, Stobaugh and Telesio (1983), that identified cost-based, technology-based and market-driven groups, and by De Meyer (1990), that identified high performance product groups, manufacturing innovators and marketing oriented groups.

2.2. Quality Function Deployment and manufacturing strategies

Quality Function Deployment (QFD) is a product planning methodology whose essence is to extract the customer’s needs or desires, expressed in his/her own words, to translate them into technical product quality characteristics and subsequently into components’ characteristics and operating decisions (Akao 1994). Quality Function Deployment is typically carried out by teams of multidisciplinary representatives from all stages of product development and manufacturing (Lai et al. 1998). Each translation of customer ‘voices’ and subsequent processes uses a matrix relating the variables associated with the specific QFD phase. The voice of the customer represents a set of customer needs, where each need has assigned to it a priority, which indicates its importance to the customer. Griffin and Hauser (1993), present a comparison of different approaches for collecting customer preferences in QFD. They consider the gathering of customer information to be a qualitative task, carried out
through interviews and focus groups, and found both person to person interviews and focus groups to be equally effective methods in articulating the customer needs.

The QFD technique here translates the strategic manufacturing improvement needs of an enterprise into improvement priorities. The customers are person to person interviewed teams comprising managers and engineers from SME samples in Israel and in France. The manufacturing strategy theories are embedded in the QFD structure. The ‘strategic priorities’ found in the manufacturing strategy theories appear here as ‘strategic improvement needs’. The ‘decision areas’ in the contingency approach to manufacturing strategy formulation are here ‘improvement decision areas’. To ensure consistency, an intermediate operational level expressing the operating improvement needs of the enterprise has been defined. This QFD structured linkage between the manufacturing improvement needs and the improvement priorities can be regarded as a contribution to the manufacturing strategy contingency approach.

3. Methodology
3.1. Basic concepts and assumptions
3.1.1. Strategic priorities

A set of strategic priorities of an enterprise is defined. It comprises the typical competitive advantages found in the manufacturing strategy literature: price, delivery (fast, dependable), quality (high design quality, consistent product quality) and product variety. To these, an internal strategic advantage is added: the employees’ involvement (see figure 1).

The possibility of achieving a competitive advantage through people (Pfleffer 1995) is thus taken into account. Management may consider it of strategic importance to empower employees with involvement over a number of issues connected with production process or service delivery. The rationale is that a highly committed workforce is more likely to engage in a beyond contract effort (Wilkinson 1997).

3.1.2. Concerns

We assume that the system improvement needs stem from concerns that express unsatisfied needs. Based on a preliminary pilot study we discovered that if one asks directly about the manufacturing system improvement requirements, the interviewed

![Figure 1. The set of strategic priorities.](image-url)
people find that very difficult. Hence, we adopted a more promising way, stemming from sociological approaches (Flanagan 1954). It is based on the assumption that the judgement of customers originates from concrete incidents and that negative, rather than positive past experiences are likely to be registered. Consequently, instead of extracting the customer improvement needs, as in QFD, we asked about specific concerns.

3.1.3. Strategic concerns and operating concerns

We differentiate between a set of strategic concerns associated with the meeting of the strategic priorities defined above, and a set of operating concerns. To enable a structured linkage between the strategic priorities, the strategic concerns and the operating concerns, they were all related to the same performance scales: cost, time, quality and human oriented performances. All concerns were measured on a similar gravity scale. Information supplied by the open questions in the pilot investigation was used to formulate specific concerns for each of the four operational performances (see ‘Operating improvement needs’ in section 5.).

3.1.4. Improvement needs

The improvement needs of a manufacturing system consider the importance attributed by the enterprise to each strategic priority, and the gravity of its associated concerns. The higher the importance of a strategic priority and the gravity of its concerns, the higher are its improvement needs. This concept is equivalent to the ‘importance–performance matrix as a determinant of improvement priority’ developed by Slack (1994). To include here the consistency perspective representing the contingency approach to manufacturing strategies, we have to differentiate and compare improvement needs at different levels such as the strategic level and the operational level.

3.2. Deployment of the improvement needs

The QFD matrix approach is adapted here to accommodate propagation of the improvement needs from the strategic level to the action level (see figure 2). As this process involves two phases, two deployment matrices are built. The input to both matrices is related to customer-based variables expressing the views of the interviewed team in each enterprise. These views regard the importance of each competitive advantage, the gravity of each strategic and operating concern and the potential contribution of each listed improvement action within the defined decision areas.

First, an indicator, denoting the strategic improvement needs, $SN_i$, $i = 1, 2, \ldots, s$, of an enterprise is determined. Following the concept of importance–performance (Slack 1994) mentioned above, this indicator is defined in terms of the importance attributed by the interviewees to a strategic priority multiplied by the gravity attributed to its respective concerns. The higher the score, the higher is the improvement need of the respective strategic priority.

Matrix I projects the gravity of the operating concerns, $OC_k$, $k = 1, 2, \ldots, p$, on the strategic improvement needs. Its output represents the operating improvement needs, $ON_k$, $k = 1, 2, \ldots, p$, of an enterprise. The strength of the relationships between an operating concern and a strategic improvement need expresses here the impact of the operating concern on the strategic improvement need. Matrix II links the operating improvement needs (output of matrix I) with the potential con-
tributions of actions pertaining to several improvement areas. The improvement areas as defined here are consistent with the majority view on the manufacturing decision areas, such as: planning, design, quality, vendor relations, human resources and others. Thus, matrix II deploys the potential contribution of the improvement actions by considering the operating improvement needs of the enterprises. The strength of the relationships between the potential contribution of an improvement action and an operating improvement need expresses the potential impact of the improvement action on the operating improvement need. Ultimately, matrix II is intended to detect the critical improvement actions of an enterprise.

All indicators in the deployment process are normalized and appear as ratios of the actual scores divided by the respective maximal possible scores (see ‘Data Analysis’ in section 4).

3.3. Survey and questionnaire

3.3.1. Sample

To test the developed methodology, we planned a small empirical study based on a sampling population of SMEs. This consisted of manufacturing companies with 50 to 200 employees and less than US$50 million annual sales. The survey sample comprised 21 enterprises from two types of industry (metal products and plastic products) and was carried out through interviews with three managers/engineers in each sampled enterprise. Usually, among the interviewees, was the plant manager or the CEO, an engineer responsible for design or quality, the person in charge of marketing or another senior employee with relevant work responsibility and professional background. As the interviews were person to person and took place at the plant sites, there were no incomplete responses.

3.3.2. Questionnaire

An interview questionnaire comprising four sections was developed using information from the manufacturing strategy literature, as well as information provided by a pilot investigation of 12 enterprises that preceded the formal questionnaire-based investigation. Each interviewee was asked to fill out the first three sections of the questionnaire. The answers had to reflect his/her views on each topic. The fourth
section was intended to provide background data (characteristic features) of the investigated enterprises and was usually filled up by the CEO or his/her representative.

The first section of the questionnaire supplied data on the importance of each strategic priority of an enterprise as viewed by each of its three interviewees. The defined set of possible strategic priorities comprised six competitive advantages, namely, low price, fast delivery, dependable delivery, high product quality, consistent product quality, product variety and the human advantage: employees' involvement. As mentioned before, these strategic advantages were selected from the strategic manufacturing literature focused on big companies. The importance of each strategic priority had to be assessed by the interviewees on a scale from 1 (not important) to 9 (most important).

The second section supplied data on the concerns facing the enterprise. The interviewees had to consider concerns regarding the performances of their products as compared with those of their competitors (to match each of the six competitive advantages), concerns regarding the involvement of their employees in solving problems (to match the human advantage) and concerns associated with the operating capability of their enterprise. The gravity of each specific concern had to be assessed on a scale from 1 (not serious) to 9 (very alarming). The operating concerns in the questionnaire were customer based, i.e. were compatible with the QFD methodology. They were extracted from the interviewed managers/engineers in six of the enterprises in the pilot study. Each interviewee in these enterprises had to formulate specific operating concerns by four performance scales: costs, delays, quality and human resources. Input from the interviewees pertaining to the other six enterprises in the pilot study was used to inspect and improve the extracted (raw) operating concerns. The operating concerns in the final version of the questionnaire are detailed below.

**Cost oriented operating concerns**: raw materials, manufacturing, inventory, quality control, coping with distribution of manufacturing overheads.  
**Delay oriented operating concerns**: frequent changes in requirements, short-term capacity shortages, in process delays, in transfer delays, lengthy supply time, supply not on time, lengthy changes in design.  
**Quality oriented operating concerns**: inadequate quality techniques, high percentage defectives, deficient storage conditions, quality of purchased materials not satisfactory, quality of purchased materials not consistent, difficulties in satisfying customer required tolerances.  
**Human oriented operating concerns**: deficient communications among departments/functions, low skill/versatility of employees, low motivation, high absence level.

The third section of the questionnaire supplied data on potential actions within several improvement areas. As mentioned earlier, the improvement areas as defined here were related to the decision areas adopted in the manufacturing strategies' formulation. We considered eight improvement areas: production planning and control, inventory and logistics, vendor relations, equipment maintenance and reconfiguration, human management, quality management, information systems and technology, research and development. The potential improvement contribution of each listed action within those areas had to be assessed on a scale from 1 (not relevant) to 9 (highly significant potential contribution). Specific improvement actions within each area (questionnaire items), were formulated by the researchers.
using published material on manufacturing strategies as well as their own expertise (see for example, Barad 2000, Gien 1999). The questionnaire items within each area were qualitatively checked in the pilot study for consistency and friendliness. The small scale of this experiment did not permit formal calculations of reliability indices such as Cronbach’s Alpha, as in customary in large scale investigations.

3.3.3. Analysis procedures

First, all scores supplied by the questionnaire were integrated and normalized to serve as input to the QFD matrices. Then, the normalized/summarized score of each operating improvement need, representing the output of the first type QFD matrix, was calculated. The low scored variables were screened out. The remaining (relevant) operating improvement needs and the normalized scores of the potential improvement actions by areas were utilized as input to the second type QFD matrix, whose calculated output represented the deployed improvement actions by areas. Again, the low scored deployed improvement actions were screened out. These calculations are described in the next section and were carried out using Excel software. To identify groups of enterprises with similar (generic) characteristics, the screened output of each QFD type of matrix was subjected to cluster analysis, a multivariate technique. The Statgraphics software was used to perform the multivariate statistical analysis of the data. The four performance scales: cost, time, quality and human performances, provided the structured linkage for analysing and comparing the generic needs and the generic actions.

4. Data analysis

Given (from the questionnaire):

\[ X_{i}^{(j)} \] = the importance of strategic priority \( i, i = 1, 2, \ldots, s \), as perceived by interviewee \( j, j = 1, 2, \ldots, n \),

\[ Y_{1i}^{(j)} \] = the gravity of concerns regarding strategic priority \( i, i = 1, 2, \ldots, s \), as perceived by interviewee \( j, j = 1, 2, \ldots, n \),

\[ Y_{2k}^{(j)} \] = the gravity of operating concern \( k, k = 1, 2, \ldots, p \), as perceived by interviewee \( j, j = 1, 2, \ldots, n \),

\[ Z_{m(a)}^{(j)} \] = the potential contribution of action \( m \) in area \( a, m(a), m(a) = 1, 2, \ldots, q(a) \), \( a = 1, 2, \ldots, r \), as perceived by interviewee \( j, j = 1, 2, \ldots, n \),

where

- \( s \) is the number of strategic priorities (here \( s = 7 \)),
- \( n \) is the number of interviewees (here \( n = 3 \)),
- \( p \) is the number of operating concerns (here \( p = 22 \)),
- \( q(a) \) is the number of improvement actions in area \( a \),
- \( r \) is the number of improvement areas (here \( r = 8 \)).

To integrate and normalize the data, some preliminary calculations are carried out.

Let

- \( SN_{i} \) be the normalized improvement need of strategic priority \( i, i = 1, 2, \ldots, s \),
- \( OC_{k} \) be the normalized gravity of operating concern \( k, k = 1, 2, \ldots, p \),
Let $\text{PA}_{m(a)}$ be the normalized potential contribution of action $m$ in area $a$, $m(a) = 1, 2, \ldots, q(a), a = 1, 2, \ldots, r$,

$$\begin{align*}
\text{SN}_i &= \left\{1/n \left[ \max_{j} X_i^{(j)} \times \max_{j} Y_1^{(j)} \right] \right\} \sum_{j=1}^{n} X_i^{(j)} Y_1^{(j)} \quad i = 1, 2, \ldots, s, \\
\text{OC}_k &= \left\{1/n \left[ \max_{j} Y_2^{(j)} \right] \right\} \sum_{j=1}^{n} Y_2^{(j)} \quad k = 1, 2, \ldots, p, \\
\text{PA}_{m(a)} &= \left\{1/n \left[ \max_{j} Z_{m(a)}^{(j)} \right] \right\} \sum_{j=1}^{n} Z_{m(a)}^{(j)}, m(a) = 1, 2, \ldots, q(a), a = 1, 2, \ldots, r.
\end{align*}$$

According to the questionnaire here, $\max_{j} X_i^{(j)} = Y_1^{(j)} = \max_{j} Y_2^{(j)} = \max_{j} Z_{m(a)}^{(j)} = 9$ for $j = 1, 2, 3$, $i = 1, 2, \ldots, s$, $k = 1, 2, \ldots, p$, $m(a) = 1, 2, \ldots, q(a), a = 1, 2, \ldots, r$.

**Matrix I**

As illustrated in figure 2, there are two inputs to matrix I: $\text{SN}_i$, the normalized improvement need of strategic priority $i, i = 1, 2, \ldots, s$ and $\text{OC}_k$, the normalized gravity of operating concern $k, k = 1, 2, \ldots, p$. These inputs are supplied by the questionnaire, i.e. they are *customer-based*.

$\text{ON}_k, k = 1, 2, \ldots, p$, the operating improvement need $k$, denoting the output of matrix I, is calculated through the following equation,

$$\text{ON}_k = \text{OC}_k \sum_{i=1}^{s} \text{SN}_i \times R_{1i,k} \quad k = 1, 2, \ldots, p,$$

where $R_{1i,k}$ represents the impact of operating concern $k$ on the realization of strategic priority $i, i = 1, 2, \ldots, s, k = 1, 2, \ldots, p$.

It is seen that the linkage between the two inputs is provided by $R_{1i,k}$. The specific values, assigned to each $R_{1i,k}$ in (4) express here the researchers views.

As is customary in all QFD matrices, three possible positive relationship levels are considered. The numerical values detailed below were arbitrarily selected to accommodate these.

$$R_{1i,k} = \begin{cases} 
0 & \text{removing operating concern } k \text{ will have no effect on strategic priority } i, \\
0.33 & \text{a weak effect on strategic priority } i \text{ is expected}, \\
0.67 & \text{a moderate effect on strategic priority } i \text{ is expected}, \\
1.00 & \text{a strong effect on strategic priority } i \text{ is expected}.
\end{cases}$$

$i = 1, 2, \ldots, s, \quad k = 1, 2, \ldots, p$.

**Matrix II**

The role of matrix II is to project the potential improvement actions by areas on the operating improvement needs. According to the quality function deployment principle, the output of a certain matrix is input to the next matrix. Here, the output of matrix I, is input to matrix II. Similarly, to matrix I, matrix II also has two inputs. One is the output of matrix I, $\text{ON}_k$, while the other is questionnaire-based, i.e. *customer-based*. It is represented by $\text{PA}_{m(a)}$, the normalized potential contribution
of action \( m \) pertaining to improvement area \( a \). The output of matrix II, \( DA_{m(a)} \), expressing the deployed contribution of improvement action \( m(a) \), is calculated using (5). Its structure is similar to that of (4).

\[
DA_{m(a)} = PA_{m(a)} \sum_{k=1}^{p} ON_k \times R2_{k,m(a)} \quad m(a) = 1, 2, \ldots, q(a), \quad a = 1, 2, \ldots, r, \tag{5}
\]

where \( R2_{k,m(a)} \) represents the potential effect of the improvement action \( m(a) \) on the operating improvement need \( k \) as viewed by the researchers.

Again, three possible positive relationship levels are considered. The numerical values selected are similar to those in matrix I.

\[
R2_{k,m(a)} = \begin{cases} 
0 & \text{action } m(a) \text{ has no influence on operational concern } k, \\
0.33 & \text{action } m(a) \text{ is expected to slightly reduce concern } k, \\
0.67 & \text{action } m(a) \text{ is expected to substantially reduce concern } k, \\
1.00 & \text{action } m(a) \text{ is expected to solve concern } k.
\end{cases}
\]

\( k = 1, 2, \ldots, p, \quad m(a) = 1, 2, \ldots, q(a), \quad a = 1, 2, \ldots, r. \)

It is seen that since matrix II is built separately for each improvement area \( a \), \( a = 1, 2, \ldots, r \), it actually represents a union of \( r \) matrices, namely, matrices II(\( a^0 \)), the improvement actions \( m(a^0) \), \( m(a^0) = 1, 2, \ldots, q(a^0) \), for area \( a^0 \), are first considered. Then, the researchers identify a subset of operating concerns, \( k(a^0) \); that, in their judgement, are positively related to at least one action \( m(a^0) \), to be included in matrix II(\( a^0 \)). Accordingly, for \( a = 1, 2, \ldots, r \),

\[
k \in k(a) \quad \text{if and only if} \quad \sum_{m(a)=1}^{q(a)} R2_{k,m(a)} > 0. \tag{6}
\]

5. Findings

Background information on the surveyed companies shows that the number of employees fluctuated between 50 and 200, with annual sales between 8 and 35 million dollars. The manufacturing costs constituted, on average, 60% of the sales while the investment in R&D expressed as percentage of sales, fluctuated between 0% and 10%. Product demand was, for most of the enterprises, the bottleneck for increasing sales. Based on their current manufacturing capacity, the sales of these companies could be increased, on average, by 30%–50%. Their products, mechanical and plastic parts/products, were marketed mostly to industrial customers. The number of their vendors fluctuated between 20–40. One of the surveyed companies constituted an exception. More than 90% of its total sales were export based while the number of its vendors reached several hundred.

5.1. Operating improvement needs

The set of indicators, \( ON_k, k = 1, 2, \ldots, 22 \), denoting the operating improvement needs of the sampled enterprises was calculated through (4). The urgency of these needs results from the projection of the gravity of the operating concerns (as assessed by the interviewees) on the strategic improvement needs.
To enable a homogeneous multi-phase analysis, the strategic priorities as well as the gravity of the operating concerns and the operating improvement needs for removing the respective concerns, are related to the same performance scales: cost, time, quality and human resource. A partial view of matrix I depicting some of the specific operating improvement concerns/needs pertaining to the four performance scales is presented in figure 3.

The normalized values of the 22 operating improvement needs were statistically summarized over all enterprises. We obtained values from 0.079 to 0.538. To reduce the number of variables in the next stage of the analysis the average scores were ranked in descending order. By examining the descending curve of the average score (in a Pareto-like manner) we selected the 12 highest ranked variables (0.538 to 0.265) to represent the set of (urgent) operating improvement needs. Thus, ‘reducing capacity shortages’ (0.538) and ‘improving skill/versatility of employees’ (0.425) were found to be the two most urgent operating improvement needs of SMEs.

It is to be noted that 6 among the 12 urgent operating improvement needs were time delay related.

- Reducing capacity shortages (0.538).
- Coping with changes in requirements (0.373).
- Improving dependability of supply delivery (0.385).
- Reducing duration of supply delivery (0.306).
- Reducing in-process delay (0.307).
- Reducing in-transfer delay (0.265).

Capacity shortages incur manufacturing delays and thus affect the time performance scale of the manufacturing system. It is seen that, besides the urgent need of

<table>
<thead>
<tr>
<th>Operating Improvement need, k = 1, 2, ..., ( P )</th>
<th>Reducing Costs</th>
<th>Reducing Time Delays</th>
<th>Reducing Quality Deficiencies</th>
<th>Reducing Human Resource Deficiencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Input 1: } \text{SN}_i )</td>
<td>( \text{Input 2: } OC_k )</td>
<td>Raw material costs</td>
<td>Capacity shortages</td>
<td>In-process delay</td>
</tr>
<tr>
<td>( \text{SN}_i )</td>
<td>Raw material costs</td>
<td>Capacity shortages</td>
<td>In-process delay</td>
<td>Dependability of supply delivery</td>
</tr>
<tr>
<td>( \text{ON}_k )</td>
<td>Operating Improvement need, k = 1, 2, ..., ( P )</td>
<td>R1,2, ..., P</td>
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Figure 3. A partial view of matrix I.
reducing capacity shortages—a rather fundamental operating improvement need—there is also an urgent need to reduce time performances, such as in-process delays and in-transfer delays. Since these delays are outcomes of capacity shortages, the above results show consistency. Improved manufacturing planning and control procedures can overcome short-term capacity shortages and their consequences.

Changes in requirements are related to conditions imposed by external factors such as customers, or imposed by internal factors such as equipment breakdowns. The degree and frequency of these changing conditions have to be taken into consideration at various stages of the manufacturing system design and operation. They determine the required flexibility level of an enterprise. Another aspect of the time delay problem is related to the dependability and duration of supply delivery. These may be considered the outcomes of the existing relations of an enterprise with its vendors.

Matrix I (operating improvement needs)
Three among the urgent operating improvement needs were human-related.

- Improving skill/versatility of employees (0.425).
- Improving employee motivation (0.343).
- Improving communication channels (0.324).

Skill/versatility are attributes of the human resources and, as such, affect the human performance scale. Accordingly, improving skill/versatility of employees is an infrastructure (fundamental) operating improvement need. Employee motivation represents an implicit condition of an individual that is very likely to affect his/her work performance. When this happens, motivation becomes an explicit working condition. Appropriate training programmes and empowerment may improve the level of these attributes. Communication channels enable relations among functions and among departments of an enterprise. Their improvement, eventually through development of information system/technology, is likely to shorten time delays.

Two, among the urgent operating improvement needs were quality-related.

- Improving the quality techniques (0.371).
- Removing difficulties in satisfying customers’ tolerances (0.289).

Improving the quality techniques practised in an enterprise is an infrastructure improvement need likely to affect the system quality performance (products and processes).

One among the urgent operating improvement needs was cost related and involved reducing raw material costs. This is an operating need that can eventually be alleviated (if at all) through improved vendor relations.

5.1.1. Grouping the enterprises by their operating improvement needs
To identify groups of enterprises with similar operating improvement needs we used cluster analysis, a multivariate technique (see for example Johnson and Wichern 1988). The set of 12 operating improvement needs above was the set of variables according to which the enterprises (cases) were clustered. Enterprises in the same group are considered closed to one another and may thus represent a generic operating improvement set of needs, while enterprises in different groups have different generic sets of needs.
There are several criteria for measuring distances among clusters, such as Nearest Neighbour, Furthest Neighbour, Ward's and others. We selected Ward's criterion and the option of calculating the distances among clusters as the sum of squares summed over all the variables (Squared Euclidean). The number of groups was selected \textit{a priori} as four. Our choice took into consideration the total number of the surveyed companies. The profiles of the four clusters of enterprises in terms of the five highest scored centroids (variable means) in descending order appear in Appendix A. A dendogram depicting the distances between enterprises within each of the four groups is presented in figure 4. To interpret better the generic operating improvement needs of the four clusters, we summed up the five highest scored variable means within each cluster by the performance scales: time, quality, human resource and costs. The results in table 1 represent the distribution of the five highest scored variables in cluster by these performance scales.

Time oriented operating improvement needs are among the most urgent in each of the four profiles, but are not the most urgent in all cases. The urgency of the time oriented operating improvement needs is particularly evident in cluster 3 (capacity shortages, changes and supply time) and in cluster 1. The most urgent operating needs of clusters 2 and 4 are improvement of the human resource performance scale (skill/versatility and motivation). It seems that the quality oriented operating needs were not so urgent in any of these clusters.

5.2. Deployed improvement actions

The set of indicators, denoting the deployed improvement actions of the sampled enterprises, was calculated through (5). As depicted in figure 2, the necessity of these actions result from the projection of their potential contribution (as assessed by the interviewees) on the urgency of the operating needs calculated above. There were 37 improvement actions, defined by areas.

The numerical values of the deployed improvement actions were statistically summarized over all enterprises. To reduce the number of action variables, their average scores were ranked in descending order. We obtained values from 1.017 to 0.022. Again, by examining the descending curve of the average score (in a Pareto-like manner) we selected the 17 highest ranked variables (1.017 to 0.422) to

![Figure 4. Distances among clusters of enterprises by their operating improvement needs.](image-url)
represent the set of (critical) improvement actions. Their detailed scores appear in Appendix B.

The 17 (critical) improvement actions lead to six structured categories.

(1) **Time reducing techniques**
Production planning and scheduling, IS/T for on-line control and IS/T for planning

(2) **Quality improvement techniques**
SPC, product quality control, DOE, quality control of raw materials performance measurement and analysis

(3) **Organizational quality procedures**
Autonomous control of work quality, quality improvement teams, quality oriented training, cellular work organization.

(4) **Human and manufacturing flexibility**
Training to improve versatility of operators, reducing set-up

(5) **Preventative/improvement oriented maintenance**

(6) **Vendor relations**

5.2.1. **Grouping the enterprises by their critical improvement actions**

To identify groups of enterprises with similar critical improvement actions, cluster analysis was again put to use. The set of 17 critical improvement actions above was the set of variables according to which the enterprises (cases) were clustered. Similarly to the clustering of enterprises by their operating improvement needs, here too the number of clusters was selected *a priori* as four. The profiles of the four clusters in terms of the seven highest scored centroids (mean scores of improvement actions) in each cluster appear in Appendix C. We shall denote these clusters as ‘generic improvement models’. Table 2 presents the distribution of the highest scored variables in each of the four clusters by the categories of improvement activities defined above.

In all models, the time reducing techniques are among the most critical improvement activities. This is particularly remarkable in generic models 1 and 3 where the production planning and scheduling activities, with strong support from IS/T for planning and IS/T for on-line control, represent over 47% of the total score of the seven highest scored improvement actions. In both models, flexibility also appears among the critical improvement categories. The differences between these two generic models are the quality related improvement actions, which seem to be more important in model 1 and, by contrast, ‘vendor relations’ and ‘maintenance’.

<table>
<thead>
<tr>
<th>Clusters</th>
<th>Time (% of score in cluster)</th>
<th>Quality (% of score in cluster)</th>
<th>Human resource (% of score in cluster)</th>
<th>Costs (% of score in cluster)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (9 companies)</td>
<td>64.8</td>
<td>16.1</td>
<td>19.1</td>
<td>—</td>
</tr>
<tr>
<td>2 (4 companies)</td>
<td>38.7</td>
<td>20.5</td>
<td>40.8</td>
<td>—</td>
</tr>
<tr>
<td>3 (7 companies)</td>
<td>77.3</td>
<td>—</td>
<td>22.7</td>
<td>—</td>
</tr>
<tr>
<td>4 (1 company)</td>
<td>21.5</td>
<td>18.5</td>
<td>42.7</td>
<td>17.3</td>
</tr>
<tr>
<td>All (21 companies)</td>
<td>54.8</td>
<td>14.5</td>
<td>24.4</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Table 1. The distribution of the highest scored variables in each cluster by the four performance.
improvement actions that are more important in model 3. Models 2 and 4 are both characterized by the criticality of quality related improvement actions (techniques and organization). In Model 2 the focus is on quality oriented organizational procedures. ‘Cellular organization’, ‘quality teams’ and ‘autonomous control of quality’ represent about 39% of the highest scored improvement actions. In Model 4, the focus is on quality technique practices. ‘Statistical process control’, ‘design of experiments’, ‘product quality control’ and ‘IS/T for improving performance measurement and analysis’ represent over 44% of the most critical improvement actions in this generic model.

5.2.2. Further analysis of the generic improvement models

The numerical information supplied by the profiles of the four generic improvement models (clusters) in terms of their highest scored improvement actions (centroids), as detailed in Appendix C, can serve an additional purpose: to assess how critical are these improvement actions to enterprises pertaining to different clusters. This can be easily achieved by examining the numerical (normalized) values of the highest scored improvement actions in each cluster. The higher the numerical values of a cluster centroids, the more critical are the improvement actions for the enterprises in the cluster. It is seen that for the 5 enterprises in clusters 2 or 4, improvement actions are paramount. These important improvement actions are quality oriented.

5.3. Validity and consistency

5.3.1. Validity

Important issues in our research are related to the validity of some assumptions. From a QFD research perspective, validity means assigning realistic numerical values to the strength of the relations between the customer desires and the designed, technical properties of a product. Here, such relationships concern realistic appraisal of two types of potential effects/capabilities: the potential effect of the removal of an operating concern on the realization of a strategic priority (matrix I) and the potential capability of an improvement action to reduce/remove a particular operating concern (matrix II). Since differences among the application conditions are expected, there is no ‘universal’ knowledge on the strengths of these relations. To appraise them, the researchers used, besides knowledge, their own previous practical experience and judgement. However, the special QFD matrix structure developed here enabled us to test empirically the validity of the numerical values assigned by the
researchers. As the two QFD matrices have two customer-based inputs it was possible to estimate the linear correlation coefficient between any pair of items pertaining to inputs 1 and 2 in the sample and compare it with its respective value as assigned by the researchers. Encouraging empirical results were obtained suggesting fitness of the assigned numerical values. A detailed statistical analysis of this validation procedure, its rational and application are described elsewhere, see Barad and Gien (2000).

5.3.2. Consistency between actions and needs
To empirically test consistency between the improvement actions and the operating improvement needs of the enterprises in the sample, a simple but robust procedure based on clustering analysis was suggested. It relies on the two separate clustering analyses that were carried out respectively to define the generic operating needs and the generic improvement actions. The two analyses used the same cases, i.e. the 21 investigated enterprises and the same number of required clusters (4), but the clustering variables were different. Clustering of the enterprises by their urgent operating needs was determined by the output of type I QFD matrix (set of variables ON), whereas clustering of the enterprises by their critical improvement actions was determined by the output of type II QFD matrices (set of variables DA). Under these conditions we deem that perfect consistency (100%) is achieved if each of the two variable sets cluster the enterprises in exactly the same way.

Formally, let

\[ N^{(\text{ON},\text{DA})} = \text{number of enterprises assigned to the same cluster by both sets of variables, ON and DA} \]
\[ E = \text{total number of enterprises in the sample} \]
\[ C_{\text{ns}}^{(\text{ON},\text{DA})} = \text{consistency index between the urgent operating improvement needs and the critical improvement actions}. \]

Our findings indicate that 15 among the 21 surveyed enterprises were assigned to the same cluster by the two sets of variables. This result represents a 71% consistency between the urgent operating improvement needs and the critical improvement actions.

5.3.3. Consistency between customers and researchers
A variation of the procedure described above was derived for a different purpose: measuring the knowledge and capability of the interviewed managers/engineers to select the most critical improvement actions as necessary to respond to the urgent operating needs. An additional analysis of the type II matrices had to be carried out. In this analysis the output of the set of matrices II (improvement priorities) was calculated without considering the questionnaire-based (customer-based) input regarding the potential contribution of an improvement action, \( PA_{m(a)}, m(a) = 1,2, \ldots, q(a), a = 1,2, \ldots, r \). Consequently, the structure of type II matrices became similar to the standard structure of any QFD matrix. The weights of the deployed improvement actions were calculated solely from the urgency of the operating improvement needs (output of matrix I) and the strengths of the respective relationships between an operating need and an improvement action, as appraised by the researchers. Equation (5) became:
\begin{equation}
RA_m(a) = \sum_{k=1}^{p} \text{ON}_{k}^* R_{k,m(a)}^2, \quad m(a) = 1, 2, \ldots, q(a), \quad a = 1, 2, \ldots, r. \tag{8}
\end{equation}

We denote this version ‘the researchers-based version’. The capability of the interviewed managers/engineers to select the most appropriate improvement actions was estimated by comparing the grouping of enterprises according to each of the two sets of variables: the customer-based variables (DA) obtained through equation (5) and the researchers-based variables (RA) obtained through equation (8).

Cns (DA, RA) was defined as the consistency index between the customer-based critical improvement actions (DA) and the researchers-based critical improvement actions (RA). Its value in the sample was calculated using an equation similar to (7) yielding: Cns (DA, RA) = 0.71.

There were but few discrepancies between the two sets of variables, RA and DA. For instance, in the researchers-based set, the potential contribution of ‘cellular organization’ and ‘re-layout’, were considered more important than they were in the customer-based set, while ‘autonomous quality control’ was considered more important in the customer-based version than it was in the researchers-based version. We may eventually interpret these differences by assuming that the managers’ preferences were affected by the investment associated with the improvement actions they selected. Definitely, cellular organization and re-layout are costly, whereas instituting autonomous quality control is a less costly action.

6. Discussion of results

Four research questions were outlined in the introduction and all four were answered throughout the paper. The first one concerned the most urgent needs of SMEs. The most urgent operating needs of SMEs were associated with delay concerns and human oriented concerns. The delay concerns were caused by short term capacity shortages, low dependability of supply delivery and frequent changes in requirements. The human oriented concerns were caused by low skill/versatility of employees and low motivation.

Ensuring that the improvement actions are consistent with the operating improvement needs was the second research question to be investigated in this research. The answer to this question is provided by the usage of QFD as such. The QFD approach was proposed here to formulate manufacturing strategies, because its matrix structure is based on a functional linkage between the operating improvement needs of an enterprise and its improvement actions. In other words consistency between actions and needs is an \textit{a priori} advantage of using the QFD approach to manufacturing strategy formulation. To measure consistency, we defined a consistency index based on ‘cluster analysis’. As expected, the sample results showed a relatively high consistency index (71\%) between the critical improvement actions and the urgent operating needs.

The same type of index was used to answer our third research question that concerned the capability of the customers (the interviewed managers/engineers) to select the most critical improvement actions for responding to their most urgent concerns. We found that although their selection of the important improvement activities was somewhat affected by the investment costs involved, a 71\% empirical consistency index between the customer-based critical improvement actions and the researchers-based critical improvement actions, was obtained.
To answer the fourth research question, we again made use of ‘cluster analysis’, that identified generic improvement needs and generic improvement models of the sampled enterprises. Four generic improvement models were identified. They were respectively featured by: (1) time reducing techniques and flexibility coupled with improved quality techniques; (2) improved quality oriented organization; (3) time reducing techniques coupled with improved vendor relations and maintenance; (4) improved quality techniques.

It seems interesting to note that some of the trends observed in the behaviour of large European manufacturers (De Meyer 1998) are also revealed in our study of small manufacturing enterprises. (1) Delivery as a competitive priority is strongly emphasized in large and small enterprises. (2) Manufacturers are putting more emphasis on human resources and less on stand-alone technology. In SMEs this is reflected in the selective decision to improve flexibility through improved versatility of operators, rather than through equipment upgrading. ‘Autonomous control of work quality’ and ‘quality improvement teams’ appeared among the most important improvement actions in the investigated sample of small manufacturing enterprises.

7. Conclusions and further research

QFD, a product oriented quality technique, has been applied in an innovative way to develop a structured model connecting the improvement actions of a company with its strategic and operating improvement needs. It provides evidence of the potential application of the approach for advancing manufacturing management. The methodology was developed as a supporting technique for determining the improvement priorities of SMEs. However, the tools and techniques proposed in this paper are of a general nature and need not be restricted to SMEs. The SMEs were the stimulus of this work and provided the sampling environment for extracting improvement needs and for validating the values assigned to some of the parameters used in this approach. However, the approach as such is applicable to a wide variety of enterprises, big or small, as well as to manufacturing or service industries. Naturally, for extracting improvement needs and for validating the values assigned to parameters, appropriate sampling conditions matching the method application, have to be considered.

7.1. Further research—usage of the QFD matrices and generic models

The two matrices are the core of the improvement methodology developed. They trace a two-way improvement path connecting the strategic level through the operational level with the improvement actions. The top-down path is followed by questionnaire-based qualitative indicators and can be used by an enterprise as a self-assessment procedure to identify its critical improvement actions. It is initiated by the flow of strategic improvement needs and ends with the deployed improvement actions corresponding to a generic model. Along the bottom-up path, will flow the results of the applied improvement actions (the re-design of the manufacturing system) intended to realize the selected improvement actions of an enterprise whose characteristics match a certain generic model. The results of these actions are system (real) performances that can be measured at the operational level and further on at the strategic level in terms of costs, delays, quality and human oriented performances. This two-way structured linkage between the manufacturing improvement needs and the improvement priorities can be considered a methodology for implementing the manufacturing strategy contingency approach.
Currently, our research continues at the enterprise level. An extension of our modelling approach at this level is making use of fuzzy logic. Introducing fuzzy variables will serve two purposes: (1) to model fuzzy relationships within the QFD matrices; and (2) to model differences in opinions among the interviewees.

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Appendix A: Clusters of enterprises by their urgent operating improvement needs

Cluster 1 (9 enterprises)
Capacity (0.566), changes (0.418), skill/versatility (0.392), delivery dependability (0.343), quality techniques (0.329)

Cluster 2 (4 enterprises)
Skill/versatility (0.789), capacity (0.759), quality techniques (0.722), motivation (0.648), delivery dependability (0.601)

Cluster 3 (7 enterprises)
Capacity (0.303), raw material cost (0.298), delivery dependability (0.264), delivery duration (0.225), changes (0.222)

Cluster 4 (1 enterprise)
Skill/versatility (1.064), capacity (1.051), motivation (1.010), satisfying customer tolerances (0.897), raw material cost (0.840)

Appendix B: Average (normalized) scores of the most urgent improvement actions

(1) Production planning and scheduling (1.017).
(2) IS/T for on-line production control (0.797).
(3) Statistical Process Control (SPC) (0.694).
(4) IS/T for production planning (0.686).
(5) Autonomous control of work quality (0.612).
(6) Training to improve versatility of operators (0.606).
(7) Vendor relations (0.586).
(8) Design of experiments (DOE) for improving quality (0.571).
(9) Quality improvement teams (0.562).
(10) Product quality control (0.559).
(11) Preventative/improvement oriented maintenance (0.543).
(12) Quality oriented training (0.514).
(13) IS/T for improving performance measurement and analysis (0.492).
(14) Cellular work organization (0.471).
(15) Quality control of raw materials (0.448).
(16) Reducing set-up (0.447).
(17) Re-layout/Manufacturing cells (0.422).

Appendix C: Profiles of the four generic models in terms of their seven highest scored centroids

Model 1 (6 enterprises)
Production planning (0.943), IS/T for improving on-line control (0.898), SPC (0.784), IS/T for production planning (0.709), improving versatility of operators (0.669), autonomous control (0.659), product quality control (0.656).
Model 2 (3 enterprises)
Production planning (2.177), SPC (1.612), quality teams 91.400), IS/T for improving on-line control (1.347), autonomous control (1.329), DOE (1.327), quality oriented education (1.305).

Model 3 (10 enterprises)
Production planning (0.610), IS/T for production planning (0.467), IS/T for improving on-line control (0.468), vendors (0.379), improving versatility of operators (0.305), IS/T for improving performance measurement and analysis (0.287), maintenance (0.276).

Model 4 (2 enterprises)
Production planning (1.530), SPC (1.443), product quality control (1.337), IS/T for improving on-line control (1.319), DOE (1.296), autonomous control (1.282), quality teams (0.999).

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