Consideration of Legacy Structures Enabling a Double Helix Development of Production Systems and Products

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Abstract Based on an increasing need of life cycle perspectives in product and production development, there is a call for more effective working methods for the reconfiguration, rearrangement, retro-fit and reuse of current equipment, systems and processes within production systems. This chapter discusses the need and character of such methods based on current research and industrial practice in production system design and development. A concluded development process is illustrated by a double helix development cycle for the production system and the product. The traditional life cycle illustration of product and production system design is in this case altered to a double helix where the same design phases of requirement analysis, alternative synthesis and alternative analysis reoccur for each project phase of conceptual design, detailed design, validation and industrialization/running-in, but for each development cycle on an elaborated level.

1 Introduction

The increasing consideration for products and production system life cycles and need for drastic increased resource efficiency in manufacturing—doing more by using less non-renewable resources—becomes clear as data on economic activity in manufacturing is presented as in Fig. 1. A number of countries show a tremendous growth in manufacturing activity. Also on a global scale manufacturing activities is increasing. During a recent decade (2001–2010), the global economic activity within manufacturing has increased by 34.7 % in constant prices over the period, while the global gross national product (GDP) has increased by 'only' 26.0 % (UN Stats 2012).

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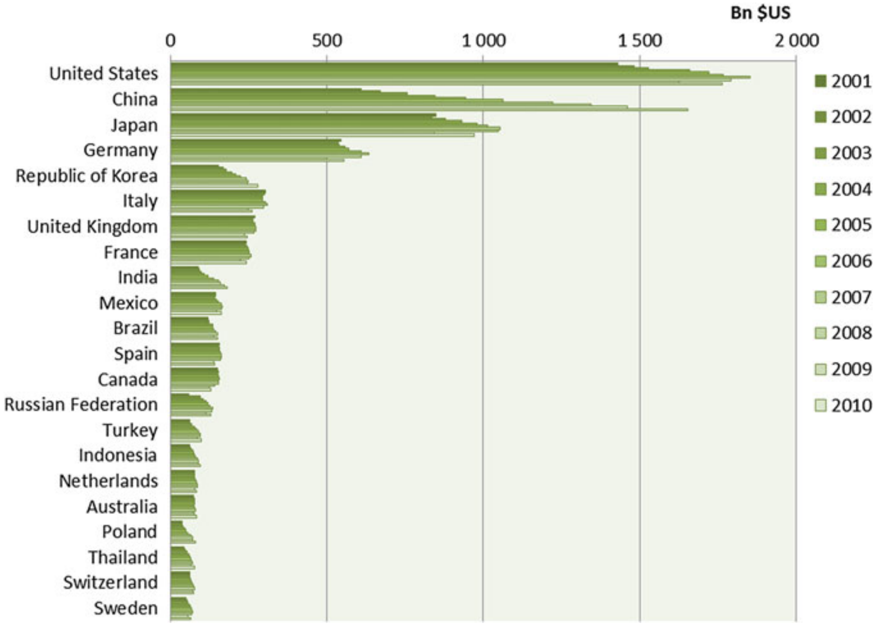

Fig. 1 Economic activity within manufacturing in constant 2005 US dollars for the top 22 countries. From year 2001 (top within each country) to year 2010 (bottom within each country). Data from UN Stats (2012)

Meanwhile, the climate change and need for absolute decrease of for instance greenhouse gases has been witnessed by numerous researchers and agreed to by governments and authorities. As industrial activities contribute to significant environmental impact, the rapid increase of manufacturing activity call for the urgent actions for resource efficiency and life cycle perspectives in product and production development.

In the light of resource efficiency and frequent product changes there is a call for effective working methods for the reconfiguration, rearrangement, retro-fit and reuse of current equipment, systems and processes. The objective of this chapter is to introduce the concept of the double helix development of production system and products, enabled by the effective consideration of legacy structures during the production system redesign and product introduction. Based on a study of industrial practice on production development processes is an elaborated production system design process presented, including redesign elements.

2 Production System Design

The research area of production system design is inherently dependent on the close interaction between academics and practitioners. State-of-the-art knowledge is created in a complex pattern of requirements, prerequisites, methodologies, empirics, implementation and deployment. The state of art can thus only be described by covering both research- as well as practitioner-based knowledge fields.

A well-established field of knowledge within production concerns implementation theories for corporate improvement initiatives with an *operational* focus, such as TPM, TQM, Six Sigma, Lean etc., represented by e.g. Ohno (1998), Liker (2004), Womack and Jones (1996). The lean production paradigm is established by theories, instruments, ontologies, values and metaphysical assumptions that are implemented in the competences, tools, methods and processes within the industry of today, as illustrated to the right in Fig. 2.

The field of knowledge concerning production system *design* have gained momentum ever since Skinner (1969) pointed out the design of the production system as a key to success by: *"what appears to be routine manufacturing decisions frequently come to limit the corporation's strategic options, binding it with facilities, equipment, personnel, basic controls and policies to a non-competitive posture, which may take years to turn around."* Throughout the recent decades, competences, tools, methods and processes required to design and realize the lean production system have been described, represented by the left box in Fig. 2.

The two areas of knowledge illustrated in the figure are of course closely interlinked by feeding experience, knowledge and data from operations to design, and feeding decisions, plans and guidelines from design to operations.

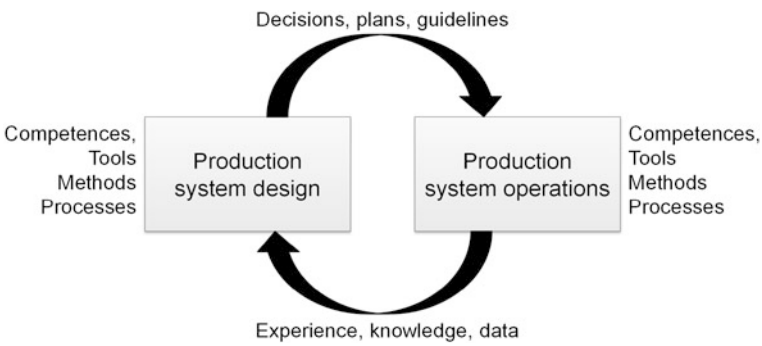

Fig. 2 Illustrating the dual and interacting activities of production system design and production system operations

2.1 The Design Structure of Analysis and Synthesis

In order to understand the requirements on a production system design process, the specifics of a design process need to be addressed. Many are the researchers who have tried to characterise and structure design—the activity aimed *"at changing existing situations into preferred ones"*, as put by Simon (1981). The design process is often described as including both phases of intuitive creativity as well as rational phases of calculation and evaluation (e.g. Rosell 1990). These two parts of the design process—the creative and analytic viewpoints—seems to separate more and more as the technical complexity increases and specialists tend to play a more important role in the design process. This impedes the development of good design, since both the analytic and creative parts are needed in the design process and it is often in the meeting of these two competencies that a successful design is made.

A general model of the events in an engineering design process is the steps of (problem) analysis, (solution) synthesis and (solution) evaluation, presented in the general ASE model by for instance Braha and Maimon (1997) linking back to Jones (1970) and Asimow (1962). However, although the rhetorical value of such a description, there is a risk of giving the impression of the design process as a linear, predictable and rational process. Instead the design process might be described as a cyclic process where an analysis of the problem—a synthesis of solutions—an evaluation of solutions leads to a new analysis of the problem with knowledge given from the first evaluation and so on. Suh (1990) described the interaction between the solution synthesis (by Suh named synthesis capability) and the solution evaluation (by Suh named analytical ability) as a feedback control loop improving and detailing the design.

2.2 Examples on Production System Design Schemes

Different research traditions have contributed to the current state of knowledge concerning production system design. The holistic and competence perspective on production system design is pointed out by e.g. Bruch and Bellgran (2012) referring to the textbook by Love (1996). The strategic fit of the production system is discussed by e.g. Hayes and Wheelwright (1979) introducing the product-process matrix in order to choose production system lay-out according to product and process life cycle stage. From an industrial engineering perspective, the textbooks by Bennett (1986) and Bennett and Forrester (1993) are examples supporting the manufacturing engineer and management on technology selection and designing the physical system. System modelling has also been an inspiration, such as the IDEF0 based method by for example Wu (2001), but also the stage-gate model (from Robert S. Cooper) developed further by e.g. Blanchard and Fabrycky (1998), Rau and Gu (1997), and Wu (1994). The system approach is taken on the production system problem by Seliger, Viehweger et al. (1987) and Bellgran and

Säfsten (2010), as well as in the work by Wiktorsson (2000) focusing the evaluation of production systems and linking to tools for performance and behavioural validation. Also the design information in the production system design process is in focus, as by Bruch and Bellgran (2012) and requirement specification by Wiktorsson et al. (2000).

2.3 The Increasing Need of Considering Legacy Structures

The research based methods described earlier, are in most cases based on a clean-sheet design process. However, production design situation ranges from a total 'green field'/full investment situation, to a redesign; rearranging and reusing existing equipment and facilities. The most common situation encompasses both aspects; new investment as well as redesign.

The increasing need for changing and adapting the production system to the ever changing requirements drives a development towards (1) more adaptive and responsive production systems and technologies, (2) more effective working methods for the rearrangement and reuse of current equipment, systems and processes. Within the first, the integration of legacy is handled by reconfigurable platforms/modular based engineering approaches that enables the reuse of legacy structures, discussed by e.g. Bi et al. (2008), El Maraghy (2006) and Rogers and Bottaci (1997). In the second case, the integration of legacy concerns the specific production design and procurement processes, enabling the record and reuse of legacy structures.

As mentioned, the earlier works on production system design have not especially focused on the aspect of production system *re*design, where the reuse of existing equipment and facilities are of specific interest. In work by Andrew (1991) and Tobias (1991) more general key issues which determine success or failure for a redesign of a manufacturing system are discussed. The issues pointed out by Andrew (1991) include the composition of project teams, manufacturing strategy, system design, manufacturing control systems, human issues and implementation. Also the textbook 'Manufacturing Systems Redesign' by O'Sullivan (1994) discusses the subject but presents a more general structure for the design of manufacturing systems. In fact, as current academic and industrial production design processes are in most cases derivatives of product development processes, not pinpointing legacy equipment and structures, an elaborated design process is needed including redesign elements, to ensure adaptability and sustainability.

3 A Case Study Illustrating Industrial Practice

The dominant way to organize a development process from an industrial perspective is by a stage-gate model with a supporting project management infrastructure. A large number of production development processes with a stage-gate procedure are in use, often within the context of a more general product realization and development process.

The documentation and influence of legacy structures is closely linked to the acquiring, sharing and use of information during the production system design process. One example on information aspects of the production system design process is the industrial case study by Bruch and Bellgran (2012) focusing the factors facilitating the information sharing during this process. In the study it is concluded that sharing of information is promoted by formalization and the study provides strong evidence for the importance of sharing information during a design process in a more sophisticated manner.

One industrial case study more specifically contributing to the empirical basis for this chapter was conducted at a Swedish automotive manufacturer. The company's product industrialization and production procurement processes were studied, as these two processes were the ones corresponding to the production system design, as described by Netz and Wiktorsson (2009). It was concluded that the current formal processes are to a large extend based on an investment or green field situation. The management of legacy structures and information retrieval was studied in order to synthesize into an elaborated design structure for focusing the production system, but in a context of new product introduction and life cycle considerations.

This procurement process for investment projects and the gates are closely related to the gates in the formal purchasing order document currently used by the company. This process was grouped into six stages and nine phases as presented in Fig. 3.

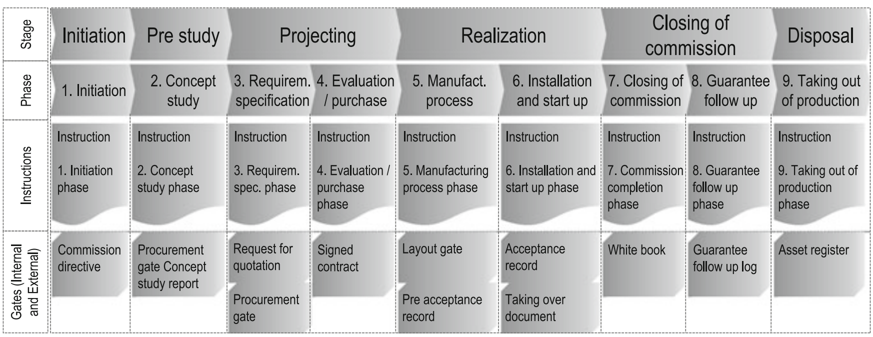

Fig. 3 The procurement process for production equipment, as used by the case company

By studying this production equipment procurement process and interviewing project members, it is concluded that the gates suitable for investment projects are not optimal for redesign projects. In a redesign there are no purchasing orders to refer to at the internal gates. Also there are important aspects in redesign project which are not emphasised in investment projects, such as in detail considering the down-time during the redesign and rearrangement. The authors conclude that there is an industrial need to formulate state-gates which could be used also for cases including legacy equipment and processes.

To conclude, by engagement and studies of product introduction projects and production system development processes, it is concluded that the observed industrial processes for production or assembly system design are realized in three forms:

- production system design considered as a sub-task in an overarching product development and industrialization process,
- production system design handled by a general project management process, not specifically addressing the challenges and characteristics of this open, complex and multidimensional system design,
- production system design handled from an equipment procurement perspective, concerning the specific elements with need of investments.

In neither of the observed industrial cases are the specific characteristics from considering legacy within a system redesign identified, and there is a potential in further formalizing the specification and information of legacy structures during the design process.

4 The Double Helix Development Cycle for Production and Product

Concluding from the brief overview of production system design schemes and industrial practice, two key characteristics of a production system development process, previously not explicitly described in production system design literature and in studied practice are:

- The design based structure of analysis and synthesis in form of three generic and iterative phases: requirement analysis, alternative synthesis and alternative analysis.
- Handling of legacy structures by a formalised specification used during the development refinement.

As these two aspects are considered, a schematically described double helix development cycle for production and product emerges, as illustrated in Fig. 4.

The traditional life cycle illustration of product and production system design is in this case altered to a double helix where the same design phases of requirement

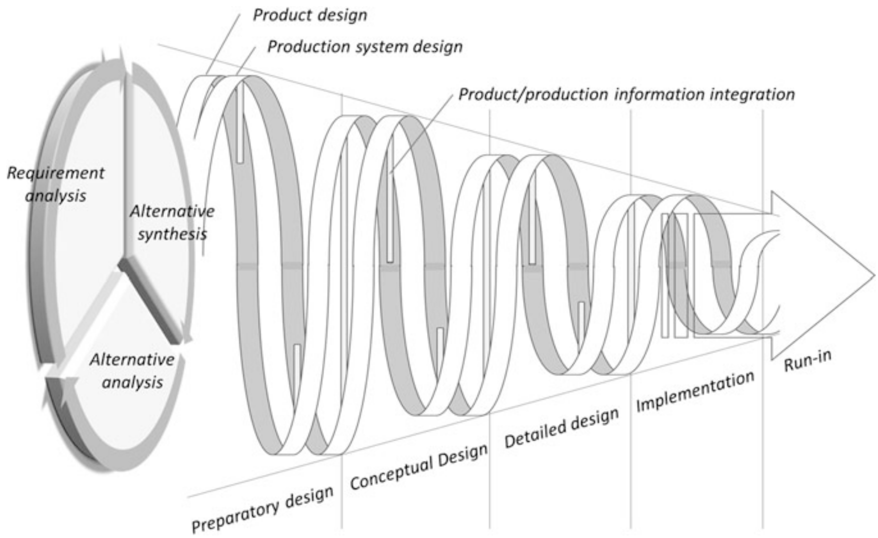

Fig. 4 The double helix development process for production system and product

analysis, alternative synthesis and alternative analysis reoccur for each project phase of conceptual design, detailed design, validation and industrialization/running-in, but for each development cycle on an elaborated level. For an efficient and goal oriented production system design helix, the synchronization with the product design helix is vital, illustrated in the double helix model by the information links between the product and production development helixes. In order to gain two harmonized, resource efficient and effective development helixes, the product and process information (the linking 'nucleobases' of this double helix) are keys, as well as the management of legacy structures.

4.1 Towards a Formal Consideration of Legacy Structures

It is concluded that from both a research perspective as well as an industrial perspective, processes and methods for production system *re*design with a focused handling of legacy in production systems are not explicitly described. The current academic and industrial production design processes are in many cases derivatives of product development processes. These process plans do not pinpoint legacy equipment and structures, since this is not in general a vital part within product development. Neither production procurement processes do for natural reasons focus on legacy infrastructure—when investing in new equipment, other aspects are more essential than considering current equipment. Production system design processes are in many cases focused on the specific details in the system that needs renewal or modification, not the entire system characteristics or architecture including legacy structures.

The consideration of legacy structures is however an established format within e.g. IT management, where a common situation is to migrate from a current situation to a new system design where current solutions are to be reused. Procedures, information formats and processes have been developed within this field. Typical solutions in this respect include discarding the legacy system and building a virtual replacement system; freezing the system and using it as a component of a new larger system; and modifying the system to give it new functionality (Lucia et al. 2008; Wang et al. 2007).

The consideration and potential reuse of legacy production structures is in the presented double helix process proposed to be solved by a formal requirement and constraint structure, to be detailed in the early design phases and used throughout the production system design helix. This phase of specification implies defining and structuring terms such as prerequisites, constraints, requirements, goals, objectives, wishes, wants, demands, musts and needs, all being internal or external. By comparison with the formulation of a traditional linear optimisation problem, the concept of constraints as a language for legacy structures is introduced by e.g. Wiktorsson et al. (2000). The requirements of the redesign are on each system level, as the iterative process proceeds, described by the four elements in the requirement analysis:

- Functional requirements: musts on performance
- Internal design constraints: musts on design solutions due to internal reasons
- External design constraints: musts on design solutions due to external reasons
- Winning criteria: wants on capabilities.

This four-element-framework is based on, encouraging and using the wide range among the criteria; from absolute musts on the system to interesting aspects to know of; from general functions to fulfil to detailed design solutions to use.

The legacy structures to be documented and considered during the development process are to be covered within the element "internal design constraints" within the framework. These constraints help the designer throughout the design by limiting the possible options.

4.2 Operationalizing the Double Helix Framework

From the conceptually described double helix development process, it is not obvious how to implement it in practice. Figure 5 illustrates an effort in clarifying the production system design process in terms of tools and phases in order to realise the concept of considering legacy structures and enabling a double helix development of production systems and products. The three design phases of analysis—synthesis—analysis, is realised by tools such as:

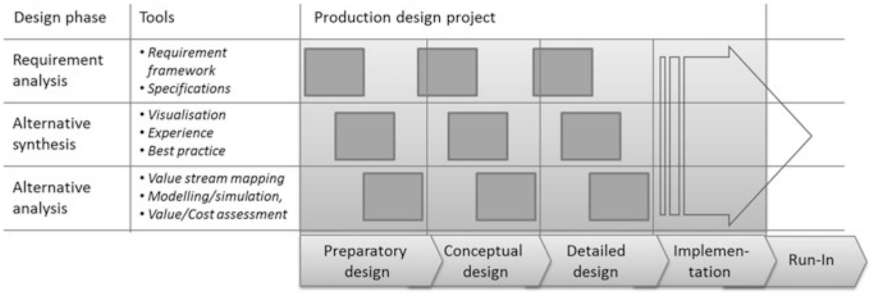

Fig. 5 Operationalizing the double helix framework into a production system design process scheme

- the requirement framework with the concept of legacy constraints for the phase of Requirement analysis,
- visualization, best practice and creativity tools for the phase of Alternative synthesis,
- evaluation, assessment and validation tools such as value stream mapping, simulation and modelling, value/cost assessment and business case models for the phase of Alternative analysis.

These three phases of design and their corresponding tools are linked to a production system design process with the classic phases within a stage-gate model from preparatory design to implementation and run-in, as illustrated in Fig. 5.

Such an implementation of the double helix model should approach the two identified weaknesses of current academic and industrial design models: the design aspects of analysis and synthesis as well as the handling of legacy structures.

By extending this operationalization to the earlier described case company, it is clear that the current development process focus on the stage-gates of the development. It describes *what* to accomplish, not *how* to accomplish it. The three design aspects could be included in a stage-gate process, similar to the one in Fig. 3 in a natural way, by specifying templates, methods and frameworks that supports the inherent design logic. By adding a helix structure of a structured iteration between requirement analysis, alternative synthesis and alternative analysis, as well as guiding instruments/tools to use during the three phases, the design logic is built into the process and the development team. In addition, the case illustrated the challenge in considering the legacy structures of manufacturing during a production development process. This is supported by adding e.g. a formal requirement and constraint structure, guidance and best practice for retro-fit of equipment, stage-gates for the redesign and rearrangement, and analysis tools for redesigned production facilities. Another example is the three industrial examples of the formal requirement and constraint structure given by Wiktorsson et al. (2000) illustrating the improvement potentials in describing objectives and legacy during development processes.

The double helix illustration of the development process emphasises the close interaction between product development and production development. However, in many situations nowadays, product development is done separately from production. From a total sustainability and efficiency perspective, there is still a need to utilize the potential in legacy manufacturing structures, even if the manufacturing is done by another company. It is here argued that the total cost, effort and environmental impact could be decreased by a closer consideration of opportunities given by the current manufacturing equipment, instead of a sequential development process where lowest offers are sought for the manufacturing of the finished product design.

5 Conclusion

To summarize, the basis for the paper is the production system life cycle and the need for more efficient reuse and adaption of the production system, both from a resource-efficiency perspective as well as a product customization perspective. From an industrial case study it is concluded that the elaborated production system design methods need to consider legacy equipment, processes and systems in an extended way that can be reused and reconfigured to suit the future need. The proposed double helix design process incorporates the inherent nature of the design process, the vital interchange of product and production information, the non-sequential nature of the design process, as well as the formal consideration of legacy structures to reuse in future production designs. Future efforts for the design process would include the formalisation of the specification structures, the incorporation of current validation and analysis tools as well as creative tools for solution synthesis.

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References

Andrew MT (1991) Managing the redesign of manufacturing systems. Int J Technol Manage 6(3/4):375–384

Asimow M (1962) Introduction to design. Prentice-Hall, Englewood Cliffs

Bi ZM, Lang SYT, Shen W, Wang L (2008) Reconfigurable manufacturing systems: the state of the art. Int J Prod Res 46:967–992

Bellgran M, Säfsten K (2010) Production development: design and operation of production systems. Springer, UK

Bennett D (1986) Production systems design. Butterworth-Heinemann, London

Bennett D, Forrester PL (1993) Market-focused production systems: design and implementation. Prentice Hall, New Jersey

Blanchard B, Fabrycky W (1998) Systems engineering and analysis. Prentice-Hall, New Jersey

Braha D, Maimon O (1997) The design process: properties, paradigms and structure. IEEE Trans Syst Man Cybern 27(3):146–166

Bruch J, Bellgran M (2012) Creating a competitive edge when designing production systems: facilitating the sharing of design information. Int J Serv Sci 4(3/4):257–276

ElMaraghy H (2006) Flexible and reconfigurable manufacturing systems paradigms. Int J Flex Manuf Syst 17:261–276

Hayes RH, Wheelwright SC (1979) Link manufacturing process and product life cycle. Harvard Bus Rev 1:133–140

Jones JC (1970) Design methods: seeds of human futures. Wiley-Interscience, London

Liker JK (2004) The Toyota way: 14 management principles from the world's greatest manufacturer. McGraw-Hill, New York

Love D (1996) The design of manufacturing systems. In: Warner M (ed) International encyclopedia of business and management. Routsledge, London

Lucia AR, Francese R, Scanniello G (2008) Developing legacy system migration methods and tools for technology transfer. Methods 2008:1333–1364

Netz E, Wiktorsson M (2009) Enabling effective production system redesign: complementing investment and design processes. Swedish production symposium 2009, SPS09, Göteborg

Ohno T (1988) The Toyota production system—beyond large scale production. Productivity Press, New York

O'Sullivan D (1994) Manufacturing systems redesign: creating the integrated manufacturing environment. Prentice Hall, Englewood Cliffs, NJ

Rau HA, Gu P (1997) Design methodology and integrated approach for design of manufacturing systems. Integr Manuf Syst 8(3):159–172

Rogers G, Bottaci L (1997) Modular production systems: a new manufacturing paradigm. J Intell Manuf 8:147–156

Rosell G (1990) Notes on the design process (In Swedish). Dissertation. KTH—Royal Institute of Technology, Stockholm

Seliger GB, Viehweger, et al (1987) Decision support in design and optimization of flexible automated manufacturing and assembly. Robot Comput Integr Manuf 3(2): 221–227

Simon HA (1981) The sciences of the artificial. 2nd ed. MIT Press Cambridge, MA

Skinner W (1969) Manufacturing—missing link in corporate strategy. Harvard Business Review May–June 1969

Suh NP (1990) The principles of design. Oxford University Press, New York

Tobias AM (1991) Managing the redesign of manufacturing systems. Int J Technol Manage 6(3):375–384

UN Statistics divisions (2012) Data available online on: http://unstats.un.org/. Data adapted by the author. Accessed 20 Apr 2012

Wang X, Hu SXK, Haq E (2007) Garton H (2007) Integrating legacy systems within the service-oriented architecture. IEEE Power Eng Soc Gen Meet 95630:1–7

Wiktorsson M (2000) Performance assessment of assembly systems. Dissertation. KTH—Royal Institute of Technology, Stockholm

Wiktorsson M, Andersson T, Broman M (2000) A note on the specification of assembly systems. Int J Prod Res 38:3997–4002

Womack JP, Jones DT (1996) Lean thinking: Banish waste and create wealth in your corporation. Simon and Schuster, New York

Wu B (1994) Manufacturing systems design and analysis-context and techniques. Chapman and Hall, New York

Wu B (2001) Strategy analysis and system design within an overall framework of manufacturing system management. Int J Comput Integr Manuf 14(3):319–341

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