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ScienceDirect
Procedia CIRP 37 (2015) 146 – 151
www.elsevier.com/locate/procedia
CIRPe 2015 - Understanding the life cycle implications of manufacturing

Critical components evaluation in Manufacturing-To-Order processes

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Abstract

In this paper we address the evaluation of the criticality of important components in *Manufacturing-To-Order* and *Assembly-To-Order* processes, where the management of the inventory is a critical problem, especially very expensive ones. In these situations, if an item is purchased only when needed for a specific order, the delivery time could cause the delay of the entire production process. In addition, these manufacturing environments are often affected by uncertainty, caused by the execution of several activities by human operators, and by the intrinsic complexity of the process (especially in assembly processes). In this background, we provide a method to evaluate the criticality level of each important component in an assembly process exploiting the *AoA* project network formalization. In particular we put the focus on the coordination between the scheduled arrive of an element from the supplier, and the actual needed of the component in the assembly process. To this aim we develop a method taking into consideration two different criticality indexes. The approach is validate in a real manufacturing case.

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Keywords: manufacturing-to-order; scheduling; uncertainty; inventory

1. Introduction

The global manufacturing sector lives in an evolving environment in which the customers ask for an increasing product's customization. The companies that want to compete in this sector have to re-design the products and the related manufacturing processes to be easily customized. From this point of view, every new order represents a new product and a new production process as well, specifically designed by the manufacturer. The complexity of elements and their cost make the production process more difficult to be managed and planned and, due to the high cost of the products, the *Make-To-Stock* paradigm is no longer suitable. Different production paradigms have been already studied and applied in the past to help the producer to handle this particular situation. The first one is the *Make-To-Order* approach, where the production of a good starts only when the order is received, hence, no stock is expected. The second one is the *Engineering-To-order* approach that provides the design of the product and the production process for every new order. These paradigms entail an heavy work to design and coordinate every new order placed; for example, for highly customized products, a new production process must be defined and the suppliers coordinated to assure raw materials and components. The focus of this is to evaluate the coordination between the arrival of a component at the production site and its utilization in a process. In particular we analyze the risk of a stock-out of these components. The analysis is focused on the mostly critical components, where critical means those components whose shortage can cause a delay in the production process, with high value and high purchasing cost or time. To this aim we exploit a method to calculate the makespan of a generic production process to assess the time when a component is expected to be needed, this value is then compared to the lead time of the suppliers. The analysis is carried out considering the uncertainty of the processed to obtain a criticality index to point the attention of the manager on the inventory of those component that can cause a delay of the production process.

2. State of Art

The presented study addresses the problem of evaluate the impact of the stock out of an important component in a *MTO* manufacturing process. There are several studies presented in the past that trying to face this issue from different point of view; in [12] and [14] are proposed two classification schemes for this evaluation, without taking into account the underlying manufacturing process. Instead, other authors, addressed this connection and proposed method for controlling the inventory process, like in [6] and in [9]; an additional evolution of this kind of approaches, that addresses also the *MTO* paradigm, is given in [1]. Regarding the manufacturing process is very important to take also into account the scheduling and planning tools, like in [13] and [5]; instead, the connection of this this

Peer-review under responsibility of the organizing committee of CIRPe 2015 - Understanding the life cycle implications of manufacturing
doi:10.1016/j.procir.2015.08.046

Criticality Estimation
1 Formalization of the *AoA* network
2 Sub-net isolation
2.a Identification of the element to analyze
2.b Isolation of the interesting sub-net
3 Estimation of the distribution functions
4 Risk Evaluation

Fig. 1: Resolution procedure pseudo-code

kind of process with the inventory model is given in [11], where and aggregate risk level is estimated starting from the stock out risk of each component and the scheduling tardiness risk. Our purpose is to cope with the uncertainty affecting the execution of a manufacturing process, like in [2], and of its inventory activities, by formalize the entire process with a stochastic project network, also called *PERT* networks. The most typical application of this instrument is the estimation of the makespan of the project, i.e., the total duration of the project. This estimation is provided using two analytical methods presented in [10] and in [15], or with a *Monte Carlo Simulation* like in [3]. In this paper we will take advantage of all these tools to support a method to measure the criticality of a given component. Our work grounds also on an econometric approach regarding the estimation of the risk: the *Survival Function* and the connected *Hazard Rate*. This approach, studied in [4], estimates the probability of the occurrence of a specific event in a given temporal window.

3. Solution Approach

The proposed approach aims to compare the arrival time of a component and the time of its utilization in the production process. It is straightforward to notice that:

- if the component is available before the production process asks for it, no problem arises;
- if the component is not available when the production process asks for it, the production operation must wait for its arrival.

Our approach is based on these two simple concepts, and it is described in Figure 1.

3.1. Formalization of the AoA network

We consider a stochastic project network, with the particular *AoA* formalization (*Activity on Arc*), modeled through a *Directed Acyclic Graph* represented with $D = (N, A, p)$ in which $A = \{1, 2, ..., m\}$ is the set of generic activities and $N = \{1, 2, ..., n\}$ is the set of generic project events (also named milestones) and p is a vector of independent random variables, modeling the duration of the activities. Using the *AoA* framework, the activities of the process are modeled through edges, instead milestones and event are represented by nodes. In addition, each activity $a \in A$ is associated to a vector p of independent random variables (discrete or continuous) modeling its stochastic duration. We assume that each activity is independent from the others and estimate each of those with a *Maximum Likelihood Estimation*. In our representation, we consider three classes of activities: *purchasing activities*, *production operation* and *dummy activities*. The *dummy activities* are fake activities, whose duration is equal to 0, useful to model specific precedence constraints on an arc with several input and output arcs.

3.2. Sub-net isolation

Our approach aims to evaluate the criticality of each component that has to be purchased by the analysis of its makespan exploiting the project network formalization. After the identification of the component that needs an evaluation, it is necessary to isolate a sub-net with the following characteristics:

- the source node of the sub-network is the source node of the original network;
- the sink node of the network is the node representing the milestone preceding the production operation requiring the component under study.

In other words, the described sub-net, represents the entire process in which is involved the component under study, starting from the beginning of the production process (source node), until the starting of the activity that uses that particular component; the sub-net contains all the edges from the original source node to the node preceding the production operation edge that uses the component under examination. This sub-net formalizes the purchasing process of a particular element and formalize also the utilization of that component in the production process. With this sub-net, then, it is possible to continue the evaluation.

3.3. Estimation of the distribution functions

After the complete formalization of the problem using an *AoA* net and the isolation of a sub-net, the following step is to calculate the distribution of the supplying time of a component at the production site as well as the time in which the component will be needed by the production process. The proposed approach estimates these two time distributions and provides a comparison between them. Let us consider *eventA* representing the event *the process needs the component*, and *eventB* the event *the component is arrived at the plant and it is ready to be used*. The associated distribution functions are, respectively, $F_A(t)$ and $F_B(t)$ given $0 \leq F_i(t) \leq 1$ with $i = A, B$. In particular, for the event A:

- $F_A(t) = 1$ if the process will need the component at time t with probability 1;
- $F_A(t) = 0$ if the process will not need the component at time t with probability 1;
- $0 < F_A(t) < 1$, otherwise.

Instead, for the event B, we have:

- $F_B(t) = 1$ if the component will be available at time t with probability 1;