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Simulation-based Optimization for Facility Layout Design in Conditions of High Uncertainty

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Abstract

Despite the increased use of Simulation based Optimization, the design of facility layout is challenged by high levels of uncertainty associated with new production processes. Addressing this issue, this paper aims to understand the conceptual modeling activities of Simulation-based Optimization for facility layout design in conditions of high uncertainty. Based on three in-depth case studies, the results of this paper show how characterization criteria of production systems can be used in conceptual modelling to reduce uncertainty. These results may be essential to support managers and stakeholders during the introduction of new production processes in the design of facility layouts.

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Keywords: Uncerntainty Reduction; Simultion-based Optimization; Facility Layout; Decision Support

1. Introduction

Simulation-Based Optimization (SBO) in layout design is recognized as a challenging task with significant impact upon manufacturing performance [1], the challenges of which are increased by high levels of uncertainty associated with the introduction of new production processes [2]. Although the study of uncertainty is a core subject in simulation literature, this has focused on the assignment of probabilities to convert imperfectly known information into calculated risks [3]. In contrast, there is limited comprehension about the agreement and acquisition of the information necessary to manage high levels of uncertainty prior to the assignment of probabilities that are critical for increased manufacturing competitiveness [4].

Addressing this issue, this paper offers a different approach from prior publications and thus aims understand the conceptual modeling activities of SBO for facility layout design in conditions of high uncertainty. Two salient issues motivate this approach. First, the need of investigating when simulation parameters must first be identified when high uncertainty is [5]. Second, publications highlighting the importance that new production processes have for increased competitiveness of manufacturing companies [6]. Therefore, this paper is framed in the context of process innovation which is defined as the introduction of new or substantially improved organizational processes in the form of new equipment, material, or reengineering of operational processes [7]. Accordingly, this paper investigates the following research question: How do uncertainties in process innovation affect the conceptual modeling of SBO in facility layout design?

Prior publications explain how a simulation model facilitates the selection of a design alternative in conditions of high uncertainty [8]. Offering a different approach, the contributions of this paper focus on the conceptual modelling of SBO when supporting facility layout design. This novel insight provides the opportunity to analyse production process changes as they are first abstracted from a proposed layout design. Thus, two contributions are presented. First, we propose a set of criteria for SBO in facility layout design and identify how these criteria can be used in conceptual modeling activities under conditions

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of high uncertainty. Then, based on these results, we identify key challenges limiting uncertainty reduction in SBO layout design and propose activities to overcome them. Managerial implications are highlighted.

2. Frame of reference

2.1. Criticality of uncertainty in process innovation

Empirical evidence shows that uncertainty is inherent to and has a moderating effect on the operational outcomes of process innovation [9, 10]. This has motivated an increased interest in the study of uncertainty in process innovation literature which adheres to the definition of uncertainty as the difference between the information one has and the information one needs to complete a task [11]. These definition overreaches the configuration of production systems, including facility layout, to express both the probability that assumptions made during design may be incorrect or that facts necessary for design are entirely unknown [12]. Based on the definition above, Table 1 presents the different levels of uncertainty starting from a condition of true ambiguity, or high uncertainty, to a clear enough future, or low uncertainty [13].

To achieve the benefits of process innovation, recent publications emphasize the need to reduce the level of uncertainty before long term commitments are made [14]. According to contingency theory, transferring from a level of higher to lower uncertainty is accomplished through organized iterative activities focused on generating agreement and acquiring information that convert uncertainty into a calculated risk [15-17].

Table 1. Characterization of increasing levels of uncertainty based on Courtney (2003)

Uncertainty level	Description
1. Clear enough future	An outcome can be forecasted
2. Alternate futures	Defined set of possible outcomes, one of which will occur
3. Range of futures	Defined range of possible outcomes
4. True ambiguity	Outcomes are unknown and unknowable

2.2. Establishing the importance of a conceptual model

Current literature reporting the use of SBO presents a shift of perspectives in its approach to dealing with uncertainty. Recent publications emphasize the importance of addressing uncertainty early to minimize the amount of prerequisite knowledge a designer should have to propose, develop, and evaluate a simulation model [18]. Example of the above include understanding the changing levels of uncertainty in emerging design [19], estimating which uncertain parameters are most relevant [20], proposing strategies to design and simulate production systems with imperfectly defined information [21], and communicating SBO results in conditions of high uncertainty [22]. This change of perspective is not contrary to consideration of uncertainty as the implicit variation of a system, its environment or inaccuracies due to a lack of knowledge [23].

In agreement with this, two circumstances underpin the importance of conceptual models for SBO facility layout design in relation to uncertainty. First, empirical evidence shows that the restrictions set forth in a conceptual model constrain the range of values or types of models in the analysis of uncertainty [8]. Second, extant literature describes the conceptual model as the point of origin for the abstraction of a real or proposed systems and the place of return for the continuous iterations of a model to reach an increased level of understanding during SBO analysis [24, 25]. Table 2 describes the activities that define the content and function of a conceptual model according to Robinson [26].

Table 2. Conceptual model activities

Activities	Description
Understand the problem situation	Definition of the need to improve a problem situation
Determine the modeling objectives	Purpose expressed in terms of achievement, performance and constraints
Identify the model output	Model responses
Identify the model input	Experimental factors. Data changes to achieve objective
Determine model scope	Model boundaries in terms of entities, activities, queues and resources
Establish level of detail	Specification of entities, activities, queues and resources
Formulate assumptions	Beliefs about real world being modeled
Single out simplifications	Essential information for rapid model development

2.3. Simulation-based Optimization in facility layout design

Facility layout design is a well-researched area that investigates the disposition of entities needed to produce goods or deliver services [1]. Studies by Azadivar and Wang [27], Heilala et al. [28], and Tempelmeier [29] evidence the frequent use of SBO for facility layout design. The incidence of SBO in facility layout design is explained because of the suitability of this technique in the analysis of process improvements for complex systems with high variability [30, 31].

Facility layout design does not lend itself to being framed into a "one-size-fits-all" procedure, and consequently the field present a broad set of SBO methodologies. This is exemplified by Moslemipour et al (2012) who present a review of intelligent approaches for designing dynamic and robust layout in flexible manufacturing systems and show a hybrid approach combining simulation and generic algorithms [32]. Also, Yang and Hung [33] review multiple-attribute decision making (MADM) methods for the plant layout design problem, and describe a MADM method considering both qualitative and quantitative design criteria.

Literature prescribes that in the introduction of new or improved processes, manufacturing companies should set objectives, conceive abstract solutions, assign details, and evaluate a production system under design, facility layout included, in an organized process [34]. This requires a trade-off analysis between the characterization of all elements in production and the form and function of a facility layout [35]. Emerging from studies focused on the characterization of production, five criteria guide the design of a facility layout: strategic objectives or high-level goals pursued by a manufacturing organization, products to be produced, market in the form of production volumes, production processes or the series of steps and resources necessary to produce a product, and the interrelation of decision in facility layout design where the criteria above are considered holistically [36-39]. The process by which facility layouts design is carried out and the criteria that play a role in this process are shown in Figure 1.

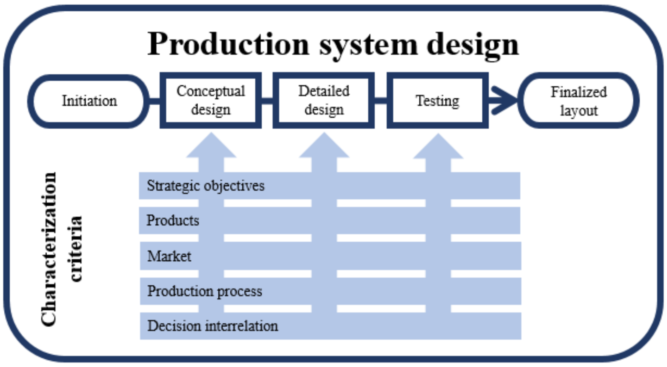

Fig. 1. Production system design process and characterization criteria including facility layout design.

3. Method

To meet the aim of this paper, a case study method was selected [40]. This decision is explained by the need to understand the changes in the subject of study, conceptual modeling activities of SBO, in a real-world context over which the researchers had no control, facility layout design [40]. This choice of method was considered important to investigate the linkage between the subject of study and circumstances upon which this took place [41], specifically the relation between conceptual modeling activities of SBO and conditions of high uncertainty.

Three cases in two manufacturing companies were considered. The cases were selected based on five criteria: first, manufacturing companies who designed a facility layout because new or substantially improved production processes were introduced; second, use of SBO in facility layout design; third, unknown outcome of form for facility layout at the start of design; fourth, a visible need from decision makers to acquire additional information during design because of incomplete information or entirely unknown facts. Finally, the companies in this study were chosen because of their experience in the development of process changes in production systems and their strong interest in the implementation of new operational processes to increase competitiveness. These characteristics of the cases are summarized in Table 3.

Data was collected during the different phases of the case studies between 2014 and 2016. This focused on design activities, hence forth referred to as data, which lead to the development of a SBO model for facility layout design and included company documents, participant observations, and simulation model documentation including conceptual models.

To provide an analysis, data were labelled based on the characterization criteria of strategic objectives, products, market, production process, and decision interrelation. Additionally, data was also labelled in relation to the targeted conceptual modeling activities of problem definition, modeling objectives, model outputs and inputs, scope, level of detail, assumptions and simplifications. This provided a link between characterization criteria and conceptual modeling activities.

Table 3. Description of cases

	Case A	Case B	Case C
Product type	Heavy vehicles	Vehicle cabins	Water pumps
Objective of change	Multi-product assembly system	Multi-product assembly system	Multi-product assembly system
Process innovation type	New production process	New production process	New production process
Expected benefits	Shorten lead time to customer, reduce manufacturing footprint, provide a common product architecture, increase flexibility	Shorten lead time to customer, reduce manufacturing footprint, provide a common product architecture, increase flexibility	Shorten lead time to customer, provide a common product architecture, increase flexibility
Design time	24 months	12 months	8 months

Afterwards, the analysis concentrated on understanding the level of uncertainty in conceptual models supporting the facility layout design in each case based on the classification as presented in Table 1. This was achieved by examining the agreement in conceptual modeling activities and information increase in conceptual model development during the process of facility layout design. Then, the point in time during the project for the development of SBO conceptual models for facility layout design within each case was established. Because each case differed in the labelling of stages for the design of facility layout, the analysis was framed in relation to stages of initiation, conceptual design, detailed design, and testing in facility layout design according to the academic description of each stage and not on whether these stages were strictly followed within a case. Cases were first analyzed separately. This was followed by a cross case analysis to increase generalizability, deepen understanding, and strengthen data analysis [42].

4. Empirical findings

4.1. Description of cases

The first company, from which Case A and Case B are drawn, specializes in the design and production of heavy vehicles and their components. This company has 12 manufacturing sites and 14,000 employees around the world. The second company develops and manufactures products for the transportation and analysis of water. This company has over 1,200 employees at its Swedish site where Case C took place. Processes considered in the different production layout were manually performed.

The objective of Case A was to design a multi-product assembly system of heavy vehicles that would increase the competitiveness of a manufacturing site in America. This required that five existing independently assembled product families ranging in weight between 5 and 56 tons with differences in size, sub assembly parts, product design, assembly procedure, and capabilities be produced in the same assembly system. Facility layout design was considered a decisive step to enable these changes and five SBO models were developed.

Parallel to and independent from Case A, Case B pursued similar objectives yet focused on the assembly of vehicle cabins at a Swedish manufacturing site. Case B required that three existing and independently assembled vehicle cabins with over 600 variants be assembled in the same assembly system. Facility layout design was supported by the development of two SBO models in Case B.

Case C was developed as a final year project in production engineering as part of an ambitious long-term transformation plan at a Swedish factory to meet demand in coming years [43]. This included the design of different concept layouts focused on increased assembly efficiency, a safe work environment, and improved use of factory space. Case C concentrated on the development of a multi-product assembly system that could cope with the assembly of 300 different product variants currently assembled in two assembly systems. This was achieved using two SBO models for facility layout design. To clarify the type of layout in focus of this research, Figure 2 shows a simplified facility layout used in the simulation models in Case C, compound by several manual stations and material façade on the sides to manufacture water pumps.

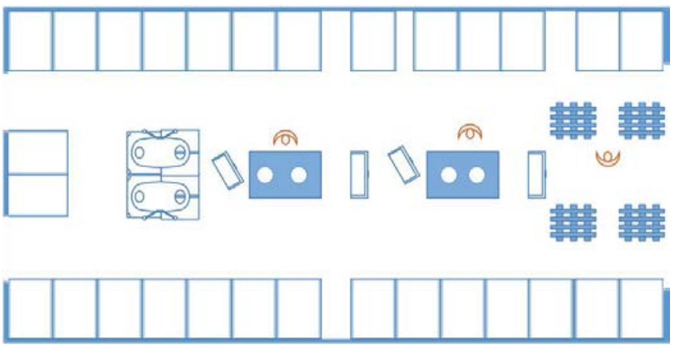

Fig. 2. Layout design of multi-product assembly system in Case C.

4.2. Process innovation uncertainty in facility layout design

Empirical data show that facility layout design was non-intuitive and required continuous investigation of characterization criteria including strategic objectives, product, market, production process, and decision interrelation. The extent of this challenge is underscored by the uncertainty levels affecting characterization criteria during the initiation, concept, detail, and test phases described in Table 4. Uncertainty about each criterion was defined as follows. Uncertainty about strategic objectives concerns a lack of agreement and information about the aim and concept of multi-product assembly and the quantification of operational benefits. Uncertainty in products and markets involves the insufficiency of agreement about the selection of products and of information concerning the effects of product demand changes in the assembly system. Production process uncertainty relates to a dearth of agreement and information about the process of assembly, organization of operators, tools, material supply and logistics, and safety requirements. Uncertainty in decision interrelation refers to the absence of agreement and information in relation to the trade-off between the criteria above and the designed facility layout. The level of uncertainty describes how uncertainty was perceived within each case for each of the above criteria ranging from true ambiguity to a clear enough future as previously described in the frame of reference.

Table 4. Level of uncertainty in characterization criteria for facility layout design

	Case A				Case B				Case C			
	Design phases				Design phases				Design phases			
Criteria	Initiation	Concept	Detail	Test	Initiation	Concept	Detail	Test	Initiation	Concept	Detail	Test
Strategic objectives	2	1	1	1	2	1	1	1	3	1	1	1
Product	4	2	1	1	2	1	1	1	2	1	1	1
Market	3	3	1	1	2	1	1	1	3	2	2	2
Production process	4	3	2	1	4	2	2	2	4	3	2	1
Layout	4	3	2	1	3	1	1	1	4	2	1	1
Decision interrelation	4	3	3	2	4	3	3	2	4	3	2	2
Conceptual model development		√	√	√		√	√			√	√	

Uncertainty measurement
4 = true ambiguity
3 = a range of possible futures
2 = alternate futures
1 = a clear enough future

4.3. Conceptual modeling activities in SBO of facility layout design

Empirical evidence shows the conceptual modeling activities in SBO of facility layout design. These findings trace the incidence of characterization criteria of facility layout design in Cases A, B, and C and are presented in Table 5.

Conceptual modeling activities were initiated by the definition of a problem which included the need to design a facility layout where new organizational processes were introduced in the form of multi-product assembly systems. Data show that within each case, models pursued independent objectives that led to the design of a facility layout. Also, model objectives described the approach taken to facility layout design. For instance, Case A included five different conceptual models with the objectives of layout selection, detailing, refinement, improvement, and preparation for implementation. In Case B the objective of the first model was to assess a proposed layout and the objective of the second was to refine this proposal. Case C included two conceptual models, the objective of the first was to assess a proposed layout and the objective of the second was to compare the current layout to the proposed one.

The validation process of the simulation models was performed regarding the throughput and processing times in each case study. Model outputs were described by the strategic objectives of each Case and were specified through the units produced, product lead time, utilization of assembly stations, and the visualization of material flow. Model inputs were determined by characterization criteria of product and market that established the product type and changes in demand over the period over which the model was evaluated. Additionally, model inputs of assembly operation sequence, assignment of resources in the form of operators, and disturbances to the assembly process were specified by the characterization criteria of production process. The scope of each model included the boundaries of layout design as well as the entities, activities, queues, and resources defined by the interrelation of decisions where strategic objectives, products, market, and production process were considered holistically. The detail of a conceptual model closely followed the level of uncertainty in the form of the lack of information about the characterization criteria for the designed facility layout. Initially, details about the layout included a range of possible characteristics lying anywhere along a continuum of loosely based information. In its final form, details were precise enough and sufficiently narrow to point to a full layout description. Model assumptions related to the amount of information about strategic objectives, products, markets, production processes, and decision interrelation. Conceptual models incurred in assumptions in the absence of information. While model simplifications did not relate to the amount of information but the agreement about the type of information considered basic to achieve the objective of a model.

Table 5. Conceptual modeling activities and characterization criteria for facility layout design

Conceptual model activity	Characterization Criteria Case A	Case B	Case C
Objective	Layout selection, detailing, refinement, improvement, preparation	Layout assessment, layout refinement	Layout assessment, layout comparison
Model output	Strategic objectives 1. Units produced 2. Lead time 3. Utilization 4. Visualization	Strategic objectives 1. Units produced 2. Lead time 3. Operator quantity	Strategic objectives 1. Units produced 2. Lead time 3. Operator quantity 4. Visualization
Model input	Product, production process, market 1. Assembly times 2. Products 3. Demand 4. Operation sequence 5. Disturbances 6. Operators	Product, production process, market 1. Assembly times 2. Products 3. Demand 4. Operation sequence 5. Disturbances	Product, production process, market 1. Assembly times 2. Products 3. Demand 4. Initial layout
Model scope	Decision interrelation	Decision interrelation	Decision interrelation
Detail level	Information amount of characterization criteria	Information amount of characterization criteria	Information amount of characterization criteria
Assumption	Information amount of characterization criteria	Information amount of characterization criteria	Information amount of characterization criteria
Simplification	Agreement on information type	Agreement on information type	Agreement on information type

5. Analysis

Our results provide new insight that can help understand the conceptual modeling activities of SBO for facility layout design in conditions of high uncertainty. Firstly, case findings show that in conditions of high uncertainty, conceptual modeling activities for facility layout design are determined by the characterization criteria and the amount and agreement of information. Thus, the characterization criteria of strategic objectives, products, market, production processes, and decision interrelation, specify the conceptual model activities of model output, input, and scope. Also, uncertainty level in the form of information amount about characterization criteria specify the level of detail and assumptions of a conceptual model. While the agreement about the type of information considered basic to achieve the objective of a model determine the simplifications incurred in the conceptual model.

Secondly, our findings show that conceptual model development of SBO for facility layout design requires transferring from a level of higher to lower uncertainty before conceptual model start. To do so, design work should include agreement about what constitutes the strategic objectives, products, markets, and decision interrelation in facility layout changes. This is followed by the acquisition of information that takes ambiguity in strategic objectives, products, markets, and decision interrelation to a level where these are neither unknowable nor entirely unknown.

6. Conclusions and future work

This paper aims to understand the conceptual modeling activities of SBO for facility layout design in conditions of high uncertainty. This was underpinned by the following research question: How do uncertainties in process innovation affect the conceptual modeling of SBO in facility layout design?

This paper showed that uncertainty in the layout design process of production systems is a considerable challenge. In this paper an analysis of the different levels of uncertainty in SBO shop-floor layout design projects, combined with a selection of relevant criteria considered during the different design phases of every case study is presented. Additionally, characterization criteria for facility layout design in conceptual modeling activities are analyzed for the three case studies.

Managerial implications of this study help identify when to use SBO for facility layout design and what criteria matter to achieve this end when dealing with conditions of high uncertainty. Taking into consideration the lack of information in layout design projects and in its support with SBO, results of this study may benefit the administration of production system layout projects and the allocation of resources. The results of this study may be used in a context of novel production process affecting facility layout design that look to increase manufacturing competitiveness.

An immediate next step would include generalization of results beyond the scope. Thus, future work could determine whether the identified characterization criteria are necessary, sufficient, and exhaustive in conditions other than those of process innovation projects. Future research could also provide a solid guideline or methodology for the reduction of uncertainty in production layout design.

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References

[1] Drira, A., H. Pierreval, and S. Hajri-Gabouj, Facility layout problems: A survey. Annual Reviews in Control, 2007. 31(2): p. 255-267.
[2] O'Connor, G.C. and M.P. Rice, A Comprehensive Model of Uncertainty Associated with Radical Innovation. Journal of Product Innovation Management, 2013. 30: p. 2-18.
[3] Kulturel-Konak, S., Approaches to uncertainties in facility layout problems: Perspectives at the beginning of the 21st Century. Journal of Intelligent Manufacturing, 2007. 18(2): p. 273-284.
[4] Frishammar, J., H. Florén, and J. Wincent, Beyond managing uncertainty: Insights from studying equivocality in the fuzzy front end of product and process innovation projects. Engineering Management, IEEE Transactions on, 2011. 58(3): p. 551-563.
[5] Javahernia, A. and F. Sunmola, A simulation approach to innovation deployment readiness assessment in manufacturing. Production & Manufacturing Research, 2017. 5(1): p. 81-89.
[6] Piening, E.P. and T.O. Salge, Understanding the Antecedents, Contingencies, and Performance Implications of Process Innovation: A Dynamic Capabilities Perspective. Journal of Product Innovation Management, 2015. 32(1): p. 80-97.
[7] Reichstein, T. and A. Salter, Investigating the sources of process innovation among UK manufacturing firms. Industrial and Corporate Change, 2006. 15(4): p. 653-682.
[8] Jalonen, H., The uncertainty of innovation: a systematic review of the literature. Journal of Management Research, 2011. 4(1).
[9] Tatikonda, M.V. and M.M. Montoya-Weiss, Integrating Operations and Marketing Perspectives of Product Innovation: The Influence of Organizational Process Factors and Capabilities on Development Performance. Management Science, 2001. 47(1): p. 151-172.
[10] Daft, R.L. and R.H. Lengel, Organizational Information Requirements, Media Richness and Structural Design. Management Science, 1986. 32(5): p. 554-571.
[11] de Weck Olivier, E.C.M. and C.P. John, A classification of uncertainty for early product and system design. Guidelines for a Decision Support Method Adapted to NPD Processes, 2007.
[12] Courtney, H., Decision ‐ driven scenarios for assessing four levels of uncertainty. Strategy & Leadership, 2003. 31(1): p. 14-22.
[13] Gaubinger, K., et al., Innovation and Product Management A Holistic and Practical Approach to Uncertainty Reduction. Springer Texts in Business and Economics. 2014, Berlin, Heidelberg: Springer.
[14] Galbraith, J.R., Designing complex organizations. 1973, Reading, MA: Addison-Wesley Longman Publishing Co., Inc.
[15] Frishammar, J., U. Lichtenthaler, and A. Richtnér, Managing process development: key issues and dimensions in the front end. R&D Management, 2013. 43(3): p. 213-226.
[16] Parida, V., et al., Managing the front-end phase of process innovation under conditions of high uncertainty. Quality & Quantity, 2016: p. 1-18.
[17] Medyna, G., et al., Modelling, evaluation and simulation during the early design stages: Toward the development of an approach limiting the need for specific knowledge. Journal of Integrated Design and Process Science, 2012. 16(3): p. 111-131.
[18] Wynn, D.C., K. Grebici, and P.J. Clarkson, Modelling the evolution of uncertainty levels during design. International Journal on Interactive Design and Manufacturing (IJIDeM), 2011. 5(3): p. 187.
[19] Kleijnen, J.P., H. Pierreval, and J. Zhang, Methodology for determining the acceptability of system designs in uncertain environments. European Journal of Operational Research, 2011. 209(2): p. 176-183.
[20] Gien, D. and S. Jacqmart, Design and simulation of manufacturing systems facing imperfectly defined information. Simulation Modelling Practice and Theory, 2005. 13(6): p. 465-485.
[21] Haveman, S.P. and G.M. Bonnema, Communication of simulation and modelling activities in early systems engineering. Procedia computer science, 2015. 44: p. 305-314.
[22] Kiureghian, A.D. and O. Ditlevsen, Aleatory or epistemic? Does it matter? Structural Safety, 2009. 31(2): p. 105-112.
[23] Oberkampf, W.L., et al., Error and uncertainty in modeling and simulation. Reliability Engineering & System Safety, 2002. 75(3): p. 333-357.
[24] Robinson, S., Conceptual modelling for simulation Part I: definition and requirements. Journal of the Operational Research Society, 2008. 59(3): p. 278-290.
[25] Robertson, N. and T. Perera, Automated data collection for simulation? Simulation Practice and Theory, 2002. 9(6–8): p. 349-364.
[26] Robinson, S., Conceptual Modelling for Simulation Part II: A Framework for Conceptual Modelling. The Journal of the Operational Research Society, 2008. 59(3): p. 291-304.
[27] Azadivar, F. and J. Wang, Facility layout optimization using simulation and genetic algorithms. International Journal of Production Research, 2000. 38(17): p. 4369-4383.
[28] Heilala, J., et al. Modeling and simulation for customer driven manufacturing system design and operations planning. in 2007 Winter Simulation Conference. 2007.
[29] Tempelmeier, H., Practical considerations in the optimization of flow production systems. International Journal of Production Research, 2003: p. 149-170.
[30] Ng, A., J. Svensson, and M. Urenda, Introducing Simulation-based Optimization for Production Systems. Design to Industry: the FACTS Game. 2008.
[31] Ramis, F.J., L. Neriz, and J.A. Sepulveda. A simulator to improve waiting times at a medical imaging center. in Winter Simulation Conference. 2008. Concepción, Chile: Universidad del Bio-Bio, Departamento de Ingeniería Industrial.
[32] 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): p. 11-27.
[33] 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.
[34] Bellgran, M. and K. Säfsten, Production Development: Design and Operation of Production Systems. 2010, New York, NY: Springer Science & Business Media.
[35] Skinner, W., Manufacturing – Missing link in corporate strategy. Harvard Business Review, 1969. 47(3): p. 136-145.
[36] Machuca, J.A.D., et al., Do technology and manufacturing strategy links enhance operational performance? Empirical research in the auto supplier sector. International Journal of Production Economics, 2011. 133(2): p. 541-550.
[37] Choudhari, S.C., G.K. Adil, and U. Ananthakumar, Congruence of manufacturing decision areas in a production system: a research framework. International Journal of Production Research, 2010. 48(20): p. 5963-5989.
[38] da Silveira, G.J.C., Market priorities, manufacturing configuration, and business performance: an empirical analysis of the order-winners framework. Journal of Operations Management, 2005. 23(6): p. 662-675.
[39] Boyer, K.K. and M.W. Lewis, Competitive priorities investigating the need for trade-offs in operations strategy. Production and Operations Management, 2002. 11(1): p. 9-20.
[40] Yin, R.K., Case Study Research: Design and Methods. 2013, Thousand Oaks, CA: SAGE.
[41] Voss, C., N. Tsikriktsis, and M. Frohlich, Case research in operations management. International Journal of Operations & Production Management, 2002. 22(2): p. 195-219.
[42] Miles, M.B., A.M. Huberman, and J. Saldaña, Qualitative data analysis: A methods sourcebook. 2013, Thousand Oaks, CA: SAGE.
[43] Gustavsson, I.B., Eldin Konceptuell robust design av monteringslinje med hög produktmix. 2016, University of Skövde.