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THE IMPACT OF LEGACY IN PRODUCTION SYSTEM DESIGN

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ABSTRACT: *Production system design ranges from a green field/full investment situation, to a redesign, rearranging and reusing existing equipment. Current academic and industrial production design processes are in most cases derivatives of product development processes, not pinpointing legacy equipment and structures. Neither production procurement processes focus legacy infrastructure. However, in design of e.g. IT and PLM processes, management of legacy is of vital importance. By contrasting the production design task to these benchmarks and a classic optimization problem, the impact of legacy - a constraint in the design task – is in this conceptual article discussed as supporting an elaborated design process, including redesign elements.*
KEYWORDS: *production system, legacy, design process*

INTRODUCTION – BACKGROUND

A production design situation ranges from a total 'green field'/full investment situation, to a pure redesign, rearranging and reusing existing equipment and facilities. The most common situation encompasses both aspects; new investment as well as redesign.

In the light of an increasing rate of product changes and introductions, combined with a strive for lean and optimized production systems, the need increases for more effective working methods and tools in the production design projects. There is an increasing need to faster obtain production systems coherent to the chosen product structure, product plan and the manufacturing strategy. 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 in e.g. [1], [2] and [3]. In the second case, the integration of legacy concerns the specific production design and procurement processes, enabling the record and reuse of legacy structures. This paper focuses the latter; the redesign process of a production system.

RESEARCH OBJECTIVE, METHODOLOGY AND LIMITATIONS

The objective of this conceptual paper is to discuss the impact of legacy in production system design processes by industrial and academic examples, as an inspiration for an elaborated production system design process, including redesign elements. The more specific examples detailed in the paper concerns design of large assembly systems, but the discussed design processes are considered suitable for most industrial production systems.

The approach applied start off by a brief review of current schemes for production system design from academic and practitioners. Based on an identified lack within these current schemes regarding production system redesign and handling of legacy, inspiration is sought within other fields of knowledge. It is concluded that processes from product life cycle management and operations management handles and defines legacy as a key element, and aspects from these can be seen as inspiration for a process that is applicable even for production redesign. Also in the formulation of a classic optimization problem, the impact and handling of legacy is detailed, illustrating the missing element in the current production design processes.

Being a conceptual paper with the objective of contributing to a continued inductive research process, the paper does not present any empirical verification, or not even a clearly defined proposition to be verified. Instead the paper pinpoints a lack in current production design research and proposes approaches in developing design schemes applicable for redesign and legacy handling.

CURRENT SCHEMES FOR PRODUCTION SYSTEM DESIGN

From a research perspective, a number of schemes for production system design have been proposed over the years - from methodological concerns, to design of processes and specific subprocesses, to more hands-on guidelines. From an industrial perspective, established processes mainly discuss production system design within the context of product industrialization or from an industrial procurement perspective. From both a research perspective as well as an industrial perspective, processes and methods for production system design with the focus on system redesign and handling of legacy in production systems are still not explicitly described, as illustrated in the following.

ACADEMIC CONTRIBUTIONS ON PRODUCTION SYSTEM DESIGN SCHEMES

Designing a production system could be seen as any other design of a large complex system, including technical and organisational elements. A general model of the events in an engineering design process is the activities of (problem) analysis, (solution) synthesis and (solution) evaluation, carried out in cyclic and iterative manner, as illustrated in Figure 1 [4], [5].

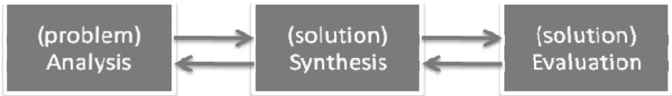

Figure 1. The general activities in an engineering design process. Adapted from [4], [5].

In order to structure these activities, one perspective within design research is to consider the design process in a more sequential scheme. From the research fields of product planning and design, a number of processes have been proposed following such a scheme e.g. [6-9]. A general feature within these approaches is that the authors adopt the concept of function/solution mapping as well as the hierarchical design approach—to initially design on an overall level and partly decompose the design by its sub-functions.

Within the field of production system design, the classic "systematic layout planning" by Muther [10] introduced a step-by-step plan for the design of a manufacturing system including worksheets. Over the years it has been followed by a number of more specific manufacturing system design schemes, presented by e.g. Benett [11]. Wu [12] proposed in his textbook on "Manufacturing Systems Design and Analysis" a general design framework, structured as in Figure 2.

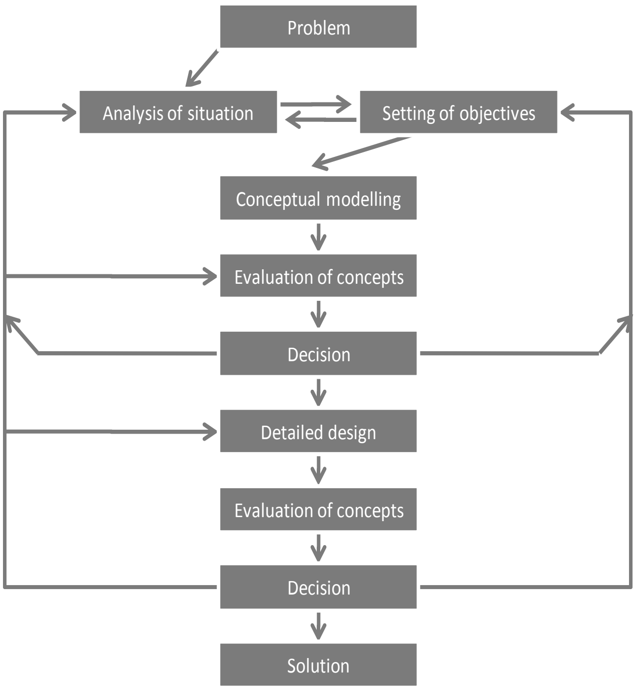

Figure 2. Structure of the manufacturing system design approach by Wu [12].

Following the sequentially based methodology of engineering and production system design as elaborated above, more specific research on assembly system design has been emerging. Baybars [13] and Ghosh and Gagnon [14] surveyed the broad theoretical foundation for assembly line balancing, sequencing and resource planning, but still are methods focusing on the actual design process of assembly systems rarer. Since Wild [15] motivated further work within assembly systems design, efforts within the field encompass methods directed towards specific phases in the design process or focusing on specific types of assembly systems. Examples on the first are the method for planning of a systematic assembly system design presented by Bellgran and Säfsten [16], the performance assessment of assembly systems by Wiktorsson [17] and the method for selection of assembly systems by Shtub and Dar-El [18]. Examples on methods focusing on specific types of assembly systems are the concentric design process for robotic assembly systems by Rampersad [19], the method for design of team-oriented assembly systems based on the Bill of Material (BOM) by Bukchin et al. [20] and textbook on assembly line design by Chow [21].

From an information perspective, there is a vast plethora of research undergoing on the emergence and realization of digital factories, surveyed in e.g. [22]. In that research context, the production system design process underpins the information needs and there is a close connection to management of the product information.

In these earlier works, the aspect of assembly system redesign, where the reuse of existing equipment and facilities are of specific interest, has not been especially in focus. In work by Tobias [23] the author discusses more general key issues which determine success or failure for a redesign of a manufacturing system. These 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 [24] discusses the subject but is in fact a more general structure for design of manufacturing systems.

EXAMPLES ON INDUSTRIAL PRACTICE

The absolute dominating 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, some are also used for assembly system design. By years of engagement and studies of product introduction projects and production system development processes by the research group, it is concluded that the observed industrial processes for production or assembly system design are characterized by:

- *production or assembly system design is considered a sub-task in a overarching product industrialization process,*
- *the production or assembly system design is handled by a general project management process,*
- *the production or assembly system design is handled by investment processes, concerning the specific elements with need of investments.*

In neither of the observed industrial cases, the specific characteristics of considering legacy given by a system redesign are specifically identified.

One specific example studying a company process used in production system design is the Production Equipment Procurement Process (PEPP), described in [25]. PEPP is a process for investment projects and the gates are closely related to the gates in the formal purchasing order document used by the company. This process was grouped into six stages and nine phases as presented in Figure 3.

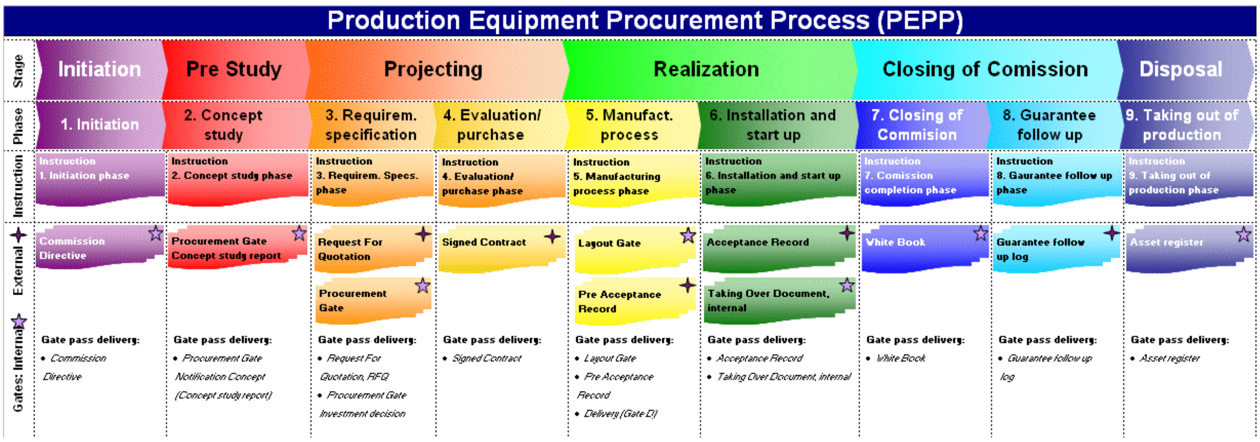

Figure 3. The production equipment procurement process (PEPP), as used by a case company [25]

Studying this production equipment procurement process, it is concluded that the gates are not the same for investment projects as for redesign projects. In redesign there are no purchasing orders to refer to at the internal gates. Also there are other aspects in redesign project which are not so important in investment projects, such as in detail considering the down-time time during the redesign. The authors in [25] conclude that there is an industrial need to formulate state-gates which could be used also for cases including legacy equipment and processes.

INSPIRATION FOR HANDLING LEGACY IN PRODUCTION DESIGN PROCESS

By the brief review of current academic and industrial production design processes, it is concluded that they 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 of natural reasons focus 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.*

However, in e.g. product life cycle management processes and for operations management processes, handling and definition of legacy is of vital importance, and aspects from these can be seen as inspiration for a process that is applicable even for production redesign. Also by contrasting the production design task to the formulation of a classic optimization problem, the impact and handling of legacy, working as a constraint in the design task, is detailed.

HANDLING OF LEGACY

Within IT management, a common situation is to migrate from a current situation to a new system design where current solutions are to be reused. Strict procedures and established 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 [26], [27]. When modifying the system, Lucia et al describes that "Changes may range from a simplification of the system through a reduction in size and complexity, to preventive maintenance operations such as redocumentation, restructuring, and reengineering, to an adaptive maintenance process entailing interface modification, wrapping, and migration. These alternatives are not mutually exclusive, and the decision as to which approach, or combination of approaches, to take is generally based on an assessment of the quality and business value of the system." [26].

Furthermore, the decomposability of the system is a critical aspect in discussing redesign aspects of systems. In terms of system architecture, the evolution of information technology has led the way in building enterprise computing acting like LEGO, the popular children's toy, as reported in [27]. The concept of service-oriented architecture (SOA) is here described as building a modular structure where blocks can play many different roles. SOA is a main approach for dealing with the challenge of interoperability of systems in heterogeneous environments. SOA also benefits the reuse of components, improved reliability, and reduced development and deployment costs. In the business world, the service-oriented approach helps automate the managing of business processes by enabling the `orchestration' of services in order to achieve the needed functionality. In other words, it allows implementation of workflows with flexibility and robustness [27]. The realization of the SOA is not only a traditional modular structure with well defined interfaces, but a multi-layer architecture with functional layers of transport, messaging, description, quality and composition.

It is anticipated that experiences and structures from these field of established knowledge concerning system architecture could be transformed to influence the development of a production system architecture including a methodology for manufacturing systems redesign.

THE DESIGN TASK IN RELATION TO AN OPTIMIZATION TASK

The success of a designed production system is to (better than alternative solutions) fulfill the stakeholders' perceptions of value. Recent developments in design research emphasise the complexity in viewing a design process as striving towards an "optimal solution". The complexity lies in both who to define what is optimal, as well a where to look for optimality - in the product or in a product life activity? [28]. It is a grand challenge to properly understand the stakeholders' perceptions of value and ideal solution.

However, a design task can in principle be seen as any other decision problem where the concept of optimisation is a well-rooted principle. The standard form of such a problem is to during design, maximise an objective describing perceived value, subject to the constraints that may limit the selection of values on decision variables. The well-established formulation of this problem is presented in equation (1) (see e.g. [29]).

Maximise	$f(\mathbf{x})$		objective function	(1)
subject to	$g_i(\mathbf{x}) = 0$	$i \in I$	functional constraints: equalities	
	$h_j(\mathbf{x}) \geq 0$	$j \in J$	functional constraints: inequalities	
	$\mathbf{x} \in S$		set constraints	

In comparing this standard form for non-linear constrained problems used within mathematical programming, to the earlier presented framework, many similarities are found. As described in [30], the assembly system design problem can be formulated as in equation (2).

Maximise	$w(\mathbf{x})$		(2)
subject to	$p_i(\mathbf{x}) = R_i$	$i \in I$	
	$q_j(\mathbf{x}) \geq R_j$	$j \in J$	
	$\mathbf{x} \in C$		
where	$\mathbf{x}$	represents the assembly system design	
	$w(\mathbf{x})$	represents the winning criteria	
	$p_i(\mathbf{x}) = R_i$	represents the functional requirements: nominal values	
	$q_j(\mathbf{x}) \geq R_j$	represents the functional requirements: threshold values	
	$\mathbf{x} \in C$	represents the design constraints	

This perspective on a design task opens the eyes for how to define a requirement specification for production systems, as described in [30], but also how to handle constraints in the design task. In the exercise of defining design constraints, legacy structures are a key. By viewing the mathematical formulation, the structure of a design task including defining winning criteria and qualifying criteria and separating the qualifying criteria in functional requirements and design constraints become more obvious. The terms reflect aspects, used for decades within analysis of decision problems.

In the case of a production system design, it is obviously not possible to define a strict optimization formula and derive the optimal solution. A production system is an open system, largely influenced by cultural, temporal and structural contexts. The paradox emerging in design of complex systems have rarely been so real: "How to decide the whole, without knowing the parts? The parts depend in turn on the whole." This paradox leads to an iterative design process where the steps of (problem) analysis, (solution) synthesis and (solution) evaluation are carried out in cyclic and iterative manner. However, by pinpointing the components of a system design task; the importance of properly understanding the stakeholders' perceptions of value and ideal solution; the functional requirements from the system context in terms of nominal or threshold values; and the constraints in terms of legacy resources and processes; the design task is believed to be clarified and more effectively managed.

CONCLUSIONS

By focusing on the specific character of the redesign of production systems, the concept of legacy structures (resources and processes) have been pinpointed. A redesign might include simple, low cost reorganization of workers, slightly higher cost scenarios such as reorganization of machines or products, or total redesign, which includes the purchase of new equipment and change in system type.

Industrial cases illustrate the increasing need of reaching an adaptive production system, enabled by both adaptive production resources, as well as redesign processes based on comprehensive system architecture. Current industrial and academic practice does not however fulfil these needs. Industrial cases show how production design processes tend to fragmentize the process and focus investments or specific modification needs. A system perspective including defining management of legacy structures have not been found.

However, from other fields of knowledge, the construct of architecture and constraints in the design task lead the way in conceptualizing the management of legacy also in production system design. In IT management processes, the handling and definition of legacy is of vital importance. Also by contrasting the production design task to the formulation of a classic optimization problem, the impact and handling of legacy, working as a constraint in the design task, is detailed.

This conceptual paper illustrates the challenges in using a single methodology in production system development. It illustrates the broad spectrum of situations a single production system development process would need to be able to handle. The paper proposes specific aspects to consider in situations of production system redesign.

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