AUTOMATION STRATEGIES
– REFINEMENT OF MANUFACTURING STRATEGY CONTENT

[004-0257]

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Abstract

Automated manufacturing systems are regarded as highly productive, which improves company’s competitiveness. Many companies consider automation as either fully automated or entirely manual. This is never true since there is always a combination of automated and manual tasks. The delicate issue is to choose the level of automation, LoA, which is best for the purpose. When planning and implementing automated manufacturing systems, a large number of issues need to be considered. Traditional manufacturing strategy theory however treats automation as one subset of process technology decision category. In our research we have come to the conclusion that automation decisions affect much more of the company’s operation activities. Thus, there is a need for developing the manufacturing strategy field in order to embrace relevant aspects/decisions in all of the decision categories. This paper aims at bridging the gap in traditional manufacturing strategy theory and highlights the additional decisions that are necessary in order to cover automation.

The authors suggest a decision support tool that highlights the different actions that are needed when changing the level of automation in manufacturing systems.

Keywords: Manufacturing strategy, Automation strategy, Level of automation, Manufacturing system
1. Introduction

Automated manufacturing systems are often regarded as highly productive, which potentially improves the company’s competitiveness. This is a relevant matter for manufacturing companies today, considering the increasing global competition and the threats of outsourcing to low wage countries, etc. When planning and implementing automated manufacturing systems there is however a number of issues to consider. Besides high investment costs, automated systems are vulnerable to unforeseen situations where no predefined solutions can be applied. The prevalent solution is to combine manual and automated operations, thus achieving a semi-automated manufacturing system. Such hybrid systems are able to reap the benefits from added efficiency and productivity resulting from automation. At the same time, semi-automated systems utilize the flexible resources provided by the humans in the system. An appropriate allocation of tasks between technology and operator contributes to the creation of competitive manufacturing system.

In order to support the achievement of a company’s overall objectives, the decisions on automation need to be in congruence with these objectives. The fulfillment of objectives is supported by formulation and implementation of strategies decomposed at different levels within a company. Based on previous results, we argue that decisions concerning automation should be treated as a number of several decisions included in a manufacturing strategy, i.e. the automation strategy is part of the functional manufacturing strategy (Säfsten et al., 2005). The specific aspect treated is the content of automation strategies.

Existing theory within manufacturing strategy field today describes decisions on automation very briefly and the choice is mainly described as whether to automate or not and this decision is a part of the process technology decision category. This gives, however, a very simplified picture and no support is given on how to choose the most adequate level of automation, LoA. Within the ongoing project DYNAMO, which aims at developing knowledge on consequences of different choices on automation, we have shown the possibilities to choose the right LoA, which in turn calls for a more developed decision model. Automation involves many other decisions from all the other decision categories. In this article we present this model, which, together with the company’s manufacturing strategy, can help the company in making successful automation decisions. The article aims at bridging the gap in traditional manufacturing strategy theory and highlights the additional decisions that are necessary to make in order to cover automation.

2. Method and material

Research presented in this paper is carried out as one part of an ongoing Swedish research project, DYNAMO\(^1\) - Dynamic Levels of Automation. DYNAMO is a three year project, ending in 2006. The aim of DYNAMO is to provide industry with design, measurement, visualisation, and management tools for dynamic levels of automation in manufacturing. Dynamic levels of automation, i.e. the possibility to change and vary the LoA in response to internal and external requirements, are useful

\(^1\) The project is financially supported by The Swedish Foundation for Strategic Research through its research program ProViking. A number of manufacturing companies also support the research by actively taking part and giving access to their knowledge and premises.
during multiple phases of the product realization process and are expected to increase manufacturing system’s overall robustness. This paper focuses on aspects mainly related to the management of dynamic levels of automation – formulation and use of automation strategies within the area of industrial manufacturing.

This paper is based on a literature review, a series of interviews of a total of 16 respondents, a Delphi-study, as well as case studies at a number of Swedish companies. Out of the respondents in the interviews, three represented companies with less than 500 employees and thirteen respondents represented larger companies. The interviews were carried out at the seven companies within the DYNAMO-project, which represent a wide range of the industrial field, both in terms of industrial sector as well as in size.

The purpose of the Delphi-study was to partly capture the perception of terms such as levels of automation and automation strategies among production managers and industrial engineers. The Delphi methodology intends to iteratively distribute a limited number of questions to a group of experts, each round presenting the results from the previous round and in that way reach consensus on important issues (Williamsson, 2002; Fredenhall and Gabriel, 2004). The study was carried out as a survey among 82 respondents out of which 45 fulfilled the second round of the Delphi-study. The respondents of the Delphi-study represented metal industry, automotive industry, furniture industry, and wood manufacturing industry.

3. **Semi-automated and dynamic manufacturing systems**

Companies often consider, according to the interviewees, automation as “On-Off”, i.e. work tasks are either fully automated or entirely manual. This is often not really true if the manufacturing system and the way of working are analyzed more thoroughly. The LoA can vary along a continuous scale between the two extremes and could normally be considered as semi-automatic. One problem that often emanates from choosing the wrong LoA is that the companies’ manufacturing capabilities, defined by Hayes & Wheelwright (1984), do not support the automation decisions. There are many driving forces concerning automation and one of the major issues is to automate for financial reasons. A focus entirely on cost issues may however lead to sub optimization (Brown, 2001). The success of an automation project is however dependent on the underlying supporting capabilities of the company and with insufficient support the project may be unsuccessful. Other objectives for automation are, according to the Delphi-survey, shown in table 1. The question was: ‘Automation decisions should be based on…’ and each suggested reason was graded.
From table 1 we can note that finance and productivity are very important issues when making automation decisions, as well as quality issues. Higher demands on the companies to improve working environment is also a highly contributing factor for automation. Lack of accessible workforce is a subordinate issue, which is a bit surprising. The number of people directly involved in manufacturing operations probably drops due to implementation of automation, but on the other hand the competence requirement increases for at least some of the remaining personnel. The fact is that, when discussing with many Swedish company representatives, one of the most severe problems mentioned is that they lack competent personnel to run the more advanced equipment.

A problem is that the ‘optimum’ LoA could vary depending on the specific circumstances, even during a product life cycle. If it is possible to alter the LoA very rapidly, as circumstances change, we could reach a very dynamic situation. Such a state is however not entirely unproblematic, since the capabilities in all the different manufacturing decision categories need to be in congruence. Either these functions are dimensioned for the most advanced situation or they are very flexible and can adjust rapidly.

### Dynamic levels of automation

Decisions on automation are more delicate than many people may consider. The decisions are not binary, i.e. either on-off, but involve the choice about to what extent the system should be automated, i.e. LoA. The LoA is also not static, but can be modified and adapt to changes of conditions for manufacturing. If this adaptation is performed rapidly we could reach a state of dynamic LoA. Frohm et al (2005) have described LoA according to a scale reaching from 1 to 9, in respect of automation of both mechanical and information tasks, see Figure 1.
Generally a high LoA has the following characteristics: *The process is performed automatically without human involvement, but the operator may be called upon in case of problems or for making decisions. Manual tasks are limited to surveillance and, in some cases, decision making.*

A low LoA could be described as: *The task will not be carried out without continuous presence of an operator who can control the process or carry out the work tasks. Only a limited number of sub-processes may be performed within one cycle without human involvement.*

These scales are intended to help companies when making decisions on what LoA could be the most advantageous for their specific conditions. A dynamic LoA is reached when the system is able of rapidly adapting to changes in the conditions for manufacturing. These changes could be that the manufacturing system is performing a ramp-up and product and processes need to be ‘debugged’ and it could be relevant to involve more operators during this phase. When the process is stable the operator involvement can be reduced, i.e. increasing LoA. Choice of a certain LoA however calls for a match between capabilities of the different manufacturing strategy decision criteria. Next section will describe some problems that may occur when having a mismatch between capabilities and choice of LoA.

### 3.2 Problems associated with automation

Investments in automation are often justified for financial reasons solely. These decisions need however to take into consideration the company’s capabilities in a number of aspects. These aspects are further described in chapter 5. If the company chooses a LoA that is not supported by a number of functions, the outcome of the automation project will not be satisfactory.

One common problem is when the operators do not have proper competence in managing the sophisticated equipment of a highly automated manufacturing system. One company, acting in the foundry branch, has invested in automated manufacturing cells. They do not however dare to connect the cells into a continuous flow system since the operators do not cope with the increase in complexity.

Another common way of regarding automation is when top management wants to invest in new and more advanced equipment just to have a show case and in that way impress on the customers. One large company, within the defence sector, had the most advanced manufacturing cell and it was described in numerous research articles. When studying this cell it was obvious why the pictures were so nice and everything...
so clean. The cell had never been operating during the two years since it was installed due to large technological problems related to computer interfaces and control.

These examples show the importance of adapting a broader perspective on automation. A further development of the existing manufacturing strategies will be described later.

4. Automation strategy - a subset of manufacturing strategy

Two approaches to decision making on automation have been identified (Winroth et al. 2006): the bottom-up and the top down approaches. Apart from which approach is adopted, best results are achieved if the decision is well supported at all levels concerned and that it is in line with the company’s overall objectives. One good example is the Swedish spring manufacturer, Lesjöfors, who had a green-field opportunity a few years ago. Lesjöfors AB is one of Europe’s leading manufacturers of springs. Their product areas are industrial springs, strip springs, automotive springs, and gas springs. In year 2003 they had about 400 employees and an annual turnover of just over 570 MSEK (2005 figures: 450 employees and 600 MSEK). The annual growth has been around 15% for the past ten years. The present plant is fairly new since the old one was destroyed by fire in year 1996. The rebuilding of the plant is described in Bellgran and Säfsten (2005). The main key to success, according to the company’s own opinion, has been a combination of good industrial engineering and business development. Important success factors are considered to be in-house product development and good control of the manufacturing process, which includes tool manufacturing and methods planning. Their competitive priorities are short development time, flexibility, and reliable deliveries. The start of the new factory was in fact an opportunity to create something really well-planned. The analysis work in connection with planning of the new plant included categories such as:

- Customer segment, qualifiers and winners
- Product mix, processing position
- Technical resources and their main characteristics
- Product-position/-profile
- Production flow analysis
- Decision management

The product range was categorized and a product profiling was performed, where products and markets, manufacturing, and different possible process choices were matched against each other. The result was that the plant was organized in four different production flows, which are well-suited for each category of products. The delivery precision and reliability have improved considerably compared with the old plant. Other consequences are reduced lead time, from between four and five weeks to ten days, the productivity has more than tripled, the capacity doubled, and the production area has been reduced to half.

Winroth et al (2006) describe several cases, both successful and unsuccessful, on consequences of linking or not linking automation decisions to manufacturing strategies. The most successful case, Lesjöfors AB, had a greenfield possibility when the plant was burned down. Thus they could start from scratch building a modern plant and designing the manufacturing system based on a strategic survey of the company’s capabilities. The result is quite amazing, with a drastic increase in productivity and profit. This proves that automation should be supported by manufacturing strategy and that it is not a question of ‘on or off’.
5. Current theories on manufacturing strategy

Manufacturing strategy theory was to a great extent developed by Wickham Skinner, starting with his seminal article in 1969 (Skinner, 1969). 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, 1995) 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). It is relevant also to make a distinction between manufacturing strategy content and process (Swink and Way, 1995).

5.1 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 areas, i.e. strategic choices.

Decision areas concern 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 areas in literature. Table 2 shows which decision areas a number of researchers have considered.
Table 2. Decision areas described in literature.

<table>
<thead>
<tr>
<th>Decision area</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 3. Manufacturing strategy decision areas (Hayes and Wheelwright, 1984; Miltenburg, 1995)

These decision areas can be divided into two groups: structural and infrastructural decision. The structural decision areas 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 areas 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. The content of the decision categories in various literature is interpreted which leaves a possibility for other groupings than the following.

For example the decision area, or equally decision category, Plant and equipment (Skinner, 1969) is also called Production process (Olhager, 2000), and Equipment and process technologies (Wheelwright and Hayes, 1985). Furthermore, different groupings than those provided originally by the decisions categories are used where it has been motivated to separate the content in smaller parts, e.g. Plant and equipment contains structural decisions concerning both the production process and the facility (Skinner, 1969), which means that both Production process and Facility get a mark in the overview provided.

Automation decisions are normally dealt with within the process choice criteria, but this is not sufficient since automation decisions influence almost the entire company.
5.2 Trade-off

Manufacturing choices and decision categories have been discussed by many authors during the years since manufacturing strategy became a widely spread theme in the late 60s and early 70s. Much of the work on identifying relevant decision areas is based on the trade-off decisions proposed and grouped by Skinner (1969, 1978). Originally the trade-offs implied the trade-off made within the decisions in the different decision areas. As, for example, the decision about span of processes involves a trade-off as to whether to buy or make. Implicitly these trade-offs bring with them trade-offs between the competitive priorities, which is also implicit in the term ‘competitive priorities’.

The trade-off decisions are necessary since there are conflicts in the structures required to support the alternative priorities (Swink and Way, 1995). Some of these conflicts are illustrated in table 4.

<table>
<thead>
<tr>
<th>DECISION AREA</th>
<th>DECISION</th>
<th>EXAMPLES OF TRADE-OFFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant and equipment</td>
<td>Span of process</td>
<td>Make or buy</td>
</tr>
<tr>
<td></td>
<td>Plant size</td>
<td>One big or several small</td>
</tr>
<tr>
<td></td>
<td>Plant location</td>
<td>Near market or near material</td>
</tr>
<tr>
<td></td>
<td>Investment decisions</td>
<td>General- or special-purpose</td>
</tr>
<tr>
<td></td>
<td>Choice of equipment</td>
<td></td>
</tr>
<tr>
<td>Production planning and</td>
<td>Frequency of inventory taken</td>
<td>Few or many breaks in production</td>
</tr>
<tr>
<td>control</td>
<td>Inventory size</td>
<td>High or low inventory level</td>
</tr>
<tr>
<td></td>
<td>Degree of inventory control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>What to control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quality control</td>
<td>High reliability or low cost</td>
</tr>
<tr>
<td></td>
<td>Use of standards</td>
<td></td>
</tr>
<tr>
<td>Labor and staffing</td>
<td>Job specialization</td>
<td>Highly specialized or not</td>
</tr>
<tr>
<td></td>
<td>Supervision</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wage system</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Industrial engineers</td>
<td></td>
</tr>
<tr>
<td>Product design and</td>
<td>Size of product line</td>
<td>Customer specials or not</td>
</tr>
<tr>
<td>engineering</td>
<td>Design stability</td>
<td>Frozen design or many ECO(^2)</td>
</tr>
<tr>
<td></td>
<td>Technological risk</td>
<td>Leader or follower</td>
</tr>
<tr>
<td></td>
<td>Engineering</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use of manufacturing engineering</td>
<td></td>
</tr>
<tr>
<td>Organization and</td>
<td>Kind of organization</td>
<td>Functional or product focus</td>
</tr>
<tr>
<td>management</td>
<td>Executive use of time</td>
<td>Large or small staff group</td>
</tr>
<tr>
<td></td>
<td>Degree of risk assumed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use of staff</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Executive style</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Trade-off decisions in manufacturing - or "you can’t have it both ways" according to Skinner (1969, 1978)

6. 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

\(^2\) ECO = Engineering Change Order
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 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.

### 6.1 Tentative decision support tool

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.
### Decision areas

- **Decisions**

<table>
<thead>
<tr>
<th>Process technology</th>
<th>Level of automation (LoA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- flexibility</td>
<td>1</td>
</tr>
<tr>
<td>- type of equipment</td>
<td>5</td>
</tr>
<tr>
<td>- technology level</td>
<td>9</td>
</tr>
<tr>
<td>- layout</td>
<td></td>
</tr>
</tbody>
</table>

- **Process technology**
  - flexibility depending on operator competence
  - general purpose equipment
  - low technology level
  - jumbled flow layout, functional

- **Facilities**
  - location
  - size
  - focus

- **Capacity**
  - generally lower capacity
  - generally higher capacity

- **Vertical integration**
  - low
  - high (JIT supply)

- **Quality management**
  - uneven quality
  - even quality, process control

- **Human resources**
  - skilled handicap
  - skilled maintenance personnel, low competence simple tasks

- **Organization structure and controls**
  - need decentralized structure
  - possible with centralized but generally better with delegated authority

- **Production planning and control**
  - decisions made by operator
  - decisions made by equipment/programs

| Table 5. Manufacturing capabilities in decision categories based on Miltenburg (1995) |

Table 5 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.

### 6.2 The issue of trade-off and automation

When improving trade-off linked decision categories, it may be appropriate to improve one decision category at a time, according to Winroth (2004). An example of a movement, following schematic two-dimensional relation curves, is shown in figure 2 (adopted from Slack & Lewis, 2002, p. 97). One problem is that the decisions are interlinked and almost all decisions may influence each other. The combination of two interlinked performance categories can follow a so-called trade-off or relationship curve. The two variables are traditionally negatively linked to each other. In the figure, position A supports a specific combination of decision area X and Y. If the
competitive analysis indicates that decision area Y is an important order-winning criterion, and reduced performance in decision area X is acceptable, the trade-off curve can be followed up to position B. If this performance reduction is not acceptable, and an improvement in both aspects is necessary, the company should aim at an improved trade-off. This could lead to position C. An improvement from point A to point C is however difficult to perform in one step. Thus, an improvement in decision area X, while maintaining decision area Y, is first performed (reaching the A’). If this improvement is maintained, the next step is to improve decision area Y, while maintaining performance of decision area X, and point C is reached. The real life is however more complicated and the trade-off situation is multi-dimensional with several factors affecting each other. This leads to the need for addressing several decision categories when trying to improve one single strategic parameter. Some of these decision categories are closely linked together and may sometimes be experienced as contradictory and thus trade-offs need to be made.

Hayes et al (2005) have elaborated further on what they call ‘Improvement pathways’, describing possible ways of improving performance. But they have still only described bi-dimensional trade-off situations. Multi-dimensional trade-offs rapidly become extremely complex.

7. Conclusion and discussion

Existing theories on manufacturing strategy do not give enough support when choosing LoA of a manufacturing system. There is too little known about the consequences of different choices of LoA. With the help of the results from the DYNAMO-project, there is at last an opportunity to refine the base for decision making. In this article, we have described ideas about what decision areas that affect, and that are affected by, choice of certain Levels of Automation, LoAs, and also how the capabilities in each decision area can be improved in order to get a better match between the areas.

8. Further research

These models need further elaboration and empirical verification in order to become a useful support tool that can help practitioners in their decision making.
9. Acknowledgement

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