Measuring and analysing Levels of Automation in an assembly system

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Abstract
The level of automation employed in semi-automated assembly systems is crucial, both to system performance and cost. This paper presents a methodology to enable selection of the right Level of Automation. The method thoroughly maps existing product and information flows as well as the automation level in separate parts of the system. It then analyses and identifies future automation possibilities, i.e. the automation potential seen from an industrial perspective. Further development of the method is based on validations and industrial case studies.

Keywords:
Levels of Automation, Assembly system, DYNAMO

1 INTRODUCTION

Products of today are becoming increasingly customized. Smaller batches and decreasing time limits for set-ups of new products are some of the resulting demands on the assembly systems, due to the increasing number of variants in the assembly flow.
Consequently, assembly systems have to get the right things, to the right place, at the right time, in the right quantity to achieve perfect work flow while minimizing waste and being flexible and able to change [1]. To achieve this, the companies can adopt automated solutions, when doing this there is a need to determine the correct amount of automation. It is also necessary to identify the optimal parts of the value-flow to be automated. In automation decisions it is necessary to consider human resources, as well as mechanical technology and information flow. By definition, automation is a technology by which a process or procedure is accomplished without human assistance [2]. Unfortunately, automation does not always fulfil expectations; the need for human intervention in cases of disturbances and system failures is still high. Smart automation is defined by [3] as the human aspect of 'autonomation' whereby automation is achieved with a human touch. However, there is a tendency among industry to consider automation investments as a" black or white" decision. This may be suboptimal, since there is not always a need to distinctly choose between humans or machines. The interaction and task division between the human and the machine should instead be viewed as a changeable factor which can be called the level of automation [4]. Thus, identifying and implementing the right level of automation in a controlled way could be a way to maintain the effectiveness of a system[5].
In this paper we will discuss a methodology that could be used to measure today's automation level and that analysis the level of automation that is possible in the future. This could help companies to choose the "right" level of automation due to their production, requirements and demands. This gives great benefits when it comes to time and cost savings in the planning and implementation phase.

2 THE DYNAMO METHODOLOGY

A method was developed in the DYNAMO project (2004-2007) [6] in association with five companies.
The aim with this project was to develop a methodology for measuring and get an accurate picture of today's information flow and automation level in production systems.
Furthermore to develop a reference scale for different Levels of Automation (LoA) that could be used in the manufacturing area [7], this is shown in table 1.

Table I Levels of Automation

Levels	Mechanical	Information
1	Totally manual	Totally manual
2	Static Hand tool	Decision giving
3	Flexible hand tool	Teaching
4	Automatic hand tool	Questioning
5	Static work station	Supervising
6	Flexible workstation	Interventional
7	Totally automatic	Totally automatic

The concept Levels of Automation was defined as;

"The allocation of physical and cognitive tasks between humans and technology, described as a continuum ranging from totally manual to totally automatic"

By physical support, [7], mean the level of automation for mechanical activities, *mechanical LoA* while the level of cognitive activities is called *information LoA.*
Due to [8] the conclusion is that most tasks in manufacturing often involves a mix of both mechanised and computerised tasks and the companies has to consider both areas when automating their system.

2.1 Validation of the methodology

The DYNAMO methodology to measure the Levels of automation consists of eight steps [9], seen in *figure 2.* These steps were validated at an industrial company which has not been participating in the development of the methodology [9]. The validation group contained of four people; two who developed the method and two that began looking at the methodology in 2006 as part of the ProAct project [10]. The group validated each step, ***except step 8***. This step was not validated because the company where the validation took place did not have any purpose regarding LoA strategy, [9].

3 Method for analysing the Levels of Automation

The methodology for analysing levels of automation is done as one step in the **ProAct [11]** research project. This is done to be able to generate possible improvements for the present assembly system. The skeleton of the methodology [7] is intact.

The further development is based on the validation that was done in the DYNAMO project and six case studies that have been done mainly within the **ProAct** project, throughout the period May-Nov, 2007 [12, 13]. The case studies were performed in SME companies.

The modification of the method contains of four different subgroups or phases, as visualised in figure 1.

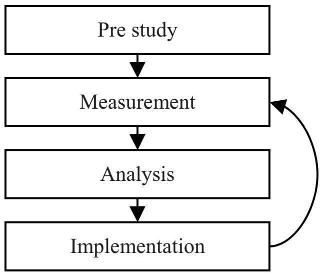

Figure 1 Phases in the measurement methodology

These phases each contains of three steps, shown in figure 2.

Results from the modification are;

- Video or tape documentation has been used in all case studies to easier analyse the assembly system.
- "Lean awareness" in the measured companies is seen as necessary (4 of 6 companies had this) to be able to perform and understand the usage of step 3-10 (modification steps).
- A simplification of the equation has been developed in order to decrease the time in step 4-9 (modification steps), and to decrease the subjective assessment in the work shop.
- No information were given out before the people who were doing the measurement were in place at the companies, i.e. off-site measurement could not been done in any of the case studies.
- Doing a Value Stream Mapping (VSM) to gather information about the time parameters, the information- and material flow in the system to get a deeper analysis of today's system.
- Measure LoA based on value adding and not value adding tasks in the system.
- Logic has been developed to simplify future simulation of levels of automation in an assembly system.
- Consideration also has to be taken about the operators' competence and education about future changes.

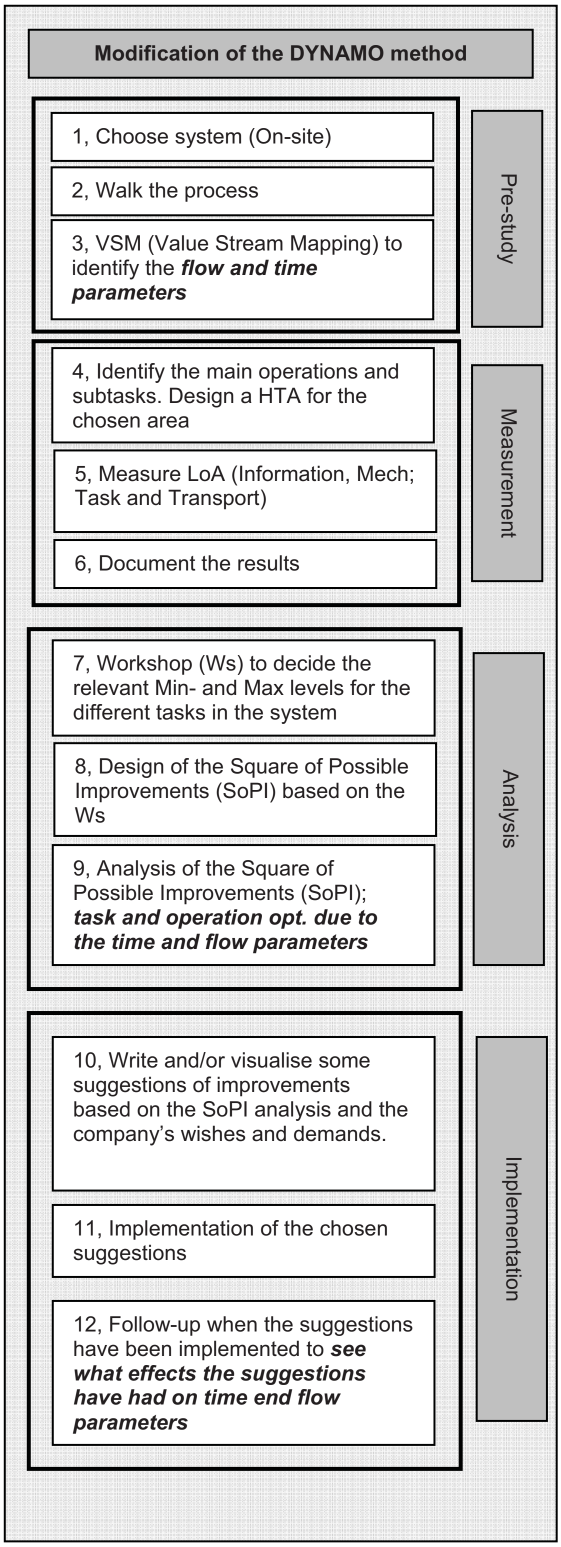

Figure 2 Method for measuring and analysing Levels of Automation

The most important development is the implementation of measurable parameters, time parameters, within the methodology. The logic ha also been very important to develop considering future simulation and visualising of the result in the analysis phase, see subsequent sections.
The analysis and implementation phase is completely new and the sections below will describe these phases.

3.1 THE MEASUREMENT PHASE

The reference scale, seen in table 1 has been developed into a matrix. This is done to get a logical ground and to be able to add dimensions or parameters to the methodology. This matrix is used to visualise the different levels of automation. It is also used in the analysis phase to show the results of the measurements and the suggestions of possible improvements.
The matrix is called LoA_{total} and contains of the vectors LoA_{mech} and LoA_{info} .
The logic for the matrix is seen in equation 1;

$$\begin{aligned}&1 \leq LoA_{total} \leq 49\\&LoA_{total} \rightarrow (LoA_{mech}) \wedge (LoA_{info})\\&\text{WHERE } LoA_{mech}\ (y) = 1 \leq y \leq 7 \text{ and } LoA_{info}\ (x) = 1 \leq x \leq 7\end{aligned}$$

Equation 1 the matrix of LoA_{total}

This means that there are 49 possible solutions that could exist or be developed in the assembly system. It also means that a measured task has to contain both a mechanical and an information part otherwise the structure of the hierarchical task analysis (HTA) is too deep.

3.2 THE ANALYSIS PHASE; Step 8 and 9

These steps are done after the work shop to analyse today's assembly system and to map the possible improvements in the LoA_{total} matrix. This is done with help of the relevant min and max value. These values form a span where the company could move within when it comes to a development of the companies' assembly system; this span forms a square called *Square of possible improvements (SoPI).* The SoPI sets boundaries for the company's future improvements in automation solutions seen from their demands.
This is done to make it easier to analyse the effects when changing/ varying the LoA and also to see if it is possible to make task and operation optimisations within the measured system.
Two different SoPI: s could be designed; task optimisation and operation optimisation. The first step is to design SoPIs´ for all the tasks in the operations.
The logic for the SoPI and $SoPI_{task}$ is described in equation 2:

$$\begin{aligned}&SoPI \rightarrow (LoA_{mech}\ (min; max)) \wedge (LoA_{info}\ (min; max))\\&SoPI = LoA_{mech}\ (min; max) * LoA_{info}\ (min; max)\\&\text{WHERE}\\&LoA_{mech}\ (x) = 1 \leq min \leq max \leq 7 \wedge LoA_{info}\ (y) = 1 \leq min < max \leq 7\\&SoPI_{task} \leq LoA_{total}\\&SoPI_{task} \subseteq LoA_{total}\end{aligned}$$

Equation 2 The Square of Possible Improvements (SoPI) and task optimisati*on*

To be able to perform an operation optimisation there is one condition, all the $SoPI_{task}$ has to be represented in the $SoPI_{operation}$ in order to make an optimisation, if not, one solution is to do an optimisation with some of the tasks and do a task optimisation on the others. It could be described as;

$$\begin{aligned}&\text{IFF } SoPI_{operation} \subseteq \textstyle\sum_{task=1}^{n} SoPI_{task}\\&\text{THEN operation optimisation is possible}\end{aligned}$$

Equation 3 Operation optimisation

The next step in the analysis phase is to evaluate what the effects are when choosing different solutions in the $SoPI_{task}$ or $SoPI_{operation}$ depending on the goal with the measurement.

4 Discussion

From the six case studies, we can declaim that the SoPI is being limited by two obvious things;

- The persons who are leading the work shop - If the leaders of the work shop do not have the skill or knowledge to ask open questions to widen the companies view about the future automation possibilities. It is also important that these persons have a deep knowledge about the methodology and some experience from the industry.

- The companies thoughts and knowledge about future automation - If the companies refrain from "thinking outside the box"

This could result in a smaller SoPi which limit both task and operation optimisations. This has resulted in further development of the assessment in the work shop. This is done to decrease the subjective assessment.
Furthermore to be able to simulate and visualise possible improvements based on the companies' demands and needs rather than their thoughts.
Future research efforts wiil be to investigate how the different solutions in the matrix are related to each other in terms of different time parameters [14]. Furthermore an investigation will be carried out to see if and how it is possible to change level of automation in real time and over time in an assembly system. Deeper knowledge will be used to improve modelling and simulation tools for different levels of automation; this is a part of a research project called SIMTER. Future research aims at simulating and visualising assembly systems with varying LoA in the system's stations and tasks. Improvement of flexibility and the flow-and time parameters will be measured; this will be done to be able to develop a proactive assembly system in the project called ProAct.

5 SUMMARY

This paper has presented a methodology for measurement of the level of automation in assembly systems. While based on the DYNAMO methodology, a development of the measurement- and analysis step has been shown to provide a good visualisation of the present assembly system.
The resulting automation matrix provides 49 different solutions that can be compared and analysed. The Square of Possible Improvements (SoPI) shows the span within the matrix where company personal believe their systems could be improved. The improvement potential is seen from different perspectives described by parameters, resources and demands.

The development of extended method logic and the addition of the time dimension to the existing LoA reference scales will provide opportunities to easier simulate different solutions for assembly systems.
Furthermore, it will provide measurable values that could be analysed in today's assembly system in view future systems. This will give the companies a solid base for decision making in planning and implementation phases of developing their future assembly system.

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Sustainable Design of Machine Tools through Load-Dependent Interventions and Adapted Services

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Abstract
Manufacturers of machine tools face an increasing demand for total cost of ownership (TCO) contracts including an availability guarantee for their products. One key figure in machine availability is Overall Equipment Efficiency (OEE), which is affected by the wear of machine components from both regular use and singular environmental conditions. This paper presents an approach to derive strategies for load-dependent interventions based on the diagnosis and prognosis of the component state, leading to a high level performance with a reliable forecast of machine and component failure in specific working environments.

Keywords:
Machine Tool, Sustainable Design, Lifecycle Engineering

1 INTRODUCTION

1.1 Starting point

One of the main challenges machine and component manufacturers are often required to cope with is lack of information from different areas. After expiration of the warranty period, field experience from operating performance and failure patterns is usually not passed on from the operators of machines and components to their manufacturers [1].

While environmental conditions are difficult to estimate, the regular wear from machining operations can be estimated as soon as the load spectrum during machining operations is known. With this information, it is both possible to derive load-dependent interventions to keep loading within desirable limits, or to derive adapted services to guarantee a high operational availability. Furthermore, feedback to the machine design process facilitates the design of machine tools with high reliability, which starts with dimensioning and selecting appropriate machine components, such as guides and bearings [2].

1.2 Objective

The investigations described in this article are performed in order to allow for the development of an integrated methodology to achieve availability increases for machine tools through continuous load and equipment condition monitoring and to optimize machine operation in terms of its life cycle. Monitoring is supposed to provide the basis for the generation of countermeasures for timely maintenance and diagnosis, and it is to allow for active intervention in the process in order to maintain or increase availability. The main focus is on capitalizing on the machine technology employed in the best possible way to achieve an availability increase. This approach allows for the estimation of potentials and risks required to determine an adapted service scheme for availability at constant costs. The implementation of this approach to machine availability increases requires a deeper understanding of the actual loads bearing on the machine tool as a whole and on its individual components, which will enable the manufacturer to match machine technology design and configuration to the requirements set out by the user in terms of load spectra. This – if combined with overload restriction – allows for machine operation to be always kept just below the allowed limit load.

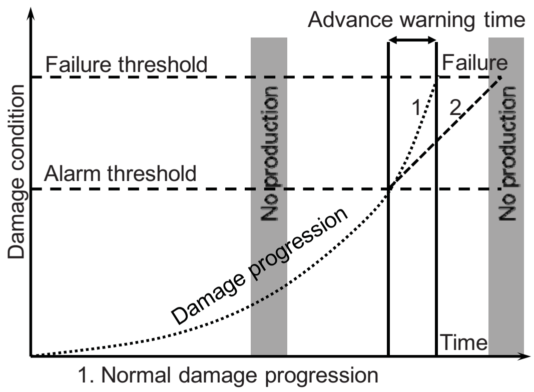

Figure 1: Intervention scenario temporary load reduction (“emergency operation program”).

Figure 1 shows one of the potential scenarios for the implementation of the intended strategy. On the basis of a known damage progression curve and an alarm threshold, the machine dynamics is temporarily reduced via a load controller to enable the operator to replace the component at a suitable time.

2 APPROACH

2.1 Machine tool modularization approach

At the beginning of the project, a comprehensive analysis of machine tools and their operating behaviour under real production conditions is to be carried out. For the different