

008-0337

**Identifying and Measuring Required-Actual
Manufacturing Flexibility Gaps**

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POMS 19th Annual Conference

La Jolla, California, U.S.A.

May 9 to May 12, 2008

Keywords: Manufacturing flexibility, measurement of flexibility, visual tool, case study

Abstract

This research develops a framework that enables managers to identify and narrow the gap between required and actual levels of manufacturing flexibility. To illustrate its applicability, the framework is presented to managers (e.g., production manager, development manager, marketing manager, supply chain manager, financial officer, business development manager, CEO) of a leading European manufacturer of food processing and chemical processing machinery in order to help identify required and actual levels of flexibility, where gaps exist between the two, and develop a set of measurements to help determine when such gaps are closed. Based on the data from the case, a variety of measurements are identified to help ensure that changes made are actually narrowing the gap between required and actual flexibility. Further analysis shows that the framework is effective in identifying flexibility deficiencies, as well as preventing an over or under investment in manufacturing flexibility. This study provides an easy to use sequence of steps to help identify actual and required levels of flexibility and what dimensions need to be addressed to narrow this gap. The study considers both over and under investments of flexibility and in doing so highlights to managers that more flexibility is not always desired.

Introduction

Flexibility has been recognized as a competitive weapon with the potential to improve the competitive position and business performance of an organization (Teece *et al.*, 2000). Although managers have recognized the strategic importance of flexibility for today's organizations, both the research literature and popular press indicate that identifying and measuring required and actual levels of flexibility needed to improve performance is a very difficult task. In response to the need to better understand flexibility, a number of researchers have developed frameworks or steps that should be undertaken to improve flexibility (e.g., Abdel-Malek *et al.*, 2000; Boyle, 2006; Narain *et al.*, 2000). The consensus of these frameworks is the need to measure flexibility and perform a resulting gap analysis. This gap analysis involves measuring actual levels of flexibility and comparing it to required levels to determine any gaps between the two (e.g., Verdú-Jover *et al.*, 2005). By narrowing such gaps, the flexibility of the organization improves and becomes more inline with environmental conditions and the various strategies (e.g., manufacturing, marketing, organizational) of the organiza-

tion. Performing such a gap analysis is not an easy task. Despite the substantial volume of research on how to measure flexibility, no general accepted measurement system has resulted from such efforts (Giachetti *et al.*, 2003; Jaikumar, 1986). Part of the reason is the complexity of existing manufacturing flexibility measurements systems and the lack of broad appeal; with many measurements specific to a machine, process, or industry.

Although the importance of performing this gap analysis has been highlighted in the research literature, suggestions on how this important piece of the flexibility improvement puzzle should be achieved are considerably lacking. This research develops a framework to help better understand required levels of flexibility needed by a company to compete, levels actually being obtained by the company, and what must change to narrow the gap between the two. To help guide framework development, we examine the flexibility challenges faced by a large food processing equipment manufacturer.

Manufacturing Flexibility

The most basic definitions of flexibility are concerned with the ability to effectively adapt to changing circumstances (e.g., Bordoloi *et al.*, 1999; D'Souza & Williams, 2000; Gupta & Gupta, 1991). Various researchers have modified this basic definition to consider the manufacturing system, process, product, or part in an attempt to develop a definition of flexibility more applicable to manufacturing activities. Within this context, manufacturing flexibility has been defined as the ability of the manufacturing system to produce a wide variety of parts or assemblies without intervention from outside to change the system (Buzacott, 1982), and the ability of the manufacturing system to adapt successfully to changing environmental conditions and process requirements (Swamidass, 1988). More recent research has highlighted the need to consider flexibility not only the manufacturing organization but also members along the company's supply chain (e.g., Kumar *et al.*, 2006; Schmenner & Tatikonda, 2005;

Stevenson & Spring, 2007; Wadhwa & Rao, 2004). The definition of manufacturing flexibility for this research considers the definitions just described, as well as the general relationship between manufacturing flexibility and environmental uncertainty. The operational definition of manufacturing flexibility for this study is a manufacturing system's capability to effectively adapt to or redefine uncertainty while still producing efficiently different products or product volumes of acceptable quality, cost, and timeframe.

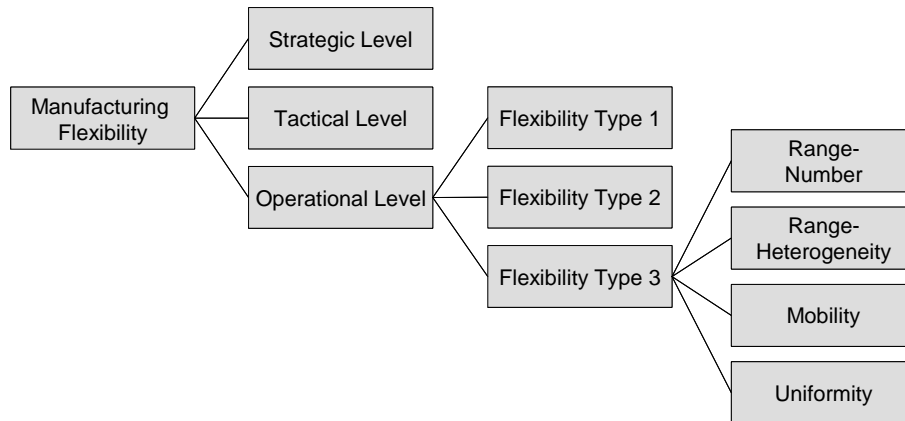
Slack (1987; 2005a) suggests that manufacturing flexibility operates in a domain that can be stated by the range of possible states for a flexibility type and the time needed to move from one state to another. Upton (1994) builds upon Slack's (1987; 2005a) work to suggest that manufacturing flexibility must also consider performance indicators other than the time of moving from one state to another. Upton (1994) identifies "three distinct 'elements' or ways of being flexible: range, mobility, and uniformity". The *range* element of flexibility is the ability to accommodate a large range on the dimension of change and include the range of sizes of components that can be processed, range of volume for profitable output, and range of products (Upton, 1994). Koste and Malhotra (2000) further break down the range dimension into range-number (i.e., number of possible option which a system or resource can achieve) and range-heterogeneity (i.e., degree of difference between the options). The second element of flexibility is *mobility*. Upton (1994) defines mobility as the transition penalties for moving within the range. These penalties may be measured in terms of set-up costs or time. Koste and Malhotra (2000) define mobility as the ease with which the organization moves from one state to another. Both range and mobility fully encapsulate the domain identified by Slack (1987; 2005a). The final element of flexibility considered by Upton (1994) is *uniformity*. Based on this element, a system is flexible when a performance measure, such as quality, is invariant with the position occupied within the range. "In general, managers see uniform performance across the range of attribute space as more flexible than peaked performance"

(Upton, 1994). Similarly, Koste and Malhotra (2000) state that "uniformity captures the similarity of performance outcomes within the range".

Sethi and Sethi (1990) examine the inconstancy in both the names and definitions of the many manufacturing flexibility types that exist in the literature. Based on these inconstancies, and a review of the manufacturing flexibility literature, Sethi and Sethi (1990) identify eleven types of manufacturing flexibility, specifically: machine, material handling, operation, process, routing, product, volume, expansion, program, production, and market. To achieve these flexibility types requires sophisticated information technologies and a flexible organizational structure and, as highlighted by Sethi and Sethi (1990), "it is because of this technology that flexibility in manufacturing has become possible without a considerable sacrifice in efficiency ... a cellular architecture with distributed information systems seems most favoured".

Adding to the difficult task of improving manufacturing flexibility is its multidimensional nature. Specifically, manufacturing flexibility can exist at different levels of the organization (i.e., strategic, tactical, operational) and is comprised of many different ways the organization can be flexible, ranging from the operational level (e.g., process flexibility) to the strategic level (e.g., market flexibility). In addition, each type of flexibility (e.g., volume, product, process) can be measured in terms of potential, actual, and required levels (Koste & Malhotra, 1999) and each of these in terms of range-number, range-heterogeneity, mobility, and uniformity, as illustrated in Figure 1.

**Figure 1: Multi-Dimensional Nature of Manufacturing Flexibility
(Adapted from Upton, 1994)**



Some of the most critical concerns when implementing and managing manufacturing flexibility such as economic and non-economic justification, potential benefits and trade-offs, and the amount of flexibility required, can only be addressed if proper measurements exist.

The research discussion on how to properly measure flexibility started almost a decade after the discussions on flexibility in general. The question as to why measure flexibility was answered by Aaker *et al.* (1984) with the statement that a firm might want to monitor its flexibility with respect to a key environmental trend over time. Even today, the measurement of flexibility has arguably remained one of the most difficult tasks in achieving flexibility (Narain *et al.*, 2000) and, subsequently, one of the most pressing problems is the development of a set of valid measures relating to the different dimensions of manufacturing flexibility (Vokurka & O'Leary-Kelly, 2000). Bateman (2006) summarizes the research in the measurement of flexibility by stating that little continuity in approaches exists and that existing measurements fail to have a general appeal. Part of the lack of continuity is that although researchers highlight that the measurement of flexibility is possible, differences exist as to whether the measure should be absolute (Bernardo & Mohamed, 1992; Brill & Mandelbaum,

1989; Giachetti *et al.*, 2003; Gupta & Goyal, 1989; Gupta & Somers, 1992; Kumar, 1987) or relative (Koste *et al.*, 1999; Suarez *et al.*, 1991).

Regardless of the specific reasons, there are different approaches to measuring manufacturing flexibility that managers can adopt. These approaches measure manufacturing flexibility at different levels, ranging from the machine level through to the strategic level. Kumar and Kumar (1988) identify the major approaches researchers have used to measure manufacturing flexibility, specifically economic consequences, performance criteria, multi-dimensional, petri-nets, information theoretic, and decision theoretic approaches.

We focus on the *multi-dimensional* approach which suggests that flexibility should be measured on the basis of range, uniformity, and mobility. This approach to measuring manufacturing flexibility has received the most attention in the research literature (e.g., Gerwin, 1993; Hutchison & Das, 2007; Upton, 1994). This approach to measuring manufacturing flexibility helps to emphasize that manufacturing flexibility is a multi-dimensional concept, and therefore a suite of measurements capturing range, mobility, and uniformity are needed to determine the true flexibility of a manufacturing system or sub-component.

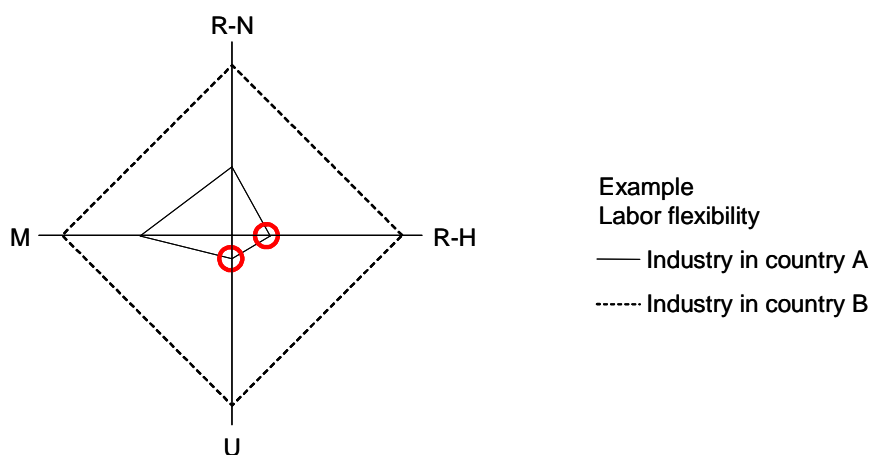
A framework for identifying and eliminating required - actual manufacturing flexibility gaps

Even after over fifty years of manufacturing flexibility research, some basic questions and research gaps still remain. Zukin and Dalcol (2000) highlight that managers do not use manufacturing flexibility practices in the same proportion that they perceive their importance. Researchers are partially to blame, as the bulk of research fails to consider many of the practical problems managers may face when implementing manufacturing flexibility. For example, the research has produced many measurements of manufacturing flexibility, yet the majority of

these measurements are only conceptual in nature, with only a handful ever tested within an organization to determine their ease of use, robustness, and frequency of usage.

Using the multi-dimensional approach to measuring flexibility as a starting point, this research presents a framework to identify where gaps may exist between required and actual flexibility levels. In addition, this research presents a set of measures that will enable a company to measure if a defined required level of flexibility has been reached and to control the compliance of the required level of flexibility as well as to decide if changes are needed in cases of discrepancies between the required and actual levels of flexibility. The framework is an extension of the research of Koste and Malhotra (2000). Specifically, Koste and Malhotra (2000) highlight that every flexibility type has four dimensions: range-number (R-N), range-heterogeneity (R-H), mobility (M) and uniformity (U). By subdividing each type of flexibility into these four elements, it can be determined where a lack of flexibility exists. A flexibility gap exists if one element has a higher or lower level of flexibility (Koste *et al.*, 2000). Figure 2 illustrates an example of a gap in the two dimensions R-H and U in labor flexibility of an industry in country A.

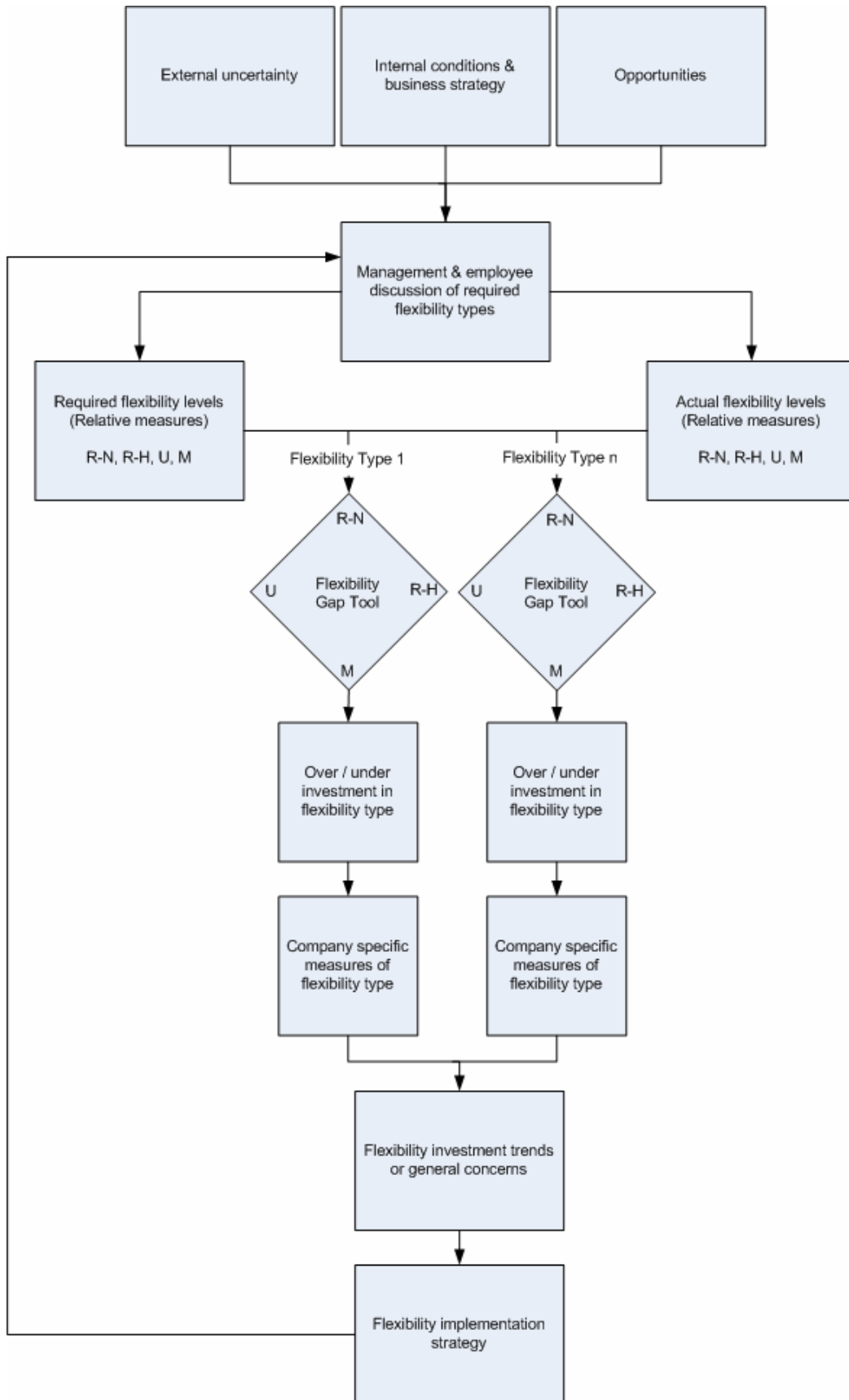
Figure 2: Example for starting-point to increase a type of flexibility (based on Koste *et al.*, 2000)



Continuing the example, a second industry in country B shows that all four dimensions of flexibility are on the same level. The industry does not need to change existing levels of labor flexibility. Koste and Malhotra's (2000) example is effective for comparing the flexibility of specific industries in different countries as well as examining where deficiencies exist against a benchmarked industry (i.e., in this case industry B).

We use this approach as a starting point to develop a framework to assist companies in identifying their required and actual flexibility levels and narrow the gap between the two. This framework is presented in Figure 3.

Figure 3 – Flexibility implementation framework



Through meetings with managers, employees, and other flexibility stakeholders, the most critical flexibility types (e.g., product, process, volume, and labor) needed to improve the performance of the organization, and address perceived uncertainty, internal conditions, and strategy fulfillment are first identified. Next, for each flexibility type identified as important, required levels for each flexibility dimension (i.e., R-N, R-H, M, U) needed to address the above conditions are identified and transposed onto a single diagram with a scale on each axis. We use a ten-point scale as it should capture in enough detail where gaps exist, yet make it easy to determine the appropriate position on the scale. It is not assumed, nor recommended, that the organization assign a score of 10 for every flexibility type, as it may result in an over investment in flexibility and result in waste and the inefficient use of resources (e.g., Van Biesebroeck, 2006). The result of this exercise is a relative measure for each dimension of a specific flexibility type. With the required flexibility types and levels identified, attention turns to examining the actual flexibility levels of the dimensions of each flexibility type identified. After the definition of the actual and required levels for each critical flexibility type, the diagram is reviewed to determine where required-actual flexibility gaps exist. With the gaps identified, the company can now develop absolute measures to help determine that the gaps between required and actual flexibility levels are being closed. In addition to a gap diagram for each flexibility type deemed important for the organization, a summary diagram is also developed that helps to identify any general flexibility trends or deficiencies such as an over investment in flexibility along many different flexibility types. With a better understanding of the status of each flexibility type and any general trends or deficiencies, the company can now develop a strategy to close any identified gaps between required and actual flexibility levels. This procedure not only focuses on short-term improvements and on quick wins in terms of flexibility, but also provides a long-term perspective. The actual and required levels of flexibility should be reviewed after a defined period of time to take the latest

internal, environmental, and strategy changes into consideration. We test and discuss the applicability of the framework using a case study of a single company. We show how the framework can give the company a complete picture of where flexibility deficiencies exist and allow them to develop a single strategy to address all deficiencies, instead of taking a piecemeal approach by focusing on each type separately.

Real world application: Machinery Inc.

To illustrate the applicability of the framework to a real organization, this research uses a single case study (Eisenhardt, 1989; Punch, 1998; Yin, 1994) involving a manufacturing company in Switzerland. We have chosen a company located in Switzerland for several reasons. Switzerland is a small high-cost country in terms of labor cost. During the past several years, the production of many standard products within the country has been relocated to low-cost countries. Therefore, companies who did not relocate face more dynamic markets, high competition, and must determine if the old structures and processes in the company fit the new manufacturing environment.

The company under study is a leading European manufacturer of food processing plants and equipment, hereafter referred to as *Machinery Inc.* Machinery Inc. employs approximately 6200 people worldwide (i.e., 3000 in Switzerland) with annual sales of over €1 billion (i.e., US \$1.35 billion). While the company is organized into three divisions, this research only focuses on the food division and specifically the manufacturing of machinery for the chocolate industry. The company was chosen because of its qualification to generate usable results rather than because of their representativeness (Firestone, 1993; Miles & Huberman, 1994).

Data Collection and Analysis

We conducted a qualitative case study from October 2006 to January 2007 that involved direct observation of company discussions focused on the identifying and measuring required levels of flexibility. Our goal was to gain insight into how companies decide what levels of flexibility are required, present the proposed framework and acquire feedback, and identify what measures should be used to ensure that gaps between actual and required flexibility are reduced. In addition to direct observation, we used multiple data sources: archival data, industry publications, manuals, company documentation, workshop participation, and employee interviews including the production manager, the development manager, the marketing manager, the supply chain manager, the financial officer, the business development manager, and the CEO to gain additional insight.

The data collection consisted of four phases. As a prerequisite to the examination of flexibility, phase one (i.e., October 2006) was focused on understanding of the business environment, key challenges facing the company, and the corporate strategy from management's point of view. To achieve this, two different group interview sessions were conducted with top- and middle-management of the company. Attending the session were the production manager, development manager, marketing manager, supply chain manager, and financial officer. The goal of the first session was to understand the company's environment, including major industry trends and issues, competitors, and customers. The second session had the goal to understanding and reviewing the various strategies (e.g., manufacturing, marketing, competitive) of Machinery Inc.

The purpose of the second phase of the data collection (i.e., November 2006) was to define those flexibility types (e.g., volume, process, product) deemed critical for the company. Again, group interview were conducted with the same managers and researchers from phase

one attending. In addition, this stage included identifying required and actual levels of flexibility for each type and placing them on the graph. To gauge actual and required flexibility levels, a combination of survey and open-ended questions were presented to managers for each type of flexibility they deemed important. Using product flexibility as an example, Appendix 1 highlights the questionnaire used. The questionnaire was used to obtain an initial indication of required and actual levels of flexibility, but more importantly it initiated deeper discussions on levels of flexibility and justification for such levels, thus allowing the company to be accurately placed on the graph. Individual interviews and internal documents such as manuals, industry publication, and other company documentations were also consulted to validate actual positioning. The end result of this phase was a completed flexibility gap analysis tool.

The third data collection phase (i.e., December 2006-January 2007) focused on developing measurements of flexibility based on the gaps identified in phase two and examining the data on the tool. We conducted seven group interview sessions within the company to identify and define measures and discussed them with the middle- and top-management. Involved in this third phase were the same managers and researchers as in the prior phases. In addition, the group was enlarged to include the business development manager and the CEO of Machinery Inc.

The final phase (i.e., January, 2007) involved a feasibility study to determine if the measurements proposed were usable and if it was possible to analyze them automatically. In order to facilitate the speed and ease of measuring, the decision was made that only those measurements that should be considered are those whose data could be easily taken out of the company's enterprise system. After this examination, a final decision on which measurements to take into consideration was made. Table I summarizes the data collection for this study:

Table I - Data Collection

	Content of the phase	Primary data sources	Secondary data sources
Phase 1: October 2006	Discussion of strategy and environment	<ul style="list-style-type: none"> • Interviews, interview minutes • Group discussions • Project management documentation • Personal research notes • Internal documents • SBU business plans 	<ul style="list-style-type: none"> • Market research documentation • Project documentation for strategy achievement • Press releases
Phase 2: November 2006	Discussion of actual and required levels of flexibility	<ul style="list-style-type: none"> • Group discussions, discussion minutes • Interviews, interview minutes • Questionnaire • Personal research notes • Project management documentation • Internal documentation 	<ul style="list-style-type: none"> • Industry publications
Phase 3: December 2006 – January 2007	Definition of measurements including targets	<ul style="list-style-type: none"> • Group discussions, discussion minutes • Employee questionnaire • Internal documentations • Personal research notes 	<ul style="list-style-type: none"> • Research papers with emphasis on measurement • Industry reports • Management literature
Phase 4: January 2007	Feasibility study and review of the measurements	<ul style="list-style-type: none"> • ERP system tests • Group discussions, discussion minutes • Interviews, interview minutes • Personal research notes 	<ul style="list-style-type: none"> • ERP consultants

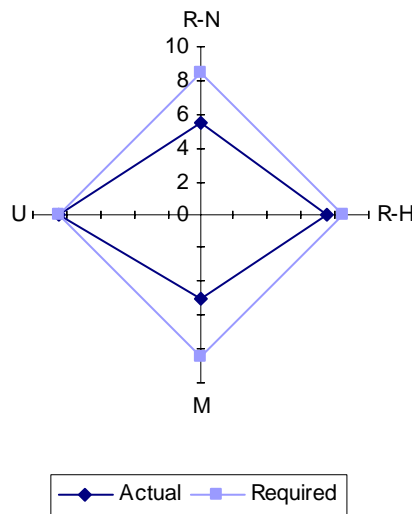
Results of the group interviews with managers identified seven flexibility types considered important for the organization, specifically production, product, machine, network, labor (not identified by Sethi and Sethi (1990) but instead by the organization), and volume. Of these six, the three most critical types were product, volume, and labor flexibility. Our discussion focuses on these three critical flexibility types, but ideally the process presented below should be carried out on all seven.

Product Flexibility

Machinery Inc. operates in a highly competitive market. Even if the company is a market leader, new products and modifications of existing products are required to satisfy changing consumer demand and remain competitive. Based on our meetings with management and the

results of the survey, the company's goal for product flexibility is to reach a level of 8.5 to fulfil the strategy of being close to the customers and producing the most sophisticated products compared to their competitors. At a product flexibility level of 8.5 out of 10, most needs of the customers are covered and most improvements are made. Based on contingency theory (Drazin & Van de Ven, 1985) each of the four dimensions of flexibility does not need to be on the same level. However, in this case Machinery Inc. feels that a level of 8.5 along all four dimensions is needed, and is illustrated in Figure 4.

Figure 4 - Actual and required level of product flexibility at Machinery Inc



The company does not require more flexibility because it is not their goal to build the general capability to cover very specific needs that are only required by a single customer, rather those needs from a wider base of customers and the more common requests. This is highlighted by the production manager who mentioned that:

“It is far too expensive and would increase our product variety too much to meet the requests of all our customers. That is why we focus on requests that more than one customer has or requests we see potential in to multiply the solution to other product groups”.

Despite the need for relatively high levels of product flexibility, the actual levels of product flexibility are fairly low. Machinery Inc. does not proactively present new solutions to address potential changes in the environment and is slow in reacting to environmental changes, as highlighted by the development manager:

“We are rather interested in developing radical innovations than in refining the tasks of our machines by introducing incremental changes based on customer demands once in a while”.

This results in a disadvantage compared to competitors, who react quickly to changing customer needs. At the moment, Machinery Inc. positions itself within the range-number (R-N) dimension at a level of 5.5 out of 10.

Despite the lag in reacting to the environment, Machinery Inc. has the ability to handle product requirements of high complexity. The actual level of flexibility of the range-heterogeneity (R-H) is therefore defined as 7.5 out of a possible 10. However, the time to market is quite slow because Machinery Inc. insists on high product quality and ensures that all product issues are resolved before ramping up production, resulting in long testing and refinement times. This is best highlighted by comments from the marketing manager:

“Our machines only leave our warehouse if we can assure a 100% quality and well working new features. A 50% solution due to a faster time to market is not acceptable for us”.

As a result, the dimension mobility (M) is defined at an actual level of flexibility of 5, whereas the goal is to reach a level of 8.5. This means, the modifications need to be offered to the market in a much shorter time period without compromising product quality. The quality of the products of Machinery Inc. is viewed by management as much higher than their competitors, and was referred to by one manager as the “Rolls Royce of chocolate machin-

ery”. Because the company has such high standards already in research and development of new machines or functionalities, the actual level of product flexibility of the uniformity (U) dimension is already matching the required level of 8.5.

Based on an assessment of required and actual levels of product flexibility for Machinery Inc., a number of flexibility gaps have been identified. Based on the diagram (i.e., Figure 4), Machinery Inc. has a major gap in the dimensions R-N and M and a minor gap in the dimension R-H.

With these gaps now identified, the next step in the process of flexibility alignment for Machinery Inc. was to develop measures to help them identify when these specific gaps are closed. Specifically, managers at Machinery Inc. developed the measurements below:

Figure 5 - Measures for product flexibility

$\text{R-N: Changes based on environment} = \frac{\text{Number of changes based on environmental changes}}{\text{Total amount of product modifications and innovations}} < 10\%$
$\text{M: Time to market} = \frac{\text{Beginning of production} - \text{beginning of development}}{\text{Amount of time (year)}} < 0.5$

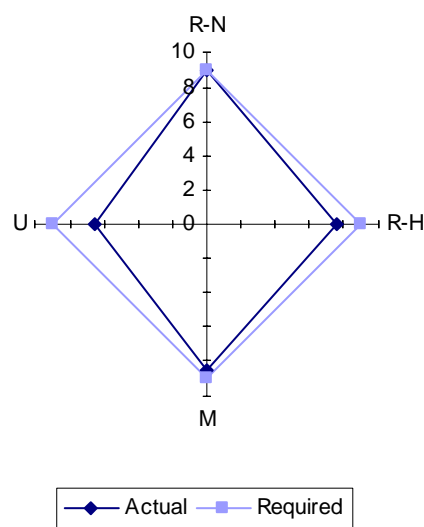
The formula for the dimension R-N represents the uncertainty of the environment. As more changes occur, the more uncertain is the environment. As mentioned above, Machinery Inc. is not interested in developing solutions for all customer needs but only for those which have the potential to be applied to a wider variety of products. Because of this philosophy, Machinery Inc. has put a target value lower than 10%, which reflects the goal of the company not being driven by the environmental changes but by modifying functionalities to continually improve the machines. The formula for the mobility (M) dimension highlights that Machinery Inc. wants to bring a modification to their machines to the market every six months.

The time frame was set so short to push the R&D department to be more proactive in product modifications and not wait until similar functionality has already been introduced by competitors. Product quality must not be neglected, but time to market is an important criterion and is needed to stay competitive in the long run.

Volume flexibility

Machinery Inc. operates in a market with high demand fluctuation. For example, the production manager highlighted that the number of machines sold in 2006 more than doubled from the previous year, and that at the beginning 2007, one fourth of the volume sold in 2006 was already ordered. In addition to this increase in product demand, delivery terms have also become more stringent, with customers expecting product delivery in three months compared to the previous delivery time of six months. The increase in demand is a comfortable situation, with the history of the company highlighting that such a high fluctuation of orders was usual. To handle such changes in demand, Machinery Inc. has defined the required level of flexibility at a level of 9 out of 10, as illustrated in Figure 6.

Figure 6: Actual and required level of Volume flexibility of Machinery Inc.



Examining Machinery Inc. in detail it is apparent that for the dimension range-number (R-N) the actual and the required levels of flexibility are matching at the level of nine. Machinery Inc. reaches this level of flexibility because the company is banking capacity, meaning that at the shop floor, there is unused space as long as the demand is low. As soon as the demand increases, the company can use this space to produce additional machines. Temporary employees are hired during times of high demand and retirees are taken back to work. Retirees are the favored choice as they do not, in comparison with temporary employees, need to be trained and are ready to rejoin the company with short notice.

One major risk within the scenario of high increases in demand is the availability of raw material. Machinery Inc. is banking some raw materials as safety stock, but more and more relies on quick delivery times of suppliers. To prevent running out of raw material during times of peak demand, the company has eliminated some long-term contracts with key suppliers. The goal of Machinery Inc. is to handle this heterogeneity (R-H) with a banking flexibility strategy (Gerwin, 1993; Ketokivi, 2006), specifically storing or holding flexibility for future needs. Even if Machinery Inc. has identified some actions/practices to handle the fluctuations, the company has chosen a level of 7.5 as the actual position of range- heterogeneity. This means that Machinery Inc. still wants to improve the ability to handle the heterogeneity of demand. The mobility (M) in volume is considered quiet high by Chocolate Inc. at 8.5. Machinery Inc. follows the production principle of a one piece flow and pull system. As the volume in demand increases, it does not mean any difference within the production process. The capacity will be increased, but the production principle stays the same. Because enough capacity is available to cover the peaks in demand, the mobility is considered as high.

Examining Machinery Inc.'s quality data, it is apparent that as volume fluctuated, the more mistakes happen. Machinery Inc. traditionally was used to have an average demand of 22

machines per year. The increase in demand from 22 to 58 machines in 2006 has shown that even enough capacity was available and temporary employees have been hired, maintaining high levels of quality during times of high volume proved difficult, the actual level of uniformity for volume flexibility is therefore defined at 6.5. Rational for this is based on the survey and comments from the production manager:

“Our employees use to know for which customer they were working on at the moment. As soon as the demand increased, we started to work with order numbers instead of customer names. After this change, our employees did not pay as much attention on their work as before, because the prestige of working for a specific customer was lost”.

Based on discussions with managers, Machinery Inc. has a gap in the dimensions of R-H, M, and U, which need to be closed. To ensure that these gaps do indeed get closed, Machinery Inc. developed the following measurements:

Figure 7: Measures for Volume Flexibility

R-H: Supplier reliability = $\frac{\text{Number of unavailable raw material}}{\text{Total amount of ordered raw material}} \times 100 < 5\%$
M: Capacity = Maximum machine hours - planned down time
U: Error rate = $\frac{\text{Number of errors}}{\text{Total amount of production}} \times 100 < 2\%$
U: Customer complaint = $\frac{\text{Number of customer complaints}}{\text{Total amount of production}} \times 100 < 2\%$

The risk in not being able to deliver what was ordered in high fluctuation demand situations is not directly caused by capacity problems at Machinery Inc. but instead by the availability of the raw material. The risk of a pull production is that if the material is not available at the right time, the production process comes to a stop. To minimize this risk, Machinery Inc. has

made long term contracts with the key suppliers and has developed a supplier development program. Supplier reliability is needed to address volume heterogeneity (R-H). The target value of the supplier reliability is defined as less than 5%. If the key suppliers work on achieving this level of performance even if Machinery Inc. is not in a high volume phase, the reliability of the supplier should increase during high demand phases.

To measure the mobility (M) of volume flexibility, Machinery Inc. decided to measure the capacity availability, which means that every resource has a certain maximum runtime within a certain time period and a planned down time, where the resource is maintained. The subtraction of these two factors results in the capacity, Machinery Inc. can expect to have per resource. If enough capacity is available, the company can easily move from one state to another.

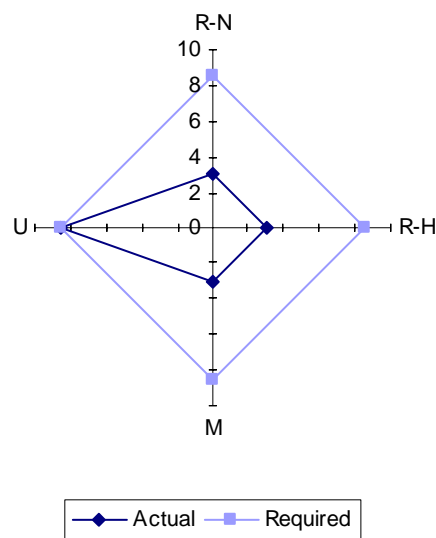
The uniformity (U) of the volume flexibility contains the amount of mistakes, which reduces the quality of the output. Machinery Inc. measures the error rates as well as the customer complaint rate to control the uniformity. To evaluate the error rate, Machinery Inc. measures the ratio between the amount of errors and the total amount of production. The target value is less than 2%: The customer complaint rate also must be smaller than 2%. Machinery Inc. does not accept a value higher than 2% because the company is committed to be a manufacturer of high quality products.

Labor flexibility

Although it could be encapsulated under volume flexibility, Machinery Inc. is also very concerned with labor flexibility (i.e., ease of employees moving from carrying out one set of tasks to a completely different set) and chose to consider it separately from volume flexibility. The production process at Machinery Inc. is very technical in nature and uses state-of-the-art machinery. In order to develop and produce new machines, the company requires well

trained employees in all departments. Because the company is isolated from the talent pool of the eastern and southern European confectionary cluster, it is not easy to obtain well trained and employees with the specific skill set relevant for the production of chocolate producing machinery. To address the lack of skilled labor, Machinery Inc. tries to train employees with less education as specialists on specific machines or processes. The process has resulted in limited cross-training as well as any tacit knowledge regarding the machinery and process leaving once the employee leaves the company. Figure 8 presents an assessment of labour flexibility for Machinery Inc.

Figure 8 - Actual and required level of labor flexibility of Machinery Inc.



Examining the range-number (R-N) dimension, the gap between the actual level of 3 and the required level of 8.5 shows this situation. Machinery Inc. requires additional highly skilled employees who can carry out a variety of tasks, as highlighted by the production manager:

“Because we are a tier-one supplier for the chocolate producers, the end customer does not know us. If it comes to hiring new employees, we do not have the same attractiveness as big and well known companies such as for example ABB or GE. Next to this, the food industry is known as an industry not paying the highest wages. Based on this starting position, you can imagine now how hard it is to find employees”.

The range heterogeneity (R-H) of the different tasks per position is high. The heterogeneity is a disadvantage if a new employee has to be hired. Based on a statement of the production manager, it takes in average 3 years until an employee is well trained and knows the different tasks. Machinery Inc. has defined the actual level of labor flexibility in this dimension as 3. Mobility (M) captures the ease by which an employee can switch from carrying out one set of tasks to another. To increase the mobility, Machinery Inc. recognizes the need to have employees cross-trained on a variety of machines and processes. Despite this need, Machinery Inc., has been slow in such training and as such rates itself at level 3 in terms of actual labor mobility. The broad knowledge that the employees have gained during their training ensures that employees understand their work activities as well understand the process steps before and after their own process step. As result, the uniformity (U) of labor flexibility, or the ability of the employees to do each task at the same level of quality is viewed to be high at 8.5.

Examining Figure 8, Machinery Inc. has gaps in the flexibility dimensions R-N, R-H, and M. To help determine when these specific gaps are closed, the following measurements have been developed by the company:

Figure 9 - Measures for Labor Flexibility

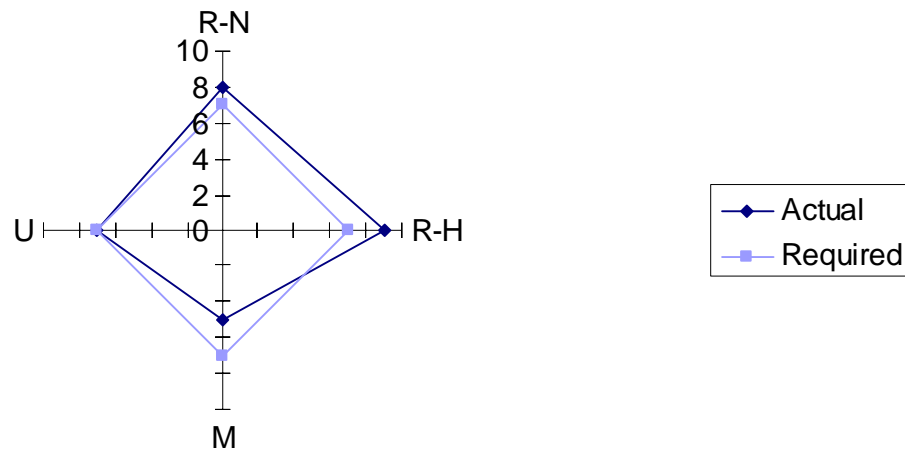
R-N: Advanced training costs = $\frac{\text{Amount of advanced training costs}}{\text{Number of employees}} < 3000 \text{ €per year (approx. 4100 US\$)}$
R-N: Advanced training time = $\frac{\text{Number of advanced training days}}{\text{Number of employees}} > 15 \text{ days per year}$
R-H: Structure of advanced training = $\frac{\text{Number of advanced trainings with a specific focus}}{\text{Number of advanced trainings}} > 10 \text{ days per year}$
R-H: Share of training costs = $\frac{\text{Training costs}}{\text{Amount of personal costs}} \times 100 < 10\%$
M: Job-Rotation = $\frac{\text{Amount of hours worked outside of the subject area}}{\text{Amount of hours worked per year}} \times 100 > 2000\text{h} = 20\%$

To capture the number of tasks that employees can carry out, Machinery Inc. has developed two measures of range-number (R-N), focused on training costs and time. The measurements focus on the average training costs and time for company employees. The employees need to have at least 15 training days per year, but the training should not cost more than 3000€ (approx. US \$ 3900) as most training is completed in-house as well as on-the-job. To capture improvements in the range-heterogeneity (R-H) of their employees, Machinery Inc. measures the structure or content of the training as a share of the training costs. The company has set a target value of at least 10 days of advanced training, but the costs per training session should not be higher than 10% of the personnel costs. With the advanced training, Machinery Inc. wants to ensure that the employees broaden their knowledge, as well as become specialists in the defined tasks they need to cover. For the measurements of mobility (M), Machinery Inc. measures the job rotation as a percentage of total hours work, ensuring that employees are familiar with a wide variety of tasks and can easily switch from one task to another.

Discussion

As we saw in the case of Machinery Inc., the company had an under investment or no gap in all relevant flexibility types. This is not necessarily always the case. A company also can have an over investment in certain dimensions of a flexibility type.

Figure 10 - Fictive example of the actual and required level of volume flexibility



Examining the fictive example in Figure 10 highlights some misalignments between actual and required flexibility. First, it is apparent that along the range-number and range-heterogeneity dimensions, the actual level of flexibility is greater than the required level. This indicates an over investment in flexibility by the organization. The organization must therefore take steps to reduce actual levels along the range dimension, as this is a waste and is not desired by the organization. By reducing actual levels of flexibility along this dimension (e.g., increase the capacity utilization of machines), managers may free up value resources (e.g., capital, labor) to address other areas of flexibility improvement or other initiatives important for the organization. The gap between required and actual levels of the mobility dimension indicates that the company must improve actual levels of this dimension. As the

required and actual levels for the uniformity dimension are equally, no changes are needed to this dimension at this time.

As shown in the case of Machinery Inc., this process is repeated for each flexibility type viewed important for the organization. The individual graphs indicate what flexibility types and along what dimensions must change. The case of Machinery Inc. showed that the graphs of the individual types of flexibility were helpful but did not satisfy the company completely. We saw that in addition to each specific flexibility type, organizations may want to identify any possible trends or patterns of deficiencies. For example, does the organization show a pattern of over investing in a specific flexibility dimension? Conversely, is the organization having a difficult time achieving a specific dimension across many flexibility types? As a result, once the critical flexibility types are developed individually, they are transposed onto a single diagram and summarized in a bar diagram. This gives the organization a complete picture of where flexibility deficiencies exist and allows them to develop a single strategy to address all deficiencies, instead of taking a piecemeal approach by focusing on each type separately. Figure 11 shows the final framework component to identify and close actual - required flexibility gaps that resulted out of the case study with Machinery Inc.

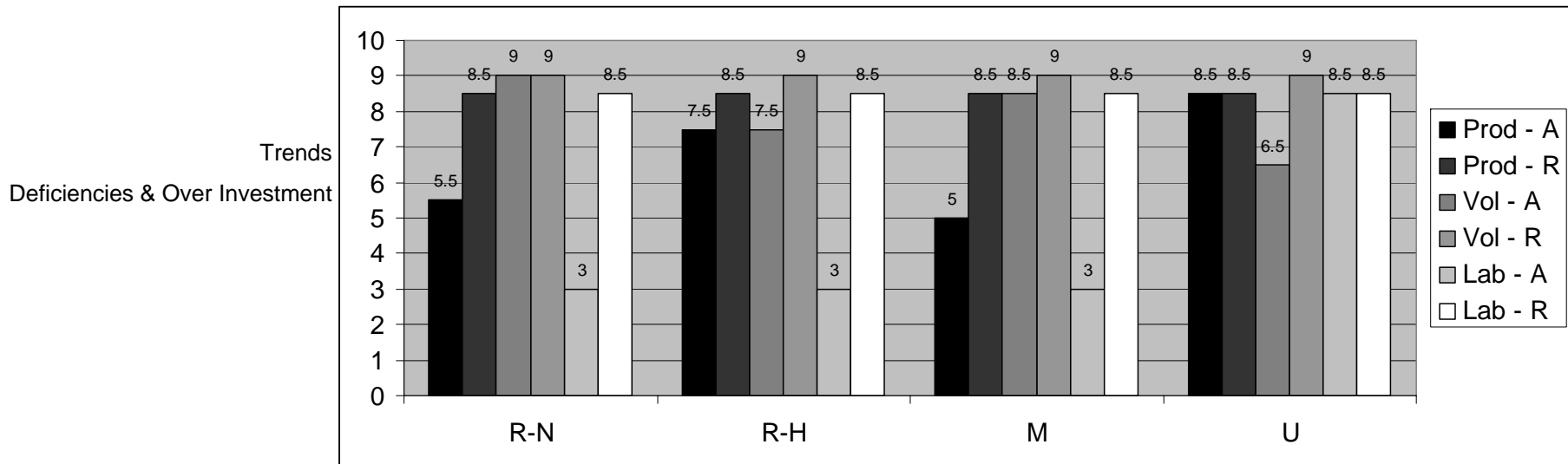
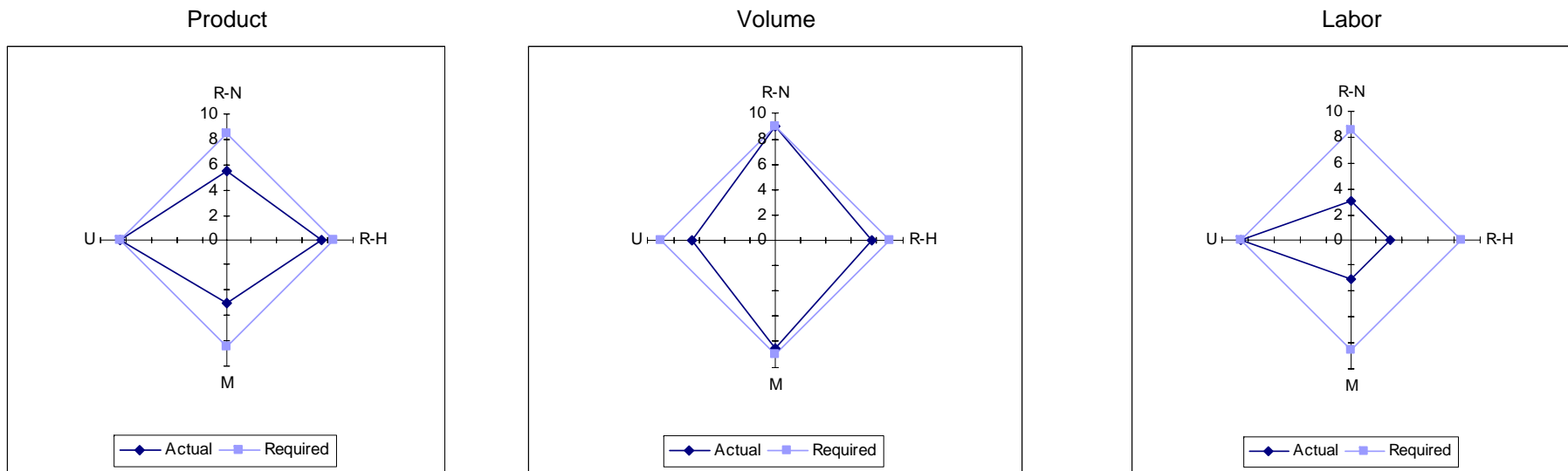


Figure 11 - Flexibility Gap Analysis of Machinery Inc

Even if Machinery Inc. had been very skeptical at the beginning of the case study, they were convinced at the end that the framework presented is a helpful instrument to visualize and measure flexibility. For example, the production manager stated that:

“The tool brought a new perspective of working with flexibility. The former buzzword has become something manageable, controllable and something that could be broken down into parts”.

Examining flexibility using an interdisciplinary and cross-departmental team is critical for the success of the framework, as it considers different perspectives of flexibility, allows for a more holistic view of flexibility, and ensures flexibility links to the different strategies (e.g. manufacturing, marketing, overall) are considered. The implications of cross-departmental input into flexibility decisions are best highlighted by the financial officer:

“The side effect of our discussions was that while we were discussing flexibility we also learned what was going on in the different departments and what their actual challenges were. Everybody learned to understand what consequences for example a delay in their tasks had within other departments and could discuss actual problems. The tool not only brought a good overview about our level of flexibility but also brought the involved departments closer together”.

The goal of a flexibility measurement exercise such as the one presented in this study is that it is not only done once, but instead performed periodically to ensure that the required levels of flexibility are still in fact required and that actual levels of flexibility are in fact being achieved. A framework, such as the one presented in this study, makes it easier for the organization to periodically measure flexibility and prevents it from becoming a one-time exercise, as emphasized by the production manager:

“We now have a simple tool to discuss our actual and required level of flexibility and because of the ease to use it, we will review the actual positioning periodically, say every six months, to ensure that we are closing the flexibility gap. We also have to discuss flexibility periodically to make sure that we have considered all the environmental changes”.

The overall summary of the feedback of the involved employees of Machinery Inc. was that the framework is easy to use, the company can use it as part of an ongoing process of flexibility measurements, and the framework has a high acceptance not only by the managers but also by the employees at the shop floor and those in related departments.

Limitations, Implications and Conclusion

This research illustrates through a case study that examining flexibility in relative form is a helpful approach for identifying the required flexibility types and levels needed by the organization and discrepancies between this required level and levels actually being achieved. Specifically, this study proposes and tests a framework for narrowing the gap between actual and required flexibility levels and helps ensure that the flexibility levels required are of the type and levels to help achieve the various strategies of the organization. The framework starts with the company through groups discussions with managers identifying the core flexibility types (e.g., volume, product, labor) needed to achieve the strategies of the organization. Next, the required levels of these flexibilities (i.e., range-number, range-heterogeneity, mobility, uniformity) are placed on a 10-point scale. After identifying required levels of flexibility, the company, using a short questionnaire, determines on the same scale actual levels of flexibility. The result of these two steps is a diagram which allows for the easy determination of where an over or under investment in flexibility exists. With the gaps identified, the company can now develop absolute measures to help trace that the gaps between required and actual flexibility levels are being closed.

This procedure not only focuses on short-term improvements and on quick wins in terms of flexibility, but also provides a long-term perspective. The actual and required level of flexibility should be reviewed after a defined period of time to take the latest internal and environmental changes into consideration. The defined target values also have to be reviewed

after some time to ensure that the targets still match the strategy the company has chosen. The significance of framework lies not only in the definition of the actual and required levels of flexibility, but also in the continuing review of them to ensure a fit between the company and its environment on the long-run.

The decision of where to position within the four flexibility dimensions (i.e., range-number, range-heterogeneity, mobility, and uniformity) is based on self-assessment. The company does not have a detailed structured questionnaire from which the position can be calculated. Instead, the position on the axes is based on environmental developments, internal knowledge and abilities, expected environmental change, and strategic goals. A more detailed questionnaire would allow for additional information about company conditions to be provided and therefore potentially allow for a more accurate determination of required and actual flexibility levels. Future research should focus on developing such a questionnaire.

To test the framework developed, a case study is used. Analysis of the case study data shows that the framework is useful for examining actual and required flexibility levels. However, as is normal with the case study approach, the generalizability of this study at this time remains unknown. Although we believe the technique is applicable across industries, the actual measurements presented in this study are specific to the needs and environmental and internal conditions of Machinery Inc. Those measurements adopted by Machinery Inc. are absolute measurements; however another company may instead choose relative measurements. Our goal was to let managers develop their own measurements, once they had a better indication of what flexibility types and dimensions they must focus on. As a result, the applicability of the absolute measures presented in this study to other companies and industrial sectors remains questionable, and their use must be approached with caution. Future research is needed to help identify a holistic set of cross-industry and industry specific measurements along each

of the four flexibility dimensions (i.e., R-H, R-M, U, M) for the most common flexibility types (e.g., volume, product, labor). In addition, this framework could be used to help examine flexibility in service organizations, which, as highlighted by Slack (2005b), is an area of research that is considerably lacking.

This framework is best used for examining the flexibility of a single manufacturing system, product, or process. It does not make much sense to use the framework for the overall organization because different product groups could possibly have different strategies (e.g. one product group can be low cost - high volume, whereas another product group from the same company can be high cost and customized). Different strategies require different levels of flexibility and with this would have different graphs in the framework.

Despite these limitations, this study has a number of important implications to both managers and researchers alike. For researchers of manufacturing flexibility, this study addresses a major gap of the existing flexibility implementation frameworks; specifically how to identify and eliminate gaps between required and actual flexibility levels. This particular study should help future researchers develop more relevant and easy to use frameworks for improving flexibility in organizations. To practicing manufacturing managers, this study provides an easy to use sequence of steps to help identify actual and required levels of flexibility and what dimensions need to be addressed to narrow this gap. The study considers both over and under investments of flexibility and in doing so highlights to managers that more flexibility is not always desired.

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Appendix

Questionnaire for product flexibility:

<p>Product flexibility:</p> <p>The ease with which new parts / products can be added or substituted for existing ones.</p>	<p>Product line: _____</p> <p><i>(R-N)</i></p> <ul style="list-style-type: none"> ▪ How often have you made modifications of your products based on environmental changes within the last three years? times ▪ How often did you make modifications of your products overall within the last three years? times <p><i>(R-H)</i></p> <ul style="list-style-type: none"> ▪ How much have the modifications differ from each other? <table border="1" style="margin-left: auto; margin-right: auto; text-align: center; border-collapse: collapse;"> <tr> <td style="padding: 2px 10px;">not at all</td> <td style="padding: 2px 10px;">minimal</td> <td style="padding: 2px 10px;">a little</td> <td style="padding: 2px 10px;">much</td> <td style="padding: 2px 10px;">very much</td> </tr> <tr> <td style="padding: 2px 10px;"><input type="checkbox"/></td> <td style="padding: 2px 10px;"><input type="checkbox"/></td> <td style="padding: 2px 10px;"><input type="checkbox"/></td> <td style="padding: 2px 10px;"><input type="checkbox"/></td> <td style="padding: 2px 10px;"><input type="checkbox"/></td> </tr> </table> <p><i>(M)</i></p> <ul style="list-style-type: none"> ▪ How long did it take in average to conduct the modifications based on environmental changes? (hours / days / weeks - underline correct entity) <p><i>(U)</i></p> <ul style="list-style-type: none"> ▪ How much did the quality decrease based on the modifications made? <table border="1" style="margin-left: auto; margin-right: auto; text-align: center; border-collapse: collapse;"> <tr> <td style="padding: 2px 10px;">not at all</td> <td style="padding: 2px 10px;">minimal</td> <td style="padding: 2px 10px;">a little</td> <td style="padding: 2px 10px;">much</td> <td style="padding: 2px 10px;">very much</td> </tr> <tr> <td style="padding: 2px 10px;"><input type="checkbox"/></td> <td style="padding: 2px 10px;"><input type="checkbox"/></td> <td style="padding: 2px 10px;"><input type="checkbox"/></td> <td style="padding: 2px 10px;"><input type="checkbox"/></td> <td style="padding: 2px 10px;"><input type="checkbox"/></td> </tr> </table>	not at all	minimal	a little	much	very much	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	not at all	minimal	a little	much	very much	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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<p>Open-ended Questions</p>	<p>Please describe circumstances that have forced you to introduce new or modify existing products.</p> <p>Please describe the process from the first trigger of a need / new idea until the product has been introduced.</p> <p>Which abilities enable you to introduce novel products or modify existing ones?</p> <p>What are the key drivers for your product flexibility?</p>																				