Proceedings of the 2015 Winter Simulation Conference
L. Yilmaz, W. K. V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. D. Rossetti, eds.

LEAN MANUFACTURING METHODS IN SIMULATION LITERATURE: REVIEW AND ASSOCIATION ANALYSIS

Henri Tokola
Esko Niemi

Department of Engineering Design and Production
Aalto University School of Engineering
Puumiehenkuja 3
Espoo, 02150, FINLAND

Ville Väistö

Department of Mechanical Engineering and
Industrial Systems
Tampere University of Technology
Korkeakoulunkatu 6
Tampere, 33720, FINLAND

ABSTRACT

The lean manufacturing philosophy includes several methods that aim to remove waste from production. This paper studies lean manufacturing methods and how simulation is used to consider them. In order to do this, it reviews papers that study simulation together with lean methods. The papers that are reviewed are categorized according to the lean methods used and result types obtained. Analysis is performed in order to gain knowledge about the volumes of occurrence of different methods and result types. Typical methods in the papers are different types of value stream mapping and work-in-process models. An exploratory analysis is performed to reveal the relationships between the methods and result types. This is done using association analysis. It reveals the methods that are commonly studied together in the literature. The paper also lists research areas that are not considered in the literature. These areas are often related to the analysis of variation.

1 INTRODUCTION

Lean manufacturing includes different methods that aim at removing different types of waste from production. These include reduction of work-in-process (WIP) methods, Single-Minute Exchange of Die (SMED), Total Productive Maintenance (TPM), one-piece flow, and automation. The effects of many lean methods are hard to estimate, but for this purpose, simulation could be used. This paper aims to find lean methods that can be considered in simulation studies and also to unearth methods that are not studied but could be studied using simulation.

Related to the topic of this paper, Gurumurthy and Kodali (2011) wrote a paper about different lean methods used in simulation-based research. They focus on the literature that uses value stream mapping with simulation and they conclude that Kanbans, push and pull systems, and sequencing are common methods that appear in the literature. They also state that multi-machine use, cycle time reduction, and processing time improvements have not received adequate importance. While studying simulation and lean methods, they do not, however, provide detailed quantitative descriptions and interaction analysis about the lean methods and results obtained, as is done in this paper.

The research is based on a literature review, the results of which are summarized in Section 2 in a table where the methods and result types of different papers are listed. This table is used for analysis in two different ways in Section 3. First, descriptive analysis shows the occurrence of different methods and result types. Second, association analysis is used to unearth the relationships between the methods, between the result types, and between the methods and result types. After that, the results of the analysis are discussed in Section 4 and interesting further research areas are listed in Section 5.

2 LITERATURE REVIEW

The literature review was performed by finding papers that study lean methods using simulation. The search process focused on the papers that had manufacturing, simulation and lean in their title. Around 40 papers were handpicked for consideration and finally a total of 26 papers were selected for review. Some papers were so closely associated that they were considered together. As simulation and lean have been actively studied from 90s to this day, the papers are from that period as well.

The results of the review are shown in Table 1, which lists the papers and describes which lean methods are used and what kinds of results are achieved. This table is used for further analysis in Section 3. In many papers, lean can be thought of as a collection of methods. From the planning perspective, the value stream mapping (VSM) method was often a starting point for lean transformation. Many papers also deal with process control issues. These methods include pull, Kanban, bottleneck control, first-in-first-out (FIFO) control, line balancing, multi-machine operation, one-piece flow, WIP control, takt time, tool path analysis, batch size reduction, better sequencing, just-in-time (JIT), grouping products, and the use of Spiderman. Lean is often associated with layout change using a U-shaped line, cells, combined stages, or production line. Some lean methods are also used to improve the actual process. These methods include SMED, kaizen, 5S, automation, Poka-yoke, kitting, quality improvement, process time reduction, visual management, and eliminating waste. In lean it is important to involve workers in the process and this is implemented in methods such as TPM, flexible capacity, team building, a multi-skilled workforce, and Standard Work Chart.

When the result types achieved are considered, it is common for simulation results to be used to achieve a reduction in variation, workers, floor space, and change-over times or increases in throughput. Simulation is also used as a training or planning tool.

3 ANALYSIS OF PAPERS REVIEWED

The results of the literature review are analyzed further in this section using descriptive methods and association analysis. The details of the papers that were reviewed were collected in a spreadsheet in such a way that the columns describe whether a paper used a specific lean method or had a specific result type. This enabled the quantitative analysis to be performed.

Figure 1 shows the usage of different methods in the papers that were reviewed. Methods that do not appear in the figure but that are used in just one paper are TPM, U-shaped lines, bottleneck control, FIFO control, automation, Spiderman, flexible capacity, one-piece flow, Standard Work Chart, Poka-yoke, kitting, tool path, lifetime extension, availability extension, batch size reduction, sequencing, optimization, combining stages, eliminating waste, team building, JIT, and a multi-skilled workforce.

Figure 2 shows the appearances of the different result types that were obtained. The result types that do not appear in the figure but are obtained in single papers are identifying WIP, finding out the impact of improvements, a reduction in process time, productivity increase, avoiding costly mistakes, current state assessment, demand variability reduction, sales volume increase, and cycle time variability reduction.

In order to find out the relationships between different components, an association analysis was performed. This was done using market basket analysis with the SPSS software (SPSS inc., 2008). The analysis was performed in such a way that associations with a 10% minimum support level, 60% minimum confidence levels, and one as the maximum number of antecedents were collected. These numbers were selected so that there would be associations among some methods and result types, but not among all. In market basket analysis, support level is calculated as percentage of papers that contain two studied items. Confidence level is defined by percentage of associations among all the occurrences of precedent items. As maximum number of antecedents is one, associations between groups of items are not considered. Association is assumed to be strong if it is above support and confidence levels. Figure 3 shows the associations between the different methods. Figure 4 shows the associations between different result types. Figure 5 shows the associations between the methods and result types.

Table 1: Results of the literature review.

Authors and year	Lean methods	Result types achieved
Abdulmalek and Rajgopal (2007)	Value stream mapping (VSM); Total Productive Maintenance (TPM); setup time reduction; Pull system	TPM reduces lead time significantly; inventories could be reduced; estimated lead time and work-in-process (WIP) inventory; setup reductions do not seem to have significant additional effects
Adams et al. (1999)	Continuous improvement (Kaizen)	Identifying WIP utilization, delays, and bottlenecks; training tool; impact of improvements; results from redesign of the lines
Al-Khafaji and Al-Rufaifi (2012)	VSM; Pull system; Kanban signal; non-value-added activities; Cell layouts; U-shaped lines; Bottleneck control; First-in-First-out control (FIFO)	Reduction in WIP; reduction in labor
Anand and Rambadu Kodali (2009a)	Process automation; Dedicated material handler (Spiderman); Layout change	Reduction in WIP; reduction in process time, idle time, and walking time of workers is reduced; floor space savings
Anand and Rambubu Kodali (2009b)	Line balancing; Multi-machine activity; Machine grouping (Cell layouts)	More production per day; reduction in WIP; reduction in CT; reduction in walking distance; reduction in manpower; reduction in floor space; better flow of material movements
Božičković et al. (2012), Božičković et al. (2011)	VSM; Eliminating returning flows; Kanban; Pull system; Product groups	Reduction in complexity of material flows; reduction in CT; reduction in WIP; reduction in idle times
Czarnecki and Loyd (2001)	Kanban; Reduced WIP; Compressed layout; Visual management; Quicker changeover	Inexpensive insuranace against costly mistakes; current state assessment; train VSM team; evaluate future state
Detty and Yingling (2000)	Flexible capacity; Pull system; One-piece flow; Standardized work charts; 5S; Visual control; Poka-yoke; Kitting; Quality-at-the-source; Reduced WIP; Reduced changeover time; Reduced floor space; Takt time	Lead time reduction; changeover times reduced; reduction in WIP; reduction in floor space; lower demand variability for part suppliers; reduced forklift truck utilization; reduction in manpower
Diaz-Elsayed et al. (2013)	Single-Minute Exchange of Die (SMED); Tool path; Quality rate; Lifetime extension; Availability Improvement; Batch size reduction	Cost reduction; increased sales volumes; waste reduction in terms of resource and energy consumption
Duanmu and Taaffe (2007)	Takt time; Limit WIP; Item sequencing using material resource planning (MRP); Adding buffer; Reduction of processing times; Optimization	Throughput increased; accelerating the speed after a common stage has a better effect on the system
Grajo (1995)	Layout; Part flows	Reduction in WIP; reduction in material

		movement and handling costs
Gurumurthy and Kodali (2011)	VSM; Combine stages; Layout change; Line balancing; Process improvements; Kaizen; Multi-machine activity, 5S	Reduction in inventory, cycle time, floor space, and manpower
Lian and Van Landeghem (2007)	VSM; Kanban; Takt time	Faster lead time; reduction in WIP; higher value-added ratio
Marek, Elkins, and Smith (2001)	Kanban; constant wip (CONWIP)	Reduction in WIP while attaining desired throughput
Marvel, Schaub, and Weckman (2008)	Kanban; Product groups; Product flow lanes	Production planning tool; adequate number of Kanban containers
Marvel and Standridge (2009), Standridge and Marvel (2006)	VSM; Kanban; Product groups; Product flow lanes	Validation of the vision of the future lean state
Ncube (2009)	Pull; Eliminating waste; Team building; Continuous improvement	Educational tool
Schroer (2004)	Takt time; Kanban	When cycle time variability is minimized, lower Kanban capacity can be used; lower WIP
Shararah, El-Kilany, and El-Sayed (2010)	VSM	-
Solding and Gullander (2009)	VSM	-
Standridge and Marvel (2006)	VSM; Kanban; Product groups; Product flow lanes	How much inventory should be kept; production plan validation
Taj et al. (1998)	Just-in-time (JIT)	JIT cell production needs quicker setups and higher machine reliability to be a plausible option
Velarde et al. (2009)	VSM; Multiskilled workforce; 5S; Takt time; Pull system; Removing WIP buffers	Multiskilled workforce and 5S improved throughput; pull system with Takt time alone reduced throughput
Xia and Sun (2013)	VSM; Controlling WIP	Identifying bottlenecks; after a certain point increasing WIP will not improve throughput

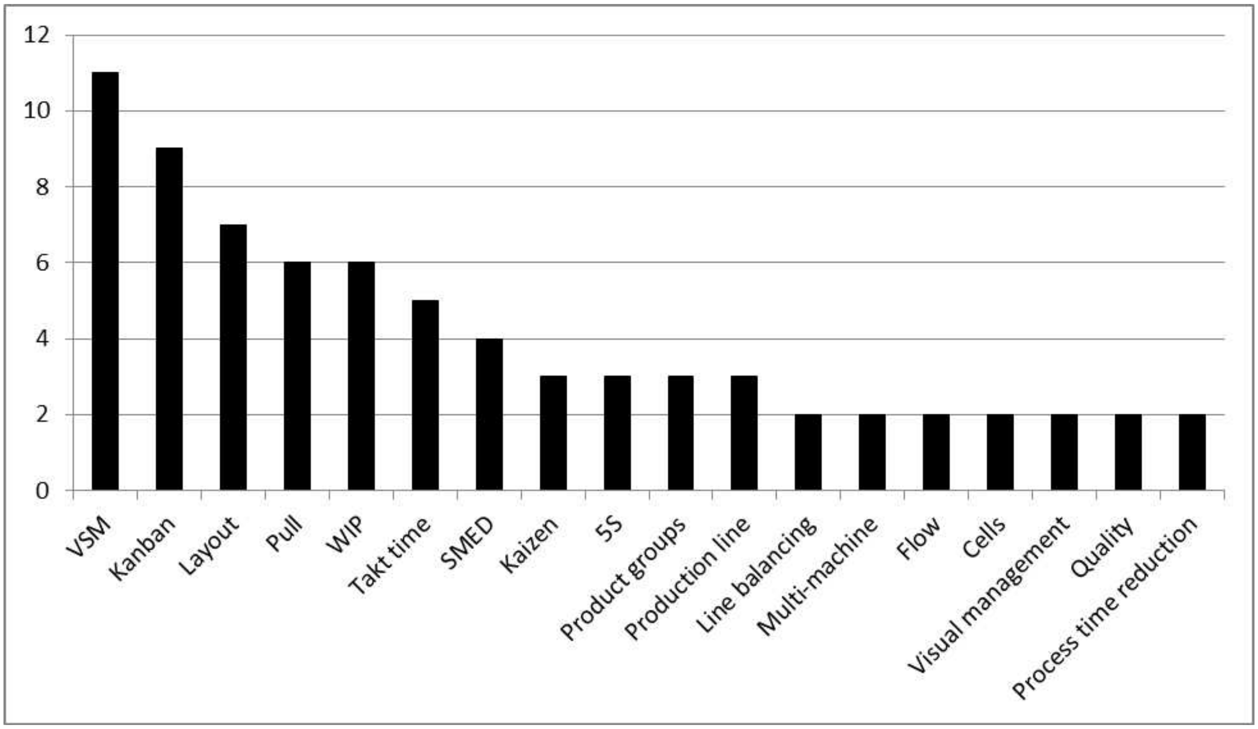

Figure 1: Occurrences of lean methods in the papers reviewed. Methods that appear only once are omitted from the results.

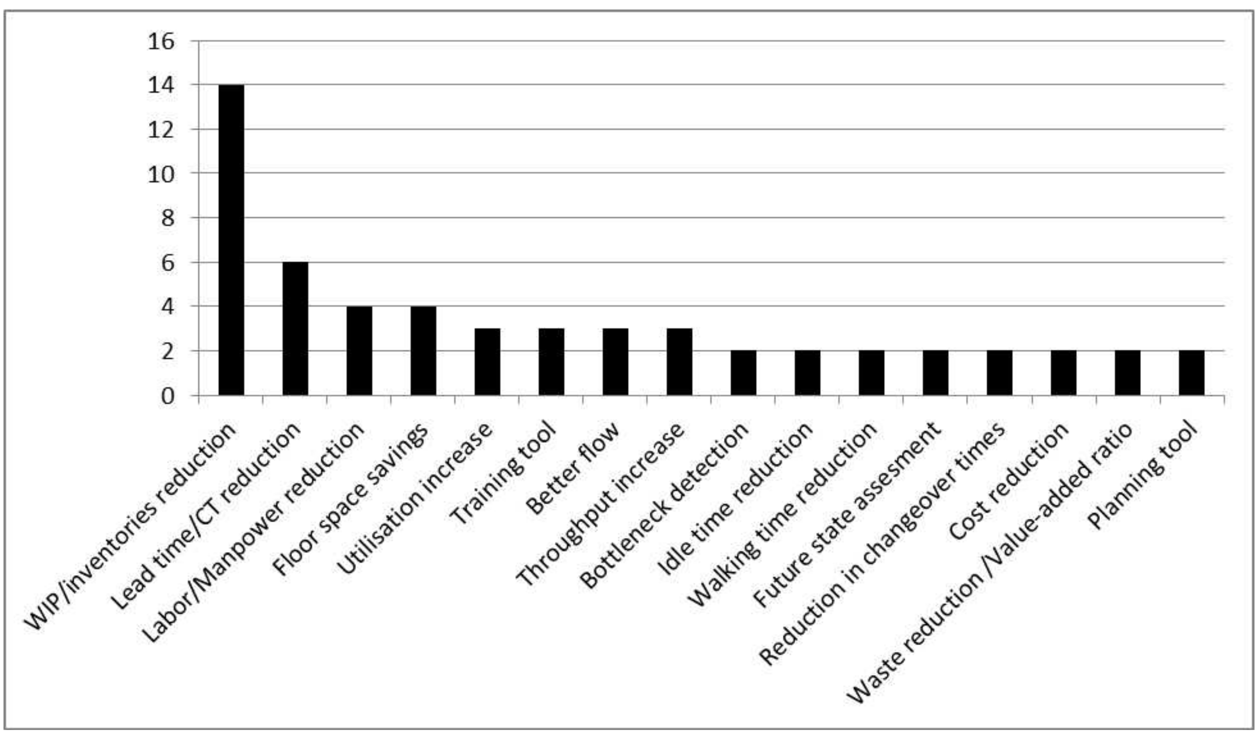

Figure 2: Occurences of different result types in the papers reviewed. Methods that appear only once are omitted from the results.

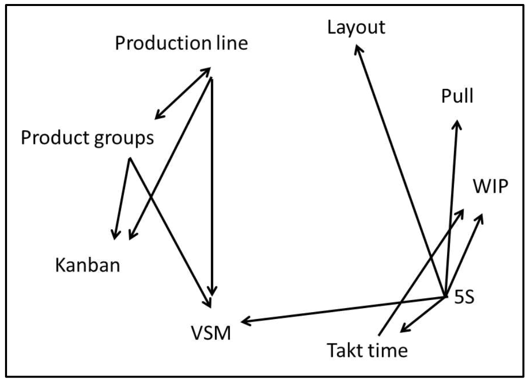

Figure 3: Strong associations between methods.

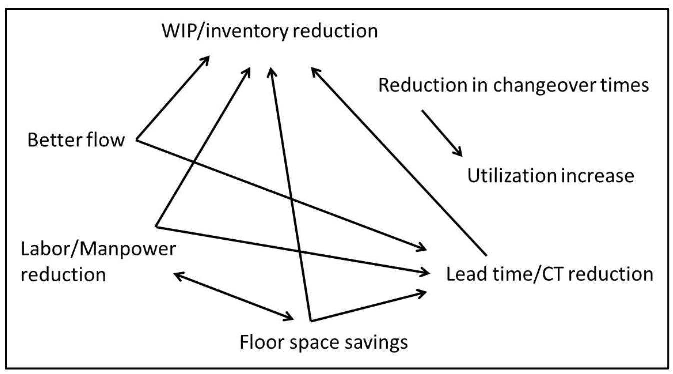

Figure 4: Strong associations between results.

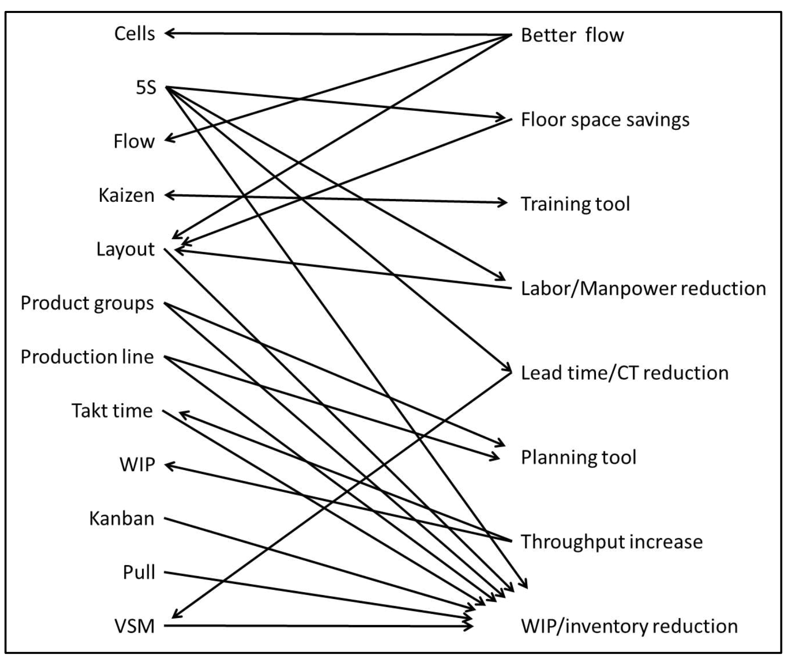

Figure 5: Strong associations between methods and result types.

4 DISCUSSION

This section discusses the analysis that was described in Section 3. The purpose is to find out insights from the results of the analysis.

Figure 1 showed the occurrences of different lean methods in the papers that were reviewed. VSM is typically often described as a starting point for lean implementation and that is why it was the most popular method (used in 46% of papers). Kanban, layout, pull, and WIP are easy to model using simulation, which is likely to be the reason why they appear in as many as nine (38%), seven (29%), six (25%) and six papers (25%), respectively. The effects of takt time (21%) and SMED (17%) are easy to model as well. It is also interesting to see which methods appear only in a few papers. Examples of these methods are automation, Poka-yoke, U-shaped line, kitting, and tool-path analysis. They appear only once (4%). A characteristic that is common to these is that it is hard to simulate or know the effect of the methods. Most of these typically reduce variation, but the amount is difficult to estimate, which makes their modeling hard.

Figure 2 shows the occurrences of different result types in the papers that were reviewed. WIP reduction (which appears in 58% of papers), lead time reduction (25%), labor reduction (17%), and floor space savings (17%) are the most popular result types among the papers. Examples of result types that are rare are analysis of the impact of improvements, reduction in process time, productivity increase, avoiding costly mistakes, demand variability reduction, and cycle time variability reduction. They appear only once (4%) in results. Similarly to lean methods, the rarity of variability reduction methods leads us to the conclusion that results related to variation are hard to understand even using simulation.

Clearly, as discussed above, there is gap in the simulation literature regarding variation reduction. According to knowledge of authors, in practice, it is well understood that variation reduction, at least in terms of mistake reduction, is important aspect in lean. However, it seems that this is not the case in simulation literature. One reason for this might be that estimating variation reduction needs processing time data from industry. Also, variation affects queue lengths that further affect the lead time. This might not be clear for all, as often in the practice it is seen that only utilization is important.

The results of the association analysis in Figure 3 give us the relations between the methods in the simulation papers. First, production lines and product groups are used with Kanbans and VSM. Second, 5S is often used together with the other methods. Third, 5S, WIP reduction, and takt time form a group, which means that they are often used together. What is surprisingly lacking, is the connection between pull related things and production line. In order to get production line efficient, production line should be complemented by pull type of production.

The results of the association analysis in Figure 4 give us quite predictable and plausible insights about the relations between the result types in the simulation papers. First, when better flow, labor reduction, or floor space reduction were achieved, lead time and WIP levels were also reduced. Second, labor reduction and floor space reduction are related. Third, changeover time reduction makes utilization higher. By considering these results, it can be seen that utilization is rarely affected by other result types. However, in practice, when different lean methods are used, it is nearly always seen that utilization is improved as well.

The results of the association analysis in Figure 5 show the relations between lean methods and result types. First, better flow was often achieved using cells, flow, and layout changes. Second, the use of 5S achieved many results: floor space savings and reductions in labor, lead time, and WIP. Third, most of the methods achieved WIP reduction.

5 CONCLUSION

This paper reviews papers that combined simulation with lean manufacturing methods. The results of the review are analyzed using quantitative methods. The main findings of the analysis are the following.

- VSM, Kanban, WIP, layout, and takt time are easy to simulate and thus they were popular lean methods among the papers. The methods that are not widely used are methods that affect the variation of processing times;
- reductions in WIP, lead time, labor, and floor space were frequent results in the simulations. Similarly to lean methods, results related to variation were rare;
- the association analysis revealed relationships between methods
    - Production lines and product groups were often used with Kanbans and VSM
    - 5S was often used with the other methods
    - When better flow, labor reduction, or floor space reduction were achieved, lead time and WIP levels were also reduced.
    - Labor reduction and floor space reduction are closely connected
    - Better flow was often achieved using cells, flow, and layout changes
    - The use of 5S achieved many results: floor space savings and reductions in labor, lead time, and WIP
    - Most of the methods achieved WIP reduction

The results point out the areas where simulation is used and where it should probably be used. These areas are mostly related to WIP, lead time, and utilization reduction. If these issues are studied, it is easy to find material to help in implementation of simulation environment.

The results also stress that methods and results related to variation are considered only rarely in simulation papers. Thus, as this is a clear gap in the research literature, the future research on lean methods could deal with methods that reduce variation. Reducing variation is one issue that helps in getting lead times shorter and thus understanding variation reduction is important. As the variation reductions are often hard to estimate, the research cannot be completely theoretical but it should collect actual data from industry.

Several lean methods, e.g., automation, Poka-yoke, U-shaped lines, kitting, and tool-path, were studied only in single papers and, in future studies, they could be fruitful starting point for future research. These methods affect variation in different ways. Automation can completely eliminate variation. Poka-Yoke reduces mistakes, U-shaped lines help in the case of variation, kitting reduces assembly time and toolpaths reduce walking time. These methods are studied in the literature, but, surprisingly, they appear in a few simulation papers.

Association analysis revealed connections between methods and result types. These connections could also be fruitful research directions. For example, future studies could focus on how floor space reduction affects labor reduction or on how 5s affects other methods.

ACKNOWLEDGEMENTS

This research was carried out as part of the Finnish Metals and Engineering Competence Cluster (FIMECC)'s MANU program in the LeanMES project.

REFERENCES

Abdulmalek, F. A., and J. Rajgopal. 2007. "Analyzing the Benefits of Lean Manufacturing and Value Stream Mapping via Simulation: a Process Sector Case Study." *International Journal of Production Economics*, 107(1), 223-236.

Adams, M., P. Componation, H. Czarnecki, and B. J. Schroer. 1999. "Simulation as a Tool for Continuous Process Improvement." In *Proceedings of the 1999 Winter Simulation Conference*, edited by P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans 766-773, ACM.

Al-Khafaji, S. K., and H. M. Al-Rufaifi. 2012. "A Case Study of Production Improvement by Using Lean with Simulation Modeling." In *Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management. Istanbul, Turkey*, 271-279.

Anand, G., and R. Kodali. 2009a. "Application of Value Stream Mapping and Simulation for the Design of Lean Manufacturing Systems: a Case Study." *International Journal of Simulation and Process Modelling*, 5(2), 86-98.

Anand, G., and R. Kodali. 2009b. "Simulation Model for the Design of Lean Manufacturing Systems – a Case Study." *International Journal of Productivity and Quality Management*, 4(5), 691-714.

Božičković, R., I. Ćosić, Z. Božičković, and M. Radošević. 2011. "An Application of Simulation and Graphic Tools in Lean Production." In *XV International Scientific Conference on Industrial Systems*, 483-489.

Božičković, R., M. Radosevic, I. Ćosić, M. Soković, and A. Rikalović. 2012. "Integration of Simulation and Lean Tools in Effective Production Systems – Case study." *Strojniški vestnik – Journal of Mechanical Engineering*, 58(11), 642-652.

Czarnecki, H., and N. Loyd. 2001. "Simulation of Lean Assembly Line for High Volume Manufacturing." In *Proceedings of the Huntsville Simulation Conference*, 1-6.

Detty, R. B., and J. C. Yingling. 2000. "Quantifying Benefits of Conversion to Lean Manufacturing with Discrete Event Simulation: a Case Study." *International Journal of Production Research*, 38(2), 429-445.

Diaz-Elsayed, N., A. Jondral , S. Greinacher, D. Dornfeld, and G. Lanza. 2013. "Assessment of Lean and Green Strategies by Simulation of Manufacturing Systems in Discrete Production Environments." *CIRP Annals-Manufacturing Technology*, 62(1), 475-478.

Duanmu, J., and K. Taaffe. 2007. "Measuring Manufacturing Throughput Using Takt Time Analysis and Simulation." In *Proceedings of the 2007 Winter Simulation Conference*, edited by S. G. Henderson, B. Biller, M. Hsieh, and J. Shortle, 1633-1640, IEEE Press.

Grajo, E. S. 1995. "Strategic Layout Planning and Simulation for Lean Manufacturing a LayOPT Tutorial." In *Proceedings of the 1995 Winter Simulation Conference*, edited by C. Alexopoulus, K. Kang, W. R. Lilegdon, and D. Goldsman, 510-514, IEEE Computer Society.

Gurumurthy, A., and R. Kodali. 2011. "Design of Lean Manufacturing Systems Using Value Stream Mapping with Simulation: a Case Study." *Journal of Manufacturing Technology Management*, 22(4), 444-473.

Lian, Y. H., and H. Van Landeghem. 2007. "Analysing the Effects of Lean Manufacturing Using a Value Stream Mapping-based Simulation Generator." *International Journal of Production Research*, 45(13), 3037-3058.

Marek, R. P., D. A. Elkins, and D. R. Smith. 2001. "Manufacturing Controls: Understanding the Fundamentals of Kanban and CONWIP Pull Systems Using Simulation." In *Proceedings of the 2001 Winter Simulation Conference*, edited by B. A. Peters, J. S. Smith, D. J. Medeiros, and M. W. Rohrer, 921-929, IEEE Computer Society.

Marvel, J. H., M. A. Schaub, & G. R. Weckman. 2008. "Assessing the Availability and Allocation of Production Capacity in a Fabrication Facility Through Simulation Modeling: a Case Study." *International Journal of Industrial Engineering*, 15(2), 166-175.

Marvel, J. H., & C. R. Standridge. 2009. "Simulation-Enhanced Lean Design Process." *Journal of Industrial Engineering and Management*, 2(1), 90-113.

Ncube, L. B. 2009. "A Simulation of Lean Manufacturing: The Lean Lemonade Tycoon 2™." *Simulation & Gaming*.

Schroer, B. J. 2004. "Simulation as a Tool in Understanding the Concepts of Lean Manufacturing." *Simulation*, 80(3), 171-175.

Shararah, M. A., K. S. El-Kilany, and A. E. El-Sayed. 2010. "Component Based Modeling and Simulation of Value Stream Mapping for Lean Production Systems." In *FAIM Conference*, 881-888.

Solding, P., and P. Gullander. 2009. "Concepts for Simulation Based Value Stream Mapping." In *Proceedings of the 2009 Winter Simulation Conference*, edited by M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin, and R. G. Ingalls, 2231-2237, IEEE.

SPSS Inc. 2008. *Introduction to Clementine and Data Mining*. DataChicago, IL.

Standridge, C. R., and J. H. Marvel. 2006. "Why Lean Needs Simulation." In *Proceedings of the 2006 Winter Simulation Conference*, edited by L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto, 1907-1913.

Taj, S., D. S. Cochran, J. W. Duda, and J. Linck. 1998. "Simulation and Production Planning for Manufacturing Cells." In *Proceedings of the 1998 Winter Simulation Conference*, edited by D. J. Medeiros, E. F. Watson, J. S. Carson, and M. S. Manivannan, 973-978, IEEE Computer Society Press.

Velarde, G. J., D. E. Saloni, H. van Dyk, and M. Giunt. 2009. "Process Flow Improvement Proposal Using Lean Manufacturing Philosophy and Simulation Techniques on a Modular Home Manufacturer." *Lean Construction Journal*, 5(1), 77-93.

Xia, W., and J. Sun. 2013. "Simulation Guided Value Stream Mapping and Lean Improvement: A Case Study of a Tubular Machining Facility." *Journal of Industrial Engineering & Management,* 6(2), 456-476.

AUTHOR BIOGRAPHIES

HENRI TOKOLA is a researcher at the Department of Engineering Design and Production of Aalto University. He holds an M.Sc. degree in Computer Science. His experience includes the modeling and optimization of various production activies from the production control perspective. His current research focuses on manufacturing execution systems (MESs). His e-mail address is henri.tokola@aalto.fi.

VILLE VÄISTÖ is a researcher at Tampere University of Technology. His main research area is the simulation of manufacturing systems. His email address is ville.vaisto@tut.fi.

ESKO NIEMI is a professor of Production Engineering at Aalto University School of Engineering. His current research interests are related to the modeling and, especially, optimization of manufacturing systems and processes. His e-mail address is esko.niemi@aalto.fi.