Abstract

Automation decisions are often based on vague ideas that it is always good to automate and thus reducing manpower. These decisions need however to be linked to company manufacturing strategies. If we study the manufacturing strategy field, we can see that these decisions give large consequences in many decision categories. Articles on manufacturing strategy content have been written by e.g. Skinner (1969), Wheelwright & Hayes (1985), Ward et al (1996), Hill (1995), and Swink & Way (1995). Hayes and Wheelwright (1984) developed the content, in terms of decision criteria, as they provided examples of decisions characteristics. This article reviews existing theory on manufacturing strategy content and highlights the implications for manufacturing strategy process when adding more decision characteristics from automation.

Keywords: manufacturing strategy, automation, decision categories

1. Introduction

Automation of production systems has often been treated as a means to reduce manufacturing cost and thus as a way of staying competitive even if the threat from low cost countries increases. In this aspect, automation has often been regarded as either on or off, i.e. either fully automated or entirely manual. This is however never the case since there could be a mixture with more or less assistance from the equipment. Even if automation decisions often lead to large investments in new equipment, and also give enormous impact on the financial result, they are rarely based on thoroughly developed strategic decisions (Winroth, et al, 2007). Säfsten et al (2007) described the content and process of automation strategies, where they state that automation does not constitute a strategy of its own, but the automation decisions
are included in a number of decision criteria within the traditional manufacturing strategy field. These criteria need however to be further developed in order to better cover automation. In this article, we propose a framework for managing the automation strategy process.

2. Method and material

This article is based on literature reviews and findings from a number of case studies within a Swedish national project, DYNAMO, aiming at developing industry’s view on automation.

3. Manufacturing strategies

Skinner (1969) presented in his seminal article findings from studies at American industry, where he stated that something needed to be done if they would not be helplessly behind in industrial development. The key success factor was coordinated manufacturing decisions based on true strategies. Today, most people accept that manufacturing is an important part of company activities, which should support overall company objectives and strategies. Several authors (e.g. Roth and Miller, 1992; Hayes and Clark, 1986) emphasise the fact that manufacturing can be a strong competitive weapon if it is run properly. According to Hill (2000), the task can be fulfilled with support from a well-formulated and implemented manufacturing strategy since a manufacturing strategy comprises a series of decisions, which, over time, provide the necessary support for the relevant order-winners and qualifiers of the different market segments of a company.

A strategy consists of the plan and the type of action needed to achieve defined objectives. Manufacturing strategy is here defined as a pattern of time-specific and market-specific decisions in structural and infrastructural areas supporting competitive priorities for a company. Manufacturing strategy is not only about making the correct decision that supports competitive priorities. It is more general than that and it creates and selecting operating capabilities for the future in a company (Hayes and Pisano, 1994). A manufacturing strategy is however long term and it should have a time perspective of two to five years.

A manufacturing strategy is a functional strategy, together with for example marketing, R&D, and accounting strategies. Together all functional strategies support the business strategy of a company (Hayes and Wheelwright, 1984). Swink and Way (1995) make a distinction between manufacturing strategy content and process.

3.1 Manufacturing strategy content

The content of a manufacturing strategy is concerned with aspects such as manufacturing capabilities and strategic choices (Dangayach and Deshmukh, 2001). The competitive priorities, often categorized as cost, quality, delivery aspects, and flexibility (e.g. Wheelwright and Hayes, 1985; Ward et al., 1996; Hill, 2000). They are achieved through a set of proper decisions within different decision criteria, which cover a number of strategic choices related to performing the manufacturing task. Production technology, capacity, facility, vertical integration, quality, production
planning and control, workforce, and organization are the most common decision criteria found in literature.

Already when defining corporate objectives, unless the procedure begins when founding the company, decisions depend on the existing capabilities of the company. The natural order when formulating the manufacturing strategies is however relevant. The whole process of formulating the manufacturing strategies is a never-ending loop, where the decisions depend on the capabilities and the strategy for developing the capabilities and the organization depend on the strategies. Thus strategies need constant revisions. But what decision criteria are important when making strategic decisions? Hayes and Wheelwright (1984) presented eight strategic decision criteria, each comprising several decisions to be considered regarding how to carry out the manufacturing, see Table 1.

Table 1 shows the decision criteria of the manufacturing strategy as described by Hayes and Wheelwright (1984) and Miltenburg (1995).

<table>
<thead>
<tr>
<th>Decision criteria</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process technology</td>
<td>flexibility, type of equipment, technology level, layout</td>
</tr>
<tr>
<td>Facilities</td>
<td>location, size, focus</td>
</tr>
<tr>
<td>Capacity</td>
<td>amount, acquisition time, type</td>
</tr>
<tr>
<td>Vertical integration</td>
<td>amount, degree, relations</td>
</tr>
<tr>
<td>Quality management</td>
<td>definition, responsibility, reporting</td>
</tr>
<tr>
<td>Human resources</td>
<td>skill level, wage, training and promotion policies, employment security</td>
</tr>
<tr>
<td>Organisation structure and control</td>
<td>relationship between groups, decision</td>
</tr>
<tr>
<td>Production planning and control</td>
<td>responsibility, rules and systems</td>
</tr>
</tbody>
</table>

Table 1. Manufacturing strategy decision criteria (Hayes and Wheelwright, 1984; Miltenburg, 1995)

Each of these decision criteria is important for the success of a manufacturing organization. The performance of the organization is never better than the weakest link and a poor result in one decision criterion can obstruct the success of the organization.

These decision criteria can be divided into two groups: structural and infrastructural decision. The structural decision criteria are characterized by their long-term impact; they are difficult to reverse or undo and they often require a substantial capital investment (Hayes and Wheelwright, 1984; Wheelwright, 1984).

Skinner (1986) further developed his thoughts about the structural decisions on manufacturing:

A manufacturing strategy describes the competitive leverage required of, and made possible by, the production function. It analyzes the entire manufacturing function relative to its ability to provide such leverage, on which task it then focuses each element of manufacturing structure. It also allows the structure to be managed, not just the short-term, operational details of cost, quality, and delivery. And it spells
out an internally consistent set of structural decisions designed to forge manufacturing into a strategic weapon. These structural decisions include:

- What to make and what to buy
- The capacity levels to be provided
- The number and sizes of plants
- The location of plants
- Choices of equipment and process technology
- The production and inventory control systems
- The quality control system
- The cost and other information systems
- Work force management policies
- Organizational structure

The infrastructural decision criteria include more tactical decisions. They generally do not require large capital investments and the decisions are more short term dealing with day-to-day questions. It can, however, be quite costly to perform changes also among the infrastructural decisions, which should by no means be neglected. The crucial issue is however to make the right combination of infrastructural and structural decisions that support each other. The infrastructural issues need to support the structural changes and technology development in order to make investments profitable.

A focused strategic objective or ‘manufacturing task’ is based on one or two of the seven objectives and is derived from the firm’s competitive strategy, economics, and technological opportunities. These performance objectives need to be supported by decisions on a number of categories concerning manufacturing. One problem encountered is that the decision categories described in the literature sometimes have different denominations for similar areas.

### 3.2 Automation in manufacturing strategy content

Automation is in the literature treated as one of the decisions concerning process technology. Since many of the decision areas are interlinked, a decision about automation directly has however impact on several of the other decision areas, as indicated in the following examples:

- The vertical integration is very important since a problem at the supplier will directly lead to problems at the systems integrator and, with an automated system, these problems will have to be taken care of probably without human support.

- The quality management system should be supportive to the technology level that we choose, including self-adjusting Statistical Process Control, SPC, and adaptive control.

- The skill level of the personnel needs to be in congruence with the technology level for managing the system, doing programming tasks etc. Some of the work tasks involved in a highly automated manufacturing system may be simple routine tasks, but it is also likely that new and very advanced tasks are created.
-With more competent personnel, who have been assigned responsibility, the corresponding authority needs to be included. If the organizational structure is highly hierarchical, the full potential of the personnel will be lost.

-The system for production planning and control also needs to be linked to the level of automation.

The other perspective of automation strategy becomes somewhat problematic, since it is a stand-alone decision and everything around the automation decision has to be adjusted to fit the automation. The decision criteria in Table 1 are however very much linked to the capabilities of the company, the whole organization, and even suppliers and customers. Thus it is a great risk that the decision makers do not have the whole picture and something happens that makes the investment less profitable.

3.3 Manufacturing strategy process

The manufacturing strategy process describes the formulation and implementation of a manufacturing strategy. This part of the manufacturing strategy area has attracted less attention in the research community than the manufacturing strategy content (Dangayach and Deshmukh, 2001), in spite of the difficulties associated with strategy implementation Maruchek et al., 1990).

<table>
<thead>
<tr>
<th>Decision area</th>
<th>Included considerations</th>
<th>Author/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant and equipment</td>
<td>Span of process, plant size, plant location, investment decisions, choice of equipment</td>
<td>Skinner (1969; 1978)</td>
</tr>
<tr>
<td>Equipment and process technology</td>
<td>Scale, flexibility, interconnectedness</td>
<td>Wheelwright and Hayes (1985)</td>
</tr>
<tr>
<td>Technology strategy</td>
<td>Type of technology, leading edge of technology or established technologies, develop technology internally or buying in</td>
<td>Slack et al. (2001)</td>
</tr>
<tr>
<td>Process technology</td>
<td>Nature of the production process, type of equipment, amount of automation, linkages between parts of the production process</td>
<td>Miltenburg (1995)</td>
</tr>
</tbody>
</table>

Table 2. Comparison of issues included within production process related decision areas.

Strategy formulation can be done mainly from two different views on competition: A resource- or a market-based view (Gagnon, 1999). With the resource-
based view, the issue is to make sure that the resources, capabilities and competencies are properly used as competitive weapons. With the latter view, manufacturing is regarded as a perfectly adjustable system following the rules dictated by the market, while the former view suggests that it is preferable to leverage the unique capabilities of the manufacturing function in order to change the rules of competition. The efforts within operations have been dominated by a market-based view of competition. Lately, a move towards a resource-based view has emerged and it is argued that focusing on developing, protecting, and leveraging a company’s operational resources and advantages to change the rules of competition is a preferred approach (Gagnon, 1999). In practice, it is, however, not a question of either applying the resource- or market-based view of competition when formulating manufacturing strategies. It is essential that requirements from market are considered, and that available manufacturing capabilities are used as wisely as possible. The formulation process is quite similar, independent of the assumed view of competition. With the resource-based view a possible process to formulate a manufacturing strategy is as follows (Gagnon, 1999):

1. An extensive analysis of the manufacturing capabilities.
2. Selection of core capabilities that can provide competitive advantages.
3. Formulation of strategies.

The traditional process for strategy formulation represents the market-based view on competition. With this as a starting-point, Hill (2000) proposed the following structure of actions in five steps:

1. Define corporate objectives.
2. Determine marketing strategies to meet these objectives.
3. Assess how different products qualify in their respective markets and win orders against competitors.
4. Establish the most appropriate process to manufacture these products (process choice).
5. Provide the manufacturing infrastructure to support production.

This list is of course very stereotyped and in reality there are iterative loops between all of these steps. Hill (2000) stated that there is no shortcut to success in the process of formulating strategies and designing supportive manufacturing processes. Already when defining the corporate objectives, unless the procedure begins when founding the company, the decisions depend on the existing capabilities of the company, which consequently have to be known to the management. Miltenburg (1995) suggests that the actual strategy implementation is guided by an implementation plan, with each decision area taken into consideration.

3.4 Automation in manufacturing strategy process

Similarly as for manufacturing strategy, the process of implementation needs consideration. The automation process, i.e. how to implement automation, is described (e.g. Kapp, 1997; Groover, 2001, Baines, 2004), as are issues to consider during implementation (e.g. Gupta and Cawthon, 1996). The USA principle, an automation strategy focusing on aspects to consider prior and during implementation of automated processes is suggested by Kapp (1997). USA stands for Understand,
Simplify, and Automate, and the strategy is applicable in different types of automation projects. Another automation strategy is described as checklists of the possibilities for improving a manufacturing system through automation or simplification (Groover, 2001). This strategy involves issues such as the combination of operations, simultaneous operations, or integration of operations.

Groover (2001) presented a specific automation migration strategy, which describes the implementation of automation during the various product lifecycle phases, see Figure 2. The purpose is to shorten the time for introducing new products to the market. It consists of a plan for evolving the manufacturing systems used to produce new products as the demand grows. Thus, during the first phase, manufacturing is performed manually and no extensive investments are needed. If the product is a hit on the market, each cell can be transformed into automated cells, and during the last phase, the high volume is met by connecting the stations together into a continuous flow with highly integrated automated cells. The advantages of the automation migration strategy are mainly:

- Short product introduction times
- Gradual introduction of automation
- It allows the company to postpone high investment costs when introducing products with an uncertain market forecast

This model suits however not all situations in manufacturing companies. It is suitable only to manufacturing of products with very long product life cycles, where it is worth the effort to change the way of producing. It does not provide any guidance concerning the appropriate task allocation and level of automation. It is also necessary to prepare the product for automated production or else the product has to be revised. Often the result after the simplification phase shows that automation is unnecessary since the manufacturing operation is better or cheaper performed manually.

Fig. 1. A typical automation migration strategy, adopted from Groover (2001).
4 Manufacturing systems

A manufacturing system is a collection of equipment, people, and procedures organized to accomplish the manufacturing operations of a company. Within a manufacturing system, a distinction can be made between facilities and support systems (Groover, 2001). The facilities of the manufacturing system consist of the factory, the equipment in the factory, and the way the equipment is organized. The support systems are the procedures used by the company to manage production and to solve the technical and logistics problems encountered in ordering materials, moving work through the factory, and ensuring that products meet quality standards.

Automation is the application of mechanical, electronic, and computer-based systems to operate and to control manufacturing. Automation implies that human labour, both cognitively and physically, is replaced by electronic or mechanical devices (e.g. Groover, 2001; Sheridan, 2002). In automated manufacturing systems, the operations are performed with a reduced degree of human participation. The level of automation is often described in discrete steps, i.e. manual, semi-automated, or automated, depending on the task allocation between operators and equipment.

4.1 Automated manufacturing systems

Process equipment may be automated in different aspects and automation has a long industrial tradition. Integrated and automated manufacturing systems, such as Flexible Manufacturing Systems (FMS), consisting of a number of integrated machines and control systems were first introduced in the early 1960’s (Merchant, 1961). Increasingly flexible automation of process equipment was enabled as computer technologies advanced rapidly during the 1970’s. The machines are equipped with computerized numerical control (CNC) and tool storage systems, which enable short setup times and thus small series production. The manufacturing systems area is constantly developing, and has dramatically improved.

Automation of manufacturing support system aims at reducing the amount of manual and clerical effort in product design, manufacturing planning and control, and the business functions of the firm. Manufacturing support systems are technologies that enhance the performance of the processes and sometimes they are absolutely essential in order to achieve the full potential of the manufacturing system.

Advanced manufacturing technology (AMT) is a collective name for modern and integrated manufacturing technology, such as computer aided design (CAD), computer aided manufacturing (CAM), and flexible manufacturing systems (FMS) (Chen and Small, 1996). Besides these technologies, AMT involves a large number of other technologies. The literature on AMT is often related to the physical equipment and its specific characteristics. AMT can be divided according to the different areas of application. A distinction can be made between design applications, manufacturing applications, and administrative applications (Boyer and Pagell, 2000). The different applications involve various types of automated tasks. CAD and computer aided engineering (CAE) are examples of design applications. Among the manufacturing applications, CAM, robotics, real-time process control systems, FMS, and automated material handling system can be mentioned. Electronic mails, knowledge
management system, decision support systems, material requirements planning (MRP), and enterprise resource planning (ERP) are examples of administrative applications of AMT. A common feature of these different applications of AMT is that they more or less involve computers and information technology, replacing human labour.

As previously mentioned one of the major problems with the technology oriented literature is that it concentrates on the specific applications and the potential improvements but fails to explain how to select technological investments that support a business (Hill, 2000). Another problem is that the issue of function allocation, i.e. the possibility of balancing the use of humans and technology is neglected.

5. **Refinement of the manufacturing strategy content**

How should decisions within process technology be regarded in order to take care of the multi-criteria area of automation? Today, consideration is mainly taken about choice of technology, but all the other manufacturing strategy criteria need to be taken into account and necessary improvements need to be identified and actions taken.

When automation is one of several aspects considered in the manufacturing strategy, the decisions concerning automation is a consequence of the manufacturing capabilities (such as cost, quality etc.) that the company wants to achieve.

The automation strategy is part of the decisions concerning the process technology. Since many of the decision areas are interlinked, a decision about automation directly has impact on several of the other decision areas, as indicated in the following examples:

- The vertical integration is very important since a problem at the supplier will directly lead to problems at the systems integrator and with an automated system these problems will have to be taken care of probably without human support.
- The quality management system should be supportive to the technology level that we choose, including self-adjusting Statistical Process Control, SPC, and adaptive control.
- The skill level of the personnel needs to be in congruence with the technology level for managing the system, doing programming tasks etc. Some of the work tasks involved in a highly automated manufacturing system may be simple routine tasks, but it is also likely that new and very advanced tasks are created.
- With more competent personnel who have delegated responsibility, the corresponding authority needs to be included. If the organizational structure is highly hierarchical, the full potential of the personnel will be lost.
- The system for production planning and control also needs to be linked to the LoA.

Process choice is often very much dependent on the actual LoA (Level of Automation) in order to create stable processes that are able of providing the desired output. The design of e.g. the facilities and the layout are closely linked to the LoA as well as how to handle the sourcing issues (Groover, 2001).
Groover (2001) points out that LoA influences the long term strategies of the company related to the level of competence and where to locate production. It also influences several output factors such as quality, delivery issues, and flexibility. The choice of automation level needs consideration already when starting up the design work. Different types of methodologies such as Design for Manufacturing/Assembly/etc (DfX) may be applied to consider automation aspects during product development.

5.1 Implications on manufacturing strategy content from choosing Level of Automation

We propose that a profiling of the capabilities is carried out prior to making a change in LoA. This profiling shows the capabilities in different decision categories and to what extent they support automation. A higher LoA normally demands more from the equipment, humans, and organization than lower levels.

<table>
<thead>
<tr>
<th>Decision areas</th>
<th>Level of automation (LoA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Process technology</td>
<td>-flexibility depending on operator competence</td>
</tr>
<tr>
<td>- flexibility</td>
<td>-general purpose equipment</td>
</tr>
<tr>
<td>- type of equipment</td>
<td>-low technology level</td>
</tr>
<tr>
<td>- technology level</td>
<td>-jumbled flow layout, functional</td>
</tr>
<tr>
<td>- layout</td>
<td>=&gt;</td>
</tr>
<tr>
<td></td>
<td>-flexible with general machines, less flexible with dedicated systems.</td>
</tr>
<tr>
<td></td>
<td>-high technology level. Often developed externally.</td>
</tr>
<tr>
<td></td>
<td>-line flow layout</td>
</tr>
<tr>
<td>Facilities</td>
<td>=&gt;</td>
</tr>
<tr>
<td>- location</td>
<td>-low cost countries</td>
</tr>
<tr>
<td>- size</td>
<td>-often smaller</td>
</tr>
<tr>
<td>- focus</td>
<td>-general purpose</td>
</tr>
<tr>
<td></td>
<td>=&gt;</td>
</tr>
<tr>
<td></td>
<td>-high cost countries</td>
</tr>
<tr>
<td></td>
<td>-often larger</td>
</tr>
<tr>
<td></td>
<td>-general/special</td>
</tr>
<tr>
<td>Capacity</td>
<td>=&gt;</td>
</tr>
<tr>
<td>- generally lower capacity</td>
<td>-generally higher capacity</td>
</tr>
<tr>
<td>Vertical integration</td>
<td>-low</td>
</tr>
<tr>
<td></td>
<td>=&gt;</td>
</tr>
<tr>
<td></td>
<td>-high (JIT supply)</td>
</tr>
<tr>
<td>Quality management</td>
<td>-uneven quality</td>
</tr>
<tr>
<td></td>
<td>=&gt;</td>
</tr>
<tr>
<td></td>
<td>-even quality, process control</td>
</tr>
<tr>
<td>Human resources</td>
<td>-skilled handicraft</td>
</tr>
<tr>
<td></td>
<td>=&gt;</td>
</tr>
<tr>
<td></td>
<td>-skilled maintenance personnel, low competence simple tasks</td>
</tr>
<tr>
<td>Organization structure</td>
<td>=&gt;</td>
</tr>
<tr>
<td>and controls</td>
<td>-need decentralized structure</td>
</tr>
<tr>
<td></td>
<td>=&gt;</td>
</tr>
<tr>
<td></td>
<td>-possible with centralized but generally better with delegated authority</td>
</tr>
<tr>
<td>Production planning and control</td>
<td>-decisions made by operator</td>
</tr>
<tr>
<td></td>
<td>=&gt;</td>
</tr>
<tr>
<td></td>
<td>-decisions made by equipment/programs</td>
</tr>
</tbody>
</table>

Table 2. Manufacturing capabilities in decision categories based on Miltenburg (1995)

Table 2 should be interpreted as follows:

- If the LoA should be increased, a LoA profiling of the capabilities should be carried out in order to detect suitable improvements that can better support the new stage.
- The higher the LoA the higher the complexity in each decision area. This means that increasing the LoA does not necessarily solve all existing problems. The underlying reasons for problems need to be identified and solved prior to increasing the LoA.
A mismatch in the profile may lead to sub-optimizing the production and in turn jeopardizing the whole project.

If we have a mismatch in the profile, the capabilities need to be adjusted. One problem is however that there may be a trade-off situation between them and this issue is described in the next section.

6. Implications on manufacturing strategy process

We propose a framework for managing the automation strategy process, combining the bottom-up and top-down activities, see Fig 2. We need both bottom-up activities, i.e. studying the existing production and its capabilities, as well as top-down, which could include market situation and top management view on the company and their long term strategies. These two approaches meet in a comparison where the existing system, LoA etc is compared with the desired corporate intentions.

Necessary decisions on actions are made when these two views do not match. This is a never ending study with the aim to take care of changes in the requirements and circumstances. In this way an agile situation is created which is able to adopt to comparatively small and short term variations. Thus robust production is enabled.

Fig 2. Automation strategy process.
The process has two parallel lines of activities:

-the bottom-up perspective, starting with the existing production system and measures its performance

-the top-down perspective, which starts at the competitive priorities and lays the path for how production shall contribute to company success.

These two perspectives meet at the final stage, where suitable changes are identified and taken. This is however a never-ending iterative loop in line with Japanese production philosophies of continuous improvements.

7. Further research

The automation strategy process framework proposed in this paper needs to be tested and further elaborated in order to become a decision support tool.

8. Acknowledgement

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