Does Level of Automation need to be changed in an assembly system? - A case study

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Abstract: Production of to day is getting more and more competitive and companies have to be on top in their area in order to survive. This paper discuss if Levels of Automation need to be changed in assembly systems in order to achieve companies goals when it comes to flexibility and time minimisation. The empirical data is gathered through case studies at six different companies.

Keywords: Levels of Automation, Flexibility, Assembly system

1 Introduction:

Production companies are constantly exposed to demands and requirements, both internal and external,that trigger changing plans for their different production areas. Trigger examples are volumes increases, new product introductions, decreases in lead times ,improved visualisation and flow [1], etc. To be able to handle such triggers and change from a current stage to a future stage as optimal as possible, production logistics has to be high priority at companies of today. Its purpose is to ensure that each machine and workstation assembles the right product in the right quantity and quality at the right time [2].

Complexity, robustness and flexibility are three areas that have been identified by industry as important in order to decrease time and cost parameters [3]. This paper will focus on the areas flexibility, time and levels of automation.

Flexibility is above all other measures of manufacturing performance, cited as a solution [4]. More flexibility in manufacturing operations means more ability to adapt to customer needs, respond to competitive pressures, and to be closer to the market. [4]. The types of flexibility discussed in this paper are defined as;

- Volume flexibility – The ability to handle a change in volume for a special unit [5].
- Routing flexibility – The ability to continue manufacturing a product in spite of a tool breakdown [6].
- Production flexibility – The ability to produce a multitude of products and handle changes in the production planning [7].

Developing rapid, dynamic and responsive manufacturing processes and systems is a core area of manufacturing system research. One powerful approach to achieve this is to create a more flexible and agile workforce in a production area [8]. Agile manufacturing is not simply concerned with being flexible and responsive to current demands. It also requires an *adaptive capability* to be able to respond to future changes [9].

To achieve lead-time reduction or a time optimisation, Just-in-Time tools and philosophies from Toyotas Production System could be used [9-11]. The tools help to decrease the lead-time through the elimination of waste such as over production, wasted time, wasted operation motions, inventory and production of defect parts [10]. Time parameters such as through-put time is very important to focus on, *reduce time and cost savings will come* [12]. Companies has to adopt these tools and have some Lean awareness to be able to achieve the best result in time reduction [13].

The assembly system needs to have the "right" levels of automation i.e. an optimal mix between human and technology for each task and operation in the system.

In 1958Daniels [14]tried to predict the future manufacturing need for automation , by increasing value in use of in-line conveyorised assembly system and semi-automatic bench- mounted machines. Furthermore, Dashchenko et al. proclaimed in 1995 [15] that the main features of a Factory of the Future are: high level of flexibility of technological processes and equipment, high degree of process automation, high productivity, and high quality of manufacturing products.

*Womak et a*l. stated in 1990 that "*by the end of the 90s we expect that team assembly plants will be populated almost entirely by highly skilled problem solvers whose task will be to think continuously of way and means to make the system run more smoothly and productively.",* p. 102 [16]

While Ohno [17] declared that *"smart automation, is automation achieved with a human touch"*.

In Fits' classical list of task allocation presented in 1951 [18] he showed which task machines and humans do best. However, the list is controversial and it is still debated what it means and how to make the task allocation [19]. In various times and context Human Centered Automation (HCA) is purported to mean: Allocating to the human the task best suited to the human, allocating to the automation the tasks best suited to it [19].

Frohm [20] defined levels of automation as:
"The allocation of physical and cognitive tasks between humans and technology, described as a continuum ranging from totally manual to totally automatic"
If the companies do not consider these three areas; Flexibility, Time, and Levels of Automation when changing the assembly system there is a risk for over or under automation, inflexible systems and operators that are over- or under-stimulated.

Thus, our hypothesis can be stated as:
Time parameters and Flexibility = f (LoA)

To find correlation within the hypotheses, a method for analysing levels of automation [21] is used in six case studies. This paper will discuss and analyse if the companies in the case studies need to change LoA in order to achieve their goals in terms of triggers for change.

2 Method for analysing Levels of Automation

The concept Levels of Automation (LoA) was described by Sheridan and Verplank in 1978 [22]. Their research was mostly focused on the areas teleoperation, telerobotics and supervisory control, in order to make humans work through machines within hazardous environment and control complex systems such as aircraft and nuclear power plants [23] e.g. primarily cognitive automation contexts.
The manufacturing context consists of a mix between both mechanised (physical) and computerised (cognitive) tasks, both of these have to be measured in order to get a clear picture of the manufacturing system. An advantage of using the two LoA reference scales proposed by [20], shown in table 1, is that the levels of both mechanical and cognitive support can be assessed in the same taxonomy.

Table 1 Levels of Automation

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

Mechanical LoA is level of automation for Physical support or mechanical activities, while the information LoA is the level of cognitive activities. But, do companies in general comprehend the term "levels of automation" and do they use it when designing or redesigning their assembly systems? Results from a Delphi study in 2005 [24] show that Swedish manufacturing companies are not acquainted with this term. A methodology called DYNAMO that was developed from 2004 to 2007 [20]. The aim of this method was to help companies to measure assessing LoA in order to find appropriate level of span of automation and, by that, maintain high productivity by reducing production disturbances [20]. The methodology was later validated in industry [25]. The validation group consisted of four people; two who developed the method and two that began looking at the methodology in 2006 as part of the ProAct project [26]. The group validated each step, *except step 8 (analysing step)* [25].
A further development with focus on the analysis step was done in 2008, DYNAMO++ [21]. The aim was to analyse whether the current systems' LoA is too high, too low, or to static in order to fulfil the companies' triggers for change.
The methodology, DYNAMO++ [21], consists of four different phases, seen in figure 1;

- Pre-study
- Measurement
- Analysis
- Implementation

Each of these phases contains three steps, i.e. the methodology contains a total of twelve steps [21]. The first two phases are carried out in the current system, to get an accurate picture of today's automation level, production-, information-, material- and resourse flow. The Level of Automation (LoA) is measured in each task within the operation with help of the reference scale.
The final two phases are used as a step towards the future state and as an input for future improvements in the assembly system. The companies´ Triggers for Change (TfC), e.g. demands and requests, as well as the two first phases is used as an input for the two last. This paper focuses on the first three phases and the companies' triggers for change.

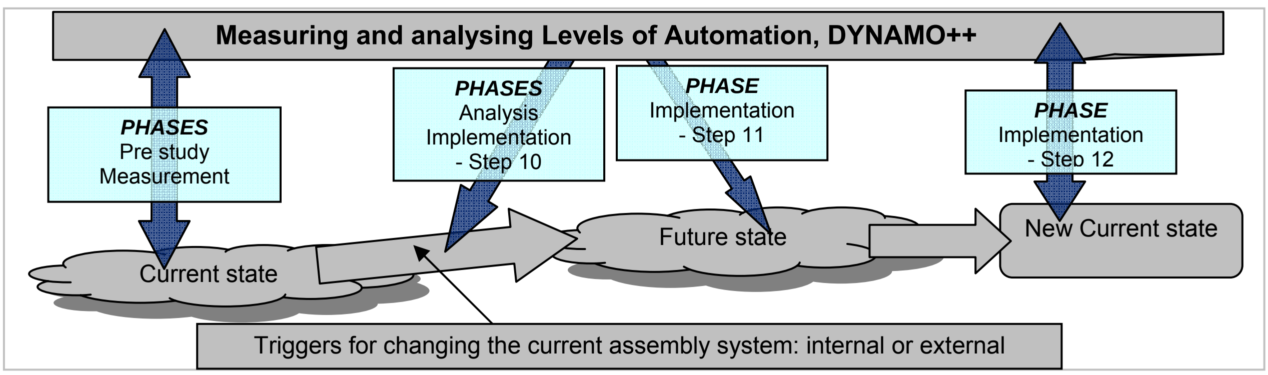

Figure 1 Measuring and analysing Levels of Automation

3 Research methodology

The results presented in this paper are combinations of both inductive and deductive approaches.

Theory (Production area with paradigms, performers , state of the art and already existing method, DYNAMO [20]) → **Empirical data** (case studies, interviews and observation to get new angles and understanding of the current stage and problems in the companies) → **Theory** (formulation hypotheses, development and progression of the old method based on theory, own experience and the collected data, the DYNAMO++ methodology [21]) → **Empirical data** (validation of hypotheses and the developed methodology in terms of case studies, observations and semi structured interviews [27]) → **Theory**

4 Case studies

The aim with the case studies is to analyse the companies' current and future state with figure 1 as base to answer the questions; How does the current stage look like? What are the triggers that make the companies change the system? What do the companies see as possible improvements that could be made in a near future? Furthermore to be able to prove the hypotheses, does time and flexibility affect change in LoA?

The companies that have been analysed and measured in the case studies are six companies in different production areas, seen in table 2.

1.1. Pre-study phase

In the Pre-study phase, data was gathered about flow, type of assembling and number of products in the measured area. Flow and time parameters were also documented. A measurement of the current stage's Level of Automation was carried out; the value is based on the automation level that the operator used to perform the task. The information was gathered with help of observations and interviews. The result of the pre-study phase is illustrated in table 2.

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Table 2 Companies participating in the case studies; current stage

Current stage	Company A	Company B	Company C	Company D	Company E	Company F
Production area	Engine parts	Chemistry [28]	Electronics	Cooling modules [29]	Trucks	Vessels [30]
Type of flow	U-cell	Line	U-cell	Job Shop	Line	U-cell
Type of Assembling	ATO	ATS	ATO	ATS	ATO	ATO
Type Assembling	Batch	Batch	One piece flow	Accord based	One piece flow	Batch
Number of Products	2 main 30 variants	2 main	2 main	3 main	3 main Costume made	4 main 8 variants
Number of Stations	4	9	5	8	5	9
Average $LoA_{information\ (Used)}$	1	5	3	1	3	1
Average $LoA_{mechanical\ (Used)}$	1	5	5	1	-	1

ATO – Assemble-To-Order
ATS – Assemble-To-Stock

1.2. Triggers of Change

All the companies had conferred about their triggers of change that they wanted to investigate further in terms of investments and flow analysis to be able to meet the internal and external demands. A majority of the companies wanted to either increase the flexibility or decrease time parameters.

Investigations about the companies' Lean awareness were also done before the analysis and results were presented. This was done to investigate if companies work on improvements in terms of waste reductions, machine layout, and visualisation etc before changing the level of automation. The result is seen in table 3.

Table 3 Triggers for change and Lean awareness

	Company A	Company B	Company C	Company D	Company E	Company F
Triggers for change	Increase quality (Increase Cognitive LoA)	Decrease throughput time	Volume and product flexibility	Wants to buy a robot (increase mechanical LoA)	Simplify the information flow to the operators	Increase volume and product flexibility, visualise the flow
Lean Awareness (use of JIT tools [11])	Middle	None	High	None	Middle	Middle

High – The message had reached the operators and almost all the tools were implemented
Middle – Started with the early-on tools [11], the implementation had stopped at the white-collar worker level
None – have almost not heard of Lean Production

1.3. Analysis phase

In the analysis phase the triggers of change and the current situation were input. As one of the outputs some suggestions were presented to the companies, seen in table 4. To be able to determinate if tasks or entire operations in the assembly system needs to and can change LoA, and in what span of automation the companies should start investigating possible solutions or improvements, an analysis phase was developed. This phase contains of three different steps, illustrated in figure 2.

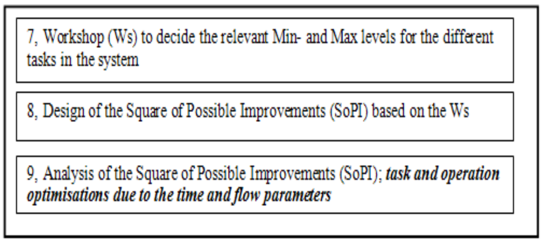

Figure 2 the steps of the analysis phase

In the following sections a brief explanation of each step will follow, with case study A as an example of the different steps;

Step 7 Work shop to decide Min and Max values

The result and gathered information from earlier phases is used in this step in order to get an accurate picture of how the current stage of the assembly system looks and so that the people present in the work shop can discuss if they think that this gives a true picture. The measured value (marked **<u>M</u>** in figure 3) is based on observation of operators with different experience performing the tasks. Semi-structured interviews were also performed with people involved in the investigated area. The workshop starts with a short briefing on the earlier steps and then if the companies has some triggers of change to redesign their system, and if, what level of automation do they think is reasonable to have in the new system. In case study A the trigger of change were; *need to decrease the redoing in the cell* e.g. increase the quality of the products and to increase the information to operators on how to assemble so that they did right the first time (cognitive LoA).

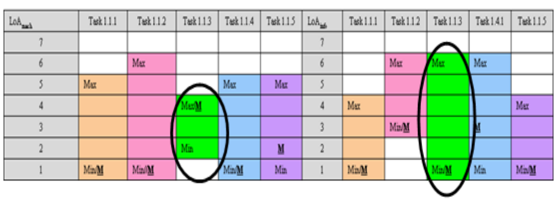

Figure 3 Result from Ws in case study A

The minimum value is the value that they need to have in order to achieve good quality and reasonable working conditions. The maximum level is a look into the crystal bowl in terms of new technology (for the company) different system methodologies, product flows etc in order to fulfil the demands on the future system. A result from one of the work shops is shown in figure 3.

Step 8 Design a Square of Possible Improvements (SoPI)

The result from the workshop is then transformed into the LoA matrix to illustrate and to be able to analyse the results. The min and max values form the boundaries for the Square of Possible Improvements (SoPI), shown in figure 4.

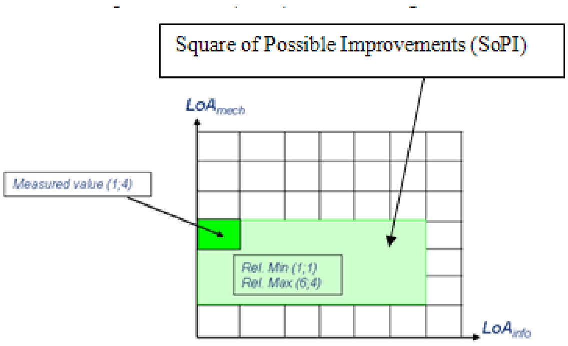

Figure 4 result from work shop illustrated in the LoA matrix

Step 9 Analyse the SoPI

The SoPI is the used in order to analyse if it is possible to do a task and/or an operation optimisation. The result from case study A was, as shown in figure 5, in need to increase the cognitive level of automation in almost all tasks, also a need to increase the mechanical LoA in some tasks.

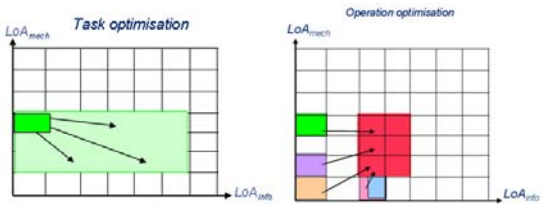

Figure 5 Task and operation optimisation

The result was that there were 18 possible improvements for task optimisation and 6 possible solutions if the whole operation should be improved. The companies then has to investigate what consequences this optimisation result in; in terms of achieving the future goal with this redesign, investments in terms of facilities, information, competence and resources?

5 Result

The result from the case studies shows that it is not always the Level of Automation that has to be changed; some of the suggestions have to do with other issues, e.g. production logistics.

Company A wanted to improve quality and decrease re-assembly rate, the suggestion for the future stage was to increase the information LoA in terms of digitalised and forced assembly instructions where the operators could choose the level of information shown, due to their competence and experience but at the same time have check-point that the operator had to trigger – this might increase the cycle-time but decrease the overall time because it decrease the re-assembling. Design For Assembling (DFA) [31] was also a suggestion. The current products had many similar parts that could be squeezed into the wrong product, by designing them so that only the correct product fitted could also decrease the re-assembling.

Company B had too much buffer capacity because they produced large batches. The company also had too many breakdowns, one reason is because the operators did not always see if the machine had stopped, furthermore the follow-up of the breakdowns did not exist. The company also had a lot of "homemade automation" which means that the machines was not optimised and worked poorly. This resulted in operators trying to fix what the machines did wrong and this decreased the number of operators needed in the system, decreased workload for the operators in terms of heavy lifting and dangerous material handling. The suggestions here were;

- To increase the information LoA in terms of state lamps on the machines; this will increase the awareness of the operators when something abnormal is happening.
- Better follow-up on the breakdowns and continuous maintenance so that the company knows what is wrong with the machines and fix the problems.

This will decrease the MDT (Mean Down Time) and hopefully the MTBF (Mean Time Between Failures) in the future. Another suggestion was to redesign the whole system with better solutions in automation then today and educate the operators in machine control and continuous maintenance.

Company C wanted to increase the volume and product flexibility if possible. The suggestion was to build an assembly system that could vary the LoA in terms of for example line replacement, redundancy or plug- and-produce [32], the system could also be constructed as module structured assembly system [33]. The operators were not involved in the maintenance of the machines which increased the MDT when machines stopped, one suggestion where to improve the competence of the operator to handle small problems.

Company D wanted to invest in a more automated cell for the last assembly task to decrease the through-put time. After the three first phases in the DYNAMO methodology the outcome were no common possible improvements due to the LoA analysis. The solution was to start improve the flow and production logistics in the current stage to achieve the goal (decrease throughput time).
The suggestions were presented in an automation stair [29] where increased level of automation where done stepwise.
The first step was to improve the material handling to the assembly stations because it was a lot of waiting time for the operators on articles that were not in the buffer and the operators were expensive because they did specialised jobs. Furthermore to do some kind of kitting [34] or FIFO for these articles so that the operators could weld instead of doing the material handling.
They also had a push system and Assemble-To-Stock (ATS) so the buffers were quiet big. Suggestions for this were to improve the production planning to be able to Assemble-To-Order (ATO) instead and move the ordering handling downstream to create a pull system [10]. The products where heavy (40 kg) and these were pushed on a non mechanical transport band, a suggestion where to increase the mechanical LoA for the transportation and also to redesign the assembly cells from a single station line to U-cells. The last suggestion was to increase the Lean awareness to at least middle level so that the white-collar workers understood the importance of production logistic and reduction of waste or non value adding tasks in the system.

Company E wanted to decrease the number of paper assembly instructions (today it is 40 000 paper a day printed out). Some of the reasons where

- up-dates took a long time to reach the operators
- it was too much information that was hard to understand on each assembly instruction
- the company had to print the assembly instruction long beforehand and it cost a lot of both money and environment cost in terms of paper (forest) to print all these papers

The suggestion was to increase the information LoA in terms of digitalise the assembly instructions an let the operators choose the information that he or she needed due to their competence and experience.

Company F wanted to improve the product and volume flexibility. Today the assembly system is islands of assembly stations and it is hard to follow the product flow. Furthermore a lot of the assembly tasks are made by hand.
If transportation lines and assembly stations got more structured and marked the visualisation could increase. This will result in a more manageable material and production flow. Furthermore to increase the mechanical LoA in term of a number of line based transportation and standardised module based assembly stations. This results in decreased set-up time between products, and to be able to assembly more then one product in each line e.g. product and volume flexibility. This also makes it easier to vary the mechanical LoA in the future to achieve higher volume flexibility.

A summary of the suggested solutions is illustrated in gray in table 4.

6 Discussion

Results from the case studies shows that companies with low lean awareness think of mechanical LoA when they want to increase automation. Companies with high mechanical LoA often forget to improve the cognitive automation. This result in long cycle times, hard for new operators to learn the assembly tasks, quality problems and longer down times.

So does Levels of Automation need to be changed in an assembly system?
The result from the case studies shows that the companies often need to change either the mechanical or information LoA to achieve their trigger for change.
One common proposal for company A, B, E were to increase the LoA information in order to get higher quality, decrease MDT and save time and money when digitalise the assembly instructions.
Suggestion for company C, D, F were to increase the LoA mechanical in order to minimize the transport time between the assembly stations but also to be able to vary LoA to achieve volume and product flexibility.
Furthermore four of the six companies also got suggestion to increase the level of lean awareness. This was done in order to understand the importance of production logistics and to reduce the waste in the assembly system in order to decrease the through-put time. The biggest wastes were over production and operation motions.
Company A and E have worked with the early-on lean tools [11] for more then a year and we think that it was time to time to evolve from lean tools to the lean philosophies.

Table 4 Suggestion for future stage

Suggestions for future stage	Company A	Company B	Company C	Company D	Company E	Company F
Production area	Engine parts	Chemistry [28]	Electronics	Cooling modules [29]	Trucks	Vessels [30]
Type of flow	U-cell	Line	U-cell	Line with U-cells	Line	Line with U-cells
Type of Assembling	ATO	ATO if possible	ATO	Kitting and ATO if possible	ATO	ATO
Type Assembling	Batch	Smaller Batches if possible	One piece flow	Batches if possible	One piece flow	Smaller Batches if possible
Number of stations	4	6	5	7	5	7
Suggestions LoA **Other suggestions**	Increase $LoA_{information}$ Improve flow between stations and other products Design For Assembly	Increase $LoA_{information}$ Improve Maintenance and competence	Increase $LoA_{mechanical}$ Bottleneck analysis Involve the operators more	Start with material handling and production logistics – “Automation stair”	Increase $LoA_{information}$	Increase $LoA_{mechanical}$ Improve flow between stations and other products Decrease non-value adding tasks
Lean Awareness (use of JIT tools)	High	Middle	High	Middle	High	High

7 Conclusions

This paper has analysed the need for six industrial companies in different areas to change Levels of Automation (LoA) in order to achieve their goals in terms of triggers for change. As shown in table 3, the companies' triggers for change contain either flexibility or time parameters.
In order to achieve the triggers for change, the majority of the companies needed to change LoA as shown in table 4;

- o $LoA_{information}$ (50 % of the companies) in terms of digital assembly instructions in different levels due to the operators' competence and experience, or visualisation of the production in terms of state lamps.
- o $LoA_{mechanical}$ (33 % of the companies) in terms of conveyers (transport automation), and variable automation in terms of redundancy [13] or plug-and-play flows.

Furthermore, it was shown that the hypothesis that LoA could be a function and DYNAMO++ a tool to demonstrate possible improvement in order to achieve higher flexibility and decrease time parameters.

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References

[1] M. Bellgran and K. Säfsten, *Produktionsutveckling - Utveckling och drift av produktionssystem*. Lund, Sweden: Studentlitteratur, 2005.
[2] H. Aronsson, B. Oskarsson, and B. Ekdahl, *Modern logistik*. Lund: Grahns Tryckeri AB, 2006.
[3] Å. Fasth, J. Frohm, and J. Stahre, "Relations between Performers/parameters and Level of Automation," in *IFAC*

workshop on manufacturing modelling, management and control Budapest, Hungary, 2007.

[4] N. Slack, "The flexibility of manufacturing Systems," *International Journal of Operations & Production Management* vol. Vol. 25 No. 12, 2005.

[5] D. Gerwin, "A framework for Analyzing the Flexibility of Manufacturing Process," in *Business Administration* Wisconsin: University of Wisconsin, 1983.

[6] J. Browne, D. Dubios, K. Rathmill, S. P. Sethy, and K. E. Stecke, "Classification of Flexible manufacturing systems," *The FMS Magazine, April,* 1984.

[7] J.-E. Ståhl, *Industriella tillverkningssystem - länken mellan teknik och ekonomi* vol. 2. Lund: Lunds tekniska högskola, 2006.

[8] W. J. Hopp, E. Tekin, and M. P. Van-Oyen, " Benefits of skill chaining in serial production lines with cross-trained workers," *Management Science,* vol. Vol 50, pp. 83-98, 2004.

[9] A. Gunasekaran, "Agile manufacturing: enablers and an implementation framework," *International Journal of Production Research,* vol. 36, pp. 1223 - 1247, 1998.

[10] J. K. Liker, *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*. USA: McGraw-Hill, 2004.

[11] P. Olsson and M. I. Johansson, "Changes in planning and control system during implementation of Lean Production," in *PLANs forsknings och tillämpningskonferens - kundfokuserade varor och tjänster* Jönköping, Sweden, 2007.

[12] H. Yamamoto, "Driving information, An industry Case to enhance manufacturing competitiveness," in *The 41st CIRP conference on manufacturing systems* Tokyo, Japan, 2008.

[13] Å. Fasth, J. Stahre, and K. Dencker, "Analysing changeability and time parameters due to levels of Automation in an assembly system," in *The 18th conference on Flexible Automation and Intelligent Manufacturing - FAIM* Skövde, Sweden, 2008

[14] R. Daniels, "A Prediction of the Future Machinery of Automation," *Production Techniques, IRE Transactions on,* vol. 3, pp. 14-16, 1958.

[15] A. I. Dashchenko, D. Ludwig, and O. Dashchenko, "Assembly automation - the way to a factory of the future," in *Emerging Technologies and Factory Automation, 1995. ETFA '95, Proceedings., 1995 INRIA/IEEE Symposium on*, 1995, pp. 259-267 vol.2.

[16] J. P. Womack, D. T. Jones, and D. Roos, *The Machine that Changed the World*. New York: Harper Collins, 1990.

[17] T. Ohno, *Toyota Production System*: Productivity Press, 1988.

[18] P. Fitts, "Human engineering for an effective air navigation and traffic control system." vol. research foundation report Columbus,OH: Ohio state university, 1951.

[19] T. B. Sheridan, "Human centred automation: oxymoron or common sense?," *IEEE,* p. 6, 1995.

[20] J. Frohm, "Levels of Automation in production systems," in *Department of production system*. vol. Doctorial Gothenburg: Chalmers University of technology, 2008.

[21] Å. Fasth, J. Stahre, and K. Dencker, "Measuring and analysing Levels of Automation in an assembly system," in *The 41st CIRP conference on manufacturing systems* Tokyo, Japan, 2008

[22] R. Parasuraman, T. B. Sheridan, and C. D. Wickens, "A model for types and levels of human interaction with automation," *IEEE transactions on system, man, and cybernetics - Part A: Systems and humans,* vol. 30, pp. 286-296, 2000.

[23] T. B. Sheridan, *Telerobotics, automation and human supervisory control*. Cambridge Massachussetts: MIT Press, 1992.

[24] V. Lindström, "Individuella bedömningar av dynamisk automationsnivå," Product and production development, Gothenburg,sweden 2005.

[25] V. Granell, J. Frohm, J. Bruch, and K. Dencker, "Validation of the DYNAMO methodology for measuring and assessing Levels of Automation," in *Swedish Production Symposium* Gothenburg, 2007.

[26] K. Dencker, J. Stahre, P. Gröndahl, L. Mårtensson, T. Lundholm, J. Bruch, and C. Johansson, "PROACTIVE ASSEMBLY SYSTEMS- Relaizing the potential of human collaboration with automation," in *IFAC-CEA, cost effective automation in networked product development and manufacturing* Monterey, Mexico, 2007.

[27] R. Patel and B. Davidsson, *Forskningsmetodikens grunder* vol. 3. Lund: Studentlitteratur, 2003.

[28] K. Jonsson, "Flow analysis and simulation of new and old production plant at Eka Chemicals AB," in *Dep. of product and production development*. vol. Master Gothenburg: Chalmers University of Technology, 2007, p. 43.

[29] P. Ottosson and G. Grundström, "Flow analysis and simulation of the cooling module production at NIBE AB," in *Product and production development*. vol. Master Gothenburg: Chalmers University of Technology 2008

[30] A. Bergmann, "Case study on varying mechanical Level of Automation in an assembly system at Bosch Rexroth," in *Department of product and production development*. vol. Bachelor Gothenburg: Chalmers, 2008

[31] G. Boothroyd and P. Dewhurst, *”Product Design For Assembly”*. Wakefield, RI, 1987.

[32] K. Dencker, J. Stahre, Å. Fasth, P. Gröndahl, L. Mårtensson, and T. Lundholm, "Characteristic of a Proactive Assembly System," in *CIRP* tokyo, 2008.
[33] K. Tanaka, N. Nakatsuka, H. Hibino, and Y. Fukuda, "Module structured production system," in *The 41st CIRP conference on manufacturing systems* Tokyo, Japan, 2008.
[34] P. Jonsson and S. A. Mattson, *Logistik : läran om effektiva materialflöden*. Lund: Studentlitteratur, 2005.