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An approach for integrated design of flexible production systems

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Abstract

The paper presents a holistic methodological approach for designing flexible production systems, integrating the management of the production resources, operations planning, internal logistics and quality. The proposed methodology relies on *lean* principles and encompasses a series of stages and tools that may be used to design and to assess the robustness of the production system for tackling small series and frequent changes in the productive processes due to customized production. This approach has been applied to the redesign of the production system of a Portuguese machinery manufacturing industrial company. Results show that it effectively led to a new flexible production system and a new industrial layout capable of responding to diverse future scenarios of products demand.

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1. Introduction

The efficient design of flexible production systems to tackle customized products in small series is key for increasing competitiveness [1]. A current business trend is to offer a larger number of products with a higher level of customization, according to the costumer requests, produced under strict quality requirements, and with shorter production lead times. Consequently, the production systems with origin in the shop floor [2] need to be designed in a flexible way in order to cope with the frequent changes in the productive processes that affect the type and sequence of operations to be performed. For this purpose, polyvalent production equipment needs to be managed in order to reduce the setups. The physical arrangement of the equipment in the layout should minimize the need to transport the materials between consecutive operations. New flexible and dynamic internal logistics infrastructures are further needed for dealing with rapid and safe materials movements.

The literature review shows that *Lean* Manufacturing principles and tools are becoming quite popular for improving production systems by eliminating the expenditure of resources that do not contribute directly for creating value as perceived by the customer (e.g. [3]). In particular the practitioner-oriented literature presents many real-world cases where *lean* tools were applied to improve some of the aspects of flexible production systems design such as capacity planning, operations management, industrial layout design and internal logistics design. The application areas are quite diverse (ranging from industrial sectors like automotive, aircraft to services like and waste recycling (e.g. [4] to [7]), empirically-driven and affected by many case-specific factors (including cultural, technological and industrial differences).

Proper methodologies for *lean* implementations are still under debate in practitioners and scientific communities and holistic approaches are rarely found. Some authors [8], [9] propose methodologies based on the Systems-of-Systems theory for adopting the *lean* principles in a systemic perspective. Other authors [10] use an axiomatic design-decomposition methodology for designing the whole production process taking into account the system and design objectives s well as their relations. Still others (e.g. [11] to [13]) emphasize the

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need to develop indicators and provide measures of the *lean* production.

Further holistic approaches are needed to extend *lean* principles and creating synergies among the interrelated aspects of production systems design. In fact, the characteristics of an industrial layout may pose constraints to operations planning and equipment physical location, while improvements in the layout and the logistics infrastructure may emerge from a more flexible planning of the production operations. Furthermore, a common diagnosis of the current status of the production system may lead to a more detailed blueprint and help to save time avoiding repetitive data gathering processes.

This paper presents a *lean*-based holistic methodological approach for designing flexible production systems, integrating all relevant components, including the management of the production resources, operations planning and scheduling, and internal logistics.

The paper starts by describing the methodology for integrated design of production systems. The focus will be in describing the main stages of the methodology together with the set of tools that may be used to support each stage. The paper will further describe the application of this methodological approach to redesign the production system of a Portuguese machinery manufacturing industrial company. Brief insights about the organization of the project for designing production systems in collaboration with the practitioners of the industrial company are further discussed.

2. Proposed methodological approach

The methodology developed in this work encompasses a series of stages and a set of tools (toolbox) that may be used to design and to assess the robustness of a production system for tackling small series and frequent changes in the productive processes due to customized production (see table 1).

Lean production provides the theoretical background for some of the key methodological stages. The Value Stream Mapping (VSM) technique [14] is used for analyzing the product flows across the production system, similarly to other empirical studies (e.g. [15], [16]) .Yet, the *lean* production techniques are here complemented by other empirical tools driven by the experience of two consultancy and research organizations specialized in lean applications.

The first stage of the methodology – project start up – starts by establishing the scope of the analysis, including the definition of the VSM families of products that will be studied. The VSM families are clusters of products that share the same resources and have similar production operations. The clusters are identified using a product-resource matrix [17], often built using only the product references that the customer considers priority or references class "A" according to a ABC analysis [17] on the sales (10-20% of the references that are responsible for 80% of the sales). Afterwards, the information for characterizing the production system is compiled by the customer in a new software – PsCap (Production Systems Capacity Model) **-**, from the company's information systems and from measurements performed in the shop floor. Relevant information includes: description of working schedules, detailed description of the production and logistics equipment (including OEE Overall Equipment Effectiveness) and workers profiles, demand for the VSM product families (current and future estimates), identification of suppliers, main clients and industrial units.

The second stage of the methodology is instrumental for providing a common diagnosis of the current situation (AS IS), in order to support the subsequent design of all the components of the flexible and integrated production system. The VSM technique is used for providing a representation of the production process, including the main operations, transport activities, stocks, product and information flows. The VSM representation is interactively built with the company's experts on the walls of the project team room using the *post-it* method. Most of the VSM representation is built based on the survey conducted during the visit to the locations where the production process takes place (also called *gemba* in the *lean* terminology). The information flow comes from the process mapping exercise that captures the chronological sequence of the tasks performed since the placing of the costumer order until the delivery of the products to the costumer. The VSM objects are documented in a new software – PsFlow (Production Systems Flow Model) - which also provides a semi-automatic representation of the VSM in MS Visio. The tool provides a link to the PsCap, includes the measurements of the cycle time for the VSM operations and transportation times, computes the stock autonomy and a set of KPIs that characterize the current situation, including the production lead time, added-value time and total distance (see table 2).

This stage further includes the description and analysis of the current business processes that relate to the production process (e.g. sales, materials acquisition, order expedition). PsFlow also supports the documentation of the processes. Flowcharts may be drawn in MS Visio or other Process Management software tool, using a standard notation (e.g. BPMN) or other notation provided by the costumer. Whenever relevant, spaghetti diagrams [18] may be drawn to highlight the current product flows across the equipment placed over the physical industrial layout.