Challenges of Simulation-based Optimization in Facility Layout Design of Production Systems

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Abstract. Facility layout design (FLD) is becoming more challenging than ever as manufacturing moves from a traditional emphasis on mass production to an emphasis on mass customization, which requires increased flexibility and adaptability. Of the software tools that support FLD, simulation and optimization are the most powerful – especially when combined in simulation-based optimization (SBO). The aim of this study is to identify the challenges of using SBO in FLD of production systems. To date, the challenges of SBO and FLD have been addressed in separate streams of literature. This paper also presents two novel contributions based on two case studies involving Swedish manufacturers. First, it shows that the challenges of using SBO in FLD identified in the literature are not the most important in industrial environments, where precedence must be given to the challenges of complexity, data noise, and standardization. Second, it shows that the challenges of SBO in FLD are not technological in nature but stem from the increased complexity of the factories required by modern manufacturing companies.

Keywords. Simulation-based optimization, facility layout design, challenges

1. Introduction

The literature posits that the use of simulation-based optimization (SBO) in facility layout design (FLD) may help manufacturing companies unlock the competitiveness necessary to cope with growing product customization and increased production flexibility. FLD can be defined as the physical allocation of space on a shop floor involving the relative positioning of resources and their tasks for the economic activity in a plant [1]. At a strategic level, FLD can significantly improve productivity by reducing material handling costs and lead time [2]. SBO has commonly been used to find solutions to complex design problems when the size and number of possible decision variables used as parameters are considerable [3]. Using SBO for FLD is essential because it can provide a deeper understanding of the dynamic nature of floor space utilization in a production system. This knowledge is critical because manufacturing

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companies lack tools that can handle the periodical analysis and redesign of facilities necessary in the high-mix, high-variety production scenarios of today.

The literature on FLD is extensive, spans several decades, and primarily focuses on methods and tools to facilitate the allocation of space in a production system. Kulkarni at al. and Moslemipour et al. [4, 5] offer extensive surveys of this facility layout problem. Today, computational advances also facilitate the use of SBO to increase the competitiveness of production systems. The optimization methods used include simulation annealing, particle swarm optimization, tabu search heuristics, meta-heuristics, hybrid meta-heuristics, and mathematical optimization modeling approaches [3–8]. There is, however, still a need for empirical studies of the challenges of using SBO in FLD. Up till now, these challenges have been addressed in separate streams of the literature. Empirical knowledge of the challenges will contribute to the development of strategies assuring the success of SBO in FLD.

Therefore, the aim of this paper is to identify the challenges of using SBO in FLD of production systems. It examines current understandings of challenges reported in the fields of SBO and FLD and analyzes the existing literature and two cases from manufacturing industry. This paper is divided as follows. Section 2 presents the current literature on the challenges of FLD and SBO. Section 3 describes the research method and case studies, and outlines the empirical results. Finally, Section 4 presents the discussion and the conclusions of the paper.

2. Challenges of Facility Layout Design and Simulation-based Optimization

This section deals first with challenges relating to FLD and then with those affecting SBO. It is based on information in journals, conference proceedings, and books published between 1999 and 2019 and identified in the Web of Science, Scopus, and ScienceDirect databases using the following search terms: simulation and optimization, facility, layout, and design. Articles were screened based on the relation of their abstracts and titles to the aim of this paper. A final selection of the articles identifying the most relevant challenges is summarized in this paper.

FLD is the task of designing the allocation plans of departments, cells, machines or equipment on a manufacturing shop floor [6, 7]. The objective is to ensure effective use of the floor space and a smooth and steady flow of production material, equipment, and manpower, and to minimize the use of material handling systems (MHS) [6]. However, designing an effective layout can be a very complicated task when there is variability in the demand, changes in product designs, introduction of new products, and the number of product families and variants is considerable.

FLD problems can be categorized as either static or dynamic. In static problems the layout is generated for a specific time period, the flow between machines never changes, and the product demands and product mix are fixed [7]. Dynamic layout problems involve fluctuations in product demand and product mix, changes in production processes, the introduction or discontinuation of products or machines, and other factors that can affect the MHS [7]. Given that the production systems in this research are complex and large, and need to be robust to accommodate dynamic layouts that will change over time, the challenges for FLD are analyzed from the perspective of multiple dynamic layouts for various time horizons [7]. The results are presented in Table 1. Many of the identified challenges were found in several articles; however, due to space constraints only the most representative references have been selected.

Table 1. Challenges affecting facility layout design reported in literature.

Challenges inherent in the nature of facility layout design
Complexity – Much of the existing layout literature relies on simplifications to represent the interrelation of elements in a production system [8, 9]
Dynamicity– Representing the consequences of changing material flows resulting from product diversity and demand in FLD [4, 9]
Randomness – The stochastic nature of production systems may not be accurately represented in FLD [2]
Simultaneity – Addressing problems in FLD simultaneously instead of sequentially [10]
Challenges affecting resources supporting facility layout design
Cost – Justifying a new FLD depends on demonstrating an increase in competitiveness that exceeds the high cost of implementation [7]
Integration – Integrating different information sources to provide quick response in evaluating alternative layouts [9]
Process – Relying on individuals instead of standardized processes for FLD [9]
Safety – Favoring operational performance over human and safety factors [4]

SBO is the intersection of two powerful traditional decision-making techniques, simulation and optimization [11]. It enables the complexity of modern production systems and their variability to be modeled to provide useful operational and managerial decision support [10]. Operational or managerial decisions may be based on a change of parameters to maximize or minimize performance measures. Due to the complexity and uncertainty of real-life systems in a layout design process, it is difficult to obtain and model precise analytical relationships between the different variables without simulation [6]. Thus simulation and optimization approaches are widely used to design and improve production systems when the analytical relationships are intractable to mathematical programming methods [3, 6]. The literature describing the field of SBO presents two sets of challenges [12], namely, those inherent in the nature of simulation or optimization, and those affecting the resources that support SBO in manufacturing, which may include people, processes, or technologies. Table 2 describes the challenges affecting SBO.

Table 2. Challenges affecting simulation-based optimization reported in literature.

Challenges inherent in the nature of simulation-based optimization
Complexity – Translating practical problems into explicit mathematical formulations, understanding the interaction, conflicts, trade-offs of objectives, determining conclusively the primacy of a solution in a stochastic system, capturing essential production processes with sufficient detail [13]
Noise – Dealing with imperfect estimates in a stochastic simulation [13]
Search – Locating and distinguishing between local and global solutions, or determining the limits of a solution space [13] [14]
Evaluation – Failing to recognize an optimal solution, the primacy of input values or decision scenarios [14]
Challenges affecting resources supporting simulation-based optimization
People – Lack of understanding or technical competence in the use of simulation and optimization [14]
Process – Deficiencies for changing routines and processes related to SBO including simulation processes, modeling standards, or integration of SBO in production system design [13]
Technology – Nature of SBO makes it hard to determine its potential benefits, generating doubts about its use [14]

3. Method and Empirical Findings

After gaining an initial understanding of the challenges in the field of SBO and FLD, this study turned to identifying the challenges of SBO in FLD of production systems as experienced by those responsible for their development. The research relied on a case study method, which facilitates a deep understanding of the context of the study, albeit in the absence of control over behavioral events [15]. Two cases were selected (A and B) based on the following three criteria: the manufacturing company was planning an FLD project; it was anticipated that SBO would be used in the FLD project; and the staff anticipated challenges that would jeopardize the success of SBO models.

Data were collected between 2016 and 2019, with a focus on the challenges identified in Tables 1 and 2. The data included company documents and field notes of informal conversations with staff responsible for the FLD projects A and B. Data analysis began by identifying the challenges of SBO and FLD reported in Section 2. Then the authors assembled the empirical data in a spreadsheet with two categories, namely SBO and FLD challenges. The challenges of SBO were associated with those of FLD based on descriptions by staff participating in the case studies, company documents, and field notes. The first two authors executed these steps separately, compared their findings, and deliberated until agreement emerged. The authors drew conclusions about each case, and later performed a cross-case analysis. Empirical data were compared to literature at every step of this process. The case studies are presented briefly below.

Case A involved an FLD project including SBO at a medium-sized manufacturing company specializing in the production of electrical cabinets. The project gave precedence to operational performance, including factory floor space and production flow to meet increasing demand and product variety. The staff developed a simplified alternative to the existing FLD that addressed existing issues sequentially. The new version was a static representation based on the production process, material flow, and equipment used to produce its most popular electrical cabinet. The FLD process did not include SBO. However, management contacted an external partner specializing in developing discrete-event simulation models to verify and validate the FLD project. The simulation experts determined that the existing information represented only a partial understanding and was insufficient to develop an SBO model. Simulation experts and staff from the company met repeatedly to acquire data from diverse sources, analyze stochastic data, and develop an SBO model. This model indicated that the initial alternative would not achieve its objective. In response, critical factors for achieving a desirable outcome were identified and a new FLD was drawn up based on the optimization of these factors. The project did not come in on budget or on time. However, the staff rated the project favorably because SBO had enabled them to avoid a poor choice. They had considered SBO necessary to progressively introduce changes in the factory floor space. However, Case A was limited by a lack of access to and understanding of SBO. The existing FLD process was not revised to include SBO after the project.

Case B involved an FLD project including SBO at a large manufacturing company specializing in the production of water pumps. The objective was to increase quality while minimizing the cost of a layout redistribution on the main shop floor. The problem was the need for space to install a new production line to increase production, as well as a new painting system to improve painting quality, and to have the capacity to introduce new products. The production requirements and MHS were also considered in the layout design. Nine project teams with nine project leaders under two production development managers were created to subdivide the project into more specific subprojects. The time frame was one year from signing the purchasing contract with a painting line supplier to production start-up. At the beginning a draft layout was proposed with the main objectives of being feasible and involving moderate cost. The possibility of working different shifts to achieve the production goals was then considered. The flexibility of the outcome was a key aspect so as to be able to adapt to future changes in the factory. Another issue considered was the impossibility of stopping production. SBO was used locally in some of the subgroups to determine some parameters and scenarios, and no generic FLD method was followed during this project.

Table 3 identifies the challenges of using SBO in FLD of production systems for cases A and B.

Table 3. Challenges of using SBO in FLD for cases A and B. ○ and ● represent Case A and B respectively.

Challenges of	Challenges of SBO						
FLD	Complexity	Noise	Search	Evaluation	People	Process	Technology
Validity	○ ●	○ ●	○				
Randomness	○ ●	○ ●			○		
Dynamic	○ ●	○ ●					
Simultaneity	○ ●	●	●	●	●	●	●
Cost	●	●					
Safety	○ ●	●	●	●	○ ●	●	●
Standardization	●		○ ●	○ ●	○	○ ●	●
Integration	○ ●	○ ●			○		

4. Discussion and Conclusions

The results of this study have significant implications for the field of SBO in FLD and extend current understanding by synthesizing the challenges of SBO and FLD, which to date have been addressed in different streams of the literature. The results show that the challenges of SBO in FLD are not all of equal importance, for the challenges of complexity, noise, and standardization took precedence in the cases studied. This result suggests that, despite the emergence of SBO in FLD, the challenges affecting this field, as perceived by manufacturing companies, are not technological in nature but stem from the complexity of modern factory floors. This result is surprising because it indicates that problems with the systemic nature of production systems, including facility layouts, continue to affect manufacturing companies despite decades of research on these topics. On the other hand, this result is encouraging for those manufacturing companies working with standardized processes and systemic thinking, and with the ability to capture knowledge about essential production processes in sufficient detail. The case data show that such companies may stand to benefit when utilizing SBO in FLD.

In addition, the case results show a difference in the type of challenges affecting resources supporting SBO between case A and B. In Case A the staff delegated SBO models to an external partner, and reported challenges related to knowledge and competence. In Case B, the staff developed their own SBO models, and reported challenges related to process and technology. This finding suggests that the challenges of using SBO in FLD may change over time and may be dependent on understanding and technical competence in the use of SBO. In Case B a clear methodology for FLD could significantly have facilitated the coordination and development of the project.

This paper presents an analysis of challenges when working with SBO and FLD. A cross-case analysis was performed in combination with two industrial case studies, identifying key common challenges when working with SBO and FLD in production systems. The results clarify the literature regarding challenges when working with SBO and FLD. The results can also support managers and stakeholders in identifying challenges and cross-relations to minimize their effect in this kind of project, for example, by performing risk analyses at the planning stage or involving increased SBO resources alongside the FLD project. However, it is also clear that for large organizations the integration of SBO and FLD in a robust methodology with a dedicated SBO team could significantly minimize the number and magnitude of the challenges to be overcome.

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References

[1] Slack, N., A. Brandon-Jones, and R. Johnston, *Operations Management*. 2013: Pitman.

[2] Azadeh, A., Heydari, R., Yazdanparast, R., & Keramati, A., An integrated fuzzy simulation-mathematical programming approach for layout optimization by considering resilience engineering factors: A gas transmission unit. *World Journal of Engineering*, 2016, **13**(6): p. 547–559.

[3] Ng, A., J. Svensson, and M. Urenda, *Introducing Simulation-based Optimization for Production Systems. Design to Industry: the FACTS Game*. 2008. In 18th International Conference on Flexible Automation and Intelligent Manufacturing, 2008.

[4] Kulkarni, M., S. Bhatwadekar, and H. Thakur, *A literature review of facility planning and plant layouts.* 2015. *International Journal of Engineering Sciences & Research Technology*, 2015, **4**(3):p. 35–42.

[5] Moslemipour, G., T.S. Lee, and D. Rilling, A review of intelligent approaches for designing dynamic and robust layouts in flexible manufacturing systems. *The International Journal of Advanced Manufacturing Technology*, 2012, **60**(1-4): p. 11–27.

[6] Pourhassan, M.R. and S. Raissi, An integrated simulation-based optimization technique for multi-objective dynamic facility layout problem. *Journal of Industrial Information Integration*, 2017, **8**: p. 49–58.

[7] Shah, D., K. Krishnan, and M. Dhuttargoan, Dynamic facility planning under production and material handling capacity constraints. *Journal of Supply Chain and Operations Management*, 2015, **15**(1): p. 78–107.

[8] Yang, T. and C.-C. Hung, Multiple-attribute decision making methods for plant layout design problem. *Robotics and Computer-Integrated Manufacturing*, 2007, **23**(1): p. 126–137.

[9] Heilala, J., Montonen, J., Salmela, A., and Järvenpää, P., *Modeling and simulation for customer driven manufacturing system design and operations planning*. In Proceedings of the 2007 Winter Simulation Conference. 2007.

[10] Nanjing, J. and S.G. Henderson. *An introduction to simulation optimization*. In Proceedings of the 2015 Winter Simulation Conference, 2015.

[11] Fu, M.C., *Handbook of simulation optimization*. International Series in Operations Research and Management Science, Volume 216. 2015, New York, New York: Springer.

[12] Fu, M. C., Bayraksan, G., Henderson, S. G., Nelson, B. L., Powell, W. B., Ryzhov, I. O., & Thengvall, B., *Simulation optimization: A panel on the state of the art in research and practice*. In Proceedings of the 2014 Winter Simulation Conference, 2014.

[13] Xu, J., Huang, E., Chen, C. H., & Lee, L. H. *S*imulation Optimization: A Review and Exploration in the New Era of Cloud Computing and Big Data. *Asia-Pacific Journal of Operational Research*, 2015, **32**(03): p. 1–34.

[14] Fu, M.C., Feature Article: Optimization for simulation: Theory vs. Practice. *INFORMS Journal on Computing*, 2002, **14**(3): p. 192–215.

[15] Yin, R.K., *Case study research and applications: Design and methods*. 2017: Sage publications.