Planning for waste minimization at a factory floor

A student project to support smarter home production practices

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INTRODUCTION

As educators we have a strong interest in knowledge on factors enhancing student learning, for example within a student project context as presented in this paper whereby industry meets engineering education, being the focus of the SEFI conference. More specifically we present findings generated by investigating the work of a student group who collaborated with managers and workers to utilize lean manufacturing tools and process modelling to reveal smarter home production practices. Generally, Lean Manufacturing is a set of techniques and activities for running a production or service operation aiming at eliminating all non-value-adding activities and waste from the business [1]. The techniques and activities have been subject to extensive investigation in the past decade [2, 3], but few authors like White [4] and Conner [5] have discussed the implementation of Lean Manufacturing in SMEs specifically [2], and research on Lean Construction is also missing [6].

The objective of the student project presented in this paper can be summarized as a task of identifying challenges and opportunities for automation at a factory floor in a Norwegian SME (Small and Medium sized Enterprise) construction company by the use of various techniques learned at school. The case company where the project was run, builds homes with a modular construction method. Most houses are delivered in the municipalities nearby the company offices and its factory for module production. For some years the company has kept a holistic perspective on business practice to ensure growth and survival. In line with this, goals for improvement have been formulated in a company specific goal model, as described in Persson al [7]. Various business improvement initiatives have correspondingly been initiated in relation to this goal model, for example within sales.

Due to the good fit between the project objective and company goals regarding process improvement at the factory floor, the company managers welcomed the project proposal when it was introduced. It was decided that the students should work in close collaboration with managers and workers at the house production plant, based on a structure known from their education; i.e. the application of basic process and quality improvement Lean tools such as process modelling, genchi genbutsu, a Japanese term translated into English as “go and see for yourself” [8], and the '5 whys' analysis, to reveal root causes of challenges [9] in the manufacturing process. It was also agreed that the students should present anticipated results of change to management together with action proposals based on Lean’s heijunka, i.e. controlling the variability of the job arrival sequence to permit higher capacity utilization [10]. This should happen both orally during the project process and at the end of the project in the form of a report. The students were via the project introduced to the building industry, a sector known to be fragmented, large and complex [11, 12].

The reminder of the paper is organized as follows: Section 1 presents theoretical background related to the student project´s main objective, while section 2 describes our research method. In section 3 findings enabling a picture of the project process are described, and main findings pertaining to educational aspects are presented. The paper is concluded in section 4 with a discussion about the students´ factory floor redesign practice discoursed from a perspective of embedding business ecosystem concepts and ideas mixed with reflections on learning. Section 5 contains our acknowledgements.

1 THEORETICAL BACKGROUND ON THE IMPLEMENTATION OF LEAN MANUFACTURING PROCESSES IN THE CONSTRUCTION INDUSTRY

Various challenges face the Norwegian construction industry, such as weak productivity growth, quality deviations and errors in build and construction processes, low rate of innovation and production processes characterized by weak interaction [13]. Such challenges also apply to construction companies globally [14]. Evidently many of the challenges relate to waste either in the flow of materials or in the work of men. Unfortunately, there is little literature providing guidance on how to start any business process initiative, and how to develop business processes [15]. In an effort to assist business executives and process practitioners with these endeavours, Harris [15] provides insight into two key components of business process management: 1) How to define the scope of business processes and subsequent business process design activities, and 2) How to develop business processes and all their supporting constructs [15]. In short, Harris [15] addresses the business process ecosystem from strategy to transformation and the need for governance and strategy to sustain the ecosystem while maintaining organizational process security and control, wherein the term business process ecosystem refers to the collection of processes and all the components that constitute and govern the behaviour of business processes and allow processes to be defined, executed, managed, measured, and optimized [15]. Harris [15] emphasizes that the Business Process Ecosystem is centred on “work” and defines the work to be done, how and who should do the work, how to control and manage the work from a regulatory and compliance perspective as well as a management controls perspective and how work integrates.

According to Greene [16] it is layout, or the physical organization of people, machines and materials within a workplace, that is at the heart of productivity. Waste regarding the flow of materials can come in the forms of overproduction, correction, material movement, processing and inventory [17], while waste pertaining to the work of men relates to waiting and motion [17]. This is not specific to the construction sector. Womack et al [18] emphasize the vast amounts of waste existing in most organizations, and argue that a systematic attack on waste can be of great benefit to the profitability of enterprises.

Regarding investigations of lean manufacturing in SMEs and/or the construction sector, Saad et al [3] and Jørgensen et al. [19] have contributed new insights. Saad et al. [3] investigated critical factors that constitute a successful implementation of lean manufacturing within SME manufacturing companies through a comprehensive literature review and visits to ten SMEs based in the East of the UK. They found that several critical factors determine the success of implementing the concept of lean manufacturing within SMEs, such as leadership, organizational culture, management, finance, skills and expertise. Jørgensen et al [19] did an extensive literature review and explored the transfer of lean manufacturing from the Japanese manufacturing industry to the construction sector in the west. They found, e.g., that there is no shared definition or understanding of what is meant by lean, lean production, and lean construction processes. Due to this, they found a need for a ‘back to basics’ discussion on many aspects of the approach.

Spann et al. [20], Melton [21] and Matt et al. [2] provide insights into potential Lean pay-offs. Spann et al. [20] did a survey, and report results of Manufacturing Extension Partnership (MEP) field agents’ knowledge of lean manufacturing and the degree to which MEP field agents have managed to transfer "lean" principles and practices to client firms. They also discuss lean manufacturing and its tools, and illustrate the benefits of transferring lean manufacturing know-how and tools to manufacturers through success stories. Melton [21] termed lean a revolution and presented findings from a real-life case study, concluding that the process industries should welcome lean with open arms due to its positive impact on working capital, supply chain speed and manufacturing costs. He referred to LERC [22] stating that for most production operations, five percentage of the activities add value, thirty-five percentage are necessary non-value activities, while sixty percentage add no value at all. Based on this, Melton [21] said, there is no doubt that the elimination of waste represents a huge potential in terms of manufacturing improvements. He also referred to well-known works of Womack et al., i.e. The Machine that Changed the World [23], Lean Thinking: Banish Waste and Create Wealth in your Organization [18] and the beginning of lean, i.e. The Toyota Production System, a time where key tools and techniques within the 'lean' system included Kanban, 5 S's, Visual control, Poke yoke and SMED (Single Minute Exchange of Dies) [21]. Additionally, Melton [21] concluded the process of 'how to lean' as: (1) Document current process performance, (2) Define value and then eliminate waste, (3) Identify undesirable effects and determine their root cause in order to find the real problem, (4) Solve the problem and re-design the process and (5) Test and demonstrate that value is now flowing to the process customer.

Matt et al. [2] investigated the suitability of existing lean methods for application in small enterprises. They refer to different authors, i.e. Denton et al. [24], Safayeni et al. [25], Achanga et al. [26] and Achanga et al. [27] believing that lean manufacturing or productivity improvement methods in general harbour immense difficulties. To reveal the difficulties in the implementation stage and to identify the critical success factors, they did an industrial case study in a small enterprise. The study illustrated a hidden potential for lean methods use, and provided insight into suitable methods for productivity improvements.

2 RESEARCH METHOD

The main research method applied in our investigation of the project group's work, was that of a qualitative case study [28]. The case study is a research strategy aiming at understanding the dynamics present within single settings [29]. More specifically we employed the following methods to gain insight into the project:

1. On-site visits to the factory and observation of the AS-IS analysis process,
2. Participation in workshop meetings with the students, managers and workers,
3. Dialogues and interviews with the students, but also with plant workers and managers
4. Participation in the presentation of the potential step-wise implementation plan, and
5. Investigation of the project report presenting three different turnaround scenarios.
6. Recall of in-depth knowledge of the company by two of the researchers due to their involvement in another project [7] where the company also participated.

With reference to Burke [30], one of the managers has cross-checked information provided. By compiling field notes with interview recordings and descriptions in the students´ project report a picture of the planning process could be painted, aiming at smarter home production practices at the factory floor as presented in section three of this paper, together with corresponding lessons-learned presented in section four.

3 THE FACTORY AS AN ARENA FOR COLLABORATION AND LEARNING: FINDINGS ON THE APPROACH FOLLOWED

The students where introduced to the factory floor whereby a pull system, i.e. a system characterized by the practice of pulling items from previous operations as needed [31], was implemented for the module production process: When a contract with a customer is signed, the construction company sends material orders to its suppliers. The production of wooden parts for each module is outsourced to a Pre-cut supplier. This supplier produces kits for each module, then packs the kits separately and delivers them to the construction company's facility for assembly. In addition to the Pre-cut firm, there are a number of other suppliers that deliver other products, such as windows, doors, insulation, gypsum panels etc. to be assembled at the factory. Walls-, trusses- and joists modules are assembled manually at the factory floor, before they are transported to the building sites.

Based on an overarching evaluation of current practice, automation of the company's manufacturing process was considered a favourable opportunity to achieve higher efficiency that needed to be evaluated more thoroughly. At the beginning of the project, one of the managers explained to the students that resources were limited and that using Lean tools would be a learning process for those at the factory floor also, calling for the necessity to start slowly and carefully.

From literature, involvement and knowledge sharing are well-known success factors of change, see for example Edmonds [32]. Resource limitations are also well known within SMEs [3]. Such aspects motivated the students´ main focus of modelling AS-IS processes and providing suggestions (not solutions carved in stone) for a TO-BE factory layout to achieve improved workflow and correspondingly increased production efficiency. This was done by investigating (1) value adding activities, i.e. those activities that, in the eyes of the final customer, make a product or service more valuable [33], (2) non value adding activities, i.e. those activities that, in the eyes of the final customer, do not make a product or service more valuable and which by now are not necessary [33], and (3) necessary non value adding activities, i.e. those activities that, in the eyes of the final customer, do not make a product or service more valuable, but which are necessary unless the existing supply process is changed radically [33]. The feedback from front-liners pertaining to the approach followed was that they felt that their opinions and proposals mattered in the students´ work towards a good factory design. The foreman had for example made a factory floor layout sketch himself, which he appreciated being welcomed as an important input to the final factory layout scenarios presented by the students. Correspondingly the students reported that they found such inputs from the plant workers necessary when making plans, due to the workers tacit and yearlong knowledge of house production.

Genchi genbutsu. To get an in-depth understanding of the current situation, the students started with genchi genbutsu, a Japanese term translated into English as go and see for yourself [3]. More specifically, the students went to the production facility, observed the production process and talked to the operators. Additionally, they filmed the AS-IS production process three days in a row. For the latter, they installed several video cameras at strategic positions in order to be able to capture the production activities at different workstations. Video was reported a useful way of storing material for later investigation off-site, making it possible to re-run blocks of information, to really grasp what was going on. Supported by the video recordings, a shared picture of the production process could be made and presented by the students: The process started with batches of kits with precut parts of modules arriving from the Precut supplier. The foreman then made a plan for which order the modules should be assembled. Correspondently to this order, operators picked out kits from the batch. The production order was important because after modules were assembled, they would be placed progressively one after the other into the mobile wagon. The modules were then ready for transportation to the building site in the sequence matching the logic of the building process there. The foreman told the students that items coming from the Precut firm in batches were not in sequence preferred by the assembly factory. Due to this, the operators needed to sort out kits from the newly arrived batch first of all. Materials such as insulation, gypsum panels, windows, doors etc. were ordered from other suppliers. Each of those materials had its own allotted place on the factory floor. The main equipment in the factory consisted of four jigs that functioned as working stations: two for wall modules, one for trusses and one for joists. One of the wall-jig was nine meters long; the other twelve meters. The redesign team observed that one operator built the entire module by himself from start to end on one jig.

The students observed three operators working in the assembly factory. They noted that the operators had to walk a lot on the factory floor to fetch materials and pick up tools. Operators reported much factory floor walking as part of the production process, and that this was exhausting. To potentially confirm what was felt and observed the workers agreed to wear step counters provided by the students. As part of this investigation, it was noted that one of the operators, the foreman, spent 50% of the time taking care of other tasks, such as controlling the inventory level, placing materials on the allotted factory floor places, planning the sequence of production and so on. Thus the present FTE (Full Time Equivalent) to assemble modules was 2.5 operators. It was also noted that the operators assembled the same kind of module in different ways, i.e. there were no Standard Operating Procedures (SOP).

Based on videos and observations, the students were able to conclude that activities accompanying the use of the gantry crane were associated with noticeable waiting. The crane supported several assembly operations at once, e.g. mounting windows or doors into the wall modules or holding the module while operator filled it with insulation fabric etc. To move finished modules from the working stations to the mobile trolley, all operators were in need of the same crane. This resulted in waste in the form of waiting at occasions where more than one operator needed the crane at the same time.

Modeling the AS-IS process. The student redesign team then analysed the data collected to make a workflow map including time used on each activity. The team had registered all steps within the assembly process including Walking to pick up materials or tools, Waiting for the crane and Moving the crane between work stations. The output workflow map was showed to management and front-liners to confirm a shared process understanding. The students, collaborating with management, then categorized activities in the process into value-adding (VA) and non-value-adding (NVA) activities, and calculated the time allocated for producing one wall element, one truss element and one joist element. Based on this analysis they could draw a joint conclusion that the processing time, or time of operations that adds value to a final product, was much less than the production time.

Thereafter a Yamazumi chart was made. By the help of such charts, NVA activities could be identified for removal [34]. The chart was made for each module, to visualize the relationship of VA and NVA activities in assembly for each module type.

Root-cause analysis. To identify the root causes of non-value-adding activities, the students used the Toyota five whys technique, motivated by Taiichi Ohno, the father of the Toyota Production System. Ohno was a proponent of this technique to root out problems and fix processes for good [35]. The students started by analysing the Waiting for the crane problem. By asking the operators and management “Why?” several times they were able to identify problem root causes, which correspondingly enabled them to suggest actions to eliminate them: (a) Balance work load between tasks so that operators do not need the crane at the same time, (b) Change the factory’s layout to achieve a very short distance between workstations where job tasks require use of the crane, (c) Improve workplace organization and standardize, placing relevant materials and tools nearby the operators and (d) Implement 5S, which initially is based on the Japanese acronyms of seiri (organization), seiton (neatness), seiso (cleaning), seiketsu (standardization) and shitsuke (discipline) [36], including SOP for assembly of each module based on Best Practice.

Tact Time. Tact time refers to the rate at which customers are buying products from the production line; i.e. the unit production rate that is required to match customer demands [37]. In order to be able to balance the workload, the students calculated this rate by investigating how many modules operators within the construction company must produce during one year to meet the customer demand. The students obtained the data from the managers. More specifically, the tact time was calculated by dividing available time per year for one operator, excluding vacation, holidays and one week of taking time off, by the average amount of modules demanded per year.

Workload Balancing. In order to distribute the assembly work between the two operators so that only one operator would need the crane at a time, the students suggested acquisition of a vacuum lifter. In relation to this, the workload distribution for assembling a wall module when having a vacuum lifter available was examined. The finding was that if one operator performed the first fifty percentage of the wall module assembly process, including mounting of windows and doors, by using a vacuum lifter, the other operator could use the crane for the rest of the process. The students anticipated that acquiring a vacuum lifter would not only allow workload distribution in wall assembly between two operators according to calculated tact time, but that the lifter also would contribute to a significant reduction of waste due to several factors: (1) elimination of waiting time for the crane regarding the wall assembly process, because only one operator would need the crane while the other operator handles the vacuum lifter, (2) reduction of the crane’s load leading to a decrease in the risk of waiting for the crane in the assembling of other modules, and (3) narrowing of the crane’s working area so that waste caused by moving the crane between work stations would be very much minimized.

The operators expressed early on in the students´ project a wish for new automated nail guns that would make nailing operations easier and more precise. Due to this, the students made market research on nail guns and introduced their findings to the operators and to management for evaluation. To avoid the lifting of wall modules between two working stations, the students proposed the possibility of investing in two twelve meter long jigs that should be equipped with lift and rolls, for transport in the longitudinal direction to ensure workflow between workstation. By placing the jigs next to each other, a wall element could be rolled easily to the next workstation. Specifically, the student analyses showed that the average time for assembling the truss and joist was approximately three hours each, in accordance with the calculated tact time. Then again, the arrangement of workflow according to a three hour long tact time per module was perceived feasible.

Scenarios. To enable start of an improvement process immediately, keeping the knowledge of capacity limitations in mind, the students suggested the following scenarios:

Scenario 0: (a) Organize work in sequence and standardize the procedure of sending kits from Precut to assembly factory, (b) Find assembly Best Practice of modules and develop Standard Operating Procedures (SOP), (c) Develop lists of tools and make shadow tool boards near workstations to avoid unnecessary walking, (d) Develop escalation plans so that everyone knows what to do when a problem or some question occurs, (e) Make permanent places with floor markings for works stations, materials, and equipment. *Scenario 1*: Include the purchase of a vacuum lifter and wall jigs to provide an optimal workflow in the assembly process of the wall modules. The students' argued that analysis showed that acquisition of new equipment could reduce the assembly time of a wall module by almost six hours. Management calculated that three hours saved on assembling one wall module would equal three new houses built per year, which meant that the return on investment on new equipment could be less than one year. According to the student evaluations, the proposed Scenario 1 layout would support optimal workload leveling and production workflow also of other types of modules in the factory. *Scenario 2:* Add the purchase of a new automated nail gun, motivated by the anticipated benefit of reducing some of the stress on shoulders that operators experienced with the existing equipment.

The analyses and three scenario descriptions were summarized in a report handed over to management, alongside a student presentation highlighting and explaining the conclusions drawn. The student group, with their background of automation and products and system design subjects, in the aftermath of the project could conclude that the project objective had demanded a broad application of their theoretical knowledge. The student groups´ role as project leaders had put an extra pressure on them to ensure a well-functioning project process. In fact, they had never been in charge of such a real-life project before. An especially useful experience had been the need to carry out economical assessments of the proposed scenarios. The understanding of the necessity to meet customer's technical requirements within economical limitations was emphasized as something new with a potentially great impact on their future working life. Also the real-life context demanding various competencies in concert had enriched their experience significantly.

Management reported that the work had been very interesting, useful, and a learning process for all parties. They emphasized that the outcome of the student work was something the educational institution could be proud of since the main goal should be to provide industry with specialists well prepared to real world challenges. Management would now aim at initiating a project to put some or all of the recommendations into real-life practice at the factory floor.

4 DISCUSSION AND CONCLUSION

In the paper we have presented the approach followed to plan for Lean production at a real-life factory floor in the form of a student project. A variety of Lean tools proved beneficial in the process of gaining increased insight and “hard evidence” of the AS-IS state of the process. The importance of involving both management and front-liners proved relevant. In the redesign process both “what” and “how much” to change became a central question. The case thus demonstrated for the students the need for making prioritizations in a context where the capacity to change at a specific moment in time is limited. As demonstrated in this study, a solution in such instances can be to follow a step-wise implementation plan in the form of aiming towards various scenarios. Evidently Scenario O was a kind of a minimum investments level, seeking to improve the production process by the help of 5S and Best Practice techniques, whilst Scenario 1 and 2 embedded a higher improvement potential.

According to Harris [15] most people think of process flow diagrams when business processes are mentioned or discussed. As this student project has demonstrated, and as Harris [15] emphasizes; there is a lot more to a business process than flow diagrams. Corresponding to business process ecosystem thinking [15], the project group had a broad focus on work to be done at the factory floor to gain insight into work balancing, standardizing and potential automation as an enabler of change. With reference to Harris [15] highlighting a need for more research on how to start any business process change initiative, a potential contribution of this paper is also insights into the combined approaches followed to plan for lean production in the SME. Both process modeling, Lean tools and other devices, such as video cameras and step counters, were used to investigate and plan for factory floor improvements resulting in increased knowledge on AS-IS practice motivating new potential solutions.

From a student learning perspective, taking into account the company’s capacity to implement the proposed changes, an important lesson-learned was that a step-wise implementation plan in the form of scenarios was necessary. This fits previous findings in the company whereby change initiatives in general have been subject to prioritization [38]. Comparing the approach towards becoming more Lean at the factory floor in the student project with the ‘how to Lean’ suggested by Melton [21], correspondence is seen with the first three steps. At the same time the factory floor redesign effort emphasizes that limited capacity for change is a quest of both “what” and “how much” to do, giving rise to the possibility of following an implementation process by starting to implement Scenario 0, the minimum investment level, and then work towards Scenario 2 through Scenario 1.

In a workshop where we were present, management stated that the process models made were beneficial to grow a Lean culture, by making it easier to understand problems tied to the AS-IS state of the process and thereby making it possible to evaluate the students’ suggestions as part of future decision-making. The workers agreed that the models made it easy to see what could be. They also saw that by comparing the AS-IS state with the suggested TO-BE state it became evident that the redesign would yield an improved production flow and reduce the need for walking on the factory floor etc. This lesson learned regarding AS-IS and TO-BE modelling fits well with previous research investigating potential benefits of using enterprise modelling in process change [38, 39].

As regards small enterprises it is highlighted by Matt el al. [2] that management involvement and commitment may be the most important prerequisite to implement a Lean production system. The findings from the student project imply that collaboration between educational institutions and industry has a great beneficial potential to all parties also, as a trigger for improvement and joint learning. As such, whatever conclusion is reached by the company's board on how to put plans into action, we sense through comments and observations, that a Lean journey to achieve smarter production at the factory floor has been lit or strengthened due to this student project.

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