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How to Plan and Implement POLCA:
A Material Control System for High-Variety or Custom-Engineered Products

Rajan Suri

Center for Quick Response Manufacturing
University of Wisconsin-Madison
1513 University Avenue
Madison, WI 53706, USA
www.qrmcenter.org

and

Ananth Krishnamurthy

Decision Sciences and Engineering Systems
Rensselaer Polytechnic Institute
5225, CII Building, 110 8th Street
Troy, NY 12180, USA

SUMMARY

In today's marketplace there is increasing demand for customized products, either through customers selecting from a large menu of options, or even through companies custom-engineering products for individual customers. Manufacturing companies that have to supply such high-variety or custom-engineered products are struggling to implement effective material control strategies on the shop floor. These companies are finding that Lean Manufacturing concepts such as Flow, *takt* time and pull/Kanban systems are not meeting their needs in such environments. POLCA (Paired-cell Overlapping Loops of Cards with Authorization) is a material control system designed with these situations in mind. It is a hybrid push-pull system that combines the best features of card-based pull (Kanban) systems and push (MRP) systems. At the same time, POLCA gets around the limitations of pull systems in high-variety or custom product environments, as well as the drawbacks of standard MRP, which often results in long lead times and high WIP. POLCA was developed as part of the overall strategy of Quick Response Manufacturing (QRM), a strategy that focuses on lead time reduction throughout the enterprise. In partnership with its member companies, the Center for Quick Response Manufacturing has implemented POLCA at several factories in the USA and Canada. In this paper, we first give an overview of the POLCA system, explain how it works, and provide qualitative comparisons with pull/Kanban systems. Then we present a step-wise procedure for implementing POLCA in a factory. Using examples from the implementation of POLCA at several factories we address practical issues such as computing the number of POLCA cards, determining the quantum of work a POLCA card represents, and addressing part shortages. We also discuss the manifold performance improvements that have resulted from these implementations including reduction in lead time and WIP, increase in percentage of on-time deliveries, and a boost in employee satisfaction.

1. NEED FOR A NEW MATERIAL CONTROL SYSTEM

The success of just-in-time (JIT) strategies, along with their pull methods of material control, have led to considerable interest in the study of material control strategies for manufacturing systems. Essentially, material planning and control systems can be classified as push, pull or hybrid push-pull systems (Karmarkar, 1986). Push systems are typically associated with material requirements planning (MRP) systems. Pull systems are also called Kanban control systems. Recently, JIT techniques have been described and popularized under the name of "Lean Manufacturing" (Womack et al., 1990; Womack and Jones, 1996) which also uses pull as a key component of its strategy. Advocates of pull systems have written extensively about the drawbacks of push/MRP systems and elaborated on how pull/Kanban strategies overcome these drawbacks (Spearman and Zazanis, 1992; Womack and Jones, 1996). The successful implementation of Kanban systems as well as analytical studies for simple manufacturing systems has led to the belief that pull/Kanban systems generally have superior performance. However we have strong reasons to believe that this is not true. In fact in many markets, pull/Kanban is not the best system, as we now discuss.

Consider a company that produces a large number of different products with highly varying demands, or a company that makes custom-engineered products in small batches, perhaps even one of a kind. For both types of companies we argue that pull/Kanban systems have significant disadvantages. To begin with, we note that pull/Kanban is essentially a *replenishment* system: for a pull/Kanban system to function, we require that a minimum inventory of each product be maintained at the output of each workstation. When one unit (or container) of inventory is taken by the downstream workstation, this immediately signals the upstream workstation to begin work to replenish this quantity. Consider the implications of this system. First, for a company manufacturing a large number of product specifications with varying demands, this will lead to proliferation of work in progress (WIP) inventories at each stage of the process (see the example in Suri, 2003). Therefore pull/Kanban systems are impractical for such manufacturing environments. Second, for a company that custom designs and fabricates *each* product, the final product is defined only after the design is specified by the customer order. There are no predefined finished goods prior to receipt of the customer order and subsequently, one cannot store inventories at the output of each workstation. In this case, pull systems fail at the very first step. Third, pull/Kanban was initially designed for manufacturing environments producing repetitive products with stable demands. In such environments, using current inventory consumption as a proxy for future demand is a reasonable approach. On the other hand, in environments with custom products, changing product mix, infrequent orders, or highly variable demand, this is not a reasonable assumption. Pull/Kanban systems also exercise rigid controls on production schedules by enforcing *takt* times, level scheduling, and *flex fences* (Womack and Jones, 1996). These involve optimizing or standardizing tasks and freezing production schedules. However, in settings where the products are customized, or demand is highly variable, setting *takt* times can be impractical. Hence, the pull system might not work well in such environments.

Recently a few authors have provided arguments similar to the above. For example, see Hopp and Spearman (1996), Suri (1998, 2003), and Krishnamurthy, Suri and Vernon

(2000). In particular, Suri (1998) argued that to achieve efficient material control in manufacturing environments with high-variety or custom-engineered products, new strategies that combined the features of push/MRP and pull/Kanban were needed. He proposed just such a system, called POLCA (Paired-cell Overlapping Loops of Cards with Authorization), as an effective material control system for such environments. Note that POLCA was introduced by Suri (1998) as one component of the overall Quick Response Manufacturing (QRM) strategy – QRM is a company-wide approach for lead time reduction.

In partnership with its member companies, the Center for Quick Response Manufacturing has now implemented POLCA at several factories in the US and Canada, with encouraging results. In this paper, we summarize the insights gained from these implementations. These insights will not only help understand why some companies are struggling to implement pull/Kanban systems, but will also help companies implement POLCA at their manufacturing facilities.

The rest of the paper is organized as follows. In Section 2, we give an overview of the POLCA system, explain how it works, and provide qualitative comparisons with pull/Kanban systems. Section 3 presents a step-wise procedure for designing and implementing POLCA in a factory. In Section 4 we discuss the POLCA implementation experiences at a few facilities to illustrate how the procedure described in Section 3 was applied in practice. We also present the various performance improvements that have resulted from these implementations. In Section 5 we present our conclusions.

2. OVERVIEW OF THE POLCA SYSTEM

As discussed above, pull/Kanban systems are not appropriate for manufacturing companies operating in high-variety and/or custom product environments. Also, push/MRP systems have their own drawbacks in terms of creating excess inventories and promoting ever-longer lead times (see the examples in Suri, 1998). POLCA is a hybrid push-pull system that combines the best features of push/MRP systems and Kanban/pull control. At the same time, POLCA gets around the above-mentioned limitations of pull/Kanban systems.

To understand the operation of POLCA, let us consider a company called CFP Corporation, which makes customized faceplates and rating plates for small appliances as well as large equipment. The plates are made from different materials, have a wide range of sizes, and contain printed information along with features such as holes and notches to assist in mounting them. CFP's competitive strategy is to go after customers that need small batches of plates for specialized markets by adopting quick response strategies and focusing on creating short lead times throughout the organization. To achieve quick response, a company such as CFP Corp. would have to reorganize as follows (Suri, 1998). First, the company would need to create cells that focus on subsets of the production process for similar parts. For a company such as CFP Corp. these cells could differ in terms of the types of printing needed, the material and size of products handled, the form of packaging to be used, and so on. Individual customer orders are served by using the appropriate combination of cells needed to print, fabricate and assemble each order (see Figure 1). Orders can have very different demands within the cells. For instance, an order for large plates with many holes may use a lot of time on a Punch Press in F3 and not much time on the Shear, while another order for small plates may have little punching time but may require a lot of shearing. The routing of products within each cell can also differ from order to order. Thus the Lean concepts of flow, *takt* times, and level scheduling are not applicable.

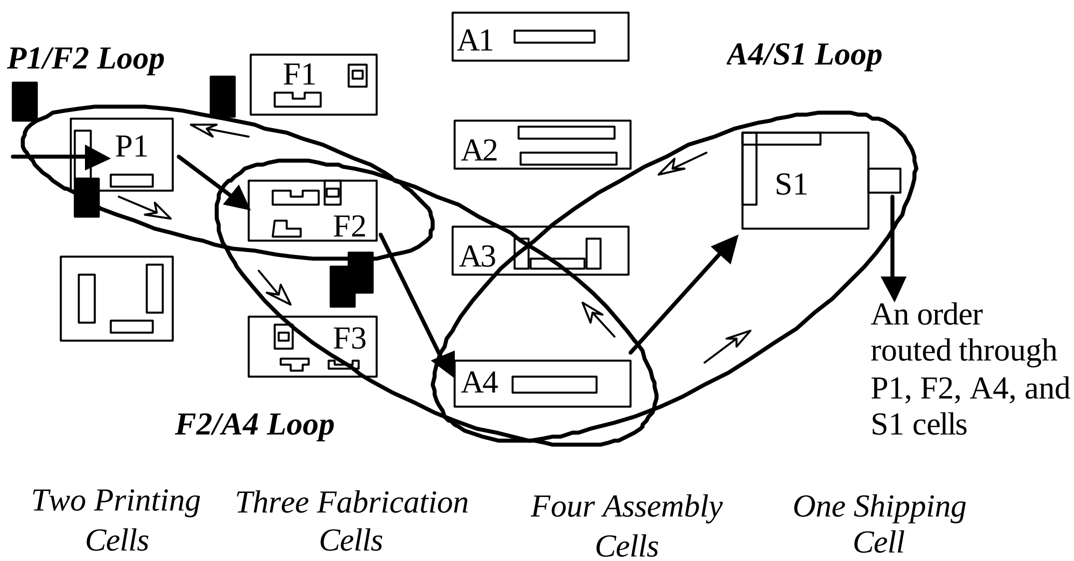

Figure 1. POLCA card flows for a particular order at CFP Corp.

In the POLCA system, the flow of orders through the different cells is controlled through a combination of *release authorizations* and *production control cards* known as *POLCA cards*. The release authorizations are generated using a High Level Materials Requirements Planning system or HL/MRP. HL/MRP is similar to an MRP system, but it does not work at the operation level. Rather, it considers each cell as a black box and only helps to plan material flow across cells. For each order, the HL/MRP first creates release authorization times at each cell. These are times when each cell *may* begin work on a particular order. However, unlike in a standard push/MRP system where a work center *should* start work at that time, in a POLCA system, the release authorization times only authorize the beginning of the work, but the cell cannot start unless the corresponding POLCA card is also available. The POLCA cards communicate and control the material movement between cells.

While this may initially seem similar to Kanban, there are some important differences. First, the POLCA cards are only used to control movement between cells, not within cells. (For material control between the workstations within a cell, cells have the freedom to use various other procedures.) Second, the POLCA cards, instead of being specific to a product as in a Kanban system, are assigned to pairs of cells. Figure 1 shows the POLCA card flows for a particular order at CFP Corp. This order's routing takes it from P1 to F2, then to A4 for assembly and finally to S1 for shipping. This order will therefore proceed through the POLCA card loops associated with the pairs P1/F2, F2/A4 and A4/S1, as shown in the figure. The third difference from Kanban is that the POLCA cards for each pair of cells stay with a job during its journey through *both* the cells before they loop back to the first cell in the pair. For example, the P1/F2 card would be attached to a job as it entered cell P1; it would stay with the job through cell P1 and as it goes into cell F2; it would continue to stay with this job until F2 has completed it; and only when the job moves on to its next cell (A4) would this P1/F2 card be returned to cell P1. Since most cells will belong to more than one pair of cells, there will be multiple loops of cards that overlap in each cell (See Figure 1). Additional details on the operation of POLCA are described in Suri (1998).

2.1. ADVANTAGES OF POLCA OVER PUSH/MRP AND PULL/KANBAN

Next we discuss how the POLCA system overcomes the drawbacks of both push/MRP and pull/Kanban systems. First, the use of POLCA cards assures that each cell only works on jobs that are destined for downstream cells that will also be able to work on these jobs in the near future. While this might seem similar to the logic used in a typical pull/Kanban system, there is a key difference: a POLCA card is a *capacity* signal, while a pull/Kanban signal is an *inventory* signal (for replenishment of the inventory for a specific product). In other words, a returning POLCA card signals available capacity at a downstream cell. If a POLCA card from a downstream cell is not available, it means that the cell is backlogged with work (or cells downstream from it are backlogged). Working on a job destined for that cell will only increase inventory in the system, since somewhere downstream there is a lack of capacity to work on this job. It is more expedient to hold off putting organizational resources into such a job: those resources would be better used in other ways, for example to make products that are actually needed by a different downstream cell. This feature of POLCA makes it better suited for high variability environments than the traditional pull/Kanban systems.

Second, the use of HL/MRP allows a make-to-order environment through flexible routings that use cells as needed. In addition, the use of authorization times prevents the build up of unnecessary inventory. As we showed earlier, pull/Kanban systems have the disadvantage of filling intermediate stages with excess inventories especially in high-variety, low volume manufacturing environments. Note that a returning POLCA card signals available capacity downstream, but the POLCA card by itself does not determine which job should be worked on next at the upstream cell. The upstream cell uses the list of authorized jobs developed using HL/MRP to make this decision. (If there is no authorized job, then no job is started, even though a POLCA card is available. Again, this is different from the pull system where a returning Kanban card *always* means that a job is to be started.) By coupling the routing and authorization procedure using HL/MRP with the cards in the POLCA system, we ensure that cells do not make products just because they have a pull signal, but rather, the system allocates cell capacity to products only when there is an explicit demand for them.

Third, unlike a Kanban system where workstations are tightly coupled via Kanban cards, the POLCA cards flow in longer loops. There is coupling of cells, but it is more flexible. Recall that the Kanban system is highly tuned to produce at a given rate. In fact, in designing a pull system, a good deal of effort is spent in determining the corresponding *takt* time. On the other hand, for high mix, custom-manufacturing environments, the products might have significantly different processing requirements at the different resources. Although the company could estimate average capacities using aggregate planning tools, the actual rates and bottlenecks would vary from day to day. This is one of the reasons for having the overlapping loops in POLCA. By making the loops longer, the additional jobs in the loop act as a buffer to absorb the variations in demand and product mix. This allows each cell to balance its capacity as best as it can for the current mix. This cannot be done with a pull/Kanban system because of the tight coupling through the Kanban cards balanced carefully with the *takt* times calculations. (Other QRM techniques are also employed to help cope with the variations in demand, see Suri, 1998).

Fourth, the paired cell and overlapping feature of the POLCA loops has two additional benefits. One, this feature explicitly recognizes that each cell in the routing for a particular order is potentially a supplier as well as a customer to another cell. Therefore the POLCA loops permit each cell to allocate capacity to jobs and schedule production using information about requirements and the current workload in its customer and supplier cells. As we shall see from the subsequent case studies, this enhanced information flow often results in significant improvements in system performance. Two, the requirement that the downstream cell finish work on the job before sending the POLCA card back ensures that jobs with problems (e.g. quality/rework issues) are not continually pushed aside in favor of starting new jobs. If a job does get pushed aside due to a problem, that will hold up a POLCA card, which reduces the number of additional jobs that can come into the cell. So there is an incentive to finish jobs already in the cell before starting new jobs. This results in speedier resolution of problems and hence a reduction in lead time in the downstream cell, as seen from the results later in this paper.

3. PROCEDURE FOR IMPLEMENTING POLCA

Next we describe a step-wise procedure for implementing POLCA in a factory. There are two main pre-requisites for implementing POLCA: (i) a High Level Materials Requirements Planning system (HL/MRP), and (ii) a cellular organization. In addition to these pre-requisites, POLCA implementation requires that: (iii) the cells involved in the implementation have the ability for rough cut capacity and lead time planning, and (iv) the HL/MRP system (or an associated scheduling system) can produce dispatch lists for each cell, sequenced according to release authorization times for jobs at that cell, and indicating the next cell for each job.

Implementation of POLCA in a factory consists of four main phases. These are: (i) pre-POLCA assessment, (ii) design of the POLCA system, (iii) launch of the POLCA implementation, and (iv) post-implementation evaluation. We discuss each of these phases below.

We recommend that the implementation efforts in these four phases be carried out by a cross-functional team comprised of factory managers, materials personnel, schedulers, operators in the cells involved in the POLCA implementation, and other shop floor personnel who would be influenced by the implementation. Our experiences indicate that it is important that the POLCA implementation team receives active support and commitment of top management. In this regard, it is useful to have members from top management involved periodically in the implementation efforts.

3.1. PRE-POLCA ASSESSMENT

The objective of this phase is to conduct a needs assessment, check the prerequisites, and set the goals and objectives before getting into the details of designing the POLCA system.

Conducting a needs assessment: The purpose of conducting a needs assessment is to ascertain whether any of the cells involved in the implementation would require some capacity or lead time planning prior to implementation of POLCA. Recall that the POLCA system helps control material flow and better utilize the cells' available capacities, but if the available capacities are significantly below the required levels, then improvement opportunities will be limited and POLCA will not solve this issue. Hence we first determine whether the facility has a feasible capacity plan by obtaining estimates of the utilizations at the different resources in the cells and the lead times for the different products at the different cells. While it is not expected that the capacity plan be the optimum, the cells must at least have the capacity to meet required throughput targets in a given planning period with some (10-15%) spare capacity, as recommended in Suri (1998). In some of our implementation efforts (see Case Study 1, for example) the needs assessment helped identify several continuous improvement opportunities that enhanced the success of the POLCA implementation.

Checking the pre-requisites: The purpose of this task is to verify that the facility satisfies the main pre-requisites required for POLCA implementation, as explained above, namely (i) a High Level Materials Requirements Planning system (HL/MRP) exists, (ii) a cellular organization is in place (at least for the portion of the shop floor involved in this implementation), (iii) cells involved in the implementation have some rough cut capacity and lead time planning ability, and (iv) the HL/MRP system (or an associated scheduling system) can produce dispatch lists with characteristics described above. If the implementation team observes that some of these pre-requisites are not satisfied, then the necessary activities are scheduled into the implementation.

Setting goals and metrics: The next step is to determine the specific goals and metrics for evaluating the POLCA implementation. These goals and metrics should be closely related to managerial objectives guiding the implementation. Once these are set, base line measurements of these metrics must be taken for the sake of future comparisons, to enable accurate evaluation of the success of the POLCA implementation.

3.2. DESIGN OF THE POLCA SYSTEM

This phase deals with the detailed design of the POLCA system. This involves: (i) identifying the POLCA loops, (ii) computing the release authorizations, (iii) determining the quantum of work a POLCA card represents, (iv) designing the POLCA card, and (v) computing the number of POLCA cards. In some situations where cells frequently encounter component part shortages, the design of the POLCA system could also include (vi) designing a "*safety*" card mechanism that provides a temporary solution to the component part shortage problem. We now discuss all these steps.

Identifying the POLCA loops: This involves analyzing the routings for the different products within the scope of the POLCA implementation, identifying the different cells in their routings, and then identifying the corresponding POLCA loops. For instance, at CFP Corporation, for all orders that have the routing sequence P1 → F2 → A4 → S1, the POLCA loops would be the P1/F2 loop, F2/A4 loop, and the A4/S1 loop (see Figure 1).

Computing release authorizations: The release authorization dates are computed for each order at each cell, based on the order due date and planned lead times at the different cells using the standard MRP logic. From this information a dispatch list is developed for each cell. This dispatch list at each cell simply records for each order: (i) the authorization date, and (ii) the next cell in its routing. This list is sorted in increasing order of the authorization dates of the different orders. (See Suri, 1998, and Krishnamurthy, 2002, for detailed examples).

Determining the quantum of work a POLCA card represents: We know that a POLCA card returning to an upstream cell signals available capacity at the downstream cell. The question being addressed here is: what is the appropriate "quantum" of capacity that should be represented by a POLCA card? Rather than describe how the optimum quantum can be determined, we present simple guidelines to assist in determining the quantum in a given situation. First, if the quantum were too large it would imply too few POLCA cards in the loop between the two cells resulting in infrequent and possibly "lumpy" signals of available capacity to the upstream cell. On the other hand, if the quantum were too small, it would result in excessive POLCA cards in the loop, making it time-consuming to manage and keep track of them. These two tradeoffs need to be considered while determining the quantum. Additionally, it is also desirable that the production batch sizes in the two cells and the size of the transfer batch between the cells are simple multiples of the quantum.

Designing the POLCA card and documenting the POLCA procedure: The design of the POLCA card itself is straightforward (see Figure 2). The main information on the card consists of the acronyms for the paired cells for which the card is used. These are written in large letters. Additional features of the card that are also important to the implementation are explained in the note to Figure 2. It is also useful to document in flowchart form the detailed POLCA procedure that will be used by the cell teams and material handlers. Our experience indicates that this flowchart serves as a valuable tool in training operators, schedulers and material handlers, and also continues to be a resource for employees to reference during the implementation.

Computing the number of POLCA cards in each loop: The number of POLCA cards for each loop is computed using a simple formula described in Suri (1998). It is repeated below for convenience. Let LT_A and LT_B be the estimated average lead time (in days) for the two cells in a POLCA loop over the planning period of length D (in days), and let $NUM_{A,B}$ be the total number of jobs (measured in terms of the quanta) that go from cell A to cell B during the planning period. Then the number of POLCA cards ($N_{A/B}$) in the POLCA loop going from cell A to cell B is given by:

$$N_{A/B} = (LT_A+LT_B) \times (NUM_{A,B} /D)$$

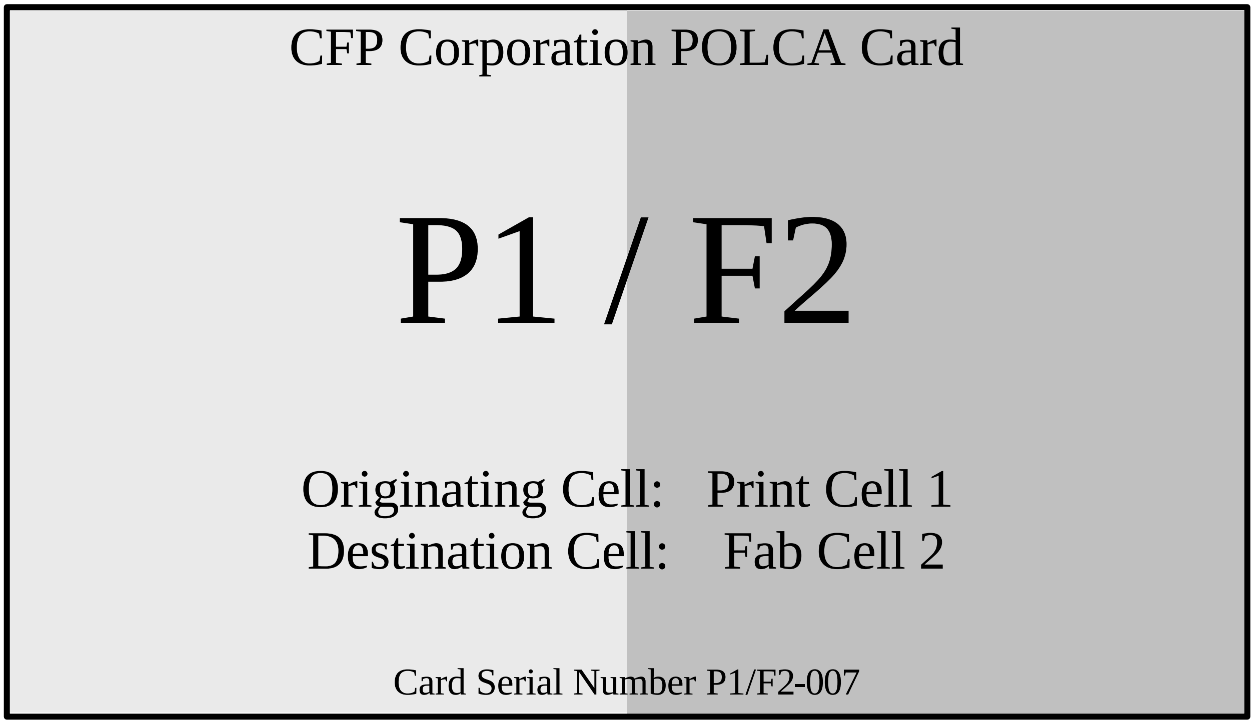

Figure 2: Example of a POLCA Card[†]

[†]Note the following features of the POLCA card: (i) Only the two cell names are indicated, the card is not part-specific like a Kanban card; (ii) The card is split into two colors, each color being associated with one of the cells. This association remains constant across all POLCA cards, so that cell workers or material handlers know that (for example) green always denotes F2. Thus when they see green on the right side of a card, they know the destination cell is F2, and similarly for the color on the left side; (iii) The card contains detailed explanations of the abbreviations for the cells in case someone on the shop floor is not familiar with a particular abbreviation; (iv) The card carries a serial number which helps material planners keep track of the POLCA cards.

Addressing component part shortages in the short term using Safety Cards: In some practical applications, specially if the cells in the POLCA loop correspond to assembly cells, the operations on a particular job could get halted due to the shortage of some component supplied by a cell or external supplier that is not part of the POLCA loop. Consequently, the job (along with the attached POLCA card) could get stuck at some intermediate workstation in the cell for a while (possibly days) till the required component becomes available. During this time, although the cell could use its available capacity to work on other orders, it would not be able to do so due to the unavailability of POLCA cards. If these stoppages due to component part shortages occur frequently, then they could significantly impact the performance of the POLCA system. The long-term solution to the problem lies in reducing the component part shortages, and this usually involves working with the supplier on process improvement activities. However, to provide a remedy to this problem in the short term, we introduce additional "*safety*" cards in the POLCA loop, as follows.

A small number of Safety Cards are maintained by an individual responsible for them, let us say the scheduler in this example. The Safety Card contains the same information as a POLCA card, except that for easy visual control these cards contain some color to distinguish them from regular POLCA cards. For example, a thick, colored border might be added to the card in addition to the other colors in the body of the card – bright red or orange could be used for the border, since these cards signify a problem. The number of Safety Cards in the loop is a small percentage (typically 10%) of the total number of POLCA cards. If the processing of a job gets halted due to a component part shortage at some intermediate workstation, and if a Safety Card is available, then the scheduler detaches the POLCA card attached to the job and replaces it with a Safety Card. The job and the attached Safety Card wait at the workstation till the supply of the required component arrives. Meanwhile the released POLCA card is sent back to the beginning of the POLCA loop enabling the release of another job into this loop. Once the required component becomes available, processing on the job resumes at the workstation. The attached Safety Card acts like a POLCA card and stays with the job till processing is completed in both the cells in the loop, after which the Safety Card is withdrawn from the loop.

There are several key points to be noted regarding the role and the use of the Safety Cards. First, the Safety Cards are only used to release POLCA cards that get stuck in the loop due to component part shortages. Second, because the number of Safety Cards is limited, they can only provide a temporary solution to the part shortage problem, and that too, to a limited extent. Hence, the Safety Cards are intended for occasional unexpected situations, and not for covering up habitual problems in the system. Third, when the workstation receives the supply of the component that is short, the processing on the job resumes and the job proceeds through both the cells with the Safety Card acting like a POLCA card. This is because subsequent to the part shortage problem being resolved we would like to complete the processing of this job as quickly as possible, and not require it to wait for yet another POLCA card. Fourth, after processing is completed at the end of the second cell, unlike POLCA cards that get routed back to the beginning of the first cell, the Safety Card is withdrawn from the loop and returned to the scheduler. Finally, the use of Safety Cards provides a terrific opportunity for continuous improvement. Every time a Safety Card is employed, data is noted on when it was employed, the reason for needing it (e.g. the specific component that was short), and when the problem was resolved (e.g. when that component was finally received). After a period of time, statistics from these incidents will provide concrete insight into root causes of the shortages or other problems. These root causes can then be addressed, leading to further improved performance.

3.3. LAUNCH OF THE POLCA IMPLEMENTATION

Once the details of the POLCA system have been developed, the next step is to launch the POLCA implementation.

Determining a POLCA champion: Although the POLCA implementation is carried out as a team effort, we recommend that during the early phases of implementation, the POLCA implementation team identify one of its members as the POLCA champion or owner of the process. The POLCA champion serves as a central point of contact to whom questions regarding the design or implementation of the POLCA system are directed. The POLCA champion also serves as the liaison between the implementation team and upper management. If Safety Cards are used, we recommend that the implementation team identify one of their members to be in charge of these cards. This person could be distinct from the POLCA champion. Our implementation experience indicates that cell schedulers or cell managers might be appropriate persons to take on this responsibility.

Training and education: It is critical that all the operators from the cells involved in the implementation, as well as the corresponding material planners, schedulers, material handlers, and any supervisors or managers responsible for these cells, be trained on the POLCA process. The training should involve both the general concept of POLCA and why it is needed for the company's manufacturing environment, as well as detailed training on the specific implementation procedures to be used at the company. We have found it useful to create a detailed flowchart documenting the flow of the POLCA cards between two sample cells, and including all decision points and tasks for operators, schedulers, and material handlers. We have also found it useful to perform a physical simulation, or "walk through" the two sample cells as part of the training, and to simulate the decisions and card handling at each step. In addition to training the personnel involved directly in the POLCA process, it is also useful to include in the training session personnel from the cells that are upstream and downstream of the POLCA loops.

Frequent reviews and management support: During the initial phases of implementation it is beneficial to schedule frequent reviews at which the implementation team addresses any issues that might have gone unnoticed during the design of the system. The POLCA implementation team should also report their progress to upper management at periodic intervals. This helps in getting continued support, addressing any operator concerns (such as changes in metrics of operator performance) or management concerns that might arise during planning and implementation. As the POLCA system becomes operational, the team should develop a plan and timeline for transferring the ownership of the process to the cell teams.

3.4. POST IMPLEMENTATION EVALUATION

Not only does implementation of the POLCA system result in performance improvements, but it also provides a wealth of information and helps identify opportunities for process improvement. Next we discuss some of the procedures that could be adopted to collect this information and initiate improvement efforts.

Tracking the key metrics: The key metrics that need to be measured during the POLCA implementation include the lead times for the products, throughputs of the cells, reliability of delivery between cells, and WIP inventories at various points in the system. Measuring the on-time delivery performance of upstream and downstream cells in the POLCA loops provides information on whether the POLCA system is assisting the cells in prioritizing jobs appropriately in order to meet the delivery targets set by the subsequent cells or the end customers. It is also useful to conduct a POLCA card audit: a periodic snapshot that tracks the location of the POLCA cards in the different loops. The POLCA audit process indicates whether there are excess cards in certain loops. If the audit process consistently reveals excess unused cards in a loop, these could be gradually withdrawn from the loop, resulting in reduction in inventories. As demand levels change over time, it will be necessary to update the number of POLCA cards assigned to the different loops – such an exercise might be carried out once a quarter, for example.

Measuring the qualitative benefits: The potential benefits of POLCA extend beyond the quantitative benefits discussed above. For manufacturing companies operating in high mix, custom product environments, POLCA provides a simple and efficient way to manage shop floor resources, identify opportunities for continuous improvement, and improve productivity. Our implementation experience reveals that POLCA implementations have resulted in reduced stress levels, improved operator morale, better communication, and increased employee satisfaction. These benefits can be measured by periodic surveys of the people working in the POLCA loops.

4. INSIGHTS FROM CASE STUDIES IN POLCA IMPLEMENTATION

In partnership with its member companies, the Center for Quick Response Manufacturing has implemented POLCA at several factories in the US and Canada. Next we discuss the insights obtained from these implementations.

Case Study 1: POLCA at a Manufacturer of Machined Parts

Olsen Engineering is a contract manufacturer located in Eldridge, Iowa, supplying hardened and precision ground steel pins, bushings, CNC parts, and tube bending parts to original equipment manufacturers (OEMs). POLCA was implemented at Olsen in the spring and summer of 2002, and the results below are based on the descriptions in Dawson et al. (2002). The manufacturing facility produces over 5000 different part numbers in a 138,000 square foot area that houses among other equipment, a heat-treating and a zinc plating facility. The POLCA implementation at this facility was motivated by two challenges faced by Olsen: (i) They had an excess of finished goods as well as WIP inventories throughout their facility, and (ii) They had long lead times that resulted in frequent expediting, frequent rescheduling, and overtime. Faced with the pressure to be more responsive to customer demand and reduce costs of production, Olsen's management was looking for a way to better control the production and inventory of its very large population of products.

Olsen already had in place a partnership with John Deere, one of its leading customers, to engage in some process improvements. Since Deere had been involved with the Center for Quick Response Manufacturing for several years, and many of its personnel were familiar with QRM methods, the Deere representative working with Olsen suggested the possibility of using POLCA. Olsen management saw the potential of POLCA for their environment and decided to investigate it further. A team including Olsen and Deere personnel attended a workshop on POLCA implementation at the Center for Quick Response Manufacturing in early 2002. This workshop accomplished three things for the team: (i) it convinced them that POLCA would be an effective method to deal with their challenges; (ii) it gave them a detailed roadmap for POLCA implementation; and (iii) it enabled them to talk with other companies that had implemented POLCA and obtain specific pointers from the experiences of those companies.

To implement POLCA, Olsen put together an implementation team comprised of factory managers, schedulers, other shop floor personnel and the representative from Deere. To focus the implementation efforts, the team decided that the scope of the initial POLCA implementation would be confined to products belonging to one of their key market segments. In the pre-POLCA assessment the team identified that these products were being manufactured in product-focused cells. The typical routing for a product involved from two to five cells. The assessment also revealed that the facility satisfied the main prerequisites for POLCA implementation. Additionally, this pre-POLCA assessment also helped to initiate several improvement activities aimed at set-up reduction, cross training, and improving quality. These were conducted in parallel with the POLCA implementation.

During the detailed design of the POLCA system, the implementation team identified over a dozen POLCA loops for implementation. Next, modifications were made to the existing scheduling procedures at the cells to incorporate release authorizations. Revised dispatch lists were then generated for each cell. The team computed the number of POLCA cards in each loop using the equation above. Next, the physical POLCA cards were designed, incorporating the dual color coding explained previously. Finally, in addition to the POLCA cards, the implementation team decided to introduce additional Safety Cards in each POLCA loop. The number of such Safety Cards was set to approximately 10% of the total number of cards in the loop. Prior to launching the POLCA system, the team conducted training sessions for all the personnel who would be affected. POLCA was implemented in the various loops in stages. It took approximately six months from attending the workshop to completion of the POLCA implementation for all these loops.

The POLCA implementation at Olsen Engineering resulted in several improvements. Lead time reduction across the different products ranged from 22% to 68%. WIP and stock inventories were reduced significantly from 75% in some cells to over 90% in others. In addition to the quantitative improvements, there were qualitative improvements as well. The POLCA process helped in achieving better visual control. It also helped surface opportunities relating to quality issues, machine down times, and material availability that would have otherwise gone unnoticed. More importantly, it significantly improved the operator morale and instilled a culture of continuous improvement at the facility. The success of POLCA implementation in one area of the facility increased the enthusiasm for implementation in other areas of the facility.

Case Study 2: POLCA at a Manufacturer of Motor Control Centers

Rockwell Automation's Packaged Control Products (PCP) Division is a leading manufacturer of Motor Control Centers. These consist of steel cabinets that enclose large modular assemblies of motor starters, variable speed motor drives, programmable controllers, and other electrical control equipment. These control panels vary significantly in size and are highly customized on an order-to-order basis. POLCA was implemented at several facilities of the PCP Division during 2001, and the description here is based on the information in Honerlaw and Cronce (2001) and Gilson (2002). We will focus here on the facility in Richland Center, Wisconsin. At this facility, all the different types of steel cabinets were fabricated and assembled in a single cabinet assembly cell. The cabinets were then sent to final assembly cells where various other components were assembled into the cabinets to form each customized Motor Control Center. The cabinet cell supplied seven final assembly cells with cabinets. As can be seen from this description, the facility had already been organized into cells.

The main motivation for implementing POLCA was as follows. At this facility, all the products were built to order or engineered to order with no finished goods support, and the quoted lead times varied from a few days to several weeks depending on the product configuration. With this large variation in lead times across orders, it was to be expected that changes in the ship dates could also range from a day to several weeks. These changes could be due to changes in customer request dates, unanticipated urgent customer orders (for example if there had been a breakdown in the field), holdups due to non availability of component parts, and so on. With all these changes taking place on different time scales, it was hard to change the cell production schedules in a timely manner, and so the assembly of cabinets in the cabinet cell would often be out of synchronization with the requirements of the final assembly cells. This resulted in excess inventories of unwanted cabinets for some cells and late deliveries of cabinets to other cells and, as could be expected, a lot of time spent by schedulers and supervisors on expediting and communication.

In summary, the motivations for implementing POLCA were: (i) the facility needed to control the WIP inventory levels of the steel cabinets throughout the facility, not so much because of cost but because these large cabinets occupied a lot of floor space in the assembly areas and constrained the assembly operations; (ii) they wanted to ensure that the cabinet manufacturing cell could effectively respond to the frequently changing demands at the final assembly cells; and (iii) they wanted to ease the stress on the cabinet assembly cell team and schedulers, who were constantly under pressure to expedite orders for one assembly cell or another.

An implementation team comprising of factory managers, schedulers, and other shop floor personnel was put together to implement POLCA. In addition, the facility also sought the help of a team of graduate students and staff from the Center for Quick Response Manufacturing (including the authors).

Pre-POLCA evaluation conducted by the team revealed that the facility satisfied the main prerequisites for POLCA implementation. With the help of the student team, a rough cut capacity planning model was developed that enabled the estimation of the lead times for the products in the different cells. The goals of the POLCA implementation were primarily to: (i) improve on-time delivery performance of the cabinets to the assembly cells, and (ii) to reduce the WIP inventories in the facility. During the detailed design of the POLCA system, seven POLCA loops were identified for implementation. Each POLCA loop included the cabinet cell as the upstream cell and one of the assembly cells as the downstream cell. Next, modifications were made to the existing MRP driven scheduling procedure at the cells to incorporate release authorizations, and a dispatch list was generated for each cell as per the specifications given previously in this paper.

The team then determined the quantum. There were several options with regard to setting the quantum. The quantum could be set equal to: (i) a single cabinet section, (ii) a block, which was composed of several sections attached together, or (iii) or an order, which was composed of several blocks. Setting the quantum to correspond to a single section would result in an excessive number of POLCA cards. On the other hand, setting the quantum to correspond to an order would result in "lumpy" signals of capacity as orders varied greatly in the number of sections they needed. Therefore, to determine the right quantum, the implementation team conducted a statistical analysis of order patterns and determined that setting the POLCA quantum to correspond to a block would work well. Even though individual blocks varied in the number of sections they contained, it turned out that on average a block contained two sections, and this average remained fairly constant from week to week. The implications of this decision was that the average load represented by a POLCA card would be two sections and this average would not vary too much (workload represented by the POLCA cards would not be too "lumpy"). Another fact that supported this choice of quantum was that the cabinet cell was already transferring the cabinets to the assembly cells in blocks.

Having determined the quantum, the implementation team computed the number of POLCA cards in each loop using the equation above. The calculations indicated that a total of 227 POLCA cards would be needed in the seven loops with approximately 30 POLCA cards in each loop. The physical POLCA cards were made out of magnets so that they would easily attach to the steel cabinets. Finally, it was observed that the cabinet and assembly cells did face component part shortage problems occasionally and hence the implementation team decided to introduce additional Safety Cards in each POLCA loop. The number of such Safety Cards was set to 10% of the total number of cards in the loop.

Prior to launching the POLCA implementation, all the shop floor personnel that would be affected by the POLCA implementation were trained. Subsequent to implementation, regular POLCA audits were conducted and the key metrics were tracked. The POLCA implementation resulted in several improvements. As we have mentioned in this article, POLCA helps allocate capacity to producing parts that are actually needed in the near future. Indeed, overproduction of unneeded cabinets at the cabinet cell was completely eliminated, and the variability in the time of delivery of cabinets to assembly cells was reduced from (plus or minus) several shifts to the point where 92% are now being delivered within *one hour* of the stated requirement! It should be noted that on-time delivery here does not just measure lateness – early deliveries are also docked as not on time in this measurement. Hence the 92% statistic shows that POLCA truly assists with allocating capacity to make just what is needed – no more and no less. Correspondingly, WIP inventories were also reduced. As observed by an assembly cell operator during one of the surveys, "We are not buried in cabinets all the time!" We also mentioned earlier in this paper that making the POLCA loop go to the end of the second cell motivates that cell to complete jobs before starting new ones. In fact, after the POLCA implementation, lead times at the seven (downstream) assembly cells were reduced by an average of 25%.

In addition to the quantitative improvements, there were qualitative improvements as well. The POLCA process considerably simplified the tasks of schedulers in trying to be responsive to demand changes. Additionally the process resulted in better communication between the cabinet and the assembly cells. The operators also discovered several opportunities for continuous improvement relating to material availability and inventory reduction. Implementations carried out at other facilities of the PCP division in US and

Canada resulted in similar benefits. In the other facilities, WIP inventories shrunk by over 30% and one facility even achieved an 18% increase in throughput. For additional details regarding these implementations see Krishnamurthy (2002).

5. CONCLUSIONS

In this paper we discussed the planning and implementation of POLCA, a hybrid push-pull material control system suited for manufacturing environments with high-variety and/or customized products. We briefly described the operation of the POLCA system and discussed how its features enable it to overcome the drawbacks of conventional push/MRP and pull/Kanban systems in such environments. Next we presented a detailed procedure for implementing POLCA in a factory. Finally, through case studies we described how this procedure was applied to implement POLCA at several facilities. Results from these implementations indicate that POLCA has helped these facilities significantly improve the effectiveness of their operations and has also enhanced employee satisfaction. These successes demonstrate that POLCA is an attractive alternative to pull/Kanban, especially for companies with high-variety or custom-engineered products.

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