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Using genetic programming and simulation to learn how to dynamically adapt the number of cards in reactive pull systems

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ABSTRACT

Pull control systems are now widely used in many types of production systems. For those based on cards, determining their number is an important issue. When the system is submitted to changes in supply and demand, several researchers have demonstrated the benefits of changing this number dynamically. Defining when and how to do so is known as a difficult problem, especially when such modifications in customer demands are unpredictable and the system behavior is stochastic. This paper proposes a Simulation-based Genetic Programming approach to learn how to decide, i.e., to generate a decision logic that specifies under which circumstances it is worth modifying the number of cards. It aims at eliciting the underlying knowledge through a decision tree that uses the current system state as input and returns the suggested modifications of the number of cards as output. Contrarily to the few learning approaches presented in the literature, no training set is used, which represents a major advantage when real-time decisions have to be learnt. An adaptive ConWIP system, taken from the literature, is used to illustrate the relevance of our approach. The comparison made shows that it can yield better results, and generate the knowledge in an autonomous way. This knowledge is expressed under the form of a decision tree that can be understood and exploited by the decision maker, or by an automated on-line decision support system providing a self-adaptation component to the manufacturing system.

1. Introduction

Pull production control systems aim at managing finished inventory and work-in-process (WIP) in order to satisfy customer demands in time while minimizing the related costs in the manufacturing process. They are generally based on the Just-In-Time (JIT) philosophy, whose objective is to deliver the right parts, at the right time, at the right place, and in the exact amount needed. The most well-known pull systems are probably Kanban (Lage Junior & Godinho Filho, 2010; Monden, 1981) and Constant WIP (ConWIP) (Prakash & Chin, 2014; Spearman, Woodruff, & Hopp, 1990), where production is allowed only upon the reception of authorization cards, used to control all the manufacturing process (Bollon, Di Mascolo, & Frein, 2004; González-R, Framinan, & Pierreval, 2012). The former uses a loop of cards at each stage of the process and the latter is simpler, since it considers the whole process as a single-stage system in which each part is pushed through the system as soon as its production is allowed at the input of the system by a card. These two types of system are illustrated in Fig. 1. One important issue of such pull control systems is to determine the appropriate number of cards for each loop. This problem has been widely addressed using optimization approaches, which aim at finding those numbers, so as to maximize given performance objectives (see for example (Paris & Pierreval, 2001)). Unfortunately, the use of a fixed number of cards implies a stable production environment (Framinan & Pierreval, 2012), which is often not the case. Indeed, today the market changes and unpredictable fluctuations in demand occur. To face these major difficulties, numerous studies have proposed to dynamically adapt the number of cards, in order to render so-called token-based pull manufacturing systems (González-R et al., 2012) capable to adapt themselves to new operating conditions (Takahashi, Morikawa, & Nakamura, 2004; Takahashi & Nakamura, 1999b).

Despite the widespread literature related to this problem, the development of adaptive control systems, whose purpose is to change dynamically the number of cards in each loop of the system, still represents a significant research challenge. Indeed, the stochastic nature of pull manufacturing systems and their complex dynamic behavior render the use of mathematical models to evaluate their performance not relevant if one wants to avoid restrictive assumptions. Moreover, determining when to add or remove

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cards in real time is a problem that is difficult to address using optimization since the system state evolves along time often in a non-predictable manner. In such cases, decisions are frequently not taken in advance, but in real time, often using heuristic strategies, which can be more or less complex, and more or less dependent on the state of the system (Coffman, 1976).

Artificial intelligence (AI), in particular machine learning, can be very useful to extract the necessary knowledge to make efficient decisions about adding or removing cards, and to make it accessible to decision makers, in view of their everyday use. Indeed, we are interested in learning rules of the following form:

If $\langle$conditions about the current system state$\rangle$,
Then $\langle$add new cards$\rangle$ or $\langle$remove cards$\rangle$ or $\langle$do nothing$\rangle$.

Unfortunately, learning require the use of suited training sets, which turn out to be quite difficult to obtain for real-time decisions (Mouelhi & Pierreval, 2007). Providing examples or observations about the effect of a given decision, taken at time t, when the system is in a given state is generally extremely difficult since good or bad performances are induced by a sequence of coherent decisions taken at different instants of time. Moreover, the efficiency of decision sequences is generally difficult to measure on the very short term. As a consequence, one of the motivations of this research is to suggest a learning approach capable of generating decisions strategies, not requiring the use of such training sets, and that can be used for various pull control systems, without restrictive assumptions. In this respect, we propose to combine Genetic Programming (GP) and simulation, so that the knowledge needed to make efficient decisions is directly extracted from simulation runs. To the best of our knowledge, the joint use of these two techniques has not yet been studied in the literature to solve this kind of problem. The knowledge learnt can be implemented in the pull control system to determine when changes should be made and how many cards should be added or removed, or communicated to production managers who wish to improve their everyday practice.

The rest of this article is organized as follows. Section 2 analyzes the literature on adaptive pull control systems, and emphasis is put on articles concerned with learning techniques. Section 3 introduces our Simulation-based Genetic Programming approach. Section 4 provides an example adapted from the literature on adaptive ConWIP control, to which our approach is applied, and our results are discussed. Finally, our conclusions and research directions are drawn in Section 5.

2. Related research

Many articles have been devoted to the improvement of pull control systems and several states of the art published (Akturk & Erhun, 1999; Bollon et al., 2004; Di Mascolo, Frein, & Dallery, 1996; González-R et al., 2012; Lage Junior & Godinho Filho, 2010; Prakash & Chin, 2014). In the eighties, Monden (1981) underlined that Kanban systems should be used only in presence of small fluctuations. It is now well recognized that, when there are frequent and wide variations in supply and demand, then it may not be efficient to size the amount of WIP circulating through the system using a constant number of cards (Takahashi & Nakamura, 1999b). As a consequence, the question of how to design pull control adjustment mechanisms has been raised and addressed by several researchers, who have suggested so-called flexible (Gupta & Al-Turki, 1997), reactive (Takahashi & Nakamura, 1999b), or adaptive pull control systems (Tardif & Maaseidvaag, 2001). Their common property is to redesign the control system by adding or retrieving cards, when it turns out to be relevant, so that the system can remain globally efficient on a long period of time, even with an unpredictable changing demand.

Among the articles related to card controlling, a number of them assume the availability of production plans or forecasts, related to periods of time, which allow them to use optimization methods when assigning the cards. This is for instance the case of Rees, Philipoom, Taylor, and Huang (1987), who developed an eight-step procedure based on the statistical estimation of the observed lead-time density function during the past period and on demand forecasts of the next period, which they assume to be obtained using standard company forecasting procedures. These two types of information are used to determine the percentage of the time that different numbers of cards will be needed during the next period. As demand and costs are considered deterministic once estimated, an analytical method is used to evaluate the different possibilities. The number of cards providing the minimum holding and shortage costs is selected and implemented for the entire period. In such approaches, changes in the number of cards are not decided in real time: they use periodic rather than dynamic adjustments of cards.

In the same vein, Gupta and Al-Turki (1997) proposed a Flexible Kanban System to minimize inventory and backlog. Their system is initialized with a number of permanent cards and additional cards can be added to compensate for the variation in processing times and anticipated surge in demand, assuming that the demand is known a given time in advance (equal to the duration of the planning period). In their simple algorithm, an analytical computation of the time required to fulfill the demand, based on processing time mean and standard deviation, determines the eventual increase in the number of cards and the exact time to do it. The additional cards are retrieved at the end of the considered planning period.

Guion, El Haouzi, and Thomas (2011) and Talibi, Bril El Haouzi, and Thomas (2013) also assume that a production plan for the coming period is available. They use a heuristic based on an estimation of the finished stock level and on replenishment delays of the kanban loop to detect possible future shortages (dates and missing quantities). This allows them to determine the number

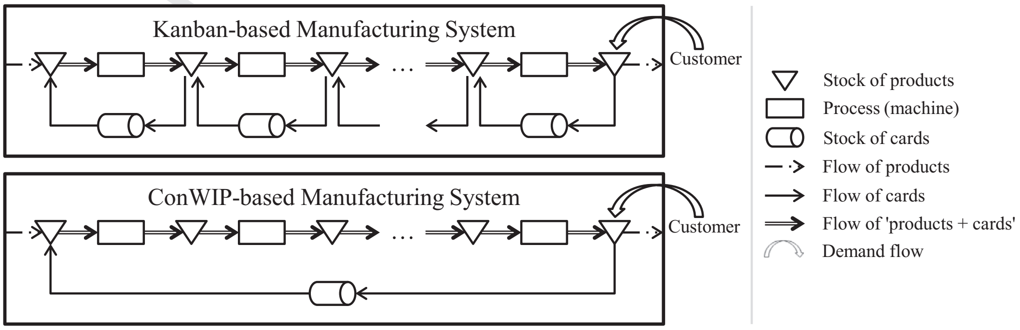

Fig. 1. Kanban and ConWIP pull control systems.

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