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A flexible simulation support for production planning and control in small and medium enterprises

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Abstract

For efficient, effective and economical production operation management in a manufacturing unit of an organization, it is essential to integrate the production planning and control system into an enterprise resource planning. Today’s planning systems suffer from a low range in planning data which results in unrealistic delivery times. One of the root causes is that production is influenced by uncertainties such as machine breakdowns, quality issues and the scheduling principle. Hence, it is necessary to model and simulate production planning and controls (PPC) with information dynamics in order to analyze the risks that are caused by multiple uncertainties. In this context, a new approach to simulate PPC systems is exposed in this paper, which aims at visualizing the production process and comparing key performance indicators (KPIs) as well as optimizing PPC parameters under different uncertainties in order to deal with potential risk consuming time and effort. Firstly, a production system simulation is created to quickly obtain different KPIs (e.g. on time delivery rate, quality, cost, machine utilization, WIP) under different uncertainties, which can be flexibly set by users. Secondly, an optimization experiment is conducted to optimize the parameters of PPC with regard to the different KPIs. An industrial case study is used to demonstrate the applicability and the validity of the proposed approach.

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1. Introduction

PPC addresses a fundamental function of productivity, management and resource utilization [1]. A survey among companies of machine and plant engineering illustrates that today’s planning systems suffer from low quality and low range in planning data, which results in unrealistic delivery times [2]. It leads to the dilemma of PPC, namely it is to achieve high process efficiency, low throughput times and good planning confidence in spite of a turbulent environment with uncertainties such as dynamic factory changes, constraints, short product lifecycles, an increasing variety and a growing individualization of demand [3].

In most cases, production planning is addressed manually by practitioners, even in modern production with sophisticated automated systems. This manual process is time-consuming, sub-optimal (as only few alternatives are considered) and completely dependent on the planner's expertise [4]. Additionally, it is well known that in the make-to-order sector an order spends up to 90% of the total time in production waiting in front of or between work centers and only 10% in actual transformation work on the machines. [5].

All above discussed challenges require that the company is able to act in its flexible PPC which can response to unpredicted situations. It is necessary to model and simulate PPC with information dynamics in order to analyze the risks which are caused by multiple uncertainties. In this context, the produced approach focuses on a flexible simulation system of medium-term of PPC with integrated internal production systems and system variants (e.g. scheduling policies, machine breakdown, quality issues, processing time fluctuation) as well as external customer forecast orders. The main objective is to

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build a flexible simulation system for medium-term PPC analysis based on the forecast and different uncertainties so that the companies can design a more feasible production plan in shorter time and update it flexibly to fulfil their production target. Furthermore, it provides the chance to make transparent design processes so that the production planning staff can reduce their workloads by using this simulation system. In chapter 2, the current state of the art in literature regarding this topic is presented. The developed method is elaborated in chapter 3. Finally, chapter 4 concludes with a summary.

2. State of the art

Regarding this topic, several approaches have been discussed in the research community. Alvandi presents a simulation-based approach to model energy and material flow and considers the hierarchical structure of energy and material consumers within the system. An evaluation of the improvement strategies on energy and material efficiency was investigated [6]. Stricker identifies and evaluates the appropriate enablers for robustness for specific production systems. Multi-objective decision support models are created to evaluate the best enablers for the levels of production network, plant and shop-floor [7]. Volling builds a framework comprising separate interlinked quantitative models for order promising and master production scheduling and evaluates their potential using simulation [8]. Lee illustrates how simulation-based shop-floor planning and control can be extended to enterprise-level activities (top floor). Nevertheless it only focuses on the transformation between shop floor and top floor [9]. Chakravorty finds the performance of Drum-Buffer-Rope (DBR) to be very sensitive to changes in the levels of free goods (FG) released into the operation based on the simulation of a job shop operation. Contrary to the way FG have been treated in the past, schedulers using DBR need to be cognizant of how orders of these items are accepted and scheduled [10]. Duffie focuses on classical control theoretical modelling of transient behaviour and fundamental dynamics of production planning and control, which generally is considered to include scheduling, sequencing, loading and controlling [11]. Gyulai presents a planning and control methodology, which is based on adaptive calculations. Besides, historical data is used as direct input of discrete-event simulations to determine the proper control policies of human operator allocation for the different scenarios [12]. Auer describes an integrated planning solution for the harmonization of sales, purchasing, supply chain and production planning along the planning cascade. By harmonizing, cost savings and additional value potential is realized [13]. Georgiadis develops a system dynamics model to support the decision-making on time-buffer policies [14]. Baldea defines several necessary directions for future development as well as a complement of promising application [15]. Leng proposes an optimal allocation mechanism based on the Theory of Constraints in face of meeting peak demand in a certain period for the whole system. A genetic algorithm has been selected for solving the optimization model [16]. Seitz clarifies the advantages of cyber-physical system (CPS) in view of production planning, controlling and monitoring. The order processing is improved through logistics models with CPS [17]. Chen inspects the effectiveness of three manufacturing rules (line balance, on-time delivery, bottleneck utilization) in terms of three important performance metrics (effective WIP (work-in-process), on-time delivery, bottleneck loading). Guidelines for manufacturing rule selection are provided [18]. Grundstein presents a quantitative, three-dimensional evaluation system. It allows for a complete quantitative evaluation of autonomous control in production systems. [19]. Suwa introduce new approaches to online scheduling based on a concept of cumulative delay. This approach can reduce frequent schedule revisions and avoid overreacting to disturbances and simplify the monitoring process of a schedule status [20]. Golmohammadi provides a number of simulation scenarios of a master production schedule and the drum-buffer rope (DBR) scheduling method. The optimization techniques are used to find optimal and/or satisfactory solutions for input variables in the simulation experiment [21]. Yan presents an algorithm whose complexity is unrelated to the batch size to obtain the starting time of a batch production. A heuristic method based on a genetic algorithm is constructed to solve the splitting and scheduling problems simultaneously [22].

Overall, existing approaches are providing PPC improvement through optimized algorithms in modelling and simulation. However, they take the production system framework and production process uncertainties into account insufficiently. Secondly, these approaches are not flexible enough and cannot be easily adapted to different segments of industries.

3. Methodology

The presented approach helps to overcome this gap mainly in two steps. In a first step, a PPC simulation system is created which integrates internal production systems and system uncertainties as well as external customer forecast orders. It can quickly obtain the KPIs (on time delivery rate, quality, cost, machine utilization, WIP) under the different uncertainties. In the first step, the hierarchy of the system, structure of the data base, the initiation of the concept module, and the flexible simulation system are developed.

Secondly, the preliminary optimization experiment to find out the optimized PPC parameters in order to achieve better KPI results under the specific situation are produced.

3.1. Hierarchy of the system

According to the VDI-3633 procedure, the establishment of simulation system starts from preparation phase. The whole structure includes four elements, which are basic production system, customer order forecast, uncertainties, KPIs. Customer order forecast as one of the key inputs mainly consists of product name, order quantity, due date and customer code. Regarding the uncertainties, the machine break down indicator (MTTF, MTTR), scheduling policies (first in first service, earliest due date, shortest processing time), quality issues (rework rate, scrap rate) and customer issues (rush order) are included. The KPIs present the simulated

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