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Citation for the original published paper (version of record):
Nåfors, D., Bärring, M., Estienne, M. et al (2018). Supporting Discrete Event Simulation with 3D Laser Scanning and Value Stream Mapping: Benefits
and Drawbacks. Procedia CIRP, 72: 1536-1541. http://dx.doi.org/10.1016/j.procir.2018.03.217

Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 72 (2018) 1536–1541

www.elsevier.com/locate/procedia

51st CIRP Conference on Manufacturing Systems

Supporting Discrete Event Simulation with 3D Laser Scanning and Value Stream Mapping: Benefits and Drawbacks

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Abstract

Discrete Event Simulation (DES) has been applied to analyze and understand production systems for many decades, however the models created may not accurately represent the spatial data of the system. 3D laser scanning can be utilized to capture and digitalize the spatial data of production systems, giving proper references for the simulation model. This paper evaluates the benefits and drawbacks of using a DES model supported with Value Stream Mapping (VSM) and 3D laser scanning to analyze a low volume production system. Results show benefits in several steps of a DES study, mainly at the cost of simulation speed.

Keywords: Discrete event simulation; value stream mapping; 3D laser scanning; point cloud; Industry 4.0; smart manufacturing.

1. Introduction

As factories are expected to improve due to globally increased competitiveness, the ability to assess and evaluate production system investments in a timely and accurate manner is vital. To support such decisions, Discrete Event Simulation (DES) can be applied, both for current systems in order to improve understanding and solve problems, as well as for decision support in investment scenarios [1]. DES models require a lot of data and modeling in order to give good representative output data of the system it models. One method of gathering data from the production system is Value Stream Mapping (VSM), a method originating from lean production. Several studies in the past have applied VSM as a method of gathering data for a DES model of a production system [2,3,4].

In recent years, 3D laser scanning has been used more in industrial cases as a method of gathering un-biased spatial data of production system in three dimensions. The technology digitizes the spatial attributes of the scan object, and has been applied in for example factory layout planning [5], robot programming [6], crime scene investigation [7] and several other areas. A previous study has shown that 3D laser scanning can be beneficial in supporting DES modelling [8,9].

The purpose of this paper is to find and evaluate potential benefits and drawbacks of combining both the VSM and 3D laser scanning approaches as support in a DES model of a production system consisting of three different product units. As this combination has yet to be evaluated, this paper will help guide future work with this particular combination as it has several upsides. The paper is based on experiences during the study, as well as recorded semi-structured interviews performed after the study with relevant stakeholders from the company. This paper is divided into four additional sections. The theory and method is presented shortly in section 2, which covers VSM, 3D laser scanning, DES modelling, and the interviews performed. Section 3 presents the modelled production system along with how the DES modelling process was supported by VSM and 3D laser scanning. Section 4 presents and discusses the outcome of the study, while conclusions and future work is presented in section 5. Some information and details regarding

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Peer-review under responsibility of the scientific committee of the 51st CIRP Conference on Manufacturing Systems.
10.1016/j.procir.2018.03.217

the studied production system are not presented in this paper due to being sensitive confidential data.

2. Theory and method

This section presents relevant theory to this paper, as well as how it was applied during the industrial study.

2.1. Value Stream Mapping

VSM is a paper and pencil method intended to describe the current state of a system and visualize where value is being added. It is performed by walking along the value stream, starting from the end of the flow and following it back to the origins. The normal VSM method however is designed for linear flows and not merging flows in complex systems as were the case for this study [10], for which reason the data gathering relied on two complementary VSM-based methods, Improved VSM (IVSM) and Value Network Mapping (VNM). These methods were adapted to suit the system in question and described in detail in [11].

2.2. 3D laser scanning

3D laser scanning is a technology that can be applied to gather un-biased spatial data. The technology stems from the field of terrain mapping among others, and sees use in many different fields today. Simplified, the technology works by emitting beams of laser light and its travelled distance in that direction to determine the distance to the reflected point [12]. The built-in distance measurement, combined with color data from a digital camera which photographs the measurand, gives a point in a three-dimensional space. The aforementioned process is repeated millions of times in 360º in order to generate a cloud of points representing the visible area from the scanner, after which the scanner can be moved to a different area in order to gather more data. For this study, a FARO Focus 3D was used to gather data via a total of over 50 scans, and a resulting point cloud of over 500 million points. An example of the data gathered from the 3D laser scanning is presented in Figure 1.

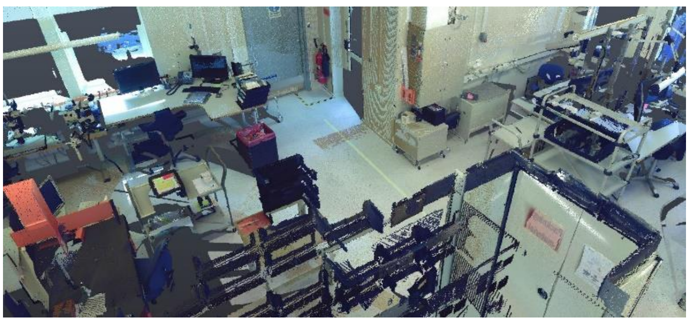

Fig. 1. Example of the spatial data gathered using 3D laser scanning

2.3. Discrete Event Simulation Modelling

DES models can represent many different kinds of systems, such as for example airports or car manufacturing facilities [13]. These models are based on logic, controlling sets of states that evolve interdependently through triggered events in the model as it is being executed. These events are scheduled to occur at a discrete time, and may cause other events to trigger. Since DES models are based solely on such events, i.e. nothing happens unless an event is triggered, time will skip until the next event. This makes well-build DES models great at simulating long time-spans of the modeled system, which can be very useful as decision support.

There are nine common steps in systematic methodologies for carrying out a DES study, in the sequence that follows [14].

1. Problem formulation
2. Model conceptualization
3. Data collection
4. Model building
5. Verification
6. Validation
7. Analysis
8. Documentation
9. Implementation

Some of these steps can be repeated, for example if the model fails the validation step, more data or changes to the model may be required. This study followed these steps, and attempted to use both VSM and 3D laser scanning as support where possible to evaluate the benefits and drawbacks. The software used in this study in order to build a DES model that incorporates 3D laser scanning data was Visual Components 4.0 premium software.

2.4. Interviews

In order to assess the outcome of this study, two semi-structured interviews were performed and recorded after the industrial study had finished. One interview was held with the product unit manager of the modeled product unit, and one was held with one of the object managers who also worked as an operator in the production system. Both these interviewees were involved in several steps of the study. The questions which these semi-structured interviews were based on are presented in Appendix A.

3. Industrial study

The main purpose for the industrial study was to analyze, evaluate and better understand the flow of the most representative product in the production system. The system has several convergence-points, produces low volumes and has very little in terms of data regarding system output and capacity. The production system produces components for rockets and satellites which must conform to the standards expected for that type of products. There are usually many different products and products types being produced simultaneously in the production facility, with prioritizations of which product to continue work on first being made on a daily basis. The production organization is divided in to three different product units, which function independently of each other but still cooperate and share some resources. Most products are Engineer-to-Order and made in very small amounts, however many of the process steps are common.

3.1. Production system

The production system at the company is rather complex, as it consisted of many parts and resources that were shared between the three different product units, but also many parts that were unique to each unit. For example, the arrival function in the production system, which handles the quality check of incoming material for two of the units, also handled the kitting process for parts of the same two units. Another example of this is the Surface Mount Technology placement machine, a common asset in the production system supporting all product units when needed. It also had one separate part of the organization planning and running the machine in order to utilize it in an efficient manner. In general, there was a designated storage area between each of the process steps in the relevant product unit of the production system. This storage area was an air-controlled cabinet, making sure the products would be un-harmed from the storing process. Having cabinets with metal doors for storage made it difficult to quickly gain an understanding of where the products are in the system. Products would manually be moved from a cabinet to the appropriate function, worked on, and placed in a different cabinet position depending on which step in the process was next for the product.

Several other resources and functions in the system were shared between product units and utilized different planning systems, making the system as a whole far from the typical flow one would expect from the manufacturing of cars for example. In the relevant product unit, there were eight sub-flows converging in to one final assembly flow, consisting of a total of over 150 process steps. A VSM of one of the shorter sub-flows, consisting of five production processes, two administrative processes, and three separate storage buffers, is visualized in Figure 2.

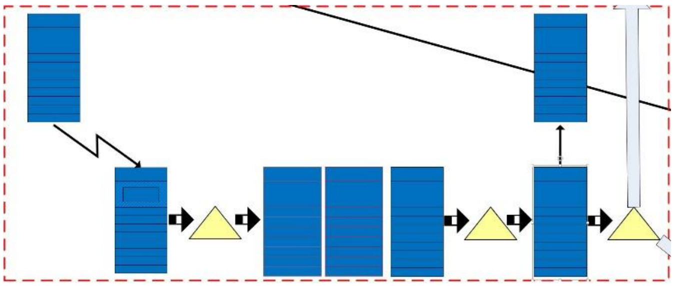

Fig. 2: Resulting VSM of one of the sub-flows. The square boxes are production processes, while the triangular ones are storage buffers.

3.2. Model building process

The DES model of the production system was built in two steps. The first step was based on the performed VSM, with additional data gathered as required where the VSM data came up short. Each process step was modeled individually in the simulation software, and connected as required from the production system. Most of the processes were connected by an operator picking up the product from a station and placing it in a cabinet, where it could be picked up by an operator when needed for the next process. An example of the model in this step is visualized in Figure 3..

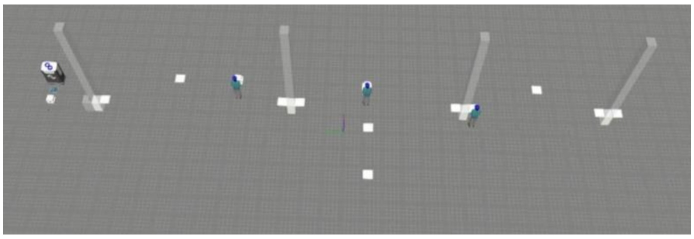

Fig. 3: Example of the simulation model after step 1 of the model building process.

The second step was to combine the model from the first step with the accurate visualization of the factory given by the 3D laser scanning in the form of a point cloud. Each process step could then be positioned at the corresponding position in the point cloud model, and operator as well as product flows could now be made accurate to those from the real system. In order to map which process was performed at which physical position in the factory, more data gathering was needed as this kind of information is not included in the VSM nor in the point cloud model of the factory. The VSM and the point cloud model were used to gain this understanding by also including an expert in the production system from the company, who could inform where the different steps of the process physically occurred. Once the logic from the first step and all processes, functions, and storage buffers had been positioned correctly in the second step, the simulation model was ready to be validated. A screenshot of how one of the sub-flows in the simulation model looked while running after step 2 is shown in Figure 4.

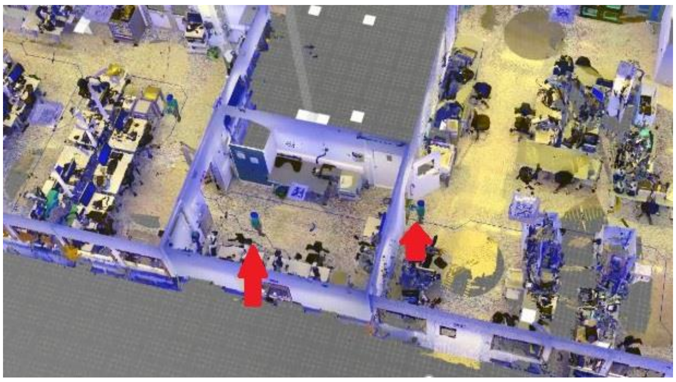

Fig. 4: One of the sub-flows in the simulation model as it looked after step 2. Operators can be seen walking through the doors in the model in the bottom middle of the figure, marked with two red arrows, with a pathing accurate to the production system.

3.3. Model validation

The model was validated in two separate ways. First, both a product unit manager and an operator from the product unit assessed the flow of operators and products in the system as the model was running, looking for deviances from their expectations of daily work. As the model was running in the point cloud environment, both the manager and the operator could recognize patterns of movement and actions in the facility. In the second validation step a product unit manager controlled the data from the VSM which served as an input to the production processes. The process times, batch sizes, process steps and the product flow were controlled to ensure that these numbers met expectations. Once both of these validation steps were completed, the model was considered valid for further analysis and evaluation.

4. Results and discussion

The results from the interviews, combined with the authors' experiences from the study, are the basis for this section.

4.1. Value Stream Mapping

The VSM performed before building this simulation model gave a lot of input to both the model conceptualization and the data collection steps of building a DES model. To our best knowledge, no alternative method that could give as good of an understanding of the different flows and their respective convergences as the type of VSM used in [11]. The VSM assisted greatly in dividing the DES model in different sub-components that in an easier way could be modeled, tested, and analyzed. This was because the VSM split the large product unit flows in to many smaller sub-flows in a visually appealing manner, making the system easier to grasp.

There are some drawbacks however to relying solely on a VSM, since the numbers within were not of the type one would require to build a good DES model. The times for production processes were estimates based on the operators' best guesses, and due to a combination of low-volume production and no automatic registering of processing times for manual tasks, distributions were not gathered. A workaround to this could be to apply a lognormal distribution to the estimated times [15]. The VSM also did not show capacity in the sense one would require to sufficiently model a system. Amount of operators and machines available for example was not a part of it, as it focused on the product flow and not production information. Some of these drawbacks were somewhat easy to solve by gathering some additional data in the model conceptualization and data collection steps of the DES study, such as amount of operators, machines, and workstations. There is some potential usefulness in a VSM specifically tailored to the needs of a DES study, as it could help break down a complicated system into more manageable parts.

4.2. 3D laser scanning

The 3D laser scanning data of the parts of the production facility used in this study took roughly seven hours of scanning to gather, and another six hours to process. The resulting point cloud was easy to import into the simulation software, and made it possible to gather information on where processes took place in the facility offline, without disrupting production and with the ability to store this information digitally. The point cloud model was accurate within less than a centimeter and photorealistic, allowing the expert to quickly recognize and point out where each process was performed, making this part of the data gathering step very swift. Once the processes were positioned in the point cloud model, the operator pathing could be constructed by ensuring the path from between processes and storage was collision free, and followed a logical path. This provided assistance in the model building step. The point cloud also supported the model building step by allowing the model builder to focus more on model logic, as walls and tablets for example didn't need to be created. Running the model in the point cloud also allowed operators to quickly assess whether the path was correct or not, providing assistance in the verification and validation steps of a DES study. Supporting the DES model with point cloud data could also help in the final step, implementation, as the resulting output and changes to the model actually could be performed in a realistic manner. This can help ensure that the solution actually can be implemented. The realistic visualizations could also possibly help reduce the resistance to change, as realistic visuals could help visualize that the planned change is well thought through. Additionally, other technologies such as for example Virtual Reality could potentially be used to help reduce the resistance to change.

One of the major drawbacks noticed while using point cloud data was the awe factor. It looks very realistic and true, and could be a new experience to many, causing what might be reduced skepticism of the model. What makes point clouds beneficial in supporting DES, and possibly also easier to verify and validate, could also be hindering the models accuracy.

4.3. Model performance

Incorporating large point clouds in DES simulation software is rather new, and require the hardware to deal with a lot larger simulation models. The way it was implemented in this study affected the performance of the model quite a lot, as it slowed down significantly after implementation of the point cloud. Smaller segments of the point cloud, such as the one shown in Figure 4 that consisted of 30 million points, would not affect the simulation model performance as much as the larger point cloud models, such as the one shown in Figure 5 that consisted of 70 million points.

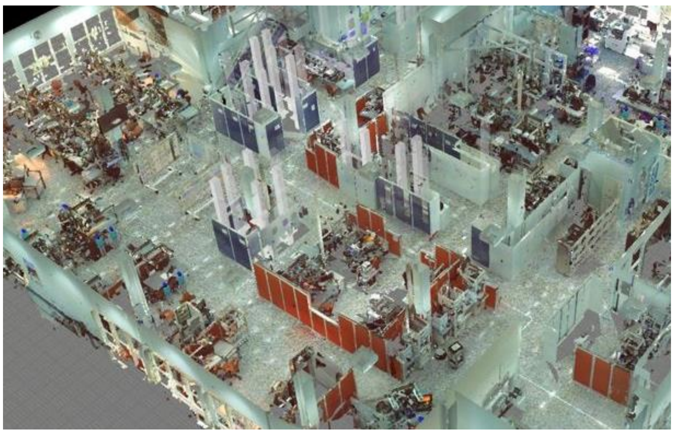

Fig. 5: Part of one of the larger point cloud models used in the simulation model. This point cloud model consisted of 70 million points.

Due to the long lead times of the production system, very few products were produced per year of production. There was a lot of operator movement during each workday, which had an effect on the system and should be simulated, hence there was no easy way to speed up the simulation. With the point clouds in place along with everything else, simulating a year of production took roughly 20 hours in real time. One possibility not looked in to during this study could be to use the point cloud model only in the model building step, to ensure pathing and placements are correct until the model is validated. After validation, the point cloud could be removed to improve model performance, and then brought back to test changes in the virtual copy of the real environment. This should shorten the lead-time of the project, combining the best parts of the point cloud based model with those of the more abstract model.

4.4. Summary of the potential benefits and drawbacks

A summary of the findings of this study in what the potential benefits and drawbacks could be in supporting a DES study with 3D laser scanning and VSM respectively is presented in Table 1.

Table 1. Summary of the potential benefits and drawbacks found in this study of supporting DES with 3D laser scanning and VSM.

Identified potential benefits	Identified potential drawbacks	Connected steps
VSM could be used to divide into sub-flows and give a greater understanding of the entire system.	Possibility of missing information, due to a lack of information around the amount of operators, machines, and workstations for example.	Model conceptualization and data collection
3D laser scanning captures the production facility as-is, allows offline work. It also supplements VSM with information regarding amount of machines and workstations.	Data captured is only a snapshot of the facility, could require extra work to confirm that the data is an accurate representation any given day.	Data collection
3D laser scanning helps in pathing and positioning, getting the proper distance relations between functions and components. It could reduce the total amount of iterations required to achieve a validated model, as the accuracy can be improved.	Has a negative effect on model performance due to the large amounts of data being input, which could affect total lead-time.	Model building and performance
3D laser scanning allows involvement of any personnel as the model is realistic and can be run in real-time, making the model easy to relate to and understand.	The realistic visualization could reduce skepticism toward the model, possibly allowing a sub-par model to be validated due to appearing to be more accurate than it is.	Verification and validation
3D laser scanning can help ensure that changes will fit and work as planned in the real production facility, as well as help reduce resistance to change.		Implementation

5. Conclusion and future work

This study has shown that there is a lot of potential in supporting DES with VSM and 3D laser scanning. The combination of the two works well as they support each other by supplying data and information that the other one does not. Beneficial support was identified in the study for several steps in the DES study, mostly around the opportunities of using 3D laser scanning. VSM was found beneficial mainly in the early steps of a study, while 3D laser scanning could be beneficial throughout a study. The main potential drawbacks identified include reduced model performance due to point cloud data, and a reduced skepticism toward the simulation model. As 3D laser scanning is a fast way to gather spatial data from the facility for an experienced user, it could be useful for almost any DES study that could have use for a good understanding of an existing facility. This includes for example when designing a new production system to fit in an existing facility and when redesigning existing production systems.

For future work, the potential of further developing a VSM method tailored to a DES study could be interesting. Further development on simulation software to improve the collaboration and functionality with point cloud data could also lead to better studies in the future. Further research on how 3D laser scanning, VSM, and perhaps Virtual, Augmented or Mixed Reality could support DES could also be interesting to make the simulation models more realistic and accurate, as well as more approachable.

Acknowledgements

We would like to extend our gratitude to NRFP for financing the project in which the work for this study took place, RUAG Sweden AB for giving us the opportunity to do this and of course all colleagues for assisting in any way possible. The work presented in this paper has been carried out within the Production Area of Advance at Chalmers University of Technology. The support is gratefully.

Appendix A. Interview questions

The bulleted questions below were the basis for the semi-structured interviews conducted in this study.

- What is your role and experience at the company?
- What are your experiences regarding simulation prior to this study?
- What are your thoughts regarding the purpose of simulation of production system?
- How accurate did you consider the model? Did you notice any deficiencies?
- Any thoughts regarding the operator pathing in the model?
- Did you feel that the point cloud had any benefits/drawbacks to the model in any sense? If so, which?
- Other benefits/drawbacks of this model from your perspective?
- If work were to continue with the model at the company, what would you like to be the next step?

References

[1] Sargent, RG Verification and Validation of Stimulation Models. In Proceedings of the 1998 Winter Simulation Conference; 1998;121-130.

[2] Erikshammar J, et al. Discrete event simulation enhanced value stream mapping: an industrialized construction case study. Lean construction journal, 2013;10;47-65.

[3] Gurumurthy A, Kodali R. Design of lean manufacturing systems using value stream mapping with simulation: A case study. Journal of Manufacturing Technology Management, 2011;22(4);444-473.

[4] Mahfouz A, Crowe J, Arisha A. Integrating Current State and Future State Value Stream Mapping with Discrete Event Simulation: A Lean Distribution Case Study. The Third International Conference on Advances in System Simulation (SIMUL), 2011;169-176.

[5] Lindskog E, Berglund J, Vallhagen J, Johansson B. Visualization Support for Virtual Redesign of Manufacturing Systems. Procedia CIRP, 2013;7;419-424.

[6] Tafuri S, Shellshear E, Bohlin R, Carlson JS. Automatic Collision Free Path Planning in Hybrid Triangle and Point Models: A Case Study. In Proceedings of the 2012 Winter Simulation Conference, 2012;3192-3201.

[7] Sansoni G, Trebeschi M, Docchio F. State-of-the-Art and Applications of 3D Imaging Sensors in Industry, Cultural Heritage, Medicine, and Criminal Investigation. Sensors, 2009;9(1):568-601.

[8] Lindskog E, Berglund J, Berlin R, Vallhagen J, Johansson B. Combining Point Cloud Technologies with Discrete Event Simulation. In Proceedings of the 2012 Winter Simulation Conference, 2012;3192-3201.

[9] Berglund J, Lindskog E, Johansson B, Stahre J, Vallhagen J. Integration of 3D laser scanning into Traditional DES Project Methodology. In Proceedings of the 2013 Winter Simulation Conference, 2013;4014-4015.

[10] Khaswala ZN, Irani SA. Value Network Mapping (Vnm): Visualization and Analysis of Multiple Flows in Value Stream Maps. In Proceedings of the Lean Management Solutions Conference, 2001.

[11] Bärring M, et al. A VSM Approach to Support Data Collection for a Simulation Model. In proceedings of the 2017 Winter Simulation Conference, 2017.

[12] Besl P. Active, optical range imaging sensors. Machine vision and applications, 1988;1;127-152.

[13] Banks J, Carson JS, Nelson BL, Nicol DM. Discrete-Event System Simulation. Fourth Edition. Upper Saddle River, New Jersey: Pearson Prentice Hall Inc; 2005.

[14] Musselman KJ. Guidelines for Simulation Project Success. In Proceedings of the 1994 Winter Simulation Conference, 2004;184–191.

[15] Knott K, Sury RJ. A study of work-time distributions on unpaced tasks. IIE Transactions, 1987;19;50–55.