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Aligning manufacturing strategy and levels of automation: A case study

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ABSTRACT

Research has shown that alignment between manufacturing strategy and decisions regarding automation are often of an ad hoc nature, i.e. the support for automation decisions is poor. Support tools to find an appropriate level of automation are thus needed in order to achieve more efficient and robust production systems. The methodology presented in this paper contains five sub-processes where the chosen level of automation is aligned with the manufacturing strategy. Together they form an automation strategy, which secures a desired direction of the firm and also supports robustness and reliability of the manufacturing system due to the holistic approach chosen.

Keywords: Levels of Automation, methodology, strategy formulation, manufacturing strategy and systems, Swedish industry

JEL classification: L23

1. Introduction and background

Research has shown the importance of integrating humans and technology in manufacturing automation, thus supporting sustainable and robust manufacturing systems. Evidence from U.S. companies indicate the importance of including human aspects when implementing advanced manufacturing technology (Chung, 1996). A balanced and holistic approach to automation makes it easier to find an appropriate level of automation for best system performance (Martin et al, 1991). The relationship between humans and technology can be viewed as a continuum from fully manual to fully automatic by approaching the sharing of tasks between the human and technology (Frohm, 2008). This concept is called levels of automation (LoA). Levels of automation is a concept which refers both to mechanized and cognitive tasks allocated between the human and technical equipment and ranges from 1 to 7 on a reference scale (Granell et al, 2007; Frohm, 2008).

Empirical findings indicate correlation between a high extent of automation and increased extent of complexity and flexibility of social factors (Lin and Chen, 2000). However, there is a difference between the content and process of manufacturing strategy according to traditional manufacturing strategy framework (Anderson et al, 1989; Leong et al, 1990). Studying manufacturing strategy process show that decisions regarding automation tend to be rather of an ad hoc nature than planned activity (Winroth et al, 2007¹), i.e. the level of automation is decided from product to product depending on volume (Granell, 2007) and there are no support systems guiding decisions. Thus, there is a need for developing tools which support alignment of both strategy and operational levels for reconfiguration of automation levels (Lindström, 2008).

Within the manufacturing strategy literature, decisions regarding automation and more specifically, levels of automation have traditionally been viewed as a structural decision category within the manufacturing strategy literature. On the other hand, decisions regarding human resources are considered as an infrastructural decision within the traditional manufacturing strategy formulation (Hill, 2000; Slack and Lewis, 2002; Miltenburg, 2005). The decision category for automation is named process technology and refers to equipment for production (Hill, 2000; Slack and Lewis, 2002; Miltenburg, 2005). This view is however technical as it does not take into consideration the integration of humans and technology and fails to explain the selection of appropriate technological investments that support a business (Hill, 2000). However, in Slack and Lewis (2008), automation is viewed as one dimension of process technology which consists of a mix of process technology and humans and stretches between high acuity and judgement and low acuity and judgement.

Thus, an alternative and newer approach in viewing automation is the task sharing approach (Satchell, 1998), which considers that a specific task is shared between both the human and technology. A survey made in Sweden during 2005 among production experts showed that 53 of the 62 respondents believed that policies regarding choice of manufacturing processes should be considered to a very high or high degree when formulating manufacturing strategies (Granell et al, 2006). Policies are here understood as modification of the manufacturing system. Moreover, the need for regular review of manufacturing strategies has been emphasized by Hayes and Wheelwright (1984) as well as by Platts and Gregory (1990), who state:

“Manufacturing strategies must not only be consciously developed but they must also be subject to regular review; otherwise there exists the danger that the elements of the strategy fail to develop, as the business develops, leading to both internal and external inconsistencies often with serious manufacturing implications” (Platts and Gregory, 1990, p.5).

To review and guide the manufacturing strategy formulation process, Platts and Gregory (1990) suggest several audits and an audit process to formulate manufacturing strategy. This audit process identifies manufacturing objectives, measures current manufacturing performance, determines the effects of current manufacturing practices, and identifies where changes are required (Platts and Gregory, 1990). The current manufacturing performance identifies existing practices from a traditional approach with viewing processes as technical entities and human resources as human processes. Hence, the integration of humans and technology is not considered in the work of Platts and Gregory (1990) and therefore there is a need to deepen and to embed human centred approaches to automation in manufacturing strategy. Also in the implementation of advanced manufacturing technology other aspects are important such as organizational culture and systematic practices (Lewis and Boyer, 2002).

Research on levels of automation presented in this paper has been done in an exploratory way, developing a methodology for measuring levels of automation (Granell et al, 2007) and a methodology for analysing and choosing levels of automation (Lindström, 2008). The purpose with the methodology for formulation of automation strategy is to choose an appropriate level of automation which is aligned with the manufacturing strategy of the firm where the measurement takes place. Further, research has shown that alignment between manufacturing strategy and decisions regarding automation are often of an ad hoc nature, i.e. the support for making automation decisions is poor. In summary, there is clearly a need for developing support tools to find an appropriate level of automation for more efficient and robust production systems. The aim with this paper is to present a framework for embedding levels of automation as part of the manufacturing strategy formulation process.

2. Theoretical framework

This section describes the frame of reference upon which the research presented in this case study is based.

2.1 Automation

The reasons for automating can be viewed from different perspectives, either from a company perspective or from the perspective of the production system designer, who pays special attention to human factors when automating. According to Groover (2001), there are nine reasons for automating from the perspective of a company where productivity is in focus, and four reasons for system designers to automate to support or replace human work (the human factors view) (Wickens et al, 2004), see table 1. Table 1 lists reasons for automating tasks, but on the other hand, there is a number of situations where manual labour is to prefer: when items are technically too complicated to assemble or manufacture with the help of a machine, when the product life cycle is short and a fast market introduction is required, for customized products, and when the demand is fluctuating (Groover, 2001).

Automating a process can be a success, or it can be accompanied by failures and problems. Consequences of automation are mostly described in the human factors literature where most frequent problems mentioned are linked to human issues when managing the automated system (Wickens et al, 2004): Attention problems, perception, and cognition. Most of these problems occur in the interface between technology and human. The consequence for the human being can be increased stress and workload (Endsley et al, 1997) and can therefore impact the whole system. Therefore, managing automation needs careful attention and integration in the manufacturing system. Automation may also give implications for suppliers such as being able of delivering just-in-time to a highly automated assembly line (Danilovic and Winroth, 2005).

Automation has different definitions depending on approach and context. For example, *automation* is described in Encyclopædia Britannica Online (2006) as

“The application of machines to tasks once performed by human beings or, increasingly, to tasks that would otherwise be impossible.”

Thus, automation in the context of manufacturing often refers to the mechanization and integration of the sensing of environmental variables, which is done through data processing, communication of information, and decision-making. However, automation is applied in other contexts than manufacturing, focusing on the complex interaction between humans and technology, which combined is referred to as automation (Sheridan, 2002). In those other contexts, the complex interaction between humans and technology is focused on how humans use computers to interpret and record data, make decisions, and visualize the information. Recently, other definitions of human-machine integrations have emerged that focus on the sharing of tasks between human and machines

and that regard them as being complimentary (Satchell, 1998). The concept which relates human and technology in the task allocation is called LoA and is briefly described below.

Table 1

Reasons for automating (after Groover, 2001 and Wickens et al, 2004).

Groover (2001)	Wickens et al. (2004)
1 Increase labor productivity	Impossible or hazardous work for humans
2 Reduce labor cost	Difficult or unpleasant work for humans
3 Mitigate the effects of labor shortages	Extension of human capability
4 Reduce or eliminate routine manual or clerical tasks	Technical feasibility
5 Improve worker safety	
6 Improve product quality	
7 Reduce manufacturing lead time	
8 Accomplish processes that cannot be done manually	
9 Avoid the high cost of not automating	

Optimizing task allocation (TA) would give benefits because of complementarities of technology efficiency with the flexibility of humans. In the context of manufacturing, the systems would be more robust. As mentioned earlier in this paper, there are several known approaches to manufacturing automation:

- *The technocentric approach* focuses mainly on optimization of automatic operations in production and on the shop floor (Martin et al, 1991). The effects of this strategy are often inflexible systems and a higher sensitivity to disturbances due to lack of concern for human factors.
- *The human-centered approach* focuses on keeping the human front and center in relation to the automation technology (Sheridan, 2002). However, as Sheridan points out, there are different meanings to human-centered approach and therefore it can be difficult to understand (Sheridan, 1995). Sheridan (1995) lists ten different meanings of human-centered automation, for example: '*Allocating to the human the tasks best suited to the human, allocating to the automation the tasks best suited to it*' and '*Achieving the best combination of human and automatic control, where best is defined by explicit system objectives*'.
- *The sharing approach*, means that qualified operators and automated equipment are supplements to each other when sharing the same task. Satchell (1998) calls this approach the complementary approach meaning that the human and technology complement each other. Within the paradigm of the complementarities of humans and technology, the task allocation between humans and technology becomes central. The concept, which explains and expresses the continuum of different degrees of task sharing between humans and technology, is called LoA (Frohm, 2008).

Task sharing is explained and applied at the operative level of manufacturing automation, and combined with a strategic intent the manufacturing automation can provide long term competitive advantages. Thus, manufacturing automation with strategic implications has become of special interest to both practitioners and researchers. Below, automation strategies are first explained followed by definition of manufacturing strategy and its formulation.

2.2 Automation strategy

There are two types of automation strategies, one in which automation is treated as one of several decisions within an existing manufacturing strategy and another in which the automation strategy is treated as the overall manufacturing strategy (Säfssten et al, 2007; Winroth et al, 2007¹). Strategic planning in manufacturing includes decision-making about automation investments and machinery replacement. These decisions are often based on other issues than collected facts and a well-defined strategy, and are rather of an ad hoc nature (Winroth et al, 2007¹; Winroth et al, 2007²). Successful decisions about automation go in line with what the company aims for in the long term and the decisions are synchronized with the manufacturing strategy and present capabilities (Winroth et al, 2007¹; Winroth et al, 2007²). Miltenburg (2005) categorizes the amount of automation in the decision category 'process technology', but a decision about a certain LoA also affects all other decision categories (Winroth et al, 2007¹). Likewise, Skinner (1969) lists some important trade-off decisions in the decision areas 'Plant and equipment', 'Production planning and control', 'Labor and staffing', 'Product design/engineering', and 'Organization and management', meaning that different alternatives in each decision area designate a specific production system. Hill (2000) calls these alternatives product profiling, which is a visualization of a current versus a future process choice mapped against different product-, market-, and manufacturing-related aspects. Suitable dimensions for characterizing process technology are *scale* (capacity of each technology unit), *degree of automation* (what the machine can do), and *degree of coupling* (how much is or can be joined together or the nature of the integration of the process technology) (Slack and Lewis, 2002). These dimensions offer a useful categorization for comparing different process technology options prior to an investment decision.

2.3 Manufacturing strategy

Manufacturing strategy is defined as a functional strategy within the literature (Skinner, 1969; Hayes and Wheelwright, 1984; Platts, 1990; Hill, 2000), meaning that it is linked to and coordinated with the overall business strategy of the firm. Since Skinner (1969) first proclaimed manufacturing strategy, there have been numerous attempts to give a fuller and more precise definition of this functional strategy. Although there are differences in the way the concept is defined, there seems to be a general agreement in the literature that manufacturing strategy has a long range thrust, and that there should be some competitive advantages defined (Skinner et al, 1985). Moreover, several authors emphasize that manufacturing can be a strong competitive weapon if run properly (Roth and Miller, 1992; Hayes and Clark, 1995). Strategies have both intended and emergent origins and the most realized strategies are a combination of these origins (Mintzberg, 1978). Platts (1990) puts forward a comprehensive definition of manufacturing strategy as follows:

“...a pattern of decisions, both structural and infrastructural, which determine the capability of a manufacturing system and specify how it will operate in order to meet a set of manufacturing objectives which are consistent with overall business objectives” (Platts, 1990, p. 9).

The decisions made should provide necessary support for the relevant order qualifiers and order winners of the different market segments of a company (Hill, 2000). To guide these decisions, several frameworks have been developed within the literature (Skinner, 1969; Wheelwright, 1978; Fine and Hax, 1985; Hill, 2000; Miltenburg, 2005). The frameworks typically visualize a hierarchical process which starts with the vision and scope of the firm, followed by assessing the business' competitive strategy including corporate objectives and marketing strategies, and finally how products win orders against competitors. After the assessment of corporate and business strategy, the formulation process typically moves into the manufacturing area where structural and infrastructural decisions are made (see the above definition by Platts (1990)).

In the manufacturing strategy literature, there is little attention paid to the process of manufacturing strategy (Anderson et al, 1991; Voss, 1992; Dangayach and Deshmuck, 2001) and more attention has been given to the content of the manufacturing strategy. 'Content' refers to the collection of decisions and 'process' means the way in which the strategy is (or can be) formulated, which is a reflection of what operations manager should do and what they actually do in practice according to Slack and Lewis (2002). In other words, 'content' can be viewed as in terms of changes to the structure and infrastructure of a company, made with the intention of fulfilling manufacturing objectives. Here, process can be regarded as '*a set of linked activities that take an input and transform it to create an output*' (Johansson et al, 1993). In the context of manufacturing, this is referred to as 'manufacturing strategy formulation'. There are two approaches to manufacturing strategy formulation according to Platts and Gregory (1990): (1) the traditional, prescriptive approach, which is analytic and rational, and (2) the descriptive approach, where the strategy rather emerges than being planned.

3. Research objectives and procedure

This section describes the development of the objectives of this paper and thus the development of a framework for embedding measurement and analysis of levels of automation in the manufacturing strategy formulation process. To achieve this goal, several underlying objectives were defined:

- Develop a methodology for measuring and analyzing levels of automation that is empirically feasible.
- Validate and test the above methodology on usability and utility.
- Review and evaluate manufacturing strategy formulation processes to identify suitable evaluation criteria and suitable methodologies for formulation of functional strategies with linkages to business strategy.
- Embed the measurement and analysis of levels of automation in a suitable methodology for formulation of business- and manufacturing strategy.

It has been shown that it would be valuable to have a structured methodology in a change process, e.g. when implementing an integrated manufacturing system (Tseng et al, 1999). Hence, the proposed research objectives led to a four-phase structured research programme described in more detail below.

3.1 Phase 1: developing the methodology for measuring and assessing levels of automation

The implementation and development of the LoA measurement methodology, called the Dynamo¹ methodology, was done during the years 2004 to 2007 in seven case studies (case studies A-G in Table 2) using the single case study method in sequence (Yin, 2003). All case studies were done in existing production systems. Since production systems also can be described as flows of materials and information (Sheridan, 2002), the lean production tool *Value Stream Mapping* (VSM) was used as a starting point for measuring LoA in those production flows (Lindström et al, 2005) together with reference scales, which are used for judgment of observed LoA, (see Table 3).

The methods used within the case studies comprised of interviews, observation and participant observation. Moreover, a review of academic literature within the fields of human factors and manufacturing was done to find out how levels of automation have been measured earlier (Granell, 2007; Frohm, 2008; Frohm et al, 2008). From

¹ The Dynamo (Dynamic Levels of Automation for Robust Manufacturing Systems) project was financed by The Swedish Foundation for Strategic Research

the review it could be concluded that the usefulness of automation is very much dependent on finding appropriate distribution of tasks between the human and the technical system (Frohm et al, 2008).

Table 2

Case studies for development of the Dynamo methodology (Granell et al, 2007).

Case study	Study period	Unit of analysis	Methods
A	October-December 2004	Manuf. process	Interviews observation
B	January-May 2005	Manuf. process	Interviews participant observation
C ²	May-July 2005	Manuf. process	Observation
D	March 2005-October 2006	Manuf. process	Interviews participant observation
E	November-December 2005	Manuf. process	Interviews
F	October 2005-June 2006	Manuf. process and information process	Interviews participant observation
G	January-March 2007	Validation of the Dynamo methodology	Observation

²Carried out by PhD Jörgen Frohm

Table 3

The Dynamo reference scales for LoA (Frohm et al, 2008).

LoA	Mechanical	Information
1	Totally manual	Totally manual
2	Static hand tool	Decision giving
3	Flexible hand tool	Teaching
4	Automated hand tool	Questioning
5	Static machine/workstation	Supervision
6	Flexible machine/workstation	Intervene
7	Totally automatic	Totally automatic

3.2 Phase 2: validating the measurement methodology

The case study for validation took place at an industrial company producing complex products during the first quarter of 2007 (Granell et al, 2007). Specifically, assembly and test of one product line were studied. The purpose with the validation was to perform the whole Dynamo methodology at an industrial company, which had not been participating in the development of the methodology and test the methodology on usability and utility. By stepwise performing the Dynamo methodology in eight steps (see Fig. 1) and carrying out each activity, the research group intended to identify (Granell et al, 2007):

- Problems with understanding the instruction of the methodology
- Problems with logic sequences of the methodology
- Efficiency potential within the methodology

A reliable methodology is one that, when used to measure LoA a work task, repeatedly and consistently gives the same findings. Methods for determining methodology and scale reliability and validity often rely on statistic procedures requiring large sample size (Yin, 2003).

3.3 Phase 3: reviewing and evaluating manufacturing strategy formulation processes

This section describes the steps taken to review literature on corporate-, business-, and manufacturing strategy formulation processes. Followed by the literature review, 20 evaluation criteria were selected by which selected manufacturing strategy formulation processes were reviewed. First, a thorough review of 36 academic works on strategy was done and listed on aim, number of stages in the process, participants, and method for accomplishment. From this sampling, 10 manufacturing strategy formulation processes were collected where a linkage between either corporate strategy or business strategy and the functional manufacturing strategy could be found. Then evaluation criteria were identified primarily from (Platts, 1994; Platts et al, 1998; Platts and Tan, 2004; Baines et al, 2005; Tan and Platts, 2005) for reviewing the sampled processes. After this step, the review of the 10 selected processes was analysed against the criteria chosen. The objective with the analysis was to identify and describe patterns of the frequency of each criteria used for evaluation of the processes. By doing the analysis, improvement areas were sought and found for improving formulation processes.

Fig. 1. The Dynamo methodology in eight steps (Granell et al, 2007; Frohm, 2008)

3.4 Phase 4: embedding the measurement methodology in the process of manufacturing strategy formulation

During the fourth phase of the research programme, a case study was done for studying a strategy formulation process intended to decide strategic positioning of a firm (Baines et al, 2005; Baines, 2008). This case study was part of a course in manufacturing strategy held at Cranfield University in the UK during January 2008 and was characterized by team work and iteration between theory and practice. The objective of the case study was to understand the design of the process and the content of each sub-process. The studied process, called StratNav (Strategic Navigator) contains five stages that takes the user and participant through a review of competitive strategy, then identification of key decision criteria, identification of key manufacturing capabilities, development of strategic initiatives, and last consolidation of outcomes (Baines et al, 2005). After the case study was done, the design of a new process for embedding the LoA measurement methodology in manufacturing strategy was initiated. The proposal for a framework for embedding the LoA methodology in the process of manufacturing strategy has resulted in a process containing three parts for the formulation of an issue statement, measuring and analyzing LoA, and alignment of LoA and strategic intent.

4. Research methodology

This section presents the execution and results of the four-phase research programme described in section 3.

4.1 Phase 1: developing the Dynamo methodology for measuring and assessing levels of automation

The result of developing the Dynamo methodology was an eight-step methodology presented in figure 1. Moreover, reference scales were developed for mechanical and information LoA, making it possible to measure, or judge, levels of automation in production, focusing on the task level. The Dynamo methodology, as described before the validation, consists of eight steps (figure 1). Based on the finding from the first six case studies A-F in table 2, the methodology included context description, judgment of automation levels and visualization and assessment of future possible levels.

Each of the sections below describes step 1 to 8 in the measurement methodology (Granell et al, 2007; Frohm, 2008):

- *Step 1.* The first step in the Dynamo methodology, which is conducted off-site, is to discuss the goal and purpose of the LoA measurement. Secondly, visiting days should be decided and also what production area that should be in focus. The explored area may have a need for more stabilized processes as disturbance rates may be high.
- *Step 2.* The second step, which is conducted on-site, is to carry out a pre-study to identify and document the purpose of the production flow and where it starts and ends, documented in a form. Also the number of products and variants produced within the production flow should be identified and documented, as well as work organization and the purpose of the machines and humans.
- *Step 3.* After the basic data for the production flow has been documented and understood, the next step is to visualize the production flow. This is done by “walk the process” and defining which sections/cells the production flow consists of. Data such as the number of products and variants that pass through the section/cell or buffer should be documented in a form, as well as the physical and cognitive tasks that have been allocated to the technology or to the human. Also the number of operators that are allocated to the section/cell or buffer is documented, and if the operator is responsible for more than one section/cell or buffer.
- *Step 4.* After the production flow has been understood, visualized and documented, the identification of the main task is done. Based on the data collected in step 2 and 3, the main task of each section/cell or buffer is identified and documented (e.g. assembly of X electronic components on a circuit card).

- *Step 5.* The identification of the sub-tasks is done once the main task is identified. The identification of sub-tasks is done by observing how the main task is achieved, which is done by breaking down the task until it reaches a level of operations, where only the human or the technology can be responsible for achieving the task. In support of the observation, the operation instructions are used as a starting point and explanation of what is going to be observed. By using the documentation of the task from the company, the measurement crew can easily identify the sub-tasks and deviations from how the task is intended to be done. To simplify and structure the down breaking of the main tasks into sub-tasks, *Hierarchical Task Analysis* (HTA) is used. The HTA is a method for description of activities under analysis in terms of a hierarchy of goals, sub-goals, operations, and plans (Stanton et al, 2005).
- *Step 6.* After the tasks have been broken down and identified, the LoA is judged based on the two reference scales for mechanical and information LoA (see table 3) and an observation of the sub-tasks performed and described in the HTA in step 5. The judged LoA for each task is then based on how the task is conducted, and what type of interaction that is observed for fulfilling the task. The type of interaction for each sub-task is mapped against the reference scale. The measurement data from the observation is documented in a form. By observing more than one operator it is possible to increase the strength of the observations, and also to identify if tasks are conducted with different LoA:s depending on which operator that conducts the task. If the case is conducted under different LoA:s, the task can then be said to be a dynamic LoA.
- *Step 7.* After the measurement of the observed LoA-values have been judged, the observer together with the operator or/and production technician on-site estimates the relevant maximum and minimum LoA for each measured task. By using respondents that has an understanding on how the tasks that has been observed is conducted, a good estimation on the relevant maximum and minimum can be assessed during the discussion. The data is documented in a form.
- *Step 8.* The final step of the Dynamo measurement methodology is to analyse the collected data from the LoA-measurement on-site, with the assessed data on relevant maximum and minimum of LoA. The analysis starts with placing the the LoA value from the observed LoA value as a black dot in the Mechanical-Information-LoA diagram for all documented sub-tasks. The LoA-measurement value shows the actual flexibility/dynamic of the automated task. By drawing the borders for the relevant maximum and minimum of each LoA, a potential area of automation of the task is given

4.2 Phase 2: validating the Dynamo methodology

Three researchers including one of the researchers from the methodology development phase set up the methodology for validation. The validation was conducted in the following sequence (Granell et al, 2007):

1. Studying the Dynamo methodology.
2. Introducing the methodology to the participating company where the validation took place.
3. Conducting the Dynamo methodology, step 1-7 (the analysis in step 8 was not validated in this case).
4. Evaluation of the measurement and the results.
5. Developing an improved methodology.
6. Documentation and reporting.

The validation process of the Dynamo methodology contains both planning, testing the methodology, evaluation, development of an improved methodology, and finally documentation.

4.3 Phase 3: reviewing and evaluating manufacturing strategy formulation processes

A literature review of manufacturing strategy formulation frameworks and processes was conducted where ten manufacturing strategy formulation frameworks and processes were reviewed against evaluation criteria. Common for those ten frameworks and processes are that they contain a functional part intended to formulate a manufacturing strategy. Most of the reviewed formulation frameworks contain a combination of corporate-, business- and functional strategy formulation. The analysis of the review showed that:

- Procedure of the processes is well described and achieves high consistency
- Tools and techniques are well described
- Managing the formulation process is an area for improvement
- Communication and commitment are areas for improvement

Apart from the ten reviewed manufacturing strategy formulation processes there are several other described processes that combine and integrate corporate, business and manufacturing strategy or describe the strategy formulation on business level (Porter, 1980; Swamidass et al, 2001; Acur and Bititci, 2004; Baines et al, 2005; Acur and Englyst, 2006).

4.4 Phase 4: embedding the Dynamo methodology in the process of manufacturing strategy formulation

The initiated design of the process for embedding levels of automation in the process of manufacturing strategy formulation has resulted in a framework, visualized as a decision process for deciding on an appropriate level of automation. The starting point for the whole methodology is need for reviewing levels of automation, for example to review new or intended investments and to reflect upon changed roles for operators and competence development. The methodology for formulating automation strategy contains five sub-processes, which are explained below:

- *Sub-process 0: Preparation.* The purpose of the first sub-process is to agree on purpose of executing the methodology and to make a plan for the execution.
- *Sub-process 1: Formulation of business and manufacturing strategy.* The first sub-process is done in the form of a workshop with active participants. The content of this part is assessments of business and manufacturing strategy with the intended purpose to understand the chosen and intended manufacturing strategy.
- *Sub-process 2: Measurement of levels of automation.* The purpose of the second sub-process is to measure and to assess levels of automation for critical sub-tasks in a production flow.
- *Sub-process 3: Linking level of automation and strategy.* As in sub-process 1, the third sub-process is done in the form of a workshop with active participants who take part in the analysis of different LoA alternatives. Moreover, actions should be listed to propose actions that are in line with the intended manufacturing strategy and also check the outcomes of sub-processes one to three to ensure quality of outcomes and should also provide a plan for implementation of the chosen LoA that is in line with intended strategies.
- *Sub-process 4: Documentation.* The last sub-process should document results found in sub-processes 1-3.

5. Conclusion

The methodology presented consists of a structured process divided into the sub-processes preparation, formulation of business and manufacturing strategy, measurement of levels of automation, linking level of automation and strategy, and documentation. By embedding measurement and analysis of levels of automation in the process of manufacturing strategy, appropriate levels of automation can be found. These appropriate levels of automation are aligned with the manufacturing strategy and form thus together the automation strategy, which secures a desired direction of the firm and also supports robustness and reliability of the manufacturing system due to the chosen holistic approach. Empirical studies done during the development of the proposed methodology have highlighted problems in execution. By validating the level of automation measurement methodology, those problems could be solved and further embedded in a methodology for formulation of automation strategy.

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