Implementation of hybrid parallel kanban-CONWIP system: A case study

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Abstract: The most common form of production control strategy in lean management is the pull system. One emerging form of pull system uses kanban and CONWIP systems to handle products with different demand patterns. Case studies have protractedly depicted the actual implementation of pull systems; however, the use of hybrid systems is rare. This paper examines the procedures involved in implementing a hybrid system in a low variety/low volume shop floor. This paper presents discussions on shop floor constraints in the proposed system and how the simplicity of a pull system is able to reduce work-in-process inventory by 23%. Guidelines for the replication of the system for similar production environments are also provided. The case study proves that pull systems can be successfully implemented in production environments that do not conform to the typical prerequisites of the kanban system.

1. Introduction

Many case studies have proven the feasibility of pull systems (Cao & Chen, 2005; Horbal, Kagan, & Koch, 2008; Mukhopadhyay & Shanker, 2005). One common element among these cases is their well-controlled process cycle times, which lead to low fluctuations. High variability in cycle times will complicate the determination of the number of kanban cards, lot size, and economic safety stock.

Employing a pull system with cycle time variation in an industry with a heavy reliance on manual tooling will be difficult. This particular environment is further characterized by stringent quality specifications,
craft work that requires visual inspection, and non-generalized operating procedures. In such a case, backorders are intolerable and a minimum finished goods inventory level is imposed by a customer.

This paper attempts to provide insights and guidelines on the implementation of a hybrid system in a low variety/low volume environment. This paper is organized as follows. Section 2 reviews literature on pull systems. Section 3 provides the methodology of study. Section 4 discusses the company background. Sections 5 and 6 discuss the development of current-state value stream map and the steps executed, respectively. Section 7 discusses the problems encountered and solutions used. Section 8 concludes.

2. Literature review
A push system is a form of production control wherein a product is produced by a workstation that strictly follows a predetermined schedule regardless of immediate downstream needs. A push system is usually implemented to use the processing capacity of a factory (Burke & Wilks, 2006). This system allows individual workstations to exploit different operating capacities. Hence, the workload assignments in each workstation are based solely on capacity; this setup ignores the possibility of starvation and blocking. Push system also neglects the additional costs accrued by transportation, storage, and staffing in the long term (Womack & Jones, 1996).

By contrast, a pull system is a form of production control wherein a product is produced by a workstation according to its immediate downstream needs. In a pull system, waste elimination is the essence of production planning (Jacobsen, 2011) because any product delivered by a workstation regardless of immediate downstream needs is considered waste. However, this strategy is unfavorable in a production environment with significant setups (Spearman, Woodruff, & Hopp, 1990). In the following literature, several notable pull systems are discussed.

Toyota Motor Corporation pioneered the use of kanban in its production environment as one of the methods to control the use of limited resources. In kanban, cards are used to initiate production between workstations. When certain parts are required from a particular workstation, card(s) is/are passed to its immediate upstream workstation to fulfill that need (Liker, 2004). In several cases, the modification of the original kanban system serves production environments with specific needs. The adaptive kanban system of Tardif and Maaseidvaag (2001) is applied to production environments with varying part batch sizes. The push–pull system of Huang and Kusiak (1998) is applied to production environments wherein each production or assembly workstation operates on either a push or pull system.

Other forms of pull systems have also emerged. However, the capabilities of the modified kanban system are still insufficient to cope with the stringent requirements of a production environment. The CONWIP system by Spearman et al. (1990) was developed to include scrap loss or job orders with short production runs. In practice, when certain parts are required at the end of a line, card(s) is/are passed to the beginning of the line to fulfill that need. CONWIP system limits WIP inventories within a line, rather than between workstations, as in the case of the kanban system.

Integrating both push and pull system is also a viable option. A vertically integrated hybrid system has two levels, namely, an upper level push system and a lower level pull system (Cochran & Kim, 1998). A horizontally integrated hybrid system (HIHS) consist of one level only; a portion of production workstations operates on a pull system, whereas remaining workstations operate on a push system (Cochran & Kaylani, 2008). A parallel integrated hybrid system (PIHS) has one level; both push and pull systems operate in parallel with independent product types (Cheikhrouhou, Hachen, & Glardon, 2009). Several push and pull systems may exist in a push–pull system, whereas only one push system and one pull system exist in HIHS. Integrated systems require adopting a holistic view to ensure the individual systems can work well as a unit (Pham, Pham, & Thomas, 2008). Failure to address the constituent elements (e.g. point of integration between push and pull systems) can cause the entire system to function as a push system.
Literature on pull system modeling and simulation is rich and can be used to build and enhance theoretical understanding. However, literature on the implementation and comprehensive coverage of case studies are limited. Mukhopadhyay and Shanker (2005) describe the implementation of the original kanban system, which was introduced to a continuous production line of a tire manufacturing plant. The case study describes the intricacies involved in the detailed steps of using kanban, 5S, and SMED on the shop floor. Other cases that implemented the kanban system have also been described in literature (Araya, 2012; Gross & McInnis, 2003; Li, 2009).

Slomp, Bokhorst, and Germs (2009) describe the implementation of the CONWIP system. They applied the CONWIP system, together with the first-in-first-out (FIFO) loading rule, to a switchgear-manufacturing company. Their results show that this approach is feasible. The paper illustrated the design and phased-implementation of a system in a “built-to-ship” production environment. Ryan, Baynat, and Choedineh (2000), Huang, Wang, and Ip (1998) and Cao and Chen (2005) discuss other CONWIP implementation cases. Although many practical cases prove that pull systems are effective, no study has investigated the implementation of a modified kanban and hybrid system.

Another issue that has arisen is the implementation sequence of lean principles. Åhlström (1998) deduces the implementation principles on the basis of a case study over the span of two and a half years. In this study, lean principles are implemented in apparent sequences, but management efforts and resources need to be devoted for a set of principles in parallel. Li (2010) investigates the coordination among layout reconfiguration, quality improvement, and setup time reduction to adopt the CONWIP system in job shops. Simulations are used to coordinate these factors in a model obtained from literature and known manufacturing processes. The simulation results are used to derive guidelines for reforming traditional job shop practices and progressing through layout reconfiguration to realize the benefits of a CONWIP system. In certain cases, the implementation sequence of lean principles is required for a specific product type rather than a substantial fraction of the shop floor activity. The case study presented examines the implementation steps for a hybrid system. The hybrid system employed is an extension of PIHS, wherein two forms of pull systems, namely, kanban and CONWIP systems, operate in parallel for two independent product types within the same product family.

3. Methodology
An implementation methodology explores the practicality of a solution developed from simulation studies. In the absence of such a methodology, inaccuracies overlooked during simulation studies may result in a magnified flaw in future pull system research. Thus, this paper also aims to contribute a sound methodology that will benefit future simulation studies.

The method used in this study consists of the “plan-do-check-act” successive cycle. Such a method is used as it is a widely adopted process improvement plan and bears concurrency with principles of lean manufacturing (Rother, 2009). In “plan,” value stream mapping (VSM) is a tool that assists in understanding the flow of material and information as a product travels through the shop floor (Rother & Shook, 1999). VSM is selected as part of the methodology because it visualizes and communicates the flow of processes effectively. In “plan,” one crucial task is identifying the root cause of the problems observed from the current state VSM. This identification also aids in determining the subsequent improvement steps as dictated in the “do” stage. In “do,” the improvement steps as identified in the “plan” phase, is materialized. Within this phase itself, the improvements steps are carried out in a structured and sequential manner in order for the team members involved are able to maintain the system over the long run.

In “check,” the performance of the new process is measured. Problems that arise are investigated and a set of corrective actions are developed and implemented. This requires a feedback to the “do” phase, where once implemented, the system is checked and refined until no short-term problems are encountered. This gives rise to the “act” phase, where the cycle repeats at a finer scope at each successive run until the system exhibits acceptable performance. Figure 1 depicts the flow of the methodology. Note that in Figure 1, the steps are presented in accordance with the improvement
steps in the subsequent sections. This intends to give readers an entirety of the improvement process and feedback where necessary.

4. Company and project background

Company X is a supplier of composite subassemblies to a well-known commercial aircraft. Production began in early 2009 in a 242,000 square feet facility. The production operates 52 weeks a year, five days a week, and one shift a day, with an average of 8 h per shift (overtime for backlogs). To date, company X has 250 employees and produces 13 sets of subassembled products. The pilot project is led by a mechanical engineer who is also the lean engineer of the company. Regular team members consist of three research students from a local public university and five stage leaders from each production stage. Weekly meetings among the mechanical engineer, research students, and stage leaders are held to discuss the progress and milestones of the project.

To introduce the pull system to the shop floor, product $p$ is selected as a pilot project. $p$ is one of the subassembled composite panels located at the underside of the aircraft wing. Reasons for the selection of $p$ as pilot include its relatively small size ($28\text{ in} \times 28\text{ in}$/panel) compared with other product types, its relatively small pack size, a stable supply of raw composite panels. A pack size is one set containing two non-identical panels; one for the right-hand wing and one for the left-hand wing. $p$ contains four product varieties, namely, $p_1$, $p_2$, $p_3$, and $p_4$, each with different demands.

5. Development of the current-state value stream map

Demand forecast is received one year in advance and revised two months before the scheduled shipment. The revised schedule will be sent to three production stages, namely, subassembly, paint
shop, and final assembly. This schedule finalizes a weekly raw material delivery schedule to inbound sections. Finished goods are packed and stored in the outbound section. Raw materials are delivered from inbound sections to subassemblies by using a reorder point system. When a minimum of four sets are present in the sub-assembly, the inbound section begins replenishment by delivering additional six sets. Other items follow a similar process.

The processes in each panel in a set are identical. The difference lies within their work content. In a subassembly, the panels undergo five processes, namely, in-jig, out-jig, extended curing, out-jig wet, mild curing, and touch-up. These stages involve hole drilling, fitting insertion, sealant fixing, air curing, and inspection. Subsequently, the panels are sent to the paint shop, where the panels undergo five processes, such as part preparation 1, primer coating, part preparation 2, top coating, and touch-up. These stages involve hole filling, oven curing, masking, primer coating, oven curing, top coating, additional curing, demasking, touch-up, and inspection. Finally, the panels are sent to the final assembly, where the remaining components are assembled prior to final touch-up and inspection. The workstations in the sub and final assemblies are arranged in a dedicated work-cell layout. Shared facilities in the paint shop constitute a generalized machine layout. The difference among $p_1$, $p_2$, $p_3$, and $p_4$ lies in the paint shop, wherein each product variety receives different top coating and touch-up colors. Cycle times, WIP inventory between processes, number of operators involved, and flow of information are presented in the current-state VSM of $p$ in Figure 2.

From Figure 2, the occurrence of high WIP inventory between processes is traced to the scheduling system used. The assignment of daily production targets to successive processes initiates production to proceed regardless of downstream needs, similar to general push systems. This effect is magnified in the immediate upstream buffer of the bottleneck workstation. In-jig continues to process at its usual pace with the intention of avoiding possible starvation at out-jig because of the substantially long curing time (24 h) even when demand is low. The WIP inventories eventually accumulate between in-jig and out-jig because of the poor estimation of downstream needs. The batch production in the primer coating and top coating also waits for the right quantity before processing resumes.

The start and end of each production stage is recorded on a job card by the operator. Each set is assigned a job card. In each job card, the start and end phases recorded upon the completion of processing are not used for future planning. A more experienced operator will be able to complete a task at a shorter time than his/her peers. Disregarding this information in future planning can lead to substantial waiting time for the WIP inventory before being moved to subsequent processes. Break times are set as a pacemaker, whereby a given quantity of operations are to be completed before each break period because of the uncertainty in the start and end phases. The presence of these wastes leads to the low ratio of value-added time to non-value-added time ($\approx .15$).

The performance target established by team members is a reduction in flow time by a minimum of four days while maintaining 100% service level. The boundaries for flow time reduction ranges from fresh sets of panels delivered from inbound sections to subassembly up to completed sets of panels in the final assembly for delivery to the outbound section. Continuous flow is not favored between production stages because of relatively large distances, which diminish its effectiveness. This limitation calls for a buffer (supermarket) system to be placed between production stages. Additionally, working on one set at a time is unfavorable because material is shared between sets. In the sub and final assemblies, adhesives and lacquer are shared between two sets and paint is shared among four sets in the paint shop. Given that material cost savings for one set at a time is not justified, the current method of producing two sets simultaneously is maintained. Consequently, no addition or removal of operators is involved in all processes.

6. Phased implementation
The four phases for the implementation of hybrid parallel kanban-CONWIP system were chosen such that each phase would show certain performance advantages as well as help workers to
Figure 2. Current state VSM of p.
gradually learn the features of the system. We named the four phases: 1—system definition phase, 2—team member training and material preparation phase, 3—implementation of kanban phase, and 4—implementation of CONWIP phase.

6.1. The system definition phase
Demand of $p_1$ constitutes 90% of the total demand, whereas $p_2$, $p_3$, and $p_4$ comprise 10% of total demand. Hence, $p_1$ (high runner or HR) follows a kanban system. The takt time of $p_2$, $p_3$, and $p_4$ is 40 h/set. The inventory of $p_2$, $p_3$, and $p_4$ are not maintained because the demand does not justify stocking. With approximately equal quantities of $p_2$, $p_3$, and $p_4$ produced in any given week (i.e. $p_2$, $p_3$, or $p_4$ each has one order), $p_2$, $p_3$, and $p_4$ (low runner or LR) follow the CONWIP system.

Figure 3 depicts the flow of HR and LR in the parallel kanban-CONWIP system according to the examples obtained from Krieg (2005). When one set of HR in $B_1$ is withdrawn, the kanban card attached to HR is detached and placed at the final assembly kanban board. When a kanban card is added at this kanban board, one set of HR is pulled from $B_1$ and begins the final assembly process for quality inspection. When the processing is completed, HR is pushed to $B_2$, and the kanban card at the final assembly kanban board is attached to HR. When one set of HR in $B_2$ is withdrawn, the kanban card attached to HR is detached and placed at the point shop kanban board. When a kanban card is added at this kanban board, one set of HR is pulled from $B_2$, and begins process preparation 1 to primer. When processing is completed, processing continues with preparation 2 to inspection. When processing is completed, HR is pushed to $B_3$, and the kanban card at the paint shop kanban board is attached to HR. When one set of HR in $B_3$ is withdrawn, the kanban card attached to HR is detached and placed at the subassembly kanban board. When a kanban card is added at this kanban board, one set of HR is pulled from $B_4$, and begins process in-jig. When the processing is completed, processing continues with out-jig for touch-up. When processing is completed, HR is pushed to $B_5$, and the kanban card at the subassembly kanban board is attached to HR.

A CONWIP card is placed at the paint shop kanban board by the planning department when an order for LR is placed. When a CONWIP card is added at this kanban board, one set of HR is pulled from $B_4$ and begins process preparation 1 to primer. When processing is completed, processing continues with preparation 2 to inspection. When the processing is completed, HR is pushed to $B_5$, and a CONWIP card at paint shop kanban board is attached to HR. By following this process, the final assembly to quality inspection is performed. When processing is completed, HR is pushed to $B_6$. Upon shipment, the CONWIP card is returned to the planning department. The remaining upstream operations resemble the HR sequence.

6.2. Training of team members and material preparation phase
A computer simulation model of the future system is developed to provide insights on the functionality of the proposed system and to discuss several performance measures of interest. A visual simulation enables the viewing of material flow that is difficult to imagine. WITNESS Simulation 2007 possesses the ability to display material flow between workstations. Input order quantity and supermarket sizes vary and their effects on system performance measures, such as flow time and total WIP inventory, are analyzed. The results reveal that flow time/set remains almost constant and WIP is maintained (as long as the number of kanban and CONWIP cards is fixed) with input order quantity varying within the forecasted demand range.

To gain acceptance from the operations manager and product development engineer of $p$, an animation model is extracted from the simulation model. The animation simplifies the visual aspect of the simulation model from a layman’s perspective. Additionally, a training course on the benefits of the pull system and the required contributions of operators to the system is conducted. A manual simulation activity for operators enables a hands-on experience on the flow of cards and their effects on running individual processes. In manual simulation, a layout of the shop floor and respective locations of the kanban boards are projected onto a large whiteboard. Markers that represent each set are positioned according to the actual quantity and position for a given day. Cards are
Figure 3. Parallel kanban–CONWIP system of p.
represented by a different colored marker. The operators simulate the movement of the markers in a real time situation. Cases such as cards being transferred late and authorized processing without a card are also simulated to demonstrate their implications. Corrective actions and contingency plans are developed and imparted to the operators.

The attachment of cards to the WIP inventory is vital. The three options for card attachments are on the panels, insert as part of the job card, and on material transfer. Attachments of cards on the panels are unfavorable because it imposes on the processing operations. Attachments of cards to the job card are also not favorable because the cards are less visible and can easily be displaced from the job card. Attachments of cards to the material transfer (trolley) are considered the most favorable because when panels are transferred between operations, the material transfer set is used to ensure that the cards are constantly visible throughout the processing cycle.

The cards are 8 cm × 20 cm laminated card boards. Each card represents one set. The card is designed to contain crucial information, such as card number, product type, and card circulation region. Kanban cards are presented in blue, whereas CONWIP cards are in pink. Kanban cards between workstations are recognized with the colored strip used. Prior to issuance of CONWIP card to the paint shop, the planning department writes on a strip of masking tape stating the product type required and fixes the tape on the CONWIP card. A kanban board is placed near the point of exit at each production stage to ensure that upon supermarket replenishment, cards are placed in the allocated compartment. Card compartments that contain kanban and CONWIP cards are placed on the material transfer. Card compartment materials are also carefully selected to withstand high temperatures (maximum of 60°C) in the oven. Standard operating procedures (SOPs) depicting the transfer of cards and its relation to each operation are placed at each production stage. This procedure enables operators to understand the sequences of transfer, particularly if a new operator is involved in the card transfer. Figure 4(a) shows an example of the kanban card design. Figure 4(b) shows the kanban card with its card compartment in place. Figure 4(c) shows the placement of a kanban board in the paint shop. Figure 5 shows the subassembly SOP.

6.3. Implementation of the kanban phase
The planning department is required to send the HR weekly production plan to the outbound section. The daily demand of other production stages is triggered by individual immediate downstream production stages. The implementation is purposely planned on a low demand season to ensure the allocation of sufficient time for production readjustment during unforeseen events. Each production stage SOP is displayed close to the kanban board to assist operators in conditions for transferring kanban cards.
Figure 5. Subassembly SOP.
Each material transfer is attached with a kanban card and placed in the card compartment. The attachment of kanban cards is also performed in stages beginning from the outbound section to the inbound section. The purpose of implementing the transfer in stages is to account for manageable tasks, instead of crowding tasks in one step. A step-by-step set of tasks, goals, and milestones are created with these increment efforts.

Once the system has operated for two weeks, free cards that are constantly not in use will be removed. The presence of these cards indicates processing beyond capacity. The quantities of cards are gradually reduced to the final supermarket sizes. First, the quantity of cards at one particular supermarket is fixed at one value. Within a week, if the downstream process does not show any significant starvation with a lower WIP turnover, one card will be removed from the system in the next shift. During this transition, sets without cards are processed first in any supermarket to allow such sets to move downstream quickly and to minimize the potential interference to the kanban system. For constant starvation, root-cause investigation and later appropriate immediate improvement are proposed. If starvation remains, a card is added. This addition occurs in the paint shop to match the WIP to the batch quantity required. Table 1 summarizes the resizing of kanban cards at each production stage throughout the implementation period. Such an approach is reactive and ensures the stability to the production at the shop floor.

6.4. Implementation of the CONWIP phase

The planning department is required to send the CONWIP cards to the paint shop according to the weekly plan. Upon LR shipment, the outbound section returns the CONWIP cards to the planning department. One issue to be addressed is the loading rules in the paint shop and final assembly. HR and LR are present in both stages. FIFO is adopted in the final assembly because the required kitting is common for both HR and LR. In the paint shop, HL rule (priority to HR over LR) is adopted because of the difference in the paint used. HR uses a more common paint and is processed first; thus, HR can be completed in batches with other available product families.

7. System evaluation and improvement

Kanban cards are remained at the kanban board as long as starvation is experienced. Although the effect of starvation is magnified in such a case, starvation perpetuates the importance of maintaining a minimum quantity of sets at each workstation. This process also ensures that the kanban system implemented does not deplete over time.

Feedbacks from stage leaders and operators are subsequently collected. A number of discrepancies between the proposed and the implemented systems are observed and require rectification. The paint shop frequently experiences starvation. This delay in receiving parts leads to delays in processing and impedes the transfer of cards to upstream production stages, thereby perpetuating starvation to upstream workstations. One solution proposed involves sending cards from the paint shop to the subassembly on the basis of the anticipated work to be completed instead of the actual work to be completed. In practice, when the paint shop receives two sets from subassembly, it will instantly deliver the two cards to the subassembly while waiting for additional two sets before processing can begin. Within two weeks of implementing this system, the paint shop shows a gradual reduction in starvation.

| Week | Subassembly | Paint shop | Final assembly | Total |
|------|-------------|------------|----------------|-------|
| 1    | 10          | 6          | 6              | 22    |
| 2    | 9           | 7          | 5              | 21    |
| 3    | 8           | 8          | 4              | 20    |
| 4    | 7           | 9          | 4              | 19    |
| 5    | 6           | 8          | 4              | 16    |
Another problem encountered is that operators are often not prompt in sending cards to upstream production stages. Operators usually conduct transfers at their convenience, such as during breaks. To solve this problem, a second session of manual simulation is performed with emphasis on the effect of card-circulating rule violations. Through this simulation, the operators relented and recommitted themselves to the pull system.

Finally, the material used for the card compartments was not durable when exposed to constant temperature changes. Consequently, the card compartments were easily detached from the material handling after a period of time. A cloth-based card compartment was adopted. In addition, spare card compartments were prepared for instant replacement of damaged cards. Table 2 summarizes the improvement achieved between the current and future state systems, while Figure 6 shows the future state VSM, referring to the newly improved system.

8. Conclusion
This paper presents the implementation sequences of a hybrid parallel kanban–CONWIP system in an environment where manual labor is intensive and back order is intolerable. The first step involved is the plotting of the current-state VSM, with the need to identify the underlying causes of problems arising on the shop floor. Once identified, several improvement plans are developed. The need to consult relevant people related to the improvement plan is a necessity because the improvement plan filters out plans that are unfeasible. Once consensus is reached on a plan, the preparation leading up to the implementation is executed. Preparation consumes a substantial amount of time to ensure that minimal hiccups are encountered upon the implementation of the final system. Among the steps involved in the preparation include the preparation of materials and the training of operators. Thereafter, the system is implemented in stages. Feedback from operators is required to detect and solve unforeseen problems. Product p has shown a decrease in flow time from 30 to 23 days, an improvement of 7 days (23%). One observation from the implementation steps is that several circumstances are overlooked during the planning phase. Decisions such as the actions required if the threshold is exceeded are difficult to forecast.

With such positive results, the management has encouraged the application of the pull system of p to the inbound section. The reduction of the number of fresh goods inventory of p is desired. One method proposed is the progressive reduction of fresh goods inventory. This method is preferred compared to the integration of pull systems with master production schedules because of the complexity of the mathematical formulation involved. In this progressive reduction, five sets of p are reserved for emergency use. The remaining sets are consumed according to demand. In the event that non-reserved sets are insufficient, the reserved sets are consumed. Older reserved sets are occasionally replaced with incoming sets to avoid the quality deterioration of fresh goods of p. The inbound section performance proceeds are monitored for one month. If no changes in reserved quantity are detected, the quantity is reduced by one and the cycle is repeated. The cycle stops when the threshold is reached, and the reserved sets are consumed. The simplicity of a pull system design has similar benefits to that of a complex pull system design, provided that a reliable team supports the system and planning is thorough.

| Table 2. Lead time improvement of p |
|------------------------------------|
| Period                             | Location                                      |
|                                   | Between inbound and in-jig | Between in-jig and out-jig | Between touch up and preparation 1 | Between primer and preparation 2 | Between touch up and final assembly | Between quality inspection and outbound |
| Before implementation             | 10 days                        | 3.9 days                    | 2.2 days                        | 2.8 days                        | 2.2 days                        | 8.9 days                         |
| After implementation              | 5.6 days                       | 1.1 days                    | 2.2 days                        | 2.2 days                        | 2.2 days                        | 9.4 days                         |
Figure 6. Future state VSM of p.
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