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Improving lean design of production systems by visualization support

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Abstract

The design process of production systems is complex with many different aspects to consider for efficiently developing and installing an effective system. Important success factors during the design process are typically the abilities to identify and manage risks, develop mitigation plans, and conduct timely proactive problem solving. The work reported in this paper is part of research addressing methods for how the design process can be supported by using virtual representations of the factory environments captured with 3D laser scanning. This support is evaluated in an industrial study of one industrialization project in the manufacturing industry. The industrialization project follows the process to design layout, work places, and plan for installation of new equipment to create a production system within a refurbished shop floor area. The area will include CNC machining centers, welding stations, product inspection, product cleaning, and material handling. 3D laser scanning is used to provide an accurate and realistic virtual representation of the current shop floor area. This virtual representation is combined with 3D CAD models of the new machining centers and other equipment to provide a realistic visualization of the planned production system. The research approach and its questions investigate the benefits of combining the lean principles to design and development of production systems using a realistic visualization, which include systematic risk analysis and problem solving as important activities. The result shows that visualization support gave a great advantage to identify the possible risks and problems, which resulted in higher confidence and substantial timesaving in planning and execution of the industrialization project.

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Keywords: Manufacturing systems; Production system design; Lean development; Visualization; 3D laser scanning

1. Introduction

The design process of a production system includes a number of aspects to consider before the final system can be installed [1]. These aspects are analyzed using different methods, such as static calculations, dynamic simulations, material handling analysis, and layout visualizations. An important success factor for all analyzes is the use of correct and up-to-date data. Designing a production system within a current shop floor area requires spatial knowledge about the area, which can be captured by either visiting the area or studying a virtual representation of the area. The virtual representations are most often 2D CAD models created from old blueprints or manual measurements of the area. Previous research has shown that such models can contain errors and the importance of using correct spatial data to minimize the risk of problems during the design and installation of production systems [2]. Such model errors can be avoided by capturing the spatial data using 3D laser scanning, which holds the capability to create a virtual representation of the current shop floor area within hours [3]. The virtual representation can be used as a realistic visualization of the current shop floor area, and if modified the planned production system can be visualized and analyzed. The possibility of visualizing and analyzing the system has shown to be of importance in the design process to ensure a high-performed system [2]. However, a method of how to work systematically with realistic visualizations is required to make sure the full potential is realized [4].

The aim with this paper is to evaluate a method for systematic use of realistic visualization to support the design process of production systems. This evaluation uses an action research approach applied in an industrial study utilizing a method for using realistic visualization in combination with

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lean principles for e.g. problem solving during a production system design process. In the study, an industrialization project was addressed where risk analysis and problem solving was supported by realistic visualization of the planned production system. The realistic visualization was created with 3D laser scan data of the current shop floor area in combination with 3D CAD models of new machining centers and equipment. The lean principles and realistic visualization were used to identify problems and risks with the planned production system during three workshops. The result of the paper is observations and comments from these workshops.

The paper is divided into five additional sections. Section 2 presents state of art on 3D laser scanning, production systems design, and lean production development. The industrial study is presented in section 3, followed by the result in section 4, discussed in section 5, and conclusions in section 6.

2. State of art

The use of realistic visualization derives in from the concept Virtual factory, which describes how to work virtually with designing and visualizing production systems [5]. This approach is primarily used for decision-support, but examples can be found where the visualizations aspire to become the factory blueprint [6]. The decisions are made with support from the analysis of conditions that are currently not present, e.g. added or removed equipment. This section will cover the technology and theoretical methods used in the industrial study to enhance the use of realistic visualization.

2.1. 3D laser scanning

3D laser scanners operate by emitting laser-beams at surfaces and capturing their returned reflection to measure the travelled distance [7]. Each captured reflection represents a sample of the surface of the closest object along the beam direction, which is referred to as a measurement point [7]. The measurement points store information about the surface’s spatial position and its reflectance value [8]. The measurement points can be complemented with color data, generated from photos taken by a built-in camera [9]. The type of 3D laser scanner addressed in this paper belongs to the group terrestrial 3D laser scanners [8]. These scanners have a typical field of view in the horizontal axis of 360 degrees and in the vertical axis of 300 to 320 degrees [10]. Systematic capturing of measurement points in the entire field of view generates a geometrical representation of the environment. This systematic capturing is referred to as a scan in which the scanners have the capability to capture tens of millions of measurement points during a few minutes [7,9]. The process of creating a representation of a complete environment, most often requires scans from a number of locations. To combine two or more scans into one dataset most often requires reference objects [9]. The reference objects are typical white spheres, black and white checkerboards, or natural features in the environment. The scan dataset can be used to generate a point cloud, which consisting of all the individual measurement points, as exemplified in Fig. 1.

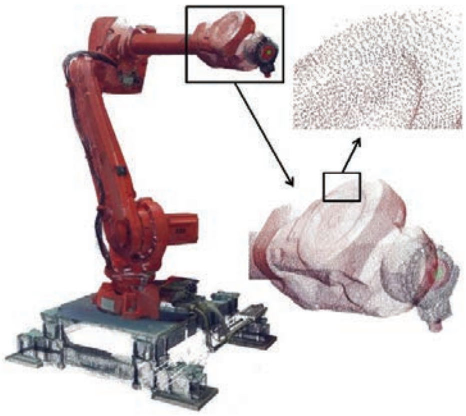

Fig. 1. Close-up of a point cloud representing a robot

2.2. Production system design

Designing, installing, and starting up a new production system includes many different aspects and functions in a company. These aspects can be strategic as well as technically and economically considerations and decision, and several others related to environmental and social aspects of a production system. There are different approaches, models, and processes for how to address these aspects and the main engineering tasks can be divided in two areas [11-13]:

1) The production and process planning for how to manufacture the product.
2) The industrialization planning and the activities to design or modify the production.

The integration of these two main activities is of great importance. Sometimes this integration is carried out as one project but also as separate ones with the product development and production planning as one, and the industrialization project in parallel.

2.3. Lean production development

The purpose of lean production development is to design an effective production system that operates according to lean production principles. The production system design process is supported and directed by a number of guidelines, which are based of the lean principles [13-16]. Besides ensuring the required processing capacity, the most important principles are customer demand, takt time, continuous flow, material supply, and related production planning and control methods [15]. The key goal is to focus on the necessary value adding and reducing possible wastes. There are different factors that need to be covered in this approach such as the overall material flow, material handling within the workstation, tasks for replacing tools, maintenance etc.

Integrated approach of production and process planning (3P) procedures focuses on how to define the value adding elements in the production methods and operations [17]. This is an important starting point, to identify the work content and the required activities in the future value steam.

Value Stream Mapping (VSM) is a well-established method to design production flows using a lean production approach [18]. VSM is a method to implement the principles in the lean methodology to create systems that can meet customer demands with short lead times and high efficiency [14,15]. The VSM tool gives a good visual view of the logical flow, but on a relatively high abstraction level. To make a more precise definition of the planned system the 7-flows of manufacturing can be used to make a more detailed and complete view of how the system should work and who will do what, when, etc. to make the system “flow”. The 7-flows are [19]:

1) Raw material
2) Components and sub-assemblies
3) Product processing / Finished goods
4) People
5) Machines, equipment and tooling
6) Information
7) Engineering

To fully describe the activities, material supply, define the hardware needs, man power and skills, etc. in this context the different flows can be supported using the 5W2H method (Who, What, When, Where, Why, How, How much) as a checklist to cover all aspects of the process. When the information is at hand, ideal layout is the next step in the factory planning process. Once the number of production resource and their space requirements have been set, possible layout alternatives can be developed. Several different alternatives should be documented and evaluated to find the one that best meet the requirement and targets. Methods like concept evaluation can be used, supported by Spaghetti diagrams and other methods for visualization and simulation.

The factory layout should be planned in a way that enables clearly structured material flows and prevents non-intersecting material flows, which result in short direct transport, material flow oriented layout, short implementation time for projects, ergonomics-friendly, and multi machine operation supporting space. The arrangement of recourses in line with the material flow in the value stream is the foundation of flow oriented ideal layout.

Risk identification, analysis, and problem solving is an important part at this stage and can be seen as continuous improvements. The purpose with the approach is to learn-by-doing through iterating the cycle over time to continuously improve and solve problems within the production system. In lean product development the LAMDA (Look-Ask-Model-Discuss-Act) approach is used [20,21], and is applicable to the production system development [4]. This approach focuses on finding the root cause, analyzing it, and then solving it to remedy the problem. The LAMDA approach can be described as a cycle, see Fig. 2, which should be repeated until all problems are solved and can be seen as a perpetual movement towards an improved system design [21]. The five steps of the cycle are according to Ward [21]:

1) Look – go and see for yourself,
2) Ask – get to the root cause,
3) Model – using engineering analysis, simulation, or prototypes,
4) Discuss – with peer reviewers, mentors, and developers of interfacing subsystems, and
5) Act – test your understating experimentally.

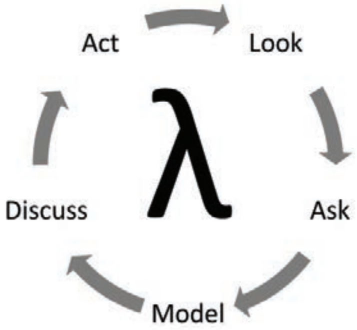

Fig. 2. The LAMDA cycle [21]

The LAMDA approach should include a structured approach for analysis and synthesis work in cross-functional teams to fully utilize the potential of high-level visualization support. The result of value stream design is a transparent factory which meets customer demand with clear information flow, low inventory and a production process in line with customer takt time [13].

3. Industrial study

The industrial study was carried out in parallel with an industrialization project at a company manufacturing components for jet engines. The project was in the design phase during the study; with tasks such as specify the required equipment, tooling, fixtures, workstations, and designing the layout for the production system. A product development project was a concurrent activity in order to prepare for the new product introduction.

The products to be produced in the production system are fabricated sub-assemblies for a structural jet engine component. The scope of the production operations include machining of parts, kitting of parts, fixturing and welding of the sub-assemblies, and machining of the interfaces. The production sequence also includes several operations for deburring, cleaning, and inspection. The primary equipment requirements were four machining centers, one welding cell, and one washing machine.

The two concurrent projects were support by an initial workshop organized prior the industrial study as an integration activity. The objective of the workshop was to identify the value adding work content, define the production process flow, and propose a rough layout of the shop floor area. The result from the workshop was part of the later selection of machining centers, their functions and capacity. The processes and layout were designed according to lean production flow. The principle steps of the workshop were:

1) Define requirements and targets,
2) Create a VSM to visualize the supply chain and all internal operations,
3) Define the production system using the 7-flows methodology,
4) Develop layout alternatives and evaluate/select.

Result from conducting the initial workshop provided the start for preparing the realistic visualization, i.e. to create a virtual model with the current shop floor area, selected machining centers, and other equipment.

After the initial workshop, that supported the decision for a block layout, the project activities continued to finalize drawings on a detailed 2D CAD layout. In the meantime, the realistic visualization was created, but still un-available to the project, and refined gradually in cooperation with the project participants.

3.1. The realistic visualization

The current shop floor area was captured using a FARO Focus 3D 120 laser scanner during an occasion when the facility was almost vacant from old equipment. The scanning took place during three hours and required nine scans to cover an area of approximately 700 square meters. To combine all scans properly, 139 millimeters white spheres were used as reference objects. Permanent reference position plates were mounted at walls and pillars to be able to fasten the reference objects at the same location during future scanning occasions. The scanning was carried out as described generally in [2].

The 3D laser scan data were processed in FARO Scene 5.3 where all scans were combined to one point cloud. To reduce the number of unwanted points, the point cloud was filtered and minor sections were deleted. The modified point cloud was exported to the E57 format and imported in Autodesk ReCap, where it was exported to the Autodesk generic point cloud format RCS. This RCS file was used in Autodesk Navisworks Manage 2015 where the realistic visualization of the planned production system was created by importing the new machining centers and equipment as 3D CAD models. The machining center models were delivered from the manufacturer and other equipment were collected from generic model libraries or created from scratch. The models were positioned in the realistic visualization according to the 2D CAD layout.

3.2. Workshops

The planned production system was analyzed and discussed using the realistic visualization during three workshops. At these workshops, the general tasks were to establishing the final layout, identify and specify the complete list of hardware, and verify the process sequence and operator tasks, as presented in Fig. 3. However, the most important task was to identify risks and eliminating possible problems before starting the installation of the new machining centers and equipment, commissioning, and production start-up.

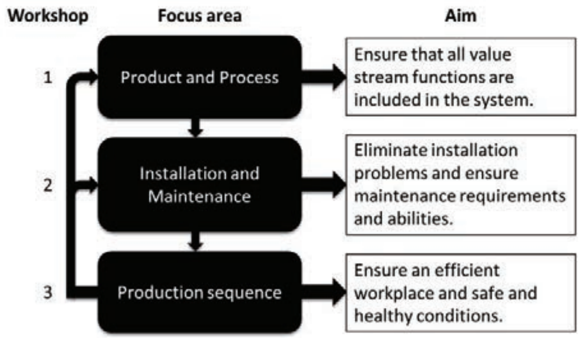

Fig. 3. The focus areas and aims of the workshops.

To fulfil the aim of each workshop, personnel with different roles and responsibilities participated according to Table 1. These participants were either working with designing or planned for operating the production system. Two persons were participating at all three workshops, the project leader and the engineer responsible for the process and layout. Additional participants were the research team, which consisted of one person moderating the workshop, one person controlling the realistic visualization, and two persons making observations.

Table 1. The participants' work responsibilities

Workshop	Work responsibilities
1	1. Industrial project leader
	2. Industrial process and layout engineer
	3. Logistics planner
	4. New product introduction leader
	5. Process planner
2	1. Industrial project leader
	2. Industrial process and layout engineer
	3. Machine acquisition
	4. Maintenance engineer
	5. Production facilities engineer
3	1. Industrial project leader
	2. Industrial process and layout engineer
	3. Production leader
	4. Machine operator
	5. Safety representative

Two parallel projectors were used during the workshops. The first projector was connected to a computer running the realistic visualization. The second projector was used to show additional information, e.g. the 7-flows analysis and 2D CAD layout alternatives.

The workshops started with an introduction by the moderator describing the aim and structure of the workshops. The remaining parts of the workshops differed for each, due to the different aim. During Workshop 1, the planned production process sequences were analyzed using the realistic visualization with support from the 7-flows analysis. During Workshop 2, mainly the areas around the machining centers were analyzed to ensure the possibility to install them as well as making necessary maintenance work; autonomous maintenance, planned preventive maintenance, and possible breakdowns and repairs. During Workshop 3, the work sequences of a machine operator were presented using the realistic visualization in a third person perspective. The time spent for Workshop 1 was three hours, Workshop 2 was one hour, and Workshop 3 was one and a half hour. During and between each workshop, modifications were made to improve the production system.

4. Result

The industrialization project was planning the layout and preparing for construction using the current tools, i.e. 2D drawings of the shop floor area and the machining centers. These tools did require several manual measurements and different drawing alternatives were created for the final positioning with the necessary floor areas and distances to soundings. These alternatives were accompanied by numerous meetings and many hours of discussions, which were often based on subjective opinions rather than facts. When the realistic visualization was available, it can verify that many of the discussions and decisions were done without the correct view and facts at hand, and much time could have been saved.

The main result from the workshops were the observations made regarding how the realistic visualization could support the design of the production system. During the workshops, a number of possible problems and risk with the initial proposed layout were identified by studying the realistic visualization. Examples of these problems and risks, and how they relate to the 7-flows are presented in Table 2.

Table 2. Problems and risk identified during the three workshops

7-flows category	Problems and risks
4, 5	The counter for tool changes is too high up on the machining center, a platform needs to be build.
1, 2, 4	The planned walkway is too narrow, equipment and material should not be placed too close to the walkway.
1, 2, 5	The cranes supporting each machining center where placed too close to a wall, causing problems with transporting materials in between.
2, 4, 5	The door entrance door was located too close to one of the machining centers, which can cause temperature problems in the machining center during winter season.
5, 6, 7	The comparison between the scan data and 2D CAD layout showed that walls and pillars in the building were positioned at the correct location. However, other parts were missing from the 2D CAD layout such as the ventilation system.

4.1. Workshop observations

The accuracy of the input information is of great importance to make the correct decisions. This may be obvious, but the level of details should be at a level pertinent to what is being analyzed. However, there are many pitfalls such as the CAD models available for the machining centers. For a rough layout and draft positioning, a model showing only the outer dimensions may be considered enough. There may be several hidden important factors to consider, such as access points for maintenance and transportation of swarf containers, cutting fluids systems, and other installations. Therefore, one needs to question and confirm the level of details and correctness of the input information at all times. However, for the machining centers the drawing in 2D CAD consisted of information about the machining centers' doors that was not included in the 3D CAD model.

The 3D view of the realistic visualization made it possible to move around freely and look from different angles of the production system. The workshop participants found it very useful to study the system from a 3D perspective. On several occasions, measurements were made in the visualization to verify available space. When the participants were explaining certain questions, they did it either by standing beside the projector canvas or by using a laser pointer.

An expected result for the three workshops was to identify risks, solve different problems, and plan for mitigations and changes. However, the situation became somewhat different. By using the realistic visualization and at the same time making updates and changes, the workshops became more of an interactive design workshop. Both the visualization and the written descriptions of the 7-flow process were updated simultaneously. There were some risks, but many were eliminated, and others confirmed to be of a reasonable level of severity, hence left to be monitored and mitigated at a later point in time. The most frequent reason for documenting a risk was lack of exact information or for something that still was not decided.

The resulting structured work method in each workshop followed the process of looking at the current process definition, following the LAMDA steps, making updates to the process description, and the realistic visualization, as presented in Fig. 4. In case of not being able to make necessary changes and updates, a risk of possible failure mode was documented and corresponding actions taken.

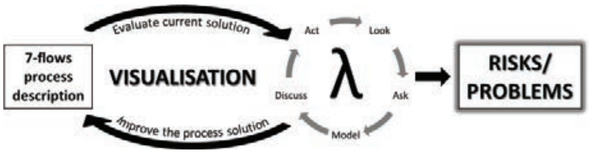

Fig. 4. The interactive work to refine the planned production system supported by visualization.

4.2. Comments from the workshop participants

The comments and reflections from the participants during and after each workshop can be summarized as following:

- The method has good potential to be used also in future industrialization projects.
- The realistic visualization makes it is easy to get an understanding and overview of the production system.
- All participants get the same view of the production system.
- The method should have been included earlier in the process of designing the production system.
- The method provides the possibility to include personnel that would not have been involved this early in the process otherwise.

- Sometimes more information is necessary, e.g. media possibility and drain pipes in the floor.

5. Discussion

The result from the industrial study showed several positive effects of using the method of realistic visualizations during the design process. However, a recurring problem during the study was to measure how much better the method is compared with the traditional method. The results are mostly based on qualitative observations by the research team and comments by the workshop participants. Quantitative data such as the actual time and cost savings would have been preferable to prove the benefits of the method. However, one can easy estimate that the actual time for scanning the building and creating the realistic visualization is much shorter than creating a CAD model with the same accuracy and level of details.

Identifying problems and risk early in a design process of a production system is critical for the outcome. The addressed process in the industrial study could have gained from making additional scanning earlier. Making additional scans could have been done within hours, and the potential time savings would have come from hours saved from reworking the 2D CAD based layout alternatives. When the 2D CAD model of the building was compared with the 3D laser scanned point cloud, the parts included in the 2D CAD was correct but some parts were missing. However, it is difficult to ensure that the 3D CAD models of the machining centers match the reality until the machining centers are installed. Therefore, additional scans should be made of the installed system to evaluate if the realistic visualization showed the actual setup.

The method made it possible to make changes to the realistic visualization during the workshop. When the changes are made directly during a meeting, no planning for additional changes in between different meetings are needed. This opportunity to make direct changes has several benefits, such as direct verifications, additional discussions of alternatives, and no need to plan for additional meetings.

6. Conclusion

The research of this paper has shown that a realistic visualization of the production system is a valuable support during the design process of production systems. Having such visualization available during e.g. project meetings, will increase the quality of discussions by giving the participants a shared clear view of the planned system and its issues, which can result in fewer misunderstandings between project members. The visualizations will enable interactive modifications of the setup during such meetings if required in real time. Applying the method of systematically using realistic visualization results in that risks and problems can be found and eliminated early in the design process, prior the installation.

Acknowledgements

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References

[1] Wiendahl H, Nyhuis P. Facility Planning. CIRP Encyclopedia of Production Engineering, Berlin, Heidelberg: Springer Berlin Heidelberg; 2014, p. 493–500.

[2] Lindskog E. Towards Realistic Visualisation of Production Systems. Chalmers University of Technology, 2014.

[3] Gregor M, Medvecký Š, Matuszek J, Štefánik A. Digital Factory. Journal of Automation, Mobile Robotics & Intelligents Systems 2009;3:123-32.

[4] Lindskog E, Berglund J, Vallhagen J, Johansson B. Lean Based Problem Solving using 3D Laser Scanned Visualizations of Production Systems. International Journal of Engineering Science and Innovative Technology 2014;3:556-65.

[5] Jain S, Fong Choong N, Maung A, Lou M. Virtual factory: an integrated approach to manufacturing systems modeling. International Journal of Operations & Production Management 2001;21:594-608.

[6] Alpman M. Nya modeller testas direkt i laserskannad kopia av fabriken. NyTeknik 2013. http://www.nyteknik.se/nyheter/automation/cad/article3641535.ece (accessed February 4, 2014).

[7] Klein L, Li N, Becerik-Gerber B. Imaged-based verification of as-built documentation of operational buildings. Automation in Construction 2012;21:161-71.

[8] Staiger R. Terrestrial laser scanning technology, systems and applications. 2nd FIG Regional Conference, Marrakech, Morocco: 2003.

[9] FARO Technologies. FARO Laser Scanner Focus3D Manual 2013.

[10] Dassot M, Constant T, Fournier M. The use of terrestrial LiDAR technology in forest science: application fields, benefits and challenges. Annals of Forest Science 2011;68:959-74.

[11] Bellgran M, Säfsten K. Production development: design and operation of production systems. Springer London; 2010.

[12] Chryssolouris G. Manufacturing Systems: Theory and Practice. Springer New York; 2006.

[13] Erlach K. Value Stream Design. Springer-Verlag Berlin Heidelberg; 2013.

[14] Womack JP. Lean Thinking: Banish Waste and Create Wealth in Your Corporation. Free Press; 2003.

[15] Liker JK. The Toyota way: 14 management principles from the world's greatest manufacturer. Blacklick, OH, USA: McGraw-Hill Professional Publishing; 2004.

[16] Modig N, Åhlström P. This is Lean: Lösningen på effektivitetsparadoxen. Stockholm School of Economics; 2012.

[17] Mascitelli R. Mastering lean product development: a practical, event-driven process for maximizing speed, profits and quality. 2011.

[18] Rother M, Shook J. Learning to See: Value Stream Mapping to Add Value and Eliminate MUDA. Lean Enterprise Institute; 1999.

[19] Wroblewski M. Understand and implement the 7 flows of manufacturing. Reliableplant n.d. http://www.reliableplant.com/Read/19651/underst-implement-7-flows-of-manufacturing (accessed March 25, 2015).

[20] Domb E, Radeka K. LAMDA and TRIZ: Knowledge Sharing Across the Enterprise. The TRIX Journal 2006. http://www.triz-journal.com/archives/2009/04/04/ (accessed February 5, 2014).

[21] Ward AC. Lean Product and Process Development. Lean Enterprise Institute; 2007.