EFFECTIVE ASSESSMENT OF PROCESS IMPROVEMENT

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Abstract— A comparison study looking at the utilization gains achieved in a manufacturing facility in Melbourne, Australia after a previous investigation in 2012. Looking at the 'Hit List' of improvement recommendations created by the authors in 2012, this paper studies the link between changes made after the previous study, and current incremental gains in utilization. An 11.6 percent improvement was observed after a total of nine out of 43 recommendations from 2012 were enacted. The study then evaluated the link between those recommendations acted upon, and their ranked or perceived benefit/risk gain ratio. Finally, a new list of observed wastes in 2014 was created.

Index Terms— Production process improvement, Efficiency assessment, time-based measurements.

I. INTRODUCTION

The rapid development of technologies in the last few decades has changed manufacturing industry in many ways. The growing trend of global logistics support means that manufacturers have to adapt new technologies for fulfilling customer demand in speed and vareity [1]. A manufacturing company in Bayswater, a suburb east of Melbourne, is a 'one-stop' metal workshop. They are one of Victoria's leading metal fabricators servicing industries including automotive, defense, marine and hospitality. For confidentiality reason, we use "ABC" to represent the company. ABC operates advanced Computer Numerical Control (CNC) machinery, press brake equipment and laser-cutting technology to provide a range of services for sheet metal fabrication and turret punching, with a specialisation in made-to-order products.

Due to the service oriented nature of the business, customer orders are usually not standard. Over 70% of the orders made are from some previously produced "typical" orders with variations in parameters such as size, number of parts, minor design changes, materials and finish. The trend is that the portion of variations from previous products is increasing, which means the company needs to adapt a made-to-order job manufacturing system.

However, studies show that due to frequent variations of products, made-to-order business required more flexible and easy to apply production planning strategies. Gunasekaran and Ngai [2] reviewed a number of build-to-order supply chain and highlighted the importance of advanced planning in this type of "pull" system. Fernandes et al [3] viewed production scheduling problems as numerous linked problems and proposed a style of decision support to improve the performance of human schedulers. Framinan et al [4] showed that scheduling workflow in job shops by heuristics was complicated.

The effectiveness of production planning is governed by the information the system contains. Past effort such as total quality management assisted industry to improve processes that captured production information readily [5]. Caron and Fiore [6] took a project management approach that integrated the manufacturing logistics and product innovation customisation requirements for complex high-tech made-to-order equipment manufacturing. It is necessary to establish a strategy that can derive reasonably accurate measures without the need for total certainty of information [7].

ABC decided to implement a barcode work registration system. All work orders were logged with time spent on each process via the barcode system, before being passed on for quality checks. However, ABC encountered ongoing challenges in the process improvement project on the shop floor. Flaws were found in the consistency and accuracy of the data they collect about they work they do, and thus there are flow-on issues in prioritizing efficiency gains that could be implemented on the shop floor. To reduce costs, prevent waste, and provide improved performance in their time management, it is imperative that the company should assess effectiveness of their improvement effort so as to design a better change.

Nicholds & Mo [8] participated the improvement project in ABC, created a Hit List of observed wastes on the shop floor, and provided recommended actions for improvement. These improvements were ranked according to a hybrid analytic hierarchy process (AHP) methodology, aiming to prioritise elements using a benefit risk analysis aligned to the company's objectives.

After two years, the team had the opportunity to re-evaluate the change outcomes. This study extends the previous methodology to capture the performance of the new manufacturing processes, and assesses the effectiveness of the improvement effort so far. By providing a scalable and tangible way to manage

process improvement, better use of asset resources can be achieved when taking a holistic approach to manage the main factors into account.

II. LITERATURE REVIEW

A. Lean Production

The philosophy of lean production has been the driving force for process improvement in the last couple of decades. Mo [9] assisted a small furniture company that applied lean and agile manufacturing concepts when implementing a new IT solution by rationalizing the manufacturing system with lean principles. The outcome was a 30% increase in productivity and proved that lean and agile manufacturing could go hand in hand. Similarly, Hines et al. [10] integrated agile and hybrid approaches in their research on the evolution of lean thinking. By creating a distinction between lean concepts at operational level and at strategic level, full realization of lean thinking was proved beneficial.

Evaluating the effectiveness of lean production requires indicators, and understanding of the relationships between the indicators. Sanchez and Perez [11] studied the influence that a company's objectives could have on the use of lean production indicators, using an integrated checklist to assess changes made towards leaner production. Their conclusion recognized the importance of production indicators and their inclusion in a company's manufacturing information system. Mo [12] developed a hierarchical model to represent key indicators in process, product and people. The model could incorporate frequency distributions into these indicators to compute the probability of success of improvement projects.

B. Six Sigma Approach

The six sigma approach is extended from lean concept but focuses on the quality management process that includes statistical analysis of outcomes from an infrastructure of people within the company. Hagemeyer et al. [13] addressed the issue of problem solving tools or quality processes by proposing a classification scheme that provides a means to identify and select the appropriate tool. They demonstrated the usefulness in process-driven six sigma approach by applying it to a problem at a large manufacturing plant.

Vella et al. [14] explored how a six sigma methodology could be used to support enterprise transformation. Using a combined six sigma approach that aligned to the various phases of the GERAM life cycle and Critical-To-Satisfaction (CTS) considerations, they were able to re-engineer processes and structures in a foreseeable, yet dynamic manner that worked well in encourage and achieve improvements in operations and service.

Dunn [15] did a case study of a mining site and applied measures of plant availability and utilizations to assess equipment performance. By measuring the stoppages, Dunn was able to find opportunities for improvement and gains. However, this work fell short in assessing and improving lean manufacturing indicators and did not prioritise for action.

These literatures illustrated the importance of a data driven methodology in projects of improving manufacturing processes.

C. Efficiency Measurement

Having sufficient data to record the state of manufacturing process is one of the critical aspects in process improvement. Efficiency indicators computed from these data need to be monitored and interpreted [16].

Ghalayini and Noble [17] studied companies which are changing their manufacturing systems to use new technologies such as computer integrated manufacturing (CIM), flexible manufacturing systems (FMS), just in time (JIT), optimized production technology (OPT) and total quality management (TQM). They found that traditional performance measures were built solely from a pure financial management perspective that necessitated the development of new performance measures. They outlined eight general limitations and three other specific limitations with traditional methods. They believe that a more integrated approach should be used to evaluate, control and improve production processes, links together these areas of improvement on the shop floor, and focuses on improvement as a whole.

Bamber et al [18] explored the concept of overall equipment effectiveness (OEE) with an aim to improve the total competitiveness of the business through an operational focus. They concluded that such a strategy would require a holistic approach to draw together of many different disciplines or functions on the shop floor to align their actions of improvements.

Similarly, Jonsson and Lesshammar [19] looked at OEE to help establish a case for an overall manufacturing performance (OMP) system. They relied on its "measure of internal efficiency" to help achieve a more proactive, competitive and continuously improving system. However, OEE has shortcomings. Schonberger [20] found that the system could be manipulated to produce false high efficiency scores by ignoring certain time elements. This system deficiency was a type of loss in the lean system where long-term quality and true efficiency are the victims. Hence, efficiency measurements need to be broad and generic, wherever possible.

A survey of performance management systems showed that the most severe problems organizations encounter in their performance management systems

was lack of top management commitment [20]. The mis-aligned culture pushed performance management to a low priority or in some cases, was abandoned after a change of management. Hence, apart from the technical side of implementation performance management, the soft system capability in process improvement should also be assessed.

III. PERFORMANCE MEASUREMENT SYSTEM

Various performance measurement systems (PMS) were used to ascertain the quantitative and qualitative achievements of a complex system and provide recommendations for the design of performance measures that would be useful in this application [22]. Neely et al [23] studied the design of PMS, with particular regard for modern manufacturing facilities, and demarcated a need to analyse performance with non accounting-based methods. Dal et al. [24] used PMS to develop indicators showing improvement in manufacturing activities.

Whittaker [25] investigated project failure issues within information technology projects and found that once the reasons for these failures were identified, it was the first and important step in working towards minimizing them in the future, and creating performance measurement systems that are tailored to the situation.

Kennerly and Neely [26] argued that while much work has gone into looked at elements of the business that should be measured today, very little has been done to look at the measures that should be measured beyond that. To address this, they proposed a range of internal and external factors that serve to inhibit and alternatively encourage the introduction of new measures, as well as modifying existing ones and removing others that are obsolescent.

In essence, due to the dynamics of modern business environment, PMS is a critical tool to help businesses to monitor their trend in performance as well as providing an indication on the effectiveness of management systems. The performance measurement system used on ABC is shown in Figure 1.

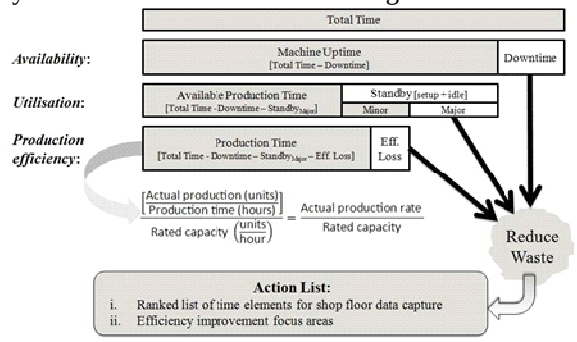


Figure 1 – Performance Measurement System on ABC

IV. DATA COLLECTION

The collection of data about wastes is a critical phase in the continuous improvement and performance measurement. But within this, it is important to ensure the data collection is at an achievable level – one that is not too onerous to collect and also analyze. Consequently, there were a number of methods used to collect data for this study, each chosen to facilitate optimum measurement.

D. Interviews with Staff

Cooperation from the staff in the company is absolutely necessary to ensure collection of useful data. The research team interviewed all the operators involved in the target machines as well as engineers who planned the work of the factory. The operators explained the reasons on their actions as well as their thoughts of possible improvements. The planning engineer was vital to the planning of the data capture sessions as well as their plans of improvement.

	Work centre	
Attribute	*Laser cutting*	*Brake press*
No. of work centres	2	3
No. of workers (direct)	2	4
Video duration (hours)	22	33
Video size (Gbyte)	71	105

Table 1 – Data to be captured in each of the work centres

E. Video Capture

Video capture was used to assess the work performed on the shop floor and to record all work performed over several days. When compared to work sampling studies, video evidence is the more superior technique. By combining video capture with concurrent interviews with the operators, all issues surrounding waste, were able to be addressed as and when they arose, giving a fuller understanding of the reasons, types and breadth of each situation. Table 1 shows the setting of video capture in this research.

F. Process Mapping

The data captured should be interpreted according to the process requirements [27]. The process map format provides estimates of performance based on data collected on key indicators such as work centre availability, utilization and production efficiency. It also allows for tracking of individual components and their assembly into products as they are logged throughout the factory, and tracking of the operators themselves as they perform the operations of one or more jobs they are working on. Table 2 was the result of combining the data captured in interviews and video recordings with process maps for the work centres.

Categories	*Work centre*	
	No.	*Description*

Production	S1	Production
	S2	Work station area preparation
	S3	Machine tooling
Initial setup	S4	Machine programming
	S5	Locating and moving materials
	S6	Other initial setup (incl. maintenance)
	S7	Delay obtaining forklift access
	S8	Job specification errors/clarifications
	S9	Other delays
	S10	Materials delivery delay
	S11	Material quality issues delay
	S12	Locating materials delay
	S13	Discussion with production manager
	S14	Discussion with other operator
Idle	S15	Discussion with dispatch
	S16	Discussion with Engineering Office
	S17	Arrange parts (setup)
	S18	Stack parts (setup)
	S19	Move/carry parts
	S20	Move/carry materials
	S21	Review job paperwork and parts
	S22	Clock jobs
	S23	Other idle time

Table 2 – Classification of time elements in the process

V. DATA ANALYSIS

G. The Initial Scenario

Prior to this study being completed, Nicholds and Mo [28] studied the processes in ABC and identified a comprehensive list of issues. A sample of this Hit List is provided at Figure 2. This Hit List was further prioritized by comparing the benefit/risk ratio of possible improvement projects on each of the waste items. Based this recommendation, ABC could then implement improvement projects of their choice.

H. Analysis of Data Collected 2 Years Later

Video capture taken in the two work centres studied was compiled and organized according to the elements listed in Table 2. These observed time losses are independent from the initial Hit List, but at times overlap with the original issues, indicating ongoing problems or partial resolution. Figure 3 shows an example of the analysed outcome from brake press 2 (BP2).

Work Centre				Potential Savings (minutes/event)		Recommendation		Department Responsibility Matrix (RACI)						
Name	Ref	Sect.	Description	Oper.	M/C	No.	Description	OM	ENG	PM	PSF	D	GM	WC
5085	[4]	2.2.3	Prototype production	0-82	0-82	R19	Evaluate the cost/benefit and technical feasibility: ▪ Second operator (shop floor foreman, etc.) supporting the primary operator by performing the machine programming tasks for prototypes on an external computer terminal prior to the setup job being performed. This has the potential to considerably increase machine utilisation. Note: An additional computer terminal running the M/C setup software etc. would be required.							
		2.2.4	Prototype part	10	10		Refer R19 above. Note: The total setup time for the observed prototype job was 16 min. Of this 10 min was used for programming the job from the M/C terminal.							

Table 2 - Example of Hit List from initial study

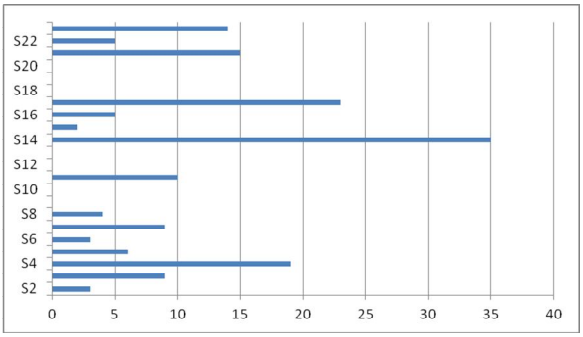


Figure 2 - Time and Waste Analysis for Brake Press 2

In Figure 2, it is clear that the operator spent a lot of time discussing jobs with operators of other two brake presses and waiting for help from the operator in BP1. This result is shown as extra idle times in BP2 (see S14). Tools and materials were located far from the machine and with difficult access as shown by S3. The operator often consulted the engineering office for verifying dimensions and visualizing folding techniques. The time spent for this purpose increased if the part has complex geometries and multi folding stages (see S16).

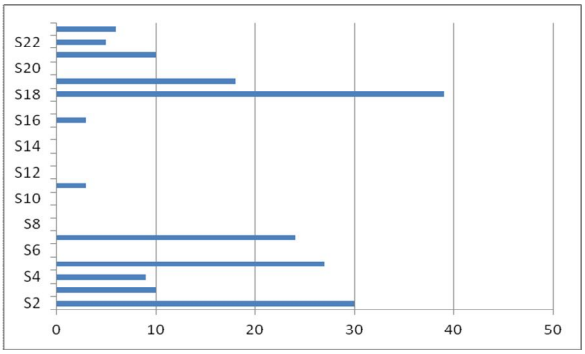


Figure 3 - Time and Waste Analysis for Laser Cutter 1

The operator also took a long time setting up the machine for new jobs, with minimum number of jobs and large quantities still the programming time similar for both stations BP1 and BP2, which indicates the lack of training and knowledge of BP2 operator (see S4). Similarly, the operator took long time to use bar code scanner when clocking jobs. This observed waste time was caused by the difficulty of using the system and the difficulty of scanning some paper works (see S22). There was also evidence that the operator could not identify dimensions on the job order papers. This posed a risk to errors in machine setting and the parts as a result of mis-interpretation (see S8).

Similarly, Figure 4 shows the video analysis result for laser cutter 1 (LC1).

Operator for this machine worked on both machines LC1 and LC2, the operator is running both machine which led to multiple idle times in both machines while the operator was busy with the other one (see S23 in Figure 4). S18 in Figure 4 also shows that the operator spent a lot of time stacking parts and shaking the metal sheets. This caused delays for jobs queuing in LC2, which was expensive if kept idel.

The operator spent around 30 minutes daily in cleaning works and preparing the workplace. This work could be assigned to non skilled labours (see S2). The operator also spent other times separating ash from steel parts for the purpose of recycling them (see S9).

From the raw record, it was found that the operator spent around 20 minutes a day waiting for the forklift. This waste was recorded by S7 in Figure 3).

Other jobs done by the operator included: cleaning lenses of laser cutter approximately 15 minutes (see S6), breakdown repairs (see S23), set up time (see S4). There were also non production times for more than one hour caused by delays of initiating work sheets to the station (see S23).

VI. KEY FINDINGS

Analysis of the data collected has clearly proved that the methodology underpinning the ranking of benefits and risks in the initial study was effective. On closer analysis of the data in this study, it appears that of the 53 recommendations presented in the initial 'Hit List', only nine have been implemented, with some other changes made that were not part of this list, but that have also been beneficial for utilization gains. While the number of recommendations implemented remains relatively low, the gains in the time saved for the brake presses and laser cutters are significant. Figure 4 shows the average savings in time from the new manufacturing processes.

Perhaps the largest of this came from reducing the machine setup time for BP3, an older machine that previously took a lot of time to get ready for each job. Following on from the initial study, this machine was allocated only to high volume jobs so as to reduce the overall setup time. This small change resulted in an average of 22.5 percent increased utilization for production. Similarly, the setup time for the Laser Cutter Work Centre was decreased by implementing a setup specification sheet that now allows for better communication of the job requirements, meaning greater efficiency and less idle time. This also amounted to an estimated contribution of about 10 percent.

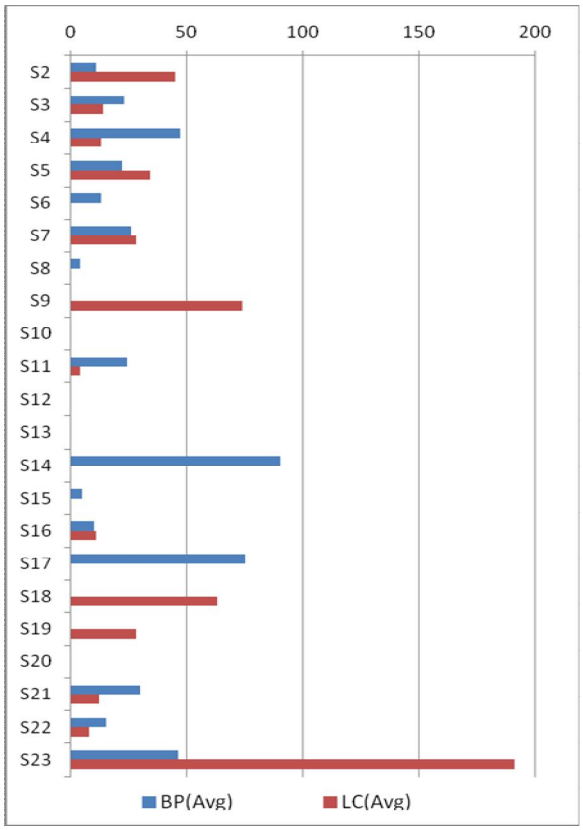


Figure 4 – Elements of time waste for all work centers (Avg)

Other savings of about 10 percent came from moving the location of nozzles for the Laser Cutter Work Centre and improving the location of the sheet work and quality tools for each work centre in the Brake Press area. Both of these greatly reduced delay

times, streamlining production. High gains were also recorded from more detailed work sheets implemented in the Brake Press area, allowing for better verification and visualization of the task at hand, and saving on the cost of items manufactured with defect. Particularly in a made-to-order style of business, the cost of reworking already completed jobs is particularly pertinent, with losses incurred in both time and wasted materials. In addition to this, forklift usage was also improved, with gains of 5 percent coming from the hiring of a full-time employee to provide continuous support with its usage – saving an average of about 11 minutes per job.

Of the recommendations that were enacted, greater levels of utilization was found in the second data collection, with overall gains of 11.36 percent (Table 3).

However, one of the biggest and most costly recommendations was the introduction of an automated barcode system to more accurately record time spent on each job, and to track its efficiency as it was moved between each of the work areas. Added to this, was the use of a new set of company performance metrics, based on the recording of these new time elements, and focusing on introducing measures that provide "the most benefit with acceptable risk". Unfortunately though, the gains provided by this barcode system have failed to prove as beneficial to the PMS process, with it unable to capture many of the causes of delays and losses. The most prevalent of these relates to workers not following the process properly – not clocking off when they leave the machine or finish the job, not registering toilet breaks within the course of the work, and other stoppages – which all contribute to an inaccurate reflection in the data of what is actually occurring. Both managers and shop floor operators agree that this system needs modification before it can prove fully useful, but agreement on how this might happen is still yet to arrive.

Year	2012	2014
Utilisation	50.0%	61.36%
Increment of utilization		11.63%

Table 3 – Improvement in utilization

Equivalent disagreement occurs between management and shop floor operators when discussing material location issues for both the Brake Press and Laser Cutter Work Centres. Actions were taken to move the storage of the materials, in line with Nicholds and Mo's recommendation, aiming to save operators and forklift drivers' time. Once this was completed, an average of 15 percent less waste was experienced. However, these gains are considered to be substantially low when compared to alternatives, with only an average of a 2 percent increase in the utilization of machinery. Again, management and operators disagree on the fix for this, with management believing it should be subjected to a benefit/risk analysis and feasibility study, while operators think that a more systematic way of locating materials would be best.

CONCLUSION

The study was successful in fulfilling its objectives - measuring the production rate, time wastage and utilization and categorizing these time wastes into different elements. Dynamic in nature, its success relies on management providing the right structure, values, skills and systems to empower employees to monitor and improve quality. By again identifying the main elements of losses on the shop floor and ranking these according to the original prioritization process, the study was able to assess the performance of the recommendations implemented, and compare the actions of the initial 'Hit List' to the utilization of the same Hit List two years later. It was then able to further investigate the impact of the improvement recommendations and the ability of the company to implement the 'Hit List' two years later. Underpinning this idea of continuous improvement is the desire to maximize the effectiveness of the Hit List and the outcome of improvement projects for the company. A key factor to this achievement is the ability to develop a performance measurement system that has a standard set of tools and procedures, and provide a consistent meaning over time.

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