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Digital assembly instruction system design with green lean perspective - Case study from building module industry

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Abstract

Manual “easy jobs” need to be efficient, standardised and quality assured to remain competitive against automated production. Digitalised work instructions offer an opportunity to support standardisation and quality assurance for manual work tasks in industry. Inspired by axiomatic design this study aims at selecting design of lean methods and equipment for digital assembly instructions and standardised work. Literature regarding standardised work and green lean production system is applied in a case study. Interviews, observations and green lean equipment design methods are used to conclude system requirements of a digital work instruction-system designed for assembly of modular buildings at Husmuttern AB.

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1. Introduction

This paper introduces a case study of a start-up company assembling house modules. The business idea is to provide low price standardised temporary modular houses for e.g. schools or living. The market for prefabricated wood houses is increasing [1]. In order to have lean and sustainable operations, standardised modules will be built in standardised operations by people in need of so called “easy jobs” adding to social sustainability. This give high requirements of the safety of equipment and efficient standardised work.

Due to, among other things, a large immigration of people with lower education level, there has been an increasing need to find “easy jobs” in Sweden, [2] e.g. more than half of the immigrants are unemployed [3]. The intention with these jobs is to train people job-skills and Swedish to make it easier to get other jobs afterwards [4]. For assembly type of operation to be competitive, efficient standardised work and continuous improvement is required [5]. Digitalisation and automation is often said to “take jobs”, but in the quest to create simple jobs in industry using lean production, support may come from

digitalisation and automated quality assurance [6,7]. Tools such as visual work instructions need to be in line with the production system principles. Lean production is a commonly used management approach where companies develop their own company specific lean principles in a Company-X production system (XPS) [8, 9].

The joint evaluation of environmental, social and economic performances is increasing in use, by the “triple bottom line”. In Green Lean, sustainability aspects (ecologic, economic and social sustainability including occupational health and safety) are integrated in a holistic management with sustainable and lean company principles and values [8,10]. The production equipment and infrastructure needs to address the challenges, be in line with the green lean XPS principles and context, equipment and operator skills etc [11].

1.1. Aim and outline

Inspired by axiomatic design this study aims at designing green lean methods and equipment for digital assembly

instructions and standardised work. The study is applied at a building module producer and tries to answer whether design parameters can be set for instructions system and assembly equipment to promote easy jobs and green lean production. In addition, the paper discusses how the digital revolution can promote easy jobs and what possibilities there is for small assembly operations and start-ups to digital technology.

Although eco-design of products is important in green lean, this paper is limited to social sustainability. Assembly equipment design, instruction and training system are used to answer the two challenges to keep personnel safe and to facilitate learning. In Husmutterns assembly in addition to personnel health and safety and ergonomics, the strive to make jobs possible to do for unskilled personnel is the most important sustainability target [12].

The paper outline after this introduction of the scope is a brief presentation of the methods used in chapter two. Then in chapter three some important concepts from literature is presented followed by the result and analysis of the empirical case. The case is compared to other cases in literature and in discussion and reflection the results are further compared to theory. Finally, conclusions on the research aim and suggestion for further research is presented.

2. Method

This case study is based on interviews and coaching green lean management with the manager of Husmuttern, observation of concept proofing trials and to some extent supervision of bachelor theses, developing production equipment and logistics concepts. Based on lean and green operation management theories, the production system design requirements and the solutions in the form of standardised work, quality assurance, mistake proofing, reduction of uncertainty, visualisation and learning were analysed and compared to other studies with regards to digitalisation.

The method for extracting design principles follows one outlined in Kurdve and Langbeck [12]. Complex systems like the assembly equipment and the instruction and training system at Husmuttern can be designed using axiomatic design (AD) where functional requirements (FR) of the system are translated into design parameters (DPs) [14]. The FR should be user centred, in this case the XPS principles and additional challenges can be seen as the main FRs [15]. For this purpose, the principles found in literature and practice by Netland [8] have been used as comparison. FRs should also be made independent, which is problematic to prove, and be few. The resulting design criteria for the system functionality [16] are then seen as the design parameters. Finally, the technologies and methods used at Husmuttern are compared to other studies in chapter 5.

In parts, the coaching and supervision can be seen as action research (AR) since the author has been involved in developing strategies with the aim to improve operations [13]. The type of and size of the study limits generalisation of results to possible validation of other research and or giving hypotheses for further research. Action research contributes incrementally in small steps to theory building by accessing operation

management more thoroughly and contextually embedded than by traditional positivist science [13].

3. Theoretical frame of reference

3.1. Green lean assembly

A framework for development (e.g. sustainable development) need to be based on constitutional principles and principles for the outcome (e.g. sustainability) [17]. These principles guide problem solving and continuous improvement, redesign of the system, and selection of tools and performance measurements [9]. As a result of the principle “health and safety first”, practical green lean production equipment and system design includes avoiding hazards, minimising risks, apply protective actions, train and equip personnel for safe and healthy operation [18].

For environmental sustainability of production equipment design, material, energy and waste efficiency may be of importance [19] In assembly processes with many manual operations but few chemicals or energy demanding operations, critical issues are product functionality and quality, material efficiency, and infrastructural energy use [20]. Eco design of production equipment thus needs to optimise function and quality of product first, and then being resource efficient with low emissions and minimal use of hazardous materials [18]. Therefor quality assurance and especially proactivity and fault proofing is the most important environmental issue in the assembly operation.

3.2. Standardised work, Job instructions and improvements

A cornerstone in Lean production is standardised work (StdW), as getting a team to adhere to the best-known way to perform a task. It is thoroughly described in lean literature. Liker and Meier [5] explains that implementation is done by: identifying the basic work steps, record time for each step, and draw a schematic picture of the work area and the operators work flow, a standardised work chart (SWC). It is pointed out that StdW is not enough to bring anyone off the street and train them to do the job, or that the SWC can be used to learn all details of the work. StdW is a necessary base for both efficient continuous improvement and job training [5]. Critical issues or mistakes that still occurs can be handled by error proofing or ‘poka-yoke’ as a problem-solving resolution. StdW should be revised regularly in an operation improvement system.

Learning to do a job the correct way cannot be left to following another employee around. Learning manual work skills can be seen as a process reducing uncertainty for doing the work task. Skills can only be learned through continued practice [21]. The personnel need to be trained in both general principles/rules and in specific job skills following the StdW [5]. In lean training within industry, each job element is trained under supervision of an instructor. First the instructor shows how to do the job correct and safe and then it is tried by the employee, coached by the instructor. For training the StdW basic work steps are broken down further into job instruction elements and as in SWC critical issues (e.g. safety or quality)

is explained. Daily repetition of the job-instruction with the instructor is recommended [21]. An effective management of information on the production system is critical [22]. A comprehensive easy accessible language can be facilitating communication of information between the users and the designers of a PS.

The operation improvement system should be set up to be self-sustained with continuous improvement and operation revision [23]. Managerial monitoring and control should focus on supporting improvements rather than controlling operations [5]. When implementing improvement tools in SMEs it is important that they are specialist independent, support learning and have clear objectives [24].

3.3. Digitalisation and visualisation

Visualisation is a key in getting fast cognitive response from people. Visual management is a cornerstone in lean production [5]. In recent years the possibilities for digitalised visualisation has increased exponentially and is an integral part in research on future manufacturing work such as Operator 4.0 and Augmented Operators [6]. Augmented reality type visualisation gives more support to inexperienced workers than experienced, levelling out performance difference. Even in less advanced setting where oculus rift glasses would be too advanced [7], digital visualisation may have great advantages over paper based instructions [25]. The development towards the smart factory will demand even higher digital skills from the workforce and training on the job arenas [26]

4. Case result and analysis



Fig. 1. Company values

Husmuttern is a new company with company value stated as: “Be good – do good - fair deals” (Fig 1). Husmuttern develops a temporary buildings production concept around two social challenges in Europe, namely the need of cheap

temporary houses (e.g. for kindergartens/schools) and the need for easy jobs, especially for unskilled personnel [12]. The development is currently in pilot production state with concept proof and verification of the standardised production cell with module fixture, tool boards and big screen monitor for visualisations, see Fig. 2. Personnel used for the concept proofing has various national background, low education and no previous manufacturing or construction working skills, some have physical handicaps. Each assembly cell should be operated by two assemblers and a logistic support person. Initially operators need fork lift driving license.

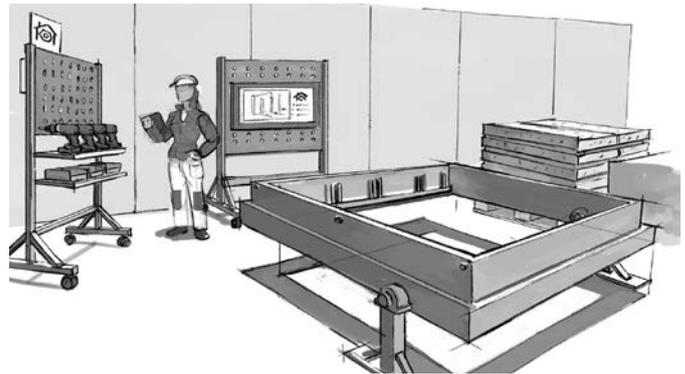


Fig. 2. Sketch of cell.

The environmental sustainability of the concept is evaluated in another paper [27] where, functionality of the work cell quality assurance and especially proactive fault proofing were the most important issues. From social sustainability point of view, it is most important to succeed with the easy and safe job approach, giving people jobs that are safe and give new skills in assembly operations.

Husmutterns values (Fig 1) emphasise on the social sustainability. When it comes to lean principles those are not yet exactly formulated but after interviews with the owner the following statements have been used as XPS-principles: *Safety first, Easy to understand, Teamwork, Quality assurance/poka yoke, be nice and keep it simple*. These are paired with XPS principles from Netland [8], with design parameters and practical implementation (Table 1). The baseline tool for implementation is standardised work. Based on the bill of material and the design of the house modules, the process of assembling the modules is decided [28].

Table 1. Functional criteria and design.

Functional requirements Husmuttern principle	General XPS principles (Netland [8])	Design parameters	Practical solution (in addition to standardised work)
Safety first	HSE	Fault proof safety	Safety poka yokes
Quality - poka yoke	Total quality	Fault proof quality	Quality poka yokes
Quality assurance	Total quality	Quality documentation, fast, easy	Camera for quality documentation
Easy to understand	Visualisation	Visual dynamic instructions for all operators	Movies based on drawings
Easy to understand	Clear communication	Language flexible instructions	Multilingual audio and written instructions
Keep it simple	-	Avoid technical complexity	Standardised tools
Be nice to each other	Teamwork	Team training	Job training with team
Friends with environment	HSE	No spill material	Quality of prefab material

The necessary assembly sequence is balanced between the two operators and tried in supervised settings. Safety and quality critical issues are noted and poka-yoke problem solving is applied to make system fault proofed. The standard includes taking photographs to document all critical operations. Finally, the operation is currently being documented in standardised operation sheets. The solutions applied for assembly equipment can be categorised as quite low-tech, in order to make it easy and safe to operate. Poka-yoke implementation is similar to poka-yoke in regular construction work [29], mainly of the physical constraint type and not digitalised. All tools are battery operated electrical tools, no pressurised air is needed. Wood materials are pre-cut why no sawing and thus wood operations are fairly dust free, although some wood drilling does take place. Low dust insulation is chosen for the same reason. There is a high focus during concept proofing on finding any safety or quality risk and via redesign of equipment or parts assuring fault proof [30].



Fig. 3. Concept proofing test cell.

The Job-instruction, visualisation and quality assurance on the other hand can be categorised as high-tech. Instruction animations are shown on a large screen (see fig. 3) Digital animations of operations, for training and digital photographs for process assurance are used. Digital animations are used for visualising all operations. Since 3D drawings of all parts and equipment are available it is possible to animate all moves. In the current animations, there is no person in the movies. The tools are pointed out and colour coded as shown in Fig. 4 a and b. This is in line with recommendations in literature [31]. The animations are perceived as useful, and even critical, to have in the training and trial settings deployed. For ergonomic-critical moves it may be necessary to add mannequins in the animation showing how to hold/move properly. This is not yet implemented. The supervised training however emphasises on doing operation in correct ergonomic way.



Fig. 4. Animation pictures (a) pointer; (b) tool

Quality critical instances of the operation are photographed giving a thorough documentation of each individual product during the production phase. It can be used for post-detection of faults and traceability of mistakes. There is also possibility to add documentation by photo or film on safety critical instances of operations.

The concept proofing trials are also filmed and analysed in order to construct standardised work charts (SWC) for each operation. The work charts are done in classical way [5], but attached to each operation there are possibility to add films showing how the operation is done in addition to the animation of the operation. The SWC can thus be changed in improvement work and documented in film whenever needed, a change management database is planned for development during 2018 to handle improvements.

Extracted from table 1, the design parameters for the further development of training and information equipment are set: The system for safety and quality assurance need to be fast and easy to operate (e.g. single click/button press). And thus, the database need to store photos with product identity and operation version and number. It also need to be easy to add comments to photos (and films). The system for instructions need to be visual, showing all movements and sequence of operations. Screens need to be easy to operate and clean. Future animated instructions should show which operator (role) is doing what to fit standardised work requirements. Oral and written instructions are planned to be input in instruction database with possibility to add translations in other languages based on the individual’s language skills.

The above requirements in part include solutions supported by digital tools. Table 2 shows the solutions at Husmuttern, if digitalisation has been applied and with reference to research cases with digital solutions.

Table 2. Applied digitalisation

Practical solution	Applied Digitalisation	Description, reference
Safety poka yoke	none	ergonomic support possible [6]
Quality poka yoke	none	electronic devices are possible [29] may require automation at supplier
Prefabricated material	none	[1]
Standardised Work	none	can be aided by digital support [32]
CIM e.g. 3D drawings	Yes	3D data in line with e.g. [1]
Animated instructions	Yes	3D colourised animation e.g. [31] critical OP's photo documentation
Quality assurance	Yes	[33]
Traceability*	Yes	digital stored data for individual parts [6]
Multilingual instructions*	Yes	auditory instructions e.g. [25]
Pick to light	Not applied	mentioned for assembly in e.g. [25]
Automated line	Not applied	mentioned for similar application in [34]
Robots	Not applied	mentioned for similar application in [34]
Augmented Reality	Not applied	mentioned for assembly in e.g. [31, 35]

*= planned, not implemented

Poka yoke, standardised work and use of pre-cut materials are currently solved by physical solutions at Husmuttern

although there are digital support available [1, 6, 29, 32]. Digitalised, animated and vocalised instructions as well as quality assurance are planned or implemented in line with what is found in literature [1, 6, 25, 31, 33]. A number of automation techniques such as pick-to-light, automation, robotization and augmented reality [25, 31, 34, 35] is consciously not currently applied since it may not fit well with the technology maturity level of workers and the social sustainability aims in the case study company.

5. Discussion and reflection

This study contributes with empirical experience from a manufacturing start-up on competitive sustainable manufacturing [36] with emphasis on the social dimension in connection to the digital revolution [26]. The application of smart manufacturing research in sustainability is an area in need of empirical research in

The solutions applied at Husmuttern show that digitalisation or smart production offer development potentials for improved learning and production control without worsening complexity/complicatedness for assembly personnel. In 2012a study of four prefabricated wooden house producers by Landscheidt et al [1], two of the companies have computer integrated manufacturing (CIM) with digital drawings of both products and equipment, and operators have access to work orders on tablets in one while the other have integrated the work information in an automated line. Automation and use of industrial robots in wood-ware and house building industry is rare compared to e.g. automotive industry, but have a future potential [34]. Common reasons for low use of automation are low volumes, lack of handling safe operation of machines and trying to automate to complex tasks. The need for documenting exactly the order of and how to perform each task in an automated line is obviously higher than in standardised manual work.

One issue to further investigate is the flexibility and agility of automated systems compared to manual systems like Husmuttern. It may be easier to improve continuously and handle redesign and therefore manual systems may be more competitive than automated systems in certain settings, especially if the manual labour is facilitated by augmented reality [6, 7, 35].

Lean practices sometimes seem to be almost a prerequisite for efficient adoption of digital technologies in assembly. Flow, standardised work and use of digital technologies is especially common in assembly compared to machining or other industrial operations [37]. A hypothesis from comparing the abovementioned studies with empirical findings in this case is that it is in particular standardised work and standard operation times [38] that give foundation for efficient digitalisation and possibly future automation. Since application in SME's have special needs [24], e.g. should be specialist independent, some more advanced tools for augmented reality may have to be omitted, but this research confirms to some extent that simple digital visualisation and documentation is useful [24] also in real assembly settings, which is in line with trials in also in large companies [31]. The animation is an expertise needed to employ or buy as external service in the Husmuttern case,

rearrangement of animation sequences should be possible by non-experts in future tools.

Generalisation possibilities for regular construction business is not made easily [29]. It is easier to maintain a safe and quality proof system in an assembly cell than in a regular non-standardised construction setting. The construction environment with many nationalities and a variety of experience among personnel does give similar but larger challenges to the studied case. Certain parts of the result, especially with regards to training of standardised sub-operations may still be applicable, which is recommended for future research. In addition, personnel trained in the researched assembly setting may have an easier step to learn to work safely in regular construction environment. Personnel trained in this setting may also be prepared for other manufacturing, especially lean manufacturing in a digitalised setting. The studied standardised assembly may thus be an easy job and a stepping-stone towards more advanced industrial work.

6. Conclusion and suggestion for further research

Standardised work is a necessity but not sufficient factor for quality and safety assurance and efficient training in assembly. In addition, error proofing, poka yoke, can be used on product, equipment and system design. A system adhering to green lean principles may require dynamic visual instructions, preventing quality and S&H mistakes by error proof process and should involve operator teams in improvements. There may be advantages in using digital technologies for photo-documentation, visualisation by animation, photos and film as complement to standardised work and job instructions. Database solutions for storing such information as well as language support will be needed in the studied company.

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