Development of production cells with regard to physical and cognitive automation

A decade of evolution

Åsa Fasth, Sandra Mattsson, Tommy Fässberg and Johan Stahre
Dept. of Product and Production Development
Chalmers University of Technology
Gothenburg, Sweden
asa.fasth@chalmers.se

Stefan Höög, Mikael Sterner and Thomas Andersson

Stoneridge Electronics AB
Örebro, Sweden

***Abstract* — This paper will discuss a company's view and evolution of physical and cognitive automation regarding four product families that have been put in production the past decade. The focus of this paper is on the mindset of the production engineers when changing the assembly cells of the products.**

Results, from observations and interviews, reveal that both the physical and cognitive automation have been considered when designing new assembly cells at the company. Automation has decreased during time covered by the studies. Further, an evolution in lean production and increased involvement of the operators have been in focus during the last two product cell designs, in order to reach recourse and volume flexibility. Moreover, in order to decrease the product complexity, the engineers always design one cell per product family.

Keywords; Assembly, Levels of automation, LoA, Flexibility

I. INTRODUCTION

Current tradition for design and usage of assembly systems may not be adaptable to the needs and future challenges that production companies have to face. Increasing customization of products, results in decreasing production batch sizes (especially in the assembly operations) where companies are forced to increase their capability to handle fast change-overs between different product groups and new products. Further, globalisation of production and short development cycles results in demands regarding lower product and production costs, higher quality and shorter throughput time. This demands a high degree of flexibility [1, 2] and more dynamic decision making later in the production chain.

The aim with this paper is to describe and analyse the evolution of both the physical and cognitive automation at Stoneridge's final assembly systems, from 2000-2010. The objective is to see how the use of physical and cognitive automation has changed during this period and why the production engineers have made these decisions. Further to perceive if Stoneridge consider these two types of automation on the same bases when investing in different solutions.

Four different product families will be compared in terms of :

- Layout design in the cells e.g. U-cell, line etc.
- Product variants
- Product flow
- Use of resources
- Lean production

Moreover, a discussion about why changes in the production cells take place will be discussed, both changes since the start of production and changes between the product families. This will be done by introducing two concepts; "Triggers for change" and "Indirect measurable parameters" (P_{IDM}) and direct measurable parameters (P_{DM})".

A. Triggers for change

Fasth et al [3] describes the concept, Triggers for change, as the basis why a company changes a system or part of a system. When changing a system, it is vital to understand why changes in the system are necessary and, if possible, break down the triggers into measurable goals. In twenty-five case studies [3-5], conducted in the late 1990s and end of 2000s, companies often used informal and unstructured evaluations of the current system to select data in order to validate changes. According to Fasth et al [3], a majority of the ten case companies conducted in 2000s, presented the motivation for changing their system. Even though the times of the studies were ten years apart the evaluations in all of the cases often were informal and unstructured i.e. presumptions rather than facts. Results from six case studies [3] reveals that the most common trigger for change is to increase flexibility (volume and resource) and to decrease different time parameters such as throughput time [6]. To be able to measure how well the change turned out there is a need to divide the triggers for change into indirect measurable parameters (P_{IDM}) and direct measurable parameters (P_{DM}).

B. *Indirect and direct measurable parameters*

In order to determine a change in an assembly system, two types of parameters could be described; indirect and direct measurable parameters. The indirect measurable parameters (P_{IDM}) could be described as qualitative parameters i.e. flexibility [7], complexity etc. The direct measurable parameters (P_{DM}) could be described as quantitative parameters i.e. time parameters, number of products, number of tasks etc. These parameters will be related to the change of physical (LoAp) and cognitive (LoAc) LoA [7].

This could be described as:

Company A wishes to increase its production volume flexibility (P_{IDM}).

This could be done:

By decreasing the throughput time (P_{DM}) through the cell by increasing the physical LoA, $P_{1IDM} = f(P_{DM};LoAp;LoAc)$

By increasing the competence (P_{IDM}) among operators by learning more tasks (P_{DM}) and by increasing the cognitive LoA,

$P_{1IDM} = f(P_{2IDM})$ *were* $P_{2IDM} = f(P_{DM};LoAp;LoAc)$

In this paper the indirect measurable parameter is flexibility, which refers to both resource and volume flexibility, where resource includes how personnel is allocated and to what degree a station can be rebuilt for a new product. Volume flexibility is connected to how volume is handled, for instance, in the number of products per hour and the pace of production.

C. *Flexibility*

High flexibility in assembly systems is vital for companies in order to respond to internal and external changes. In the 1950s the market was saturated by mass produced goods, and the request for more diversified and customised products increased [8]. The lot size decreased as products were launched more and more frequently in an attempt to adapt them to the preference of the customer [8]. Small-batch manufacturing became increasingly important, and manufacturing flexibility emerged as a key competitive feature for organizations [9]. An early definition of flexibility was provided by Stigler in 1939 [10], who defined it as; "*Those attributes of a manufacturing technology which can accommodate greater output variations"*. Since then, numerous definitions of flexibility have been suggested. Sethi [11] for example, demonstrated the use of over 50 separate terms describing flexibility in 1990. Dashchenko et al. [12] stated in 1995 that the main features of the future are: high level of flexibility of technological processes and equipment, high degree of processes automation, high productivity and a high quality of manufacturing products. Also an increased flexibility is seen to correlate with an increased complexity [13]. Further, the main challenge in realisation of these features take place in the field of assembly processes [12]. Sawik [14] agrees by stating that a flexible assembly system is an extremely complex system, consisting of many interconnected components of hardware and software. In these complex systems humans have still not been replaced by automation when it comes to flexibility and adaptability. As Parasuraman and Wickens puts it: *Humans are still vital after all these years of automation [15]*. However, finding an appropriate automation level is important in order to avoid under- or over- automation.

D. *How to handle flexibility*

In order to meet these challenges appropriate Levels of Automation (LoA), both cognitive and physical, must be selected. By doing this an increased information flow can be achieved as well as avoidance of over or under automated systems. This means that suitable allocation of tasks between resources (operators and machines) and technique has to be made and must be able to be dynamically changeable over time. However, it is common that designers automate every subsystem that leads to an economic benefit for that subsystem and leave the operator to manage the rest [15]. Slack argues that flexible technology cannot be effective without flexible operators and vice versa [16]. In addition, current research [15, 17, 18] argues that operators have still not been surpassed by conventional automation in terms of flexibility and high product variation. Therefore, operators should be used for more than supervision of machines and should therefore be integrated and seen as complementary to machines rather than to be divided into recourses in man- machine thinking when performing task allocation in system production design [17, 19-22]. It becomes vital to consider the cognitive level of automation with humans in control, the same way that the physical automation has been evolving and considered during the last three decades. The technologies for cognitive automation have had an enormous evolution the last decades, from paper instruction to more electronic assembly instruction, smaller and cheaper PDAs, pick-by-light, vision systems etc.

II. METHODOLOGY

Levels of automation (LoA), in terms of cognitive and physical levels of automation, is studied with the DYNAMO++ methodology and the concept model [23, 24]. Production layout, lean production and use of resources are studied by looking at resource and volume flexibility and the concept model. Further, development strategies was studied looking at internal and external triggers for change and challenges gathered from the case studies and from semi-structured interviews held in 2007 and 2010.

A. *DYNAMO++*

The DYNAMO++ method [23, 25] and the concept model [24] for task allocation were developed during 2007-2009. The main aim is to evaluate and analyse changes in an assembly system due to triggers for change i.e. the company's internal or external demands and Levels of Automation. The LoA analysis is done at working place level [26] i.e. on task, in stations [27] [28] [13, 29] and from an operator's perspective.

The measurement parameters used for task allocation is a seven by seven matrix [23], seen in figure 1.

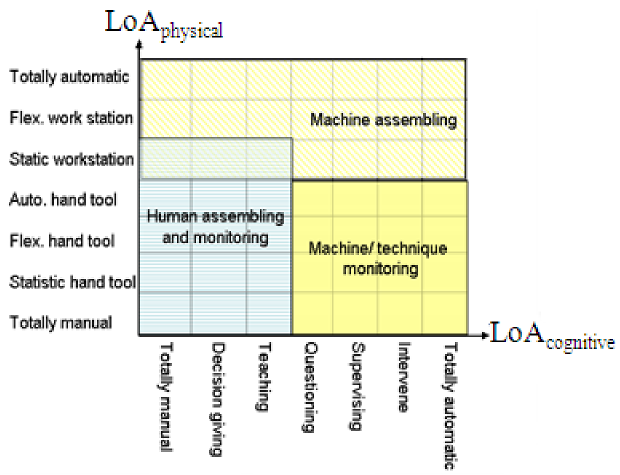

Figure 1. LoA matrix

This is a further development of a taxonomy described by Frohm et al. [30], considering both cognitive and physical levels of automation. Parasuraman et. al [31] argues that automation design is not an exact science but continues, however, neither does it belong in the realm of the creative arts or successful design dependent upon the vision and brilliance of individual creative designers. In this paper the DYNAMO++ has been used to investigate the LoAs for the production stations in order to see what changes has been made.

The concept model also considers the competence of the operator group (LoC) and the information flow to and from the operators (LoI). In this paper LoC has been investigate as use of resources in the production cells. LoC can be described as the accumulated and combined knowledge of an operator group working in the system. An example of an indirect task is planning of assembly.

B. *Interviews*

Semi-structured interviews were held in 2007 and 2010. The interviews were done within different levels and roles of the company in order to capture development opinions from all roles of the production cells, illustrated in Figure 2. Of the interviewees, 90% were the same in these two series.

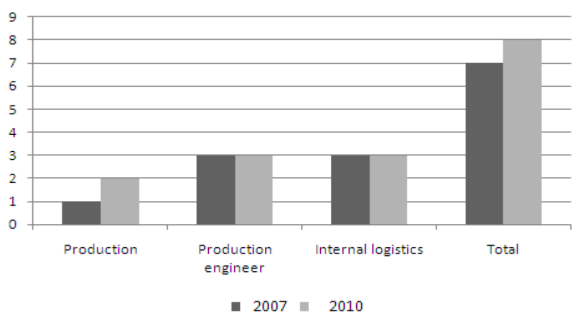

Figure 2. Interviewees

III. RESULTS

The company is a subcontractor to four of the world's leading truck companies/models and has been analysed during the period of 2000-2010. The company was chosen for its reputation of performing in a very competitive market and its stringent conformity for high quality.

Four product families and their final assembly cells will be discussed:

- Product A, put in production in 2000
- Product B, put in production in 2003
- Product C, put in production in 2008
- Product D, will be put in production in 2011

TABLE 1. SUMMARY OF THE INVESTIGATED PRODUCT FAMILIES

Product family	A	B	C	D
Put in production	2000	2003	2008	2011
Variants	7	18	6	**?**
Layout	U-Cell	Pallet-line	U-Cell	U-cell
Studied Stations	3	9	2	-
Tasks	31	23	22	-

A. *Levels of automation*

Figure 1 shows how LoA has changed over time. The figure describes an average of a sub system in the final assembly, which seemed to be similar on all products and thus comparable.

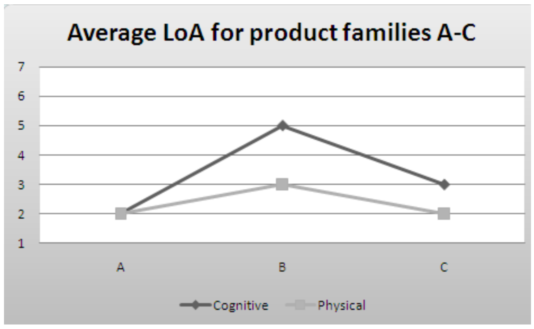

Figure 3. Development of LoA over time

The result shows an increase of automation, both physical and cognitive going from product A to B. This is explained by a strategy which included automation in terms of robots and conveyor systems. This strategy was later revised for product C. This product station is similar to product station A, but with an evolved concept.

As for increasing the level of automation in mechanics; there have been discussions about more automated work at times but since many of the control stations require pressing and a manual level this has been abandoned.

Cognitive automation - Assembly instructions

The assembly instruction has gone through an evolution during the four product families, based on a maturity in the lean production concept and thoughts about the cognitive automation i.e. assembly instructions.

The main difference between A and B is the increase of cognitive automation which was accomplished by cognitive support systems such as pick-by-light systems. For product B and C the assembly instructions is paper based, describing how to assemble the product by a flow chart with text and pictures, seen in Figure 1a, while for the assembly cell that will be put in production 2011 (product D), a pilot for assembly instructions in A3 format has been carried out (Figure 1b). The instruction is a picture of the station with simple numbers and explanations on how to assemble. The instructions are put onto the new lines in cooperation between the operators and the technicians.

> "*However, it is hard to find a good level for them and how much freedom there should be*" says one of the production technicians.

During the pilot case, movies are made and afterward the production leader holds a meeting where time and work procedures are discussed together with the operators.

Physical automation

The difference between the production stations lies in the thoughts when planning the cells. Product C has more lean production thinking and has more modern tools than A and B. In the future two more lines (one is product family D) will be built where further development stages are made. In C some lean thinking was introduced and these thoughts are advanced in cell D. Simplifications in fixtures, technology and lean production concepts have been done in combination. More thought has been put on dividing the work amongst the operators and simplifying the fixtures. One example is that the material comes to the station from behind and the fixtures are built so that it is easy to access them.

> *"There are differences when you are going to adapt the older lines, not that we were clumsy when we made them, it's just that we didn't think in the same way then"* says one of the production leaders.

Both the new lines are u-cells and when the same changes were made with C the result are that it feels a bit incoherent. One of the production technicians stated that they are not really happy about the lines today and would like to make them more effective in order to work with flexible operators.

> *"We are always working with improvements. About two years ago I felt that we were pretty done and that we were good at what we were doing. But then we were out looking at other facilities and I was inspired since we still have a lot of improvement potential",* says one of the production planners, 2010.

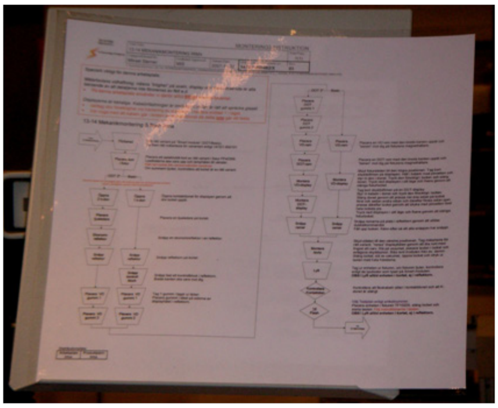

Figure 1a. Flowchart from product B

Figure 1b. A3 instructions for product C

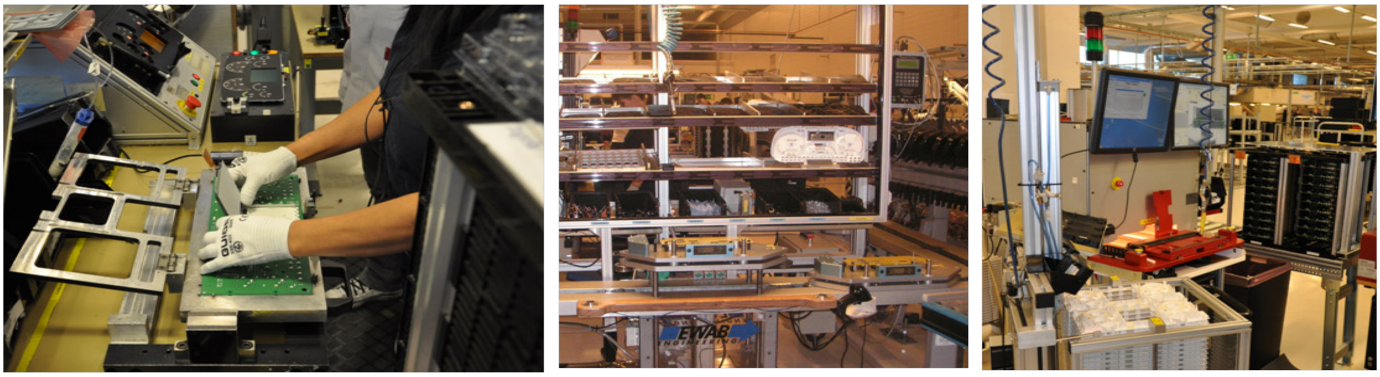

Figure 2. Example of the assembly station for product A, B and C

B. Use of recourses

Results from 2007 shows that operators had main responsibility for less than 20 % of defined work tasks in an assembly system [25], these tasks were mostly direct tasks such as assembling. Operators had no participation in planning and maintenance. This means that the information flow between operators and other roles in the system becomes important. In order to reach resource flexibility, the Level of Competence (LoC) has increased, mostly in the indirect tasks. This means that the operators get more freedom when planning their pace of assembling. Furthermore, a change of mindset was seen for maintenance and in making the operators more part of production changes and the cognitive automation.

IV. ANALYSIS AND DISCUSSION

This paper presents an evolution of automation at Stoneridge Electronics in Örebro. In order to cope with challenges the company has changed their mind set and work procedures. The change of layout, levels of automation, lean production is seen to change the assembly system concept evolution at the company. These parameters found can all be considered enablers in order to achieve flexibility, as stated by Slack et al. is seen as a common trigger for change [23, 24].

The concepts of lean production and the way to handle instruction has been part of the change in cognitive level of automation. Lean production has been more and more included in the production thinking where the cells are built tighter, with smaller batches where one-piece-flow have been introduced and more thought has been put into how the operators work should work coordinated and how the assembly instructions should be formed. As Slack stated [23, 24] flexible technology cannot work without flexible operators and it was seen that the operators are more included in the work today than before and that much effort is put on better coordination of the work amongst the operators.

The change in level of mechanical automation is influenced by the companies search for new ways for improvements where travelling is a big part for finding inspiration. In comparison to other companies where improvement potential can be found from European companies, the production technicians at Stoneridge have also travelled to Japan, to get a more global view when it comes to technical solutions.

The change in concept evolution is seen in the iterative work of building new cells and trying to adapt the old cells to the new way of thinking. However, this process ranges from easy to more complicated tasks.

One clear result is that the evolution of the different production cells goes from a higher physical automation in terms of conveyors, pallet systems and robot cells, and higher cognitive automation in terms of pick-by-light and test stations, to a decreased physical automation and other solutions when it comes to the cognitive automation. Layout changes have been seen when tighter u-cells are formed and a greater deal of work has been put into improving the fixtures. Another interesting result is the mindset of the production engineers that works with the development of the production systems. In short, their opinion is to work with the best suppliers of machines and technical solutions, despite their geographical location, competent operators and the best production and improvement methods in order to stay at the front in their field.

V. CONCLUSIONS

Over time, the company have changed both levels of automation and assembly system layout in order to keep up with today's challenges and demands. Levels of automation was increased both physically and cognitive after rebuilding one line into a robot line, but after some time the line was re-built again for manual work. In the newer stations the cognitive levels of automation are increased again. The assembly system layout changes for all stations are seen going from more space-demanding u-cells to tighter ones. Both levels of automation and assembly layout are part of the assembly system concept evolution and it is evident that the company always had a very strong drive to evolve and to improve. However, some difficulties are seen in rebuilding the older stations to fit the new thoughts regarding lean production, operator work, planning, and fixture simplifications. As stated by Weindal et al. [13]: *With flexibility comes complexity*. However, these problems are met with pilots and test projects on working instructions, introduction of a material wagons, more flexible work stations, and increased maintenance.

It is seen that DYNAMO++ can be used as a tool for analysing company changes and concept evolution at a company.

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