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Adaptive card-based production control policies

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ABSTRACT

This article is about adaptive production control policies based on Kanban and CONWIP. First, it is shown that the Extended Kanban and the Generalized Kanban control policies, which have not been considered up to now in the relevant literature, actually fall within the category of adaptive card-based production control policies. Moving further, two novel adaptive production control policies are proposed, the Adaptive Generic Kanban and the Adaptive Extended Kanban. The proposed policies along with Extended Kanban and Generalized Kanban are compared in a simulation study to five existing adaptive approaches for controlling Kanban and CONWIP systems. It is noted that a comparative evaluation of these five existing adaptive policies is also absent from the relevant bibliography. The set of nine policies is tested in a tri-objective optimization problem, i.e. minimizing mean Work-In-Process, mean finished goods inventory and mean length of backorders queue under three different demand patterns. A multi-objective evolutionary algorithm is used to find optimal or near-optimal parameters for the control policies, and the resulting Pareto fronts are compared in terms of several metrics. In this experimental trial, the Extended Kanban, the Generalized Kanban and Adaptive Extended Kanban policies achieve the highest ranking.

1. Introduction

Card-based production control policies, with their main representative being Kanban (Krishnamurthy, Suri, & Vernon, 2004; Ohno, Boh, Nakade, & Tamura, 2016), have been studied extensively over the years. In this type of control mechanisms, production processes are coordinated with the use of signals called kanbans or production authorizations or simply cards. The performance of policies that belong to this class depends heavily on the design parameters, i.e. the fixed (constant) number of cards. In highly volatile systems, e.g. in cases where the demand fluctuates considerably, it might not be the best practice to keep the number of cards fixed. Therefore, various authors have proposed control policies that dynamically adjust the number of cards in response to environmental changes (Renna, Magrino, & Zaffina, 2013). Card-based policies of this type are known as "adaptive" and they have the potential to achieve, e.g. less backorders and higher throughput, compared to standard control policies in dynamic environments.

There are no published results which indicate that some existing adaptive card-based policy is optimal for one or more performance metrics. Even more, there are also no conclusive results which suggest that some adaptive card-based policy is *generally* better than alternative existing adaptive policies. Up to now, the literature on adaptive card-based pull control policies has disregarded Generalized Kanban (Buzacott & Shanthikumar, 1993) and Extended Kanban (Dallery & Liberopoulos, 2000) because they have been considered to be standard card-based control mechanisms. Finally, there is no published experimental study where more than two or three adaptive control policies are systematically compared in a multi-objective framework.

Given the aforementioned observations, the authors were motivated to:

- Bullet provide evidence that the Generalized Kanban and the Extended Kanban control policies actually fall within the category of adaptive card-based systems, through a careful examination of their mechanics (the reader is referred to Sections 2 and 3). This has both theoretical and practical significance because these two control mechanisms can be used for benchmarking purposes.
- Bullet propose two novel adaptive production control policies, the Adaptive Generic Kanban and the Adaptive Extended Kanban. The first proposed policy is based on the Generic Kanban mechanism (Chang & Yih, 1994; Gonzalez-R, Framinan, & Pierreval, 2012) and extents the card adjusting method of Framinan, Gonzalez, and Ruiz-Usano (2006). The second

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proposed policy is loosely based on the Extended Kanban policy, in the sense that the card/demand propagation scheme of Extended Kanban is applied not at the production stage level but at the production system as a whole. Similarly to other adaptive production control policies, a queue with extra cards is maintained but unlike all existing approaches the extra cards are not released directly to the shop floor but to an intermediate queue of cards that are not attached to parts.

Bullet conduct a comparative study that involves an extensive set of nine adaptive production control policies; five existing (the policy of Tardif and Maaseidvaag (2001), two policies by Framinan et al. (2006), and two policies by Renna et al. (2013)), two newly proposed and two existing but unidentified so far (Extended Kanban and Generalized Kanban). All policies are: (a) optimized or meliorated in respect to three conflicting objective functions, with the use of a multi-objective evolutionary algorithm, (b) tested on various dynamic environments, and (c) compared in terms of several metrics for assessing Pareto fronts. To the authors' knowledge, this is the most systematic and broad comparison of adaptive control policies and provides insights that were not available up to now.

The structure of this article is the following. In Section 2 a survey of related publications is presented. In Section 3 the analysis of the Extended Kanban and the Generalized Kanban policies is given along with evidence for characterizing them as adaptive. In Section 4 the two novel control policies are presented. In Section 5 the results of the simulation experiments are presented together with the analysis of the findings. Section 6 contains the concluding remarks, the limitations of this research and some directions for future research.

2. Related work

The policies examined in this research were selected on grounds of the following criteria: (a) they are heuristic, (b) they make limited assumptions regarding the properties of the underlying production system, (c) they can be applied and tested in the same context, (d) they can be easily implemented in production systems of any arbitrary size. Furthermore, we restrict our attention to adaptive policies that adjust only the number of cards and not other parameters such as capacity and so forth.

The Extended Kanban mechanism was initially proposed as a hybrid Kanban/Base Stock control policy (Onyeocha, Khoury, & Geraghty, 2015). The Generalized Kanban policy was initially introduced as a generic framework that would encompass standard pull-type mechanisms such as Kanban, Base Stock, CONWIP etc. In Section 3, the Generalized Kanban and the Extended Kanban are described and analyzed in detail.

The approach of Tardif and Maaseidvaag (2001) is based on the CONWIP system (Lee & Seo, 2016; Spearman et al., 1990). The policy is completely characterized by four integer parameters; the initial number of cards, the number of extra cards, and the release/capture thresholds. Decisions on releasing or capturing extra cards into the shop floor are triggered by customer arrivals. Upon an arrival event, the policy checks the number of available extra cards, the finished goods inventory, the queue of backorders and makes a decision according to the release/capture thresholds.

Framinan et al. (2006) present two adaptive policies based on the standard CONWIP system. According to the first policy, the event that triggers the extra card release/capture decisions is the completion of a part and these decisions are based on the number of currently available extra cards and the system's throughput. According to the second policy, the decision-making epoch is the arrival of a customer and release/capture actions regarding extra cards depend on the number of currently available extra cards and the customer service level. Together with the initial number of cards and the number of extra cards, the target for the monitored quantity (service level or throughput) is the only other control parameter of this policy. In Gonzalez-R, Framinan, and Ruiz-Usano (2011), an approach based on response surface methodology is utilized in order to set these parameters.

The approach of Renna et al. (2013) is time-driven, it allows for more than one extra cards to be released/captured in a decision-making epoch, and it allows the number of cards that circulate in the shop floor at some time point to be less than the initial number of circulating cards. The method of Renna et al. (2013) relies on two moving averages that monitor the time series of demand arrivals. Their method is applied to a CONWIP system, and two Kanban systems where the changes in the number of cards in each stage occur in a centralized and decentralized manner, respectively. In this paper only the CONWIP-based and the centralized Kanban-based policies are considered primarily because of the results reported in Renna et al. (2013) which indicate that the former policies outperform the decentralized system. The policies of Renna et al. (2013) are demanding in respect to the number of control parameters that need to be tuned.

Several other adaptive card-based production control policies have been proposed in the bibliography but they are not considered in this study largely because they are rather singular as they are not directly comparable to more than two or three alternative adaptive mechanisms. Moreover, they do not meet the criteria defined in the beginning of Section 2.

In the STC policy by Hopp and Roof (1998) there is a warm-up period of n completed jobs after each change in the number of circulating cards and if a specified condition is met then the capacity of the manufacturing system is revised. The adaptive CONWIP approach of Korugan and Gupta (2014) is singular as it pertains to a hybrid production system with two manufacturing lines, one that produces parts from raw materials and one that remanufactures returned parts. The adaptive pull approach of Takahashi, Doi, Hirotani, and Morikawa (2014) is also applied to remanufacturing systems. The control chart-based method (Takahashi, 2003; Takahashi & Nakamura, 2002) makes a strong assumption that the appropriate number of cards associated to specific levels of mean inter-arrival times is known beforehand. The Flexible Kanban System by Gupta, Al-Turki, and Perry (1999) assumes demand information known in advance and a planning period. The approach of Liu and Huang (2009) relies on the assumption that the production stages have only one machine and that they behave as M/G/1 queues. Sivakumar and Shahabudeen (2008, 2009) offer a minor extension of the approach by Tardif and Maaseidvaag (2001) to a multi-stage production system. Belisario and Pierreval (2015) and Renna (2015) use genetic programming and fuzzy control to obtain adaptive pull-type control policies, respectively. They are beyond the scope of this paper in the sense that the resulting control policies are the outcome of optimization algorithms and soft computing methods.

3. Analysis of the Generalized Kanban and the Extended Kanban policies

In this section and its sub-sections the Generalized Kanban and the Extended Kanban policies are described and evidence is provided that facilitates their classification in the family of adaptive card-based production control policies.

3.1. Generalized Kanban: how it works

Fig. 1 shows the queueing network model of a Generalized Kanban system with three production stages in tandem. The