JOB SHOP MATERIAL CONTROL BASED ON THE PRINCIPLES OF QUICK RESPONSE MANUFACTURING

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ABSTRACT: Today cutting-edge companies will capitalize on time as a key driver of competitive advantage. Although the Paired-cell Overlapping Loops of Cards with Authorization (POLCA) of Quick Response Manufacturing (QRM) is universally adopted as a material control mechanism in the shop floor, this paper is exploring its other principle. The newly thought approach, Utilization Based (UB) system is driving a whole new ways of controlling material flow in the production with the emphasis on operate the factory at optimum machine utilization. A simulation study was conducted to compare the POLCA and UB system. The deterministic metrics such as Manufacturing Critical-path Time (MCT), Throughputs (TP), Work in Progress (WIP) show that UB system is a viable alternative especially in the job shop environment with process layout. However, this method involves subcontracting in order to maximize output and minimize waiting time. The simulation study fulfilled the objectives of evaluating two different systems using the same set of inputs. The related performance measures prove the UB approach is as feasible as POLCA adopted in the job shop environment with some outperforming results.

KEYWORDS: *Quick Response Manufacturing; POLCA; MCT; Job Shop; Material Control*

1.0   INTRODUCTION

When the words Time is Money first phrased in 1748 by Benjamin Franklin [1], it was used to advise the young businessman at that time. In 1989, Stalk [2] described Time is the next source of competitive

advantage in the business world. Today, Time is on the cutting edge for all walks of life. Companies will capitalize on time as a key driver of competitive advantage – shortening the planning and the production process across the organization, managing time the way most companies manage quality and cost. These companies are classified as time-based competitors.

Among the studies of time-based competition (TBC) paradigms [3], Quick Response Manufacturing (QRM) was introduced by Suri [4] to achieve customer satisfaction through reducing the lead time in a low-volume high-mix manufacturing environment. To realize this goal, a control strategy tool called POLCA (Paired-cell Overlapping Loops of Cards with Authorization) was designed and implemented to regulate the flow of jobs at various stations of the manufacturing system.

This study proposed an alternative option to POLCA by using the utilization based approach to control material flow. Data was collected from the actual job shop and simulated. Section 2 provides an overview of the QRM principles and the POLCA and the Utilization Based control mechanisms are explained. Section 3 describes the methodology of the study. Section 4 discussed the quantitative and qualitative analyses of the experimental results followed by the concluding remarks and future research directions in section 5.

2.0   QUICK RESPONSE MANUFACTURING

The common nature in job shop environment of low-volume, high-mix and custom-engineered production is in line with the characteristics of Responsive Manufacturing described in the comparative study with other manufacturing paradigms i.e. Current Mass Manufacturing, Lean Manufacturing, Mass Customization and Agile Manufacturing [5]. The QRM system was opted in this project due to its similarity, conceptually to Responsive Manufacturing. In a comparison of the modern manufacturing paradigms, Nambiar [6] revealed QRM as the most suitable strategy for a manufacturer's setup along with these three characteristics i.e. high-mix, low-volume and custom-engineered. In the QRM system, material flow is controlled through application of the POLCA mechanism. Distinctiveness of POLCA and constant work in process (CONWIP) [7-8], for controlling

work in process (WIP) in such a complex environment are illustrated why one may be advantages over the other in regard to lead time, work in process and throughput. Generic POLCA (GPOLCA) was a customized POLCA material control system experimented by Fernandas and Silvo [9]. Unlike the genuine POLCA, the main different feature is that GPOLCA triggers to process the job when all the required GPOLCA cards are available at the production [10]. The review of POLCA, GPOLCA and material requirement planning (MRP) suggest that GPOLCA is the best production control approach for manufacturing environment with multi-product systems or make-to-order (MTO) mode [9]. Load-based POLCA (LB-POLCA) was designed to increase effectiveness of POLCA mechanism through an advance resource planning (ARP) system, which acts as the stochastic nature of manufacturing system as well as the high-level tuning and planning tool [11]. This system is much simpler and dynamic compare with finite scheduling system but there are several issues yet to be addressed [11].

Figure 1 gives you a quick view of the 10 QRM principles that counters the 10 traditional beliefs. The risk of the situation today is that not only are the wrong in operation based on the traditional beliefs, but managers may not know that these principles are amiss. Only when management clearly understands the basis for each QRM principle can it lead the organization along the QRM journey [4].
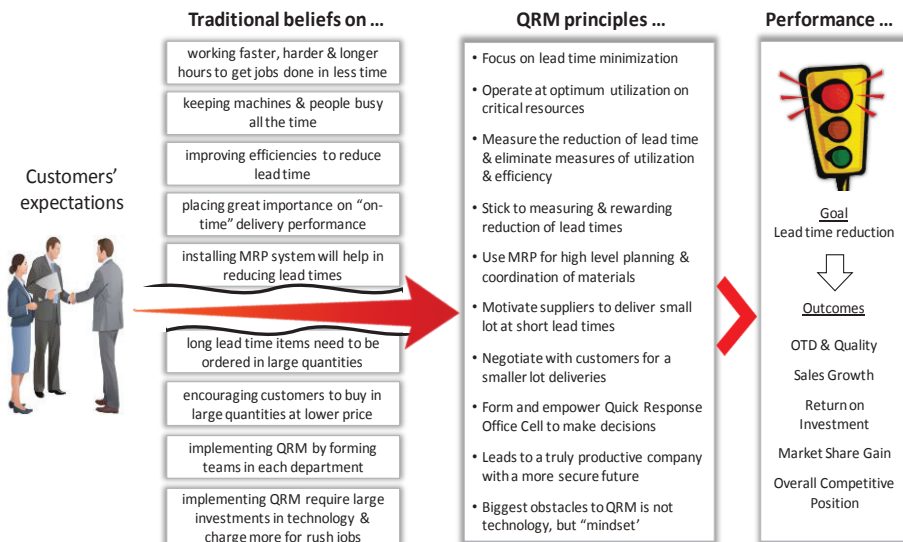

Traditional beliefs on ...	QRM principles ...	Performance ...
working faster, harder & longer hours to get jobs done in less time	• Focus on lead time minimization	
keeping machines & people busy all the time	• Operate at optimum utilization on critical resources	
improving efficiencies to reduce lead time	• Measure the reduction of lead time & eliminate measures of utilization & efficiency	
placing great importance on "on-time" delivery performance	• Stick to measuring & rewarding reduction of lead times	Goal Lead time reduction
installing MRP system will help in reducing lead times	• Use MRP for high level planning & coordination of materials	
Customers' expectations	• Motivate suppliers to deliver small lot at short lead times	Outcomes
long lead time items need to be ordered in large quantities	• Negotiate with customers for a smaller lot deliveries	OTD & Quality
encouraging customers to buy in large quantities at lower price	• Form and empower Quick Response Office Cell to make decisions	Sales Growth Return on Investment
implementing QRM by forming teams in each department	• Leads to a truly productive company with a more secure future	Market Share Gain
implementing QRM require large investments in technology & charge more for rush jobs	• Biggest obstacles to QRM is not technology, but "mindset"	Overall Competitive Position

Figure 1: QRM principles supersede traditional beliefs [4]

2.1 QRM: POLCA Material Control Mechanism

POLCA is exclusively designed for low-volume, high mixed type environments [4]. Hopp and Spear [12] define POLCA as pull system due to its triggering authorization mechanism. The card (Figure 2) used as the triggering mechanism can be in physical or electronic form [13].

The visual authorization mechanism of POLCA enables the planner to regulate flow of jobs by stating planned release dates on each received customer order. In order to start production, a cell needs to attach a card that specifies the next cell to visit after completing the order in this cell. The triggering mechanism determines an upper limit of the Work-in-progress (WIP) on the production and hence on the production throughput time [14]. Figure 2 shows a typical POLCA card and Figure 3 demonstrates how POLCA cards regulate the materials movement within the production zone.
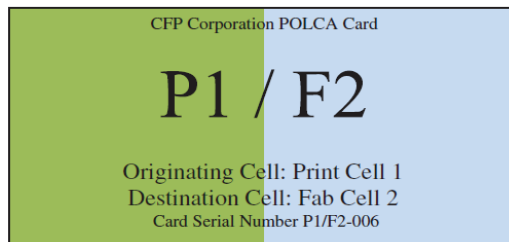
Figure 2: POLCA card for loop P1/F2 [4]
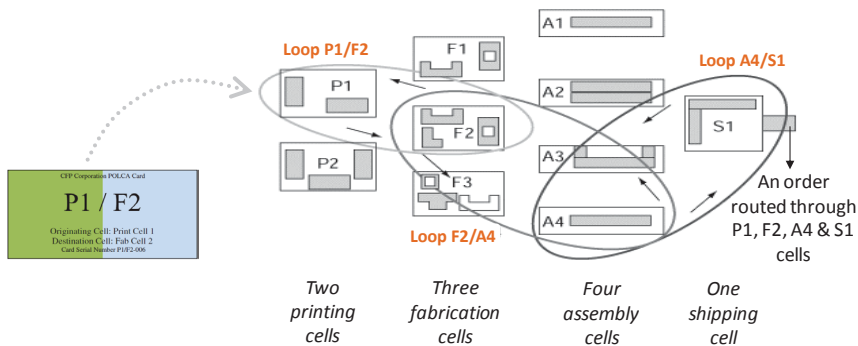
Figure 3: Pulling in action of POLCA cards [4]

2.2   Utilization based (UB) Material Control Approach

The UB approach is mainly applying some QRM key principles as shown in Figure 1. The approach is driving a whole new way of completing a job with the focus lead time minimization rather than emphasizing on traditional utilization and efficiency [4]. Taking time out of the system requires completely rethinking how production, materials supply, office-based and other non-operational works are organized.

One of the most striking concepts emphasized in the QRM approach is that critical resources do not have to be running all the time as illustrated on the traditional view in Figure 4a. QRM suggests that critical resources be utilized at 80% or even 70% capacity (Figure 4b). QRM will eliminate the complex series of dysfunctional interactions, long lead times, growing queues, jobs spending a lot of time waiting for resources that result from the present 100% utilization policy. QRM will show how idle capacity actually serves as a strategic investment that will pay for itself many times over in increased sales, higher quality and lower costs [16].

It is impossible to manage utilization driven material control without a proper monitoring system. Hence, here comes another QRM principles of having Manufacturing Requirement Planning (MRP) system serve an important function of assisting with material supply. In this case study, MRP is used for a higher level of planning via real-time utilization monitoring and providing authorization but not for micro-managing work centres. Complementing the MRP with a UB material control method combines the best of push and pull strategies.

To realize all the principles above, the organization must have an empowered quick response office cell or planning team. This team helps to get significant reduction of lead times for jobs such as quoting, order processing especially quick decision making upon jobs received from the customers. The closed-loop monitoring of real time machine utilization enables the team to response quickly to either continue production in-house or outsource to other selected and qualified suppliers.
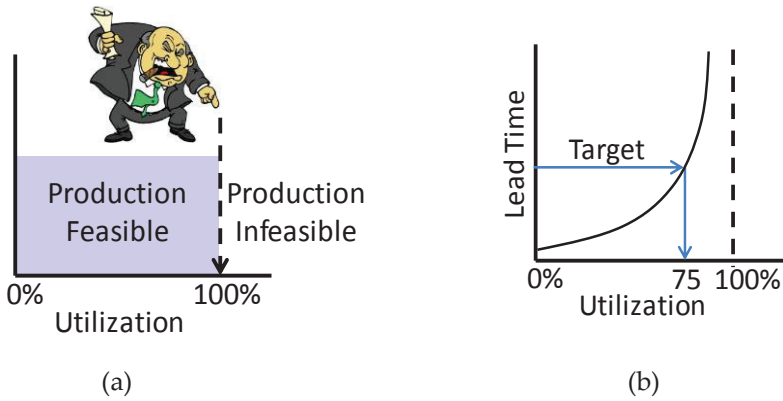
Figure 4: (a) Traditional View and (b) QRM Capacity Management [15]

2.3　　　Order Release or Outsource

Order release rule determined the time to release a particular job into the production to be processed [9]. Material flow control regulates the flow material throughout the production [14]. POLCA not only regulates the material flow at the shop floor however it is also decide on when to release of orders to the shop floor [13] based on the number of cards calculated for each loop (Figure 1, 2 and 3). Shop floor throughput time and on time delivery performance are greatly affected by the decision what and when to release to the shop floor [17]. This was different for the UB model which only needs to determine the rule of job release or outsource. The incoming orders are decided for in-house production or triggered for outsource depending on the real time machine loading in the shop floor. 'What-if' analyses were performed since there's no study has been conducted to determine the optimum level of utilization on the UB model. Various possible scenarios such as 80%, 85% and 90% loading at critical resources had been considered for preliminary study. The summary of simulated results is presented in Table 1 and Figure 7.

2.4　　　Manufacturing Critical-path Time

Suri [18] defined Manufacturing Critical-path Time (MCT) as the time captured in calendar days starting from the customer order, through the critical path, until the delivery of the first end-item of that order. MCT is a simple yet powerful metric to quantify total system-wide waste of an organization.

The analysis of this real time measurement help to identify which part or subset of an enterprise is needed for improvement. The MCT can be illustrated at best in an MCT Map. Figure 5 illustrates an example of the MCT Map for an order from receipt at a company until the order is completed and shipped to customer.

In Figure 5, we can clearly view the lead times of different processes at this specified subset of the organization. For example, we can see in this map that the gear parts take 47 days and hence the longest critical path. The map provides a clear insight of what is going on in the process with very little explanation required. The waiting times that shown proportionally on the map exposes the highest potential areas of lead time reduction.
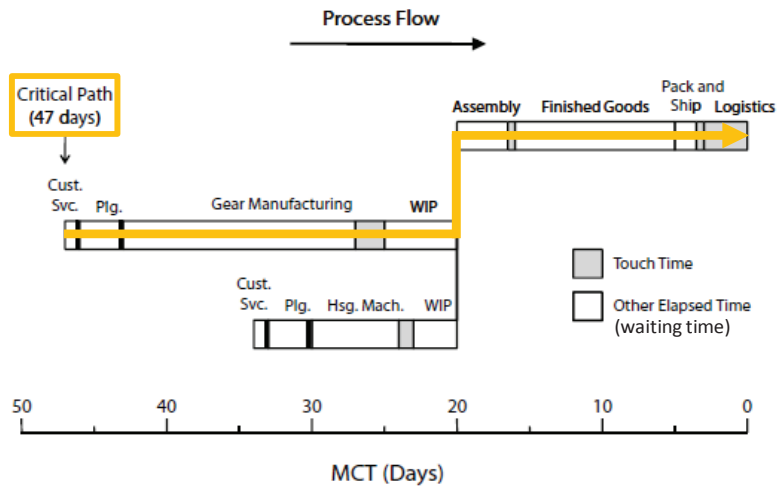

Figure 5: MCT example [19]

3.0 METHODOLOGY

Simulation offers the advantage of developing a feasible production model in shorter computation times compared to other techniques [20-21]. Figure 6 shows the procedure of carrying out the simulation study for this project.

As in most simulation studies, the major effort for this project was spent in collecting input data to construct a valid model to represent the current scenario in the case company. The study was conducted in

a real job shop environment manufacturing high precision components. Hence this methodology relies heavily on shop floor involvement throughout all phases of the simulation activities. The input data such as process time, route, set up time and arrival time are gathered for the modelling. This project used the WITNESS discrete event simulation software to develop and execute the model. After the base model was developed and statistically validated, a subsequent and more detailed model was validated against the actual factory historical data. More input and detailed data were added to model only as needed to answer specific questions. Throughput (TP), work in progress (WIP), flow time (FT) and MCT are used as the performance measures. The objectives is to analyse the results of the current and POLCA model with machine utilization based (UB) simulation models set at 80%, 85% and 90% as maximum loading limit. WIP is defined as the numbers of jobs stay between first work center and end point of product routing [22]. TP is defined as the number of completed products per time unit [22]. Flow time is the referred to time between the job release and its end of routing [22]. The results are discussed in the following section.
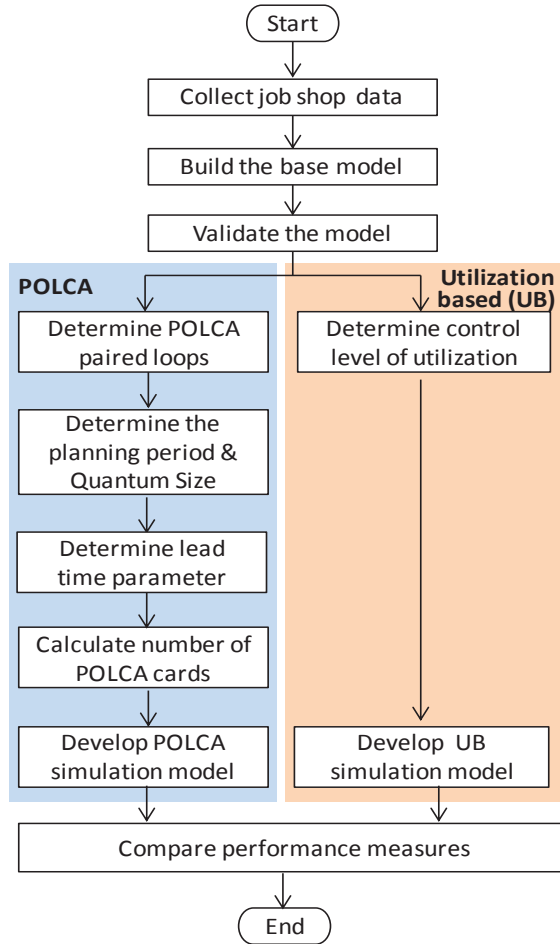
Figure 6: Process of the simulation study

4.0 RESULTS AND DISCUSSIONS

The current, POLCA and machine utilization based simulation models were processed with the same set of orders. The performance measures were compiled and summarized in Table 1 and Figure 7.

As shown in Table 1, results of TP, WIP and FT under POLCA system are better than current system which is consistent with the previous study [23]. From this study, UB system needs shorter FT to clear the WIP as compared to POLCA. However, TP percentage in UB system is showing lower for all scenarios set at 90%, 85% and 80% loading. Some important (in author's view) points of this simulation effect can be interpreted.

Firstly, lower WIP generally reduces TP provided the process time remains constant according to Little's Law [24]. Second, increase of capacity reserve at the critical resource reduced machine operational time, thus reducing TP on the production as a whole. Third, as the focus is on lead time minimization, UB is designed flexibly to allow outsourcing the orders without having to wait in the queue for the green light to utilize in-house capacity. Hence, this had directly shortened the FT and MCT as shown in Table 1. Indeed the outsourced TP, if added with the in-house TP, UB system has increased overall TP by 45%-75% (assuming 50%-75% of the outsourced jobs were completed on time) as compared with POLCA (Table 1). Practically, it is a common business strategy in order to capture bigger market share and maximize profit.

Table 1: Performance results of different mechanisms

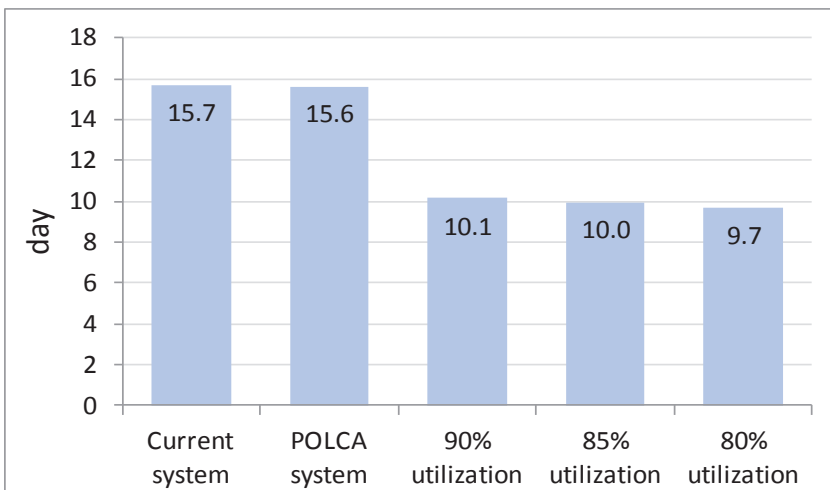| Mechanism	TP(a) (#jobs/day)	WIP (#jobs)	FT (hours)	Out-source (#jobs/day)	Total TP (TP (a) + 50% out-sourced)	Total TP (TP (a) + 75% out-sourced)	Additional TP Gain from UU (vs POLCA)
Current	48	1021	21.4	Not applicable			
POLCA	52	973	18.7				
90% UB	42	662	15.8	66	75	91	
85% UB	39	486	12.3	74	76	95	45-75%
80% UB	36	381	10.5	80	76	96	

Figure 7: Average MCT per job for different mechanisms

The advantage of UB system is the strategy developed based on QRM view (Figure 4b). The direct relationship between utilization and lead time enables company to determine the level of loading to be controlled in order to meet the desired lead time. For example, Figure 7 shows an estimated MCT of 10 days if the production controls at the range of 80-90% loading. The simple loading-control decision to regulate the order release reduces MCT of UB system by 33% vs. POLCA (Figure 7). This means any job order received can be completed within 2 weeks or less. The shorter MCT is desired, the lower utilization control is required. This will help the company to excel in the market with the shortest MCT in the long run.

Form the simulation study, this paper offers two clear strategies for QRM implementation. The conventional POLCA presents a more economical way by regulating the material flow using cards. The challenges include the maintenance of the cards for constant changes in the busy shop floor and longer MCT (vs, UB system). UB system introduces a more flexible method through utilization control in the shop floor. Additionally, UB enables quick decision change for the utilization control level to response unpredictable delivery demand of customers. It must be integrated with MRP system or some basic material tracking system for real-time capacity utilization monitoring. As such, higher cost may be incurred. Though POLCA and UB system are originated from QRM, having both implemented simultaneously seems not viable due to different job release rule, which may create confusion in the shop floor.

The limitations in the modeling include all the machines are treated universal to run any job at any time as long as the machines are available. Besides, the modeling assumes all the jobs are outsourceable regardless of which process reached the loading limit set by the management.

5.0   CONCLUSION

The simulation model was developed to study the job shop based on data collected from a real world industrial environment. The performance of the current system, POLCA and the Utilization Based (UB) Material Control mechanisms were experimented. Overall UB

system performed better by having lower WIP, shorter FT and MCT, and better overall TP (inclusive of outsourced jobs). Measuring the cost impact of implementing this specific recommendation is not within the scope. Besides, a change in product mix requires substantial effort for costing analysis, which opens an opportunity for future research.

The intention of this study is not only to appreciate the outcome of the experimentations but also to put forward recommendations for decision-making process and implementation on the shop floor. The integration of the UB control mechanism in an overall QRM framework to be implemented in the company is conceptualized in Figure 8.

Overall UB system performed better by having lower WIP, shorter FT and MCT, and better overall TP (inclusive of outsourced jobs). Measuring the cost impact of implementing this specific recommendation is not within the scope. Besides, a change in product mix requires substantial effort for costing analysis, which opens an opportunity for future research.

Either POLCA or UB system is a viable lead time reduction strategy depending on the company's capability. POLCA is more economical with the fragile cards system while UB method demonstrates flexible utilization control mechanism by integrating with material tracking system where additional cost will be incurred.
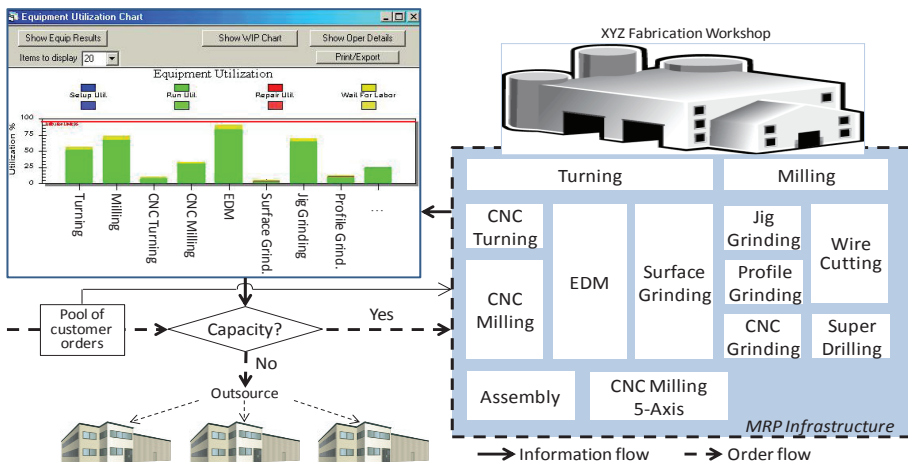

Figure 8: QRM principles based material control conceptual framework

In general, the simulation team acknowledges that the implementation of the UB system contributed to MCT decrease by 33% (Figure 7). This has directly boosted the confidence level to finish the incoming customer orders with the shortest time possible, making it a viable strategy with competitive advantage to be considered by companies that want to secure more business tomorrow.

ACKNOWLEDGMENTS

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