A MODEL FOR ASSESSMENT OF PROACTIVITY POTENTIAL IN TECHNICAL RESOURCES

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ABSTRACT

The ultimate aim when designing an assembly system is to make it strategically and operationally competitive. Competitive systems for manufacturing, especially assembly systems, have to cope with frequent changes of demands. The aim to have a short response time to customer demand, e.i. mass customization, requires assembly systems that are reliable, have high availability and have ability to produce the right product correctly. This means a combination of short resetting time and ability to vary the systems output of products. A major challenge is to minimize the lead-time that directly has influence on order-to-delivery time, while maintaining product flexibility and robustness to absorb late market changes. Given that the assembly system is working the way it is supposed to do, the order-to-delivery time is directly dependant on the setup time and the operation time. The problem is that automated assembly systems have a low availability due to that technical equipment does not work, caused by lack of knowledge, breakdowns, limited ability to perform the operation etc. This often leads to that when a company needs variant flexibility they keep the assembly system tasks manual. Totally manual assembly system is not the future for competitiveness. Therefore we need to develop assembly systems that are available and have product flexibility to absorb late market changes, and still have a short order-to delivery time. This paper focuses on the level of automation and is a contribution to future evaluation of how technical solutions either support or work counter to proactivity. The result is a model for evaluation of technical solutions contribution to proactivity

This paper describes a model for assessment of technology and assembly system solutions that fulfil requirements for a proactive assembly system. Criteria for proactivity in different technical solutions of assembly system are reviewed.

KEYWORDS

Proactive assembly system, measuring level of automation.

1. PROACTIVITY IN AN ASSEMBLY SYSTEM

Well-known characteristics of assembly systems capable of rapid change are e.g. *Flexibility*, *Robustness* and *Evolvability* coupled with ability to handle frequent and dynamic changes, disturbances and deviations. The authors suggest further development and propose *proactivity* as a vital

factor of semi-automated assembly. Future assembly systems must have readiness for planned and unplanned changes and at the same time be robust, i.e. it should be designed to handle both planned and unplanned changes without losses in effectiveness and profitability.

In a proactive assembly system, the full potential of both human operators and technical systems is

utilized. The concept of proactivity; taking action by causing change towards a state and not only reacting to change when it happens (Dencker et al, 2008), is a complement to necessary reactive actions.

In terms of system resources, we suggest that the proactive assembly system constitutes an integrated combination of the competence of “knowledge workers” (Drucker, 2008), *information* and *automation*. The proactive assembly concept is presented by Dencker et al, 2009, along with arguments for focus on levels of automation, information and competence as main drivers for the degree of proactivity. A proactive assembly system must be a meticulously and carefully planned combination of automation and manual knowledge work where the level of automation (LoA), the level of competence (LoC) and the level of information (LoI) are decisive factors.

Proactive assembly systems require operator’s knowledge, training and mandate to make the system proactive. Equipment itself is not proactive but well designed equipment supports the human - machine interaction and reinforces the necessary human skills and the overall proactive system behaviour. Tasks performed by the proactive assembly system are according to e.g. performing assembly, short-term planning, real-time resource allocation and actions in disturbance handling. The identified tasks for the assembly system based on Mårtensson and Stahre, 2003 are presented in figure 1. Sheridan (1997) elaborates on several alternative meanings for the concept of human-centered automation, e.g. elaborates on several alternative meanings for the concept of human-centered automation, e.g. “allocate to the human the tasks best suited to the human, allocate to the automaton the tasks best suited to it” and in that way “achieve the best combination of human and automatic control, where *best* is **defined by explicit system objectives**”. These changes take the focus from a function-oriented perspective to a process oriented perspective. Further, the possibilities to dynamically allocate tasks between human and technical resources are required. What do we expect from the system and what duties, tasks and actions will the system be responsible for e.g. information handling, communication and decision making in normal operations and occurrences (predicted and unpredicted) Stahre (1995) suggested a complementary re-definition of the monitoring and intervening roles where more interaction with the physical process was included, as would be normal in manufacturing and assembly systems. By adding this perspective to a system containing different tasks both performing

assembly operation and use and develop the knowledgebase. Instead of having the view that the operator is a user of the system the humans and the machines are resources within the system.

In evolvable systems research efforts, integration of human operator abilities into evolvable assembly systems is presently limited. Humans are often delimited from the system. The successful integration of human operators into the system thus constitutes a potential for future research efforts. One idea is that assembly systems should go through an evolution rather than adaptation. This evolution could be exemplified by stepwise accumulative level of automation of tasks concerning performing assembly work, control, monitoring, diagnosing etc. within the system.

The tasks and their subtasks could either be performed by technical equipment or by human. The concept of proactivity; taking action by causing change towards a state and not only reacting to change when it happens requires ability to real-time allocation and reallocation of tasks.

Figure 1- Operator roles and work tasks in an assembly system

To explain the proactivity it is helpful to distinguish the subtle difference between robustness, evolvability and proactivity.

Robustness in an assembly system is the ability to handle predictable and unpredictable variations with minimal loss of functionality causing penalty time. It determines the magnitude of changes within which the respond occurable to accommodate permanent changes in context (*e.g.*, product shift). An evolvable system is a system based on many simple, re-configurable, task-specific elements (system modules), allows for a continuous evolution of the assembly systems ability to react at /recover from finite changes in context (*e.g.*, impulse events), (Onori 2002, Onori 2005). Proactivity is to add the ability to detect and prepare for or eliminate the disturbance before it occurs and thereby shorten or eliminate the reaction time. The ability to vary LoA contributes to a larger range of possible solutions but put new demands on technology, on disturbance handling as well as the information system and the knowledge support (Fasth, 2008).

Existing systems engineering methodologies have difficulties with evaluating the proactive measures of the technical solutions. This paper focuses on the LoA factor and is a contribution to future evaluation of how technical solutions either support or work counter to proactivity. The result is a model for evaluation of technical solutions contribution to proactivity, *e.g.*, to be able to answer the question: “equipment A vs. equipment B - which supports a proactive assembly systems demands?” The paper describes a model for assessment of technology and assembly system solutions and how they fulfil the requirements of a proactive assembly system.

2. STATE OF THE ART

This section provides an overview of identified factors influencing proactivity. The ongoing, three-year ProAct project is presently in the process of structuring empirical data from six case studies in SME companies in Sweden, in order to test the applicability of the proactivity concept and demonstrate features of proactivity. Methods used include semi-structured interviews, video-based task analysis, and value-flow analysis. Close collaboration with the case study companies has been established on shop floor and top management level.

A proprietary method for measurement of the level of automation has previously been developed by two of the project partners (Fasth 2008). The method provides reference scales for the levels of automation related to mechanical/physical tasks and information/cognitive tasks. Similar instruments are being developed and deployed for LoI and LoC.

The following sections provide a deepened

description of the three parameters.

2.1. THE LEVEL OF AUTOMATION (LOA)

Qualified automation can give competitive advantages. However, highly automated assembly systems tend to be rigid and complex. This increases system vulnerability for both predictable and unpredictable occurrences and complex assembly systems are often expensive compared to achieved product flexibility. Future assembly systems must have the ability to be evolutionary developed in close cooperation between assembly operators and product- and production development. This includes aspects of availability, reconfiguration, flexibility and technical solutions regarding evolvability. Further there is a need to combine information and insights across multiple disciplines and perspectives with the common goal to achieve a desired balance between automation, information and human competence. In this study the DYNAMO++ methodology for measuring LoA has been used. The DYNAMO++ methodology was developed (Fasth 2008) based on previous research, where a taxonomy for measuring both cognitive (information) and physical (mechanical). Level of Automation (LoA) in the current stage of the system has been conducted. The aim was to measure accessible LoA in order to find an appropriate span of levels of automation and, by that, maintain high productivity by reducing production disturbances.

The focus of the further development is on the analysis and clarify whether the current systems' LoA is too high, too low, or too static in order to fulfil the aim for proactivity. The DYNAMO++ methodology contains four different phases; 1) Pre study, 2) Measurement, 3) Analysis and 4) Implementation. These phases or methods are used to answer different questions in order to redesign the system in a structured way and avoid over or under automated Figure 2 shows the average LoA levels used in the different operations based on the research casestudies at the participating companies.

Figure 2- Current stage LoA in the case studies assembly systems.

2.2. THE LEVEL OF INFORMATION (LOI)

Within this domain there is a lot of research going on and this paper does not thoroughly discuss the principals. Continuous exchange of information between different departments and between people is crucial for fast “decision-loops” correctly updated with the real manufacturing and market conditions. Operators are supposed to take responsibility for more than just handling assembly operations and their disturbances. Frequent reconfiguration, either initiated by explicit demands, or changes due to proactively predictive problems or requirements needs support of different kinds of information. The operators should have a long-term, proactive perspective on the development of their own assembly system and actively participate in the product design and manufacturing development process (Bruch et al, 2008). This gives the assembly system and its operators the ability to autonomously manage changes within the assembly systems local layout and its disturbances during operation. This requires the correct information to be exchanged at the right time.

2.3. THE LEVEL OF COMPETENCE (LOC)

A part of the ProAct project is cognitive task analysis, in order to get the views of the operator on his work and in order to provide product developers with information on critical issues in assembly work. Resulting functional analyses address the questions: What do we expect from the system and what duties, tasks and actions will the operator be responsible for. A cognitive task analysis builds on interviews of the assembly system “users” at different levels in the companies in the project. Interviews will focus on mental activities, e.g. information handling,

communication and decision making in normal operations. Further, the project will identify the “expert” work in comparison to the “novice”.

The criteria support correct situation awareness for the operator team. This put requirements on the information to have ability to both provide correct information about the system, the resources and the system as a whole. Information also needs to be presented it in a way that supports the operator team to have the correct situation awareness in a short time. The competence of the operator team is crucial because this realises the system’s proactivity that is built in. Competence is not replaceable with information but it could be reinforced with the right level of information. Without correct competence it is not possible to have correct situation awareness in a short time. The competence is the ability to do the right action and also to predict the consequences of the action taken.

A proactive assembly system has a larger space of possible solutions and is illustrated in figure 3 as the knowledge operator action space.

Figure 3- The action space decreases in a proactive assembly system.

3. SUGGESTED METHOD FOR DETERMINATION OF PROACTIVITY

The proactive system has the ability of reduction of the likelihood or magnitude of a disturbance (a complement to preventive maintenance that could be scheduled by exposed to wear and probability factors) by adding the in real-time predictable ability by sensing the systems deviation. To be able to sense system deviation during running time the normal work has to be well defined. This requires lean awareness by for example well defined processes. How you reconfigure the processes and allocate your resources is a result of a proactive ability. Variable LoA enlarges the range of possible solutions. In order to expand the operator action space the authors have developed a methodology for determination of how technique can contribute to proactivity.

One difficulty is that a proactive assembly system doesn't have the same appearance at all times. The appearance could differ between different setups. This makes it more difficult to predefine deviations compared to a steady system solution.

However, proactivity at the system architecture level is a poorly understood system property that extends beyond questions of component reliability and node hardening (Neumann 2000) to internalize the role of operational behavior, human factors, supporting infrastructures, and the technical system architecture in the assessment of proactivity (Hollnagel, Woods, Levenson, et al. 2006). Indeed, when considered above the component level, proactivity is an emergent property of system architecture that has meaning primarily in the overall context to which it relates. Although highly efficient, concepts for emerging, evolving, and highly reconfigurable assembly systems previously described, rely on rapid adaptation to changing conditions. This paper suggests that even higher competitiveness can be achieved by a complementing proactive behaviour. Proactivity is not a new concept, as proactivity often can be observed in the behaviour of highly skilled and experienced workers. Unfortunately, proactive requirements are difficult to specify, develop, procure, operate, and maintain. Existing systems engineering methodologies have difficulties with evaluating the **benefits of protective measures**. The structure should be readily deployable to the design of future assembly systems. The fundamental goal of this research is to address this challenge by developing a design process that enables speed of change analysis of proactivity to be performed at the architecture level (*e.g.*, to be able to answer the question: "...vs. —which is more proactive?") An ideal out-come of this research would be a systems engineering methodology that allows decision makers to explicitly trade between utility, cost, and proactivity in system architecture design.

The research focus is to define assembly system factors that support proactivity concerning speed of change and the systems ability to handle changes.

A first step is the suggested evaluation model presented I section 3.

A literature review and case studies support a well defined range of possible solutions as contributing factors to proactivity, (Dencker et al, 2009). To receive and maintain a large range of possible solutions the results from the case studies define the following factors as contributors:

Ability to produce different product variants (Product Flexibility)

Requirements:

Evolvable including Reconfigurability and Plugability

Evaluating factor:

Open Architecture

Modular

Interoperable

Decentralized

Ability to produce different product volumes (Volume flexibility)

Evaluating factor:

Decentralized

Scalable

Ability to produce different product variants time effectively

Speed of change

The results from the case studies show that it is not only the setup time that is the decisive factor, but also the human aspects and the operators ability to influence the process. It must be beneficial to setup, both for the assembly systems results and for the individual operator.

Evaluating factor:

Robustness

Evaluating factor:

Standard mechanical modules (finite reconfiguration range)

Ability to handle frequent changes:

Planned frequent changes requires

Evaluating factor:

Interoperable

Unplanned changes caused by disturbances requires

Evaluating factor:

Interoperable

Result

A larger range of possible solutions requires:

Independent

Distributed control system

Decentralized

Open Architecture

Modular (Mechanical)

The role of people in the modern flexible production system has changed as new systems principles and technologies have been introduced. Employees are now expected to interact with the technical resources, not just execute simple

repetitive tasks. MacDuffie and Krafcik (1992) stated that there is an increasing need for understanding of the employee's role in the production system due to the necessity to identify and solve problems the moment they arise on the line. Kaber and Endsley (2003) explored effects of different levels of automation on human performance and situation awareness. Bley, *et al.*, (2004) discuss appropriate human involvement in assembly systems. They focus on system adaptation to external constraints like products and internal human behavior. Thus, the operator is treated like a system component. Production employees require knowledge and training to solve problems on the production line, as they occur. Today the operator must be able to identify problems, isolate their occurrences, determine root causes, and conduct remedial actions to prevent reoccurrence. These requirements highlight the importance of information sharing and decentralizing of specialized staff skills, such as those involved in maintenance and technical engineering. Further, this additional knowledge will assist operators when facing daily issues, and help integrate them into the concept of the "production system." Earlier the authors stated that

equipment itself is not proactive but well designed equipment supports the human - machine interaction and reinforces the necessary human skills and the overall proactive system behaviour.

Experience, pattern recognition, and other human cognitive skills support the way working people prepare themselves and their workplaces for expected and planned events. A classical model for proactive behaviour, Situation Awareness (SA), was proposed by Endsley and Kaber (1999). The three levels of situation awareness were defined as:

Perception of elements within the current situation.

Comprehension of the current situation

Projection of future state.

Thus, in addition to planned events, proactivity, as well as SA, involves anticipation of situations and events that have not previously been explicitly defined and described. Based on Endsley, 1997 the project has developed evaluation methodology presented in picture 3. By defining the causes for false projections the technique for proactivity is identified. The future studies will show and exemplify the resources that support proactivity.

Scenario	Perception	Comprehension	Projection	Intervention	Cause
Operators/system not able to notice signals from deviations	Not Ok	Don't exist	False	Wrong	
Operators/system notice the signals, are not able to interpret and therefore no ability to act or acts not correctly.	Ok	Not ok	False	Wrong	
Operators/system notice the signals, but don't think the interpretations are correct.	Ok	Not ok	False	Wrong	
Operators/system notice the signals, are able to interpret but do not know what tool to use.	Ok	Ok	False	Wrong	
Operators/system notice the signals, are able to interpret but do not have the tools.	Ok	Ok	True	Wrong	
Operators/system notice the signals, are able to interpret and has the tools to act correctly.	Ok	Ok	True	Correct	

Table 1 –Evaluation tool for determination of Proactivity

Further studies to evaluate the possibility to determine assembly systems proactivity are conducted.

4. CONCLUSIONS

The authors' approach to proactive assembly systems has been presented and aligned with the arguments to focus on automation, information and competence as main drivers for proactivity.

This paper describes a model for assessment of technology and assembly system solutions that fulfil requirements for a proactive assembly system. Criteria for proactivity in different technical solutions of assembly system are reviewed. Arguments are based on theory and industrial case studies.

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