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Case-Based Reasoning system for mathematical modelling options and resolution methods for production scheduling problems: Case representation, acquisition and retrieval

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ABSTRACT

Thanks to a wide and dynamic research community on short term production scheduling, a large number of modelling options and solving methods have been developed in the recent years both in chemical production and manufacturing domains. This trend is expected to grow in the future as the number of publications is constantly increasing because of industrial interest in the current economic context. The frame of this work is the development of a decision-support system to work out an assignment strategy between scheduling problems, mathematical modelling options and appropriate solving methods. The system must answer the question about which model and which solution method should be applied to solve a new scheduling problem in the most convenient way. The decision-support system is to be built on the foundations of Case Based Reasoning (CBR). CBR is based on a data base which encompasses previously successful experiences. The three major contributions of this paper are: (i) the proposition of an extended and a more exhaustive classification and notation scheme in order to obtain an efficient scheduling case representation (based on previous ones), (ii) a method for bibliographic analysis used to perform a deep study to fill the case base on the one hand, and to examine the topics the more or the less examined in the scheduling domain and their evolution over time on the other hand, and (iii) the proposition of criteria to extract relevant past experiences during the retrieval step of the CBR. The capabilities of our decision support system are illustrated through a case study with typical constraints related to process engineering production in beer industry.

1. Introduction

This research is focused on the issue of capitalizing simulation modelling knowledge to efficiently develop relevant models for short term scheduling applications. Indeed, the supply chain of a company is a complex network which involves the integration of information, transportation, procurement of raw materials, inventory, transformation into finished products, warehousing, material handling and distribution of finished products to end users. The goal is to reach a high end user satisfaction level at a low cost. One of the main functions in the supply chain is the production which aims to use available production capacities to produce the desired products. The coordination of the production is one way to achieve high efficiency with low cost. This can be done through the production planning. But planning refers to a wide range of activities with different decision levels and different time scales. Among them, scheduling is a crucial step which is a short term planning dealing with the allocation of resources to tasks (assignments and sequencing of tasks to units) over time with one or various objectives to optimize.

However, the growing worldwide competition in the current context imposes new industrial strategies based on more and more flexible processes affording a greater reactivity to remain competitive in the global marketplace. Indeed, for the manufacture of chemicals or materials, the production process or the demand pattern is likely to change. The inherent operational flexibility of industrial plants provides the platform for great saving in good

Abbreviations: AI, Artificial Intelligence; BBT, bright beer tank; CBR, Case Based Reasoning; CTR, continuous time representation; MILP, Mixed Integer Linear Programming; MINLP, Mixed Integer Non Linear Programming; NMF, non negative matrix factorization; PSE, process system engineering; RBT, raw beer tank; RTN, Resource Task Network; STN, State Task Network; USTE, Unit Specific Time Events.

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production schedules as it is the core of production management. This flexibility is increased because of the demand for greater product customization and diversification. As a consequence production processes become more complex with multi-products or multipurpose plants with batch mixing/splitting, multi units, multi recipes for products constructions and an increasing set of production constraints. Moreover, processes need reengineering to respect new constraints coming from the legislative world (environmental, security constraints) or from the enterprise itself (cost reduction, production centralization). Furthermore, the application of process engineering towards new areas, such as food, biotechnological, electronic or pharmaceutical industries is generating new production and scheduling problems with additional resource constraints, batching decisions, process restrictions, handling mixing and splitting streams. To address all of these scheduling issues, the process system engineering community has developed several models, and resolution methods.

The research area on scheduling has been broadly studied by both the industry and the academia world resulting in significant advances in relevant modelling and solution techniques. Numerous research studies have been made of this area, e.g. (Blazewicz, Ecker, Pesch, Schmidt, & Weglarz, 2007; Esquirol & Lopez, 1999; Maravelias, 2012). Scheduler show inventiveness to propose new modelling options and improved mathematical methods to address to these complex highly combinatorial problems. The increasing number of research articles dedicated to short term scheduling problems bears out this trend. Accordingly, plenty of possibilities of association between modelling options, and between models and resolution methods are thus available. More and more difficult and larger problems than those studied years ago can be now solved, sometimes even to optimality in a reasonable time thanks to more efficient integrated mathematical frameworks. This important achievement comes mainly from huge advances in modelling techniques, algorithmic solutions and computational technologies. This results in different possibilities to model a scheduling problem, but also multiple mathematical formulations for the same model. The diversification of modelling options, the combination and creation of resolution methods are increasing and will going to grow in the following years in order to enlarge the classes and the size of the problems treated. For instance in Sundaramoorthy and Maravelias (2008) the number and size of batches are now included as decision variables (material based approach) in a job shop problem whereas before they were fixed (batch based approach).

To show the richness of the modelling options developed to deal with the increasing complexity of problems, we call reference here to the well-known and widely used example: the chemical process problem proposed by Kondili, Pantelides, and Sargent (1993). As shown in Fig. 1, three raw materials (A, B and C) are required, three intermediates and two final products are produced through five stages: heating, reactions 1–3, and separation.

In their work Kondili et al. (1993) have solved this problem by applying a discrete time representation model with the following assumptions: process times are invariable and independent of size, products of the same task can arrive in different times, all transit/changeover times are included into process times or neglected. Other models have been successfully applied to the same problem by Maravelias and Grossmann (2003) and Ierapetritou and Floudas (1998) with the assumptions that products of the same task arrive in the same time, and process times can be size-dependant. They applied a global and a unit-specific time event based model respectively. Pan, Li, and Qian (2009) reused the Kondili problem and applied six different models successfully. They also tested the problem with different objectives: makespan minimization and profit maximization respectively. They performed a comparative

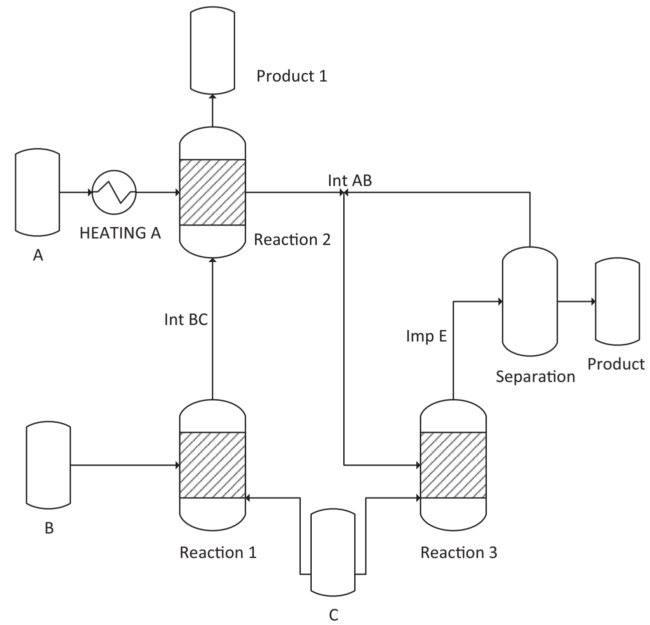

Fig. 1. Example of Kondili et al. (1993).

analysis of this example, showing that numerous models are available to the same problem, without a unique "best one".

Table 1 summarized some of the above research studies but the list is far from being exhaustive, not mentioning yet the different possible solving methods: Hegyhati and Friedler (2011) precise that most of the published approaches are based on a mixed integer programming formulation and they analyze the combinatorial nature of batch scheduling problems. Therefore, this mere example underlines that in order to choose between modelling options and solving methods strategies, we need a decision support system, especially as the process and manufacturing industries gather a wide range of applications leading to a variety of processing characteristics and constraints to take into account. Accordingly, the number of research papers has increased to develop new model options and numerical methods to account for these specific constraints, reinforcing the need for a decision support system. The goal of this decision-support system is to help user in choosing the modelling options and the appropriate solving methods thanks to a detailed description of the faced scheduling problem. But in front of the difficulty to build such a system and the huge interest of the process engineering community to mathematical approaches, in the rest of the study we voluntary limit this work to a decision support dedicated to mathematical approaches.

Zhou, Son, Chen, Zhang, and MA (2007) have explained that the model development is a time consuming and knowledge intense activity that require skills from three different fields: domain expertise, modelling and simulation, and implementation. For the development of models, Meyer (2004) has formalized a process commonly used in process system engineering (PSE), Fig. 2. This process clearly demonstrates that the development of a model is an activity which relies on the skills and experiences of a working group composed of experts with diverse background and knowledge: domain of application (for instance physics, chemistry, biology), PSE, computer science. Indeed, to facilitate the resolution it is often necessary to realize a preliminary work for structuring the system of equations or to give it a specific form to easy initialization and have a stable, accurate and robust resolution. Moreover, as Zhou, Chen, He, and Chen (2010) have underlined most of simulation models developed are often customized and specific ones