Variation of CONWIP Systems

Joshua Prakash, and Chin Jeng Feng

Abstract—The paper describes the workings for four models of CONWIP systems used till date; the basic CONWIP system, the hybrid CONWIP system, the multi-product CONWIP system, and the parallel CONWIP system. The final novel model is introduced in this paper in a general form. These models may be adopted for analysis for both simulation studies and implementation on the shop floor. For each model, input parameters of interest are highlighted and their impacts on several system performance measures are addressed.

Keywords—CONWIP, hybrid CONWIP, mixed CONWIP, multi-product CONWIP.

I. Introduction

THE main function of WIP is to decouple parts among machines running at different capacities, set-up times, and failure rates. An excessive amount of WIP prolongs lead time, whereas an insufficient amount of WIP results in the occasional starving and blocking of machine during production [1] [2]. Thus, the pertinent question is how to maintain the minimum amount of WIP in a production system. One way is to move WIP only when needed, rather than pushing it on the next machine. This is the essence of the pull system. Specifically, a preceding machine produces parts only after receiving a request from its succeeding machine for the immediate replacement of items removed from the stock. Therefore, the flow of information is in the opposite direction of the material flow [3]. Lean practitioners often use cards to signal the production for the next batch of material [4].

One such pull system commonly used is the constant work-in-process (CONWIP) system. The principle of CONWIP, introduced by [1], is to limit the inventory level at a production line by the circulation of CONWIP cards. When a batch of parts reaches the end of the line, a card is sent to the beginning of the line to signal the processing of the next batch of parts. The part batch is pulled into the first workstation, and then pushed to subsequent workstations. As such, the number of parts in the line is limited by the number of cards present.

CONWIP systems have been applied in production environments based on real-time application, most recently by [5] and in simulation studies by [6] [7] and [8]. CONWIP systems have been adopted in assembly environments as well [9] [10]. One common element among the systems described in these papers is the absence of integration with other form of pull systems and the absence of separation of product types. The fact remains that the use of pure CONWIP system alone might not cater to all production environments.

The hybrid system that combines push and pull systems emerged as a consequence of this. Hybrid systems can be divided into three categories [11] [12]: vertically integrated hybrid systems (VIHSs), horizontally integrated hybrid systems (HIHSs), and parallel integrated hybrid systems (PIHSs). VIHS typically consists of an upper level push system and a lower level pull system. HIHS focuses on a single level, where the production workstations operate via push system and pull system, while succeeding assembly process operate via pull system. In PIHS, both push and pull system exist in one level despite dealing with independent types of products.

While the hybrid system has proven feasible application-wise [13], studies have shown that another form of such variation imposed significant effect on performance of a production line. This variation is an extension of PIHS, where several pull systems exist in one level, each operating with independent product types. We are rather interested in systems where CONWIP system operates for each product type. In this multi-product CONWIP system, cards are dedicated to specific product types. This is in contrast to the original CONWIP system, where cards are shared between product types. Such CONWIP systems have been tested widely in simulation studies [14] [15] [16].

For systems comprising only of pull systems, [17] described such systems as a mixed pull system or c-type pull system. In such systems, the products to be processed are categorized by volume. The category representing infrequent orders is regulated by a special pull system with limited inventory capacity. This mixed pull systems runs in parallel, side-by-side horizontally, throughout an entire value stream. In this aspect, we are interested in a mixed pull system, where CONWIP system regulates either categories of the production volume. Simulation studies of such systems have been described by [18] and [19].

This paper aims at presenting the variations of CONWIP system noted above. The systems are presented with respect to a common production model, developed specifically for this study. The models are drawn based on examples from [20]. Within each variation, several issues of interest are addressed, and their impacts on system performance are discussed. It is intended that the paper provides readers with deep understanding on current systems developed, as well as paves way for further development of the CONWIP system.

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II. Description of Manufacturing Process

The manufacturing processes included in the present study are denoted as MP. The MP represents an unbalanced and asynchronous system that consists of four distinct stages, denoted individually as D1, D2, D3, and D4. D1, D2 and D3 each consists of one machines. Four buffers, namely, B1, B2, B3, and B4, are installed as input storages. B1, B2, and B3 are the input storages for D1, D2, and D3, respectively, whereas B4 functions as the finished goods storage.

The product family in consideration is p, with three product types going through the MP, namely p_1, p_2, and p_3. Of the three, p_1 falls under the category of high-runner (HR), while p_2 and p_3 falls under the category of low-runner (LR). High-runner denotes products having a constantly high demand, and low-runner denotes products with orders arriving occasionally and in relatively inconsistent quantity.

III. Annotations and Symbol Description

Fig. 1 describes the system elements used in subsequent figure, and the annotations in the figures are denoted separately below.
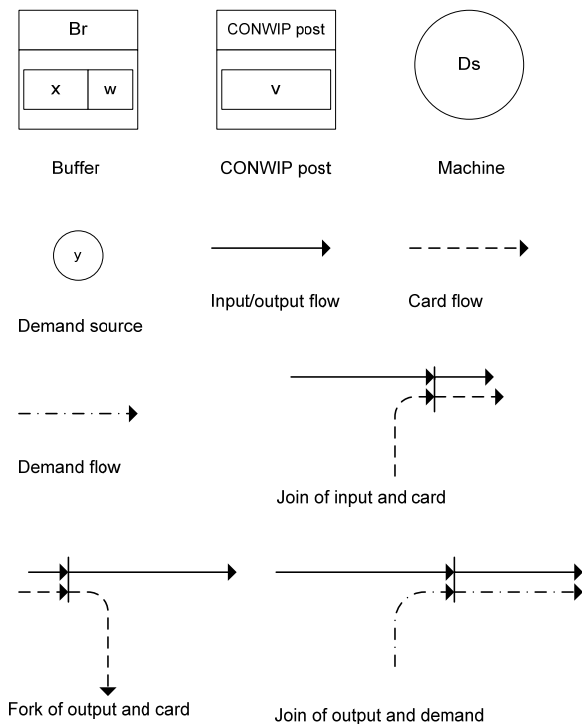

Fig. 1 Card and part batch movement

$$r = 1, 2, 3, 4$$
$$s = 1, 2, 3$$
$$x = \text{buffer storage capacity}$$
$$= \infty$$
$$w = p, p_1, p_2, p_3, LR, HR$$
$$v = \text{card storage capacity}$$
$$= n_c^{p}, n_c^{p1}, n_c^{p2}, n_c^{p3}, n_c^{LR}, n_c^{HR}$$

$$y = p, p_1, p_2, p_3, LR, HR$$
$$n_c^{p} = \text{number of } p \text{ CONWIP cards}$$
$$n_c^{p1} = \text{number of } p_1 \text{ CONWIP cards}$$
$$n_c^{p2} = \text{number of } p_2 \text{ CONWIP cards}$$
$$n_c^{p3} = \text{number of } p_3 \text{ CONWIP cards}$$
$$n_c^{LR} = \text{number of } LR \text{ CONWIP cards}$$
$$n_c^{HR} = \text{number of } HR \text{ CONWIP cards}$$

IV. System Description

A. Basic CONWIP System

In the basic CONWIP system, p_1, p_2, and p_3 share a set of CONWIP cards. Upon arrival of demand of one batch of p_1, one batch of finished goods of p_1 is withdrawn from B4. When this happens, the CONWIP card attached is returned to the B1 and attached to a p_1 batch. The batch is pulled to D1. When processing completes, the batch is pushed to B2. The batch is then pushed to D2. This proceeds to downstream workstations until the batch reaches B4. The cycle repeats upon withdrawal of finished goods. The cycle is identical for p_2, and p_3. Refer to Fig. 2.

B. Hybrid CONWIP-push System

In the hybrid CONWIP system, p_1 follows the CONWIP system, while p_2 and p_3 follows the push system. p_1 possess its own set CONWIP cards. The cycle for p_1 resembles that in basic CONWIP system. Upon arrival of demand of one batch of p_2, a p_2 batch is pulled from B1 to D1. When processing completes, the batch is pushed to B2. The batch is then pushed to D2. This proceeds to downstream workstations until the batch reaches B4. This batch fulfills the demand of p_2. The cycle repeats upon withdrawal of finished goods. The cycle is identical for p_2, and p_3. Refer to Fig. 3.

C. Multi-product CONWIP System

In the multi-product CONWIP system, p_1, p_2, and p_3 each possess their own set CONWIP card. The cycle of p_1, p_2, and p_3 resembles that of the basic CONWIP system. Refer to Fig. 4.

D. Parallel CONWIP System

In the parallel CONWIP system, p_1 possess a set of HR CONWIP cards, while p_2 and p_3 share a set of LR CONWIP cards. The cycle of p_1, p_2, and p_3 resembles that of the basic CONWIP system. Refer to Fig. 5.

V. Evaluation of System Performance

A. Basic CONWIP System

One notable benefit of the basic CONWIP system, as opposed to kanban system, is the ease of implementing at the shop floor level [1]. In particular, this is beneficial in production environments where a product family is made up of many product types. On the shop floor itself, CONWIP yields superior to kanban in that WIP is not maintained for

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each part type [1]. These attributes demonstrates on the shop floor as less clutter and improved quality monitoring.

While these benefits portray that CONWIP is indeed superior, it is compared to kanban and push systems. Till date, no form of comparison has been performed on all three existing modes of CONWIP systems.

B. Hybrid CONWIP-push System

Till date, the hybrid CONWIP-push system has not been implemented. A close approximation of thee system is the kanban-MRP system, by [11]. This system has been tested both simulation wise as well as at the shop floor level.
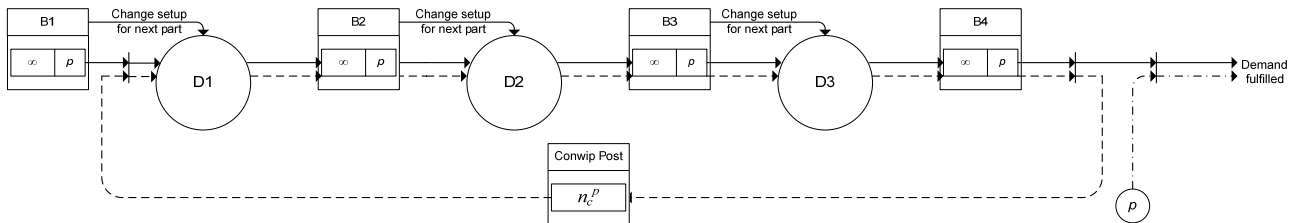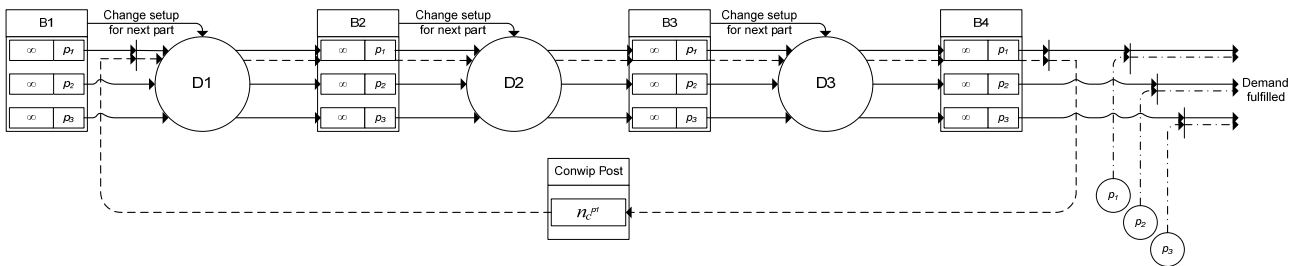

Fig. 2 Basic CONWIP system
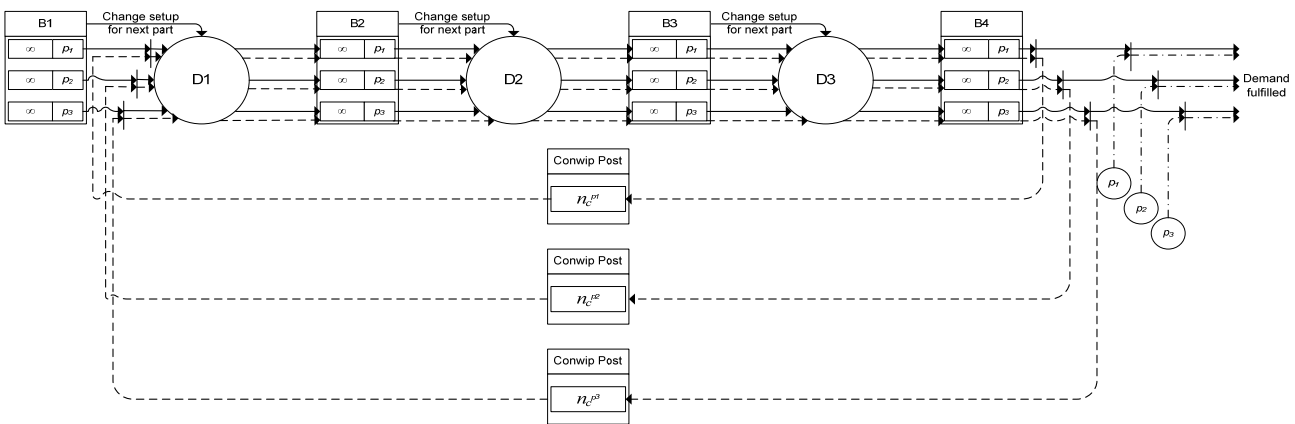

Fig. 3 Hybrid CONWIP-push system

Fig. 4 Multi-product CONWIP system

Fig. 5 Parallel CONWIP system

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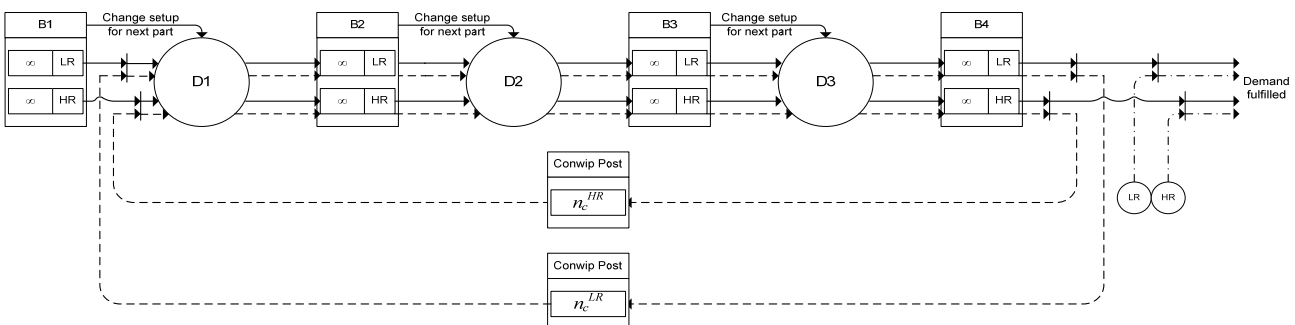International Journal of Mechanical and Mechatronics Engineering
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In the factory of study, prior to implementation of the hybrid system, the factory operates via a MRP system. Once again, comparison is performed with an existing push system. In this study, several performance improvements are noted. Lead times have improved significantly along with the service levels. It is to be noted that the derivation of such system occurs upon the fact that the use of MRP alone does not cater to shop floors with limited resources [11].

An additional study on comparison between push-pull systems and CONWIP-pull systems show that the two systems approximate each other, through several performance measure comparisons [12].

It has to be noted that there exist a significant difference between two notable hybrid systems, namely [12] and [13]. In [12], one form of pull system exists, while in [13], several pull system exists. In [13], the existence of several pull systems deems difficult to measure performance improvement. This is noted in [13], where no performance analysis is conducted.

Through existing literature it is sufficient to conclude that VIHS hybrid system generally outperforms push systems, and PIHS hybrid systems also performs as good as its variation, where two forms of pull operate concurrently.

C. Multi-product CONWIP System

The multi-product CONWIP system is first introduced by [16] through simulation studies. No papers relating to further studies of the system on shop floor has been discovered since. [16] highlights the impact of assigning CONWIP cards to each distinct product type rather that sharing of cards between them. The simulation results reveal that in cases with and without bottleneck machines, service level of the multi product CONWIP is consistently superior to a system where CONWIP cards are shared. In the light of its superiority, the next logical study is the determination of number of CONWIP cards according to the demand of each product type. While [13] provides substantial evidence that it can indeed be determined, on a practical note, this deems unfavorable in shop floors where a product family consist of large number of product types. This is noted in the basic CONWIP systems as well. In this study, no comparison is made against push systems.

D. Parallel CONWIP System

The parallel CONWIP system is a novel system that counters the problems associated with the multi-product CONWIP system. In cases where a product family consists of multiple product types, parallel CONWIP system divides these products according to their demand rate. Such systems have been tested both through simulation and at the shop floor level. In regard to simulation studies, two parallel pull systems have been tested, namely the parallel kanban-CONWIP system and the parallel CONWIP system. In [19] and [20], both systems have been studies, with the admittance of rework parts into the production line. They are compares against push systems with the inclusion of rework parts. In additions, variation of these systems with different loading rule has been studied as well. The loading rule determines the sequencing of part category entering a machine. Both studies reveal that for different performance measures, different loading rules appear superior. However, in most performance measures, the parallel pull systems appear superior to push systems. Apart from this, two reworking methods are addressed. The inclusion of rework in pull systems is paid less attention due to the fact that in lean manufacturing, defects are not acceptable, hence not addressed. It is to be remembered that the transformation for a shop floor running on a push system to a completely lean environment requires a series of incremental changes. Hence, the issue of rework requires attention. [19] and [20] also appears to be one of the few papers on pull systems to address the issue of rework.

On a different note, the parallel pull system has been tested in a factory manufacturing aircraft parts. While the system is new, it has brought about remarkable changes in a span of six months of implementation. The system implemented however, it a parallel kanban-CONWIP system. It is believed that implementation of the parallel CONWIP system will yield positive results, if deemed suitable to be implemented in a given production environment. Table I shows the improvements noted with the parallel kanban-CONWIP system noted above.

TABLE I
LEAD TIME IMPROVEMENT

Period	Work Station 1	Work station 2	Work station 3	Total lead time	Inventory turnover
Push system	11.1 days	4.4 days	2.2 days	26.6 days	9.4
Parallel kanban-CONWIP system	5.6 days	4.4 days	2.2 days	21.6 days	11.6

VI. CONCLUSION

One apparent not between all systems performance evaluated is the absence of comparison between the three existing systems. It is hoped that with the emergence of the parallel CONWIP system, a simulation study on the benefits attributed to each of the systems can be developed. In addition, future research will also yield beneficial if a set of prerequisites for each form of CONWIP system variation is able to be determined. Aside from this, the furtherance of CONWIP system in shop floors will yield beneficial, not only in the academic field, but also in the industry, if a practical approach to CONWIP systems can be developed for ease of implementation. This paper presents one novel system, with the intention that future research will enable more insightful comparisons between pull system alternatives, rather than between pull system and push system, as is typically performed in academic papers.

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