LEAN SIX SIGMA APPROACH FOR LABOR PRODUCTIVITY IMPROVEMENT AT FINAL TEST SEMICONDUCTOR MANUFACTURING

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ABSTRACT: Labor productivity improvement is all about getting more units out with the same or lesser amount of labor. Due to the economic downturn, the semiconductor company under study wanted to determine the ideal number of operators to be employed especially at the critical operations in order to minimize the labor cost and improve labor productivity. Thus, the main focus of the study is to perform analysis at the bottleneck area in order to determine the labor utilization and also toidentify the ideal man to machine ratio at the semi-automatic final test operation. The lean work study analysis using Process Mapping and Maynard Operational Sequence Technique (MOST) also enabled the authors to unveil the various types of wastes occurring at the final test area in order to propose lean improvement activities. Six Sigma Define, Measure, Analyze, Improve and Control (DMAIC) approach was employed during the implementation of the study.
The results of the final test area Lean Six Sigma study showed significant improvements could be made on the labor utilization and man to machine ratio. With the knowledge of how to improve the labor productivity, the semiconductor company will be on the right track towards achieving a leaner and more cost effective operation.

KEYWORDS: Labor productivity, Lean Six Sigma, Work Study.

1.0   INTRODUCTION

Productivity has become an important issue in a business organization because high productivity means higher profit margin. According to Stevenson (2009) productivity can be defined as a ratio of a measure of output to a measure of resources used for the input. Productivity is important as it is used to benchmark the standard of the organization. A more productive organization is able to produce high number of output from a minimum input count. Hence, productivity is improved if the productivity index or ratio is increased. Most organizations failed to find the ultimate productivity because they have not really understood the true meaning of productivity. Productivity initiatives by the industries and the pro-business policies by the government provided favorable environment for productivity growth (Productivity Report, 2007).

Labor productivity can be measured in terms of either employee number or labor costs (Chapman and Khawaldeh, 2002) and is a key factor to achieve project goals. Thus, it is paramount to understand the main determinants of labor productivity in an organization as it contributes to the organization or company's performance. Greater labor productivity enables firms to produce a given amount of goods and services with smaller number of labor hours (Lardaro, 2001).

An established semiconductor company was faced with high labor turn over due to competitions with other emerging companies in the same area. The company policy did not allow for hiring of foreign worker to work as the manufacturing operator thus making the hiring process more difficult since the potential candidates often will select company that was able to offer better salary and more conducive working environment. The existing practice to hire manufacturing operator was by the manufacturing supervisors determining the number of operators required. Unfortunately, the management has no method to check whether this quantity was higher than the actual requirement or not. Therefore, the management had to find an accurate way to determine the actual number of operators required especially for the critical processes. In addition, the management also wanted to focus on identifying opportunities to reduce or eliminate waste in the production line and improve labor productivity. Consequently, these issues have become the basis of this paper where a work study technique called Man to Machine (M2M) ratio was developed and used to measure the existing labor utilization and suggest an ideal man to machine ratio. Lean six sigma Define (D), Measure (M), Analyze (A), Improve (I), and Control (C) methodology was employed to conduct

the study in order to identify productivity improvement opportunities at the final test which was also the bottleneck of the operation at the back-end semiconductor manufacturing.

2.0   LEAN SIX SIGMA

Lean manufacturing is known as the most influential manufacturing paradigm of recent times that can be considered as multi-dimensional approach that encompasses a wide variety of management practices in an integrated system that produces finished products at the pace of customer demand with little or no waste (Holweg, 2007; Shah and Ward, 2003).

Lean is a term coined by the Americans originating from the famous Toyota Production System (Meyers *et.al.*, 2002). The Lean productivity improvement effort is solely on waste elimination. Svensson (2001) explained that in terms of cost, waste refers to any incurred cost such as inventory, set-up, scrap, and rework that do not add to the value of the product. From the perception of the end users, waste is internal and external resources that are consumed without adding value to the customers (Emiliani, 2001). Waste or "Muda" in Japanese are categorized into seven types; Transporting, Defects, Overproducing, Waiting, Inappropriate Processing, Unnecessary Inventory or Work In Progress and Unnecessary Motion.

The outcomes of lean manufacturing include significant reduction in inventory and lead times, improved delivery performance, better space and resource utilization and enhanced productivity and quality (Pavnaskar *et.al.*, 2003).

Abdul Malek and Rajgopal (2007) mentioned that the lean manufacturing tools and techniques such as Just-In-Time (JIT), cellular manufacturing, total productive maintenance, single-minute exchange of dies, and production smoothing have been widely used in discrete manufacturing which spanned in many sectors including automotive, electronics and consumer products manufacturing. Bicheno (2006) added that among the lean manufacturing tools used to reduce wastes are Kaizen, synchronize manufacturing, standardized work and work place organization.

However, it is quite common for companies to combine Lean Manufacturing and Six Sigma in what is sometimes called Lean Six Sigma. The two are quite complimentary since Six Sigma is a powerful

tool for helping to make the company leaner. Likewise, some of the processes often used in Lean Manufacturing may be the solutions to problems addressed in a Six Sigma projects (Bendell, 2006). Both Six Sigma and Lean Manufacturing have unique strengths and they integrate well together. Lean is broader in nature since it sets a broad objective of eliminating all waste, and recommends certain processes for achieving that. Six Sigma is more focused in nature since it is a set of tools for achieving clearly defined improvements, which are likely to result in a leaner company.

Harry *et.al*. (2000) defined Six Sigma as a business process that allows companies to drastically improve their bottom line by designing and monitoring everyday business activities in ways that minimize waste and resources while increasing customer satisfaction. The standard approach to Six Sigma projects is the Define, Measure, Analyze, Improve and Control or DMAIC methodology developed by General Electric which is central to Six Sigma process improvement projects. The DMAIC phases provide a problem solving process in which specific tools are employed to turn a practical problem into a statistical problem, generate a statistical solution and then convert that back into a practical solution (Henderson *et.al.*, 2000). Figure 1.0 illustrates the Six Sigma DMAIC model.
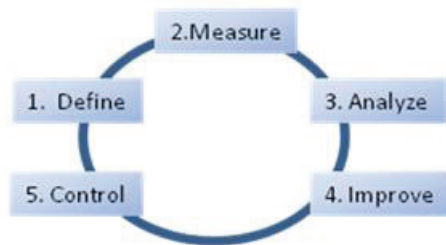

Figure 1.0:Six Sigma DMAIC Model (Sheldon, 2005)

3.0   MAN TO MACHINE (M2M) RATIO TECHNIQUE

M2M ratio technique was developed based on the evaluation of the common work study tools such as Process Mapping and Multi Machine Chart. Thefirst important element that contributes to the labor productivity determination is the operator's utilization or the time spent to perform a set of activities over a period of time. Operator's utilization consists of the operator's activity time, the number of time each activities is repeated (frequency) and the time-frame in which

the whole process is repeated. Hence, the operator's utilization can be defined as shown in Equation

$$\text{Operator Utilization}(\%) = \frac{Activity\ time\ x\ Frequency}{Total\ Time} x\ 100 (\text{Equation}........\ 1)$$

Where,
Activity Time = time taken by an operator to perform a task
Frequency = rate of recurrence of an activity
Total Time = Total working time of an operator in a shift

Since the equipment used at the back-end semiconductor manufacturing line are semi automatic, for a machine to process a lot of product, the operator will need to perform the machine set-up, loading the unprocessed product on the machine and documentation on the shop order. This set of activities will be repeated when a new lot is started on the machine. Since the mode of operation is machine dependent, the operator will be performing a set of tasks while the machine is processing a batch of products or a lot.

Through the evaluation of the Multi Machine Chart, the next key element found was the lot cycle time or the time taken for the machine to complete a certain quantity of product in a lot or lot size. The data regarding the lot cycle time can be obtained through measuring the time to process the lot using a stop watch. However, the lot cycle time can also be obtained when information on lot size, the number of units produced in one hour or Units Per Hour (UPH) and the Overall Equipment Efficiency (OEE) are available from the manufacturing shop floor. The relationship between these variables is defined as shown in Equation 2.

$$\text{Lot Cycle Time} = \frac{Lot\ Size}{UPH\ x\ OEE}(\text{Equation} .... \ 2)$$

Where,
Lot size = the set quantity of a unit to be processed
Units per Hour (UPH) = Number of units processed in an hour
OEE = Overall Equipment Efficiency

From the operator utilization in Equation 1, we know that in order to measure the labor utilization, the activity time and the frequency is multiplied and then divided by the total working time. However, since many of the activities are done repetitively for each lot, the

labor utilization can be sampled based on the lot cycle time because it represents the utilization of the labor handling a machine in a shift. Figure 2.0 shows the concept of M2M utilization.
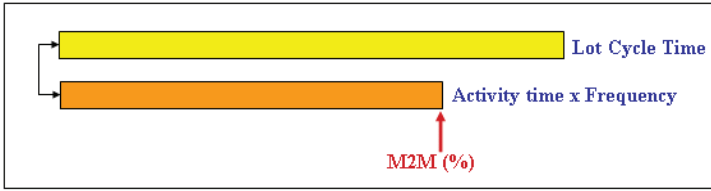

Figure 2.0: Man to Machine (M2M) Utilization

Since the operator needs to perform activities within a lot cycle time, each individual activity time interval must be multiplied by the frequency and then the summation of the product of activity time interval and its frequency of occurrence have to be computed. If this summation is divided by the total lot cycle time, then the man to machine ratio (M2M) can be computed using Equation 3.

$$M2M(\%) = \sum_{i=1}^{n} \frac{Activity\ time\ x\ Frequency}{Lot\ Cycle\ Time} \ x\ 100 \quad (Equation\ \ldots\ldots\ldots\ldots3)$$

Where,

i = number of activity time and the frequency
n = total number of activity time and the frequency

Table 1.0: Man to Machine (M2M) Calculation Example

	Activities	Time (min)	Frequency / lot	Lot cycle time (min)	M2M(1)	M2M(2)	M2M(3)	M2M(4)
		a	b	c	d	e	f	g	h
1.	Wafer Preparation	0.3	1	15	0.020	0.040	0.060	0.080
2.	Wafer Mount	0.5	1	15	0.033	0.067	0.100	0.133
3.	Machine Set-up	3	1	15	0.200	0.400	0.600	0.800
M2M utilization (%)					25.33	50.67	76.00	101.33

Table 1.0 is used in order to further explain Equation 3. Column (a) indicates the activity element of the operator and column (b), (c) and (d) is the time for the activity element, frequency and lot cycle time respectively. Thus, the M2M (1) in column (e) is obtained using Equation 3.

$$M2M = \sum_{i=1}^{n} \frac{(\text{Activity Time})_i \times (\text{Frequency})_i \times 100\%}{(\text{Lot Cycle Time})}$$

$$
\begin{aligned}
M2M \quad &= \frac{(0.3 \times 1) + (0.5 \times 1) + (3 \times 1)}{15} \times 100\% \\
&= (0.020 + 0.033 + 0.200) \times 100\% \\
&= 25.33\%
\end{aligned}
$$

From Table 1.0, the wafer preparation, wafer mount and machine set-up activity elements are repetitive work elements and the utilization of the operator will be doubled if the operator needs to handle two machines as indicated in column (f) or M2M (2) of 50.67%. The operator's utilization will keep on increasing when more machines are added to the operator as indicated by M2M (3) in column (g) where the utilization is at 76%.

To ensure that the operator is not overloaded with tasks, the personal, fatigue and delay (PFD) allowances need to be considered based on the International Labor Standards (ILO) (APRC, 1997). Since all the operators working at the back end semiconductor manufacturing process are women, 7% personal need allowance, 4% basic fatigue allowance and 4% standing allowance or 15% PFD allowances were agreed by the management to be used in the computation of the M2M and thus, the ideal utilization of an operator is targeted at 85%. Since M2M (4) in column (h) is 101.33%, this utilization exceeds the capability of the operator. Consequently, the ideal man to machine ratio for the wafer saw operation is determined at 1 operator to 3 machines which resulted in the operator's utilization of 76% as indicated in column (g).

4.0 FINAL TEST LEAN SIX SIGMA

The Final Test was the area selected as the back-end semiconductor that the Lean Six Sigma study was conducted since this operation was identified as the bottleneck area for the production line. This process is where each device is tested for the electrical performance based on customer's specification. In addition, each unit will be marked using the same machine with company's logo, device number and production date for traceability purposes. Each completed unit will automatically be inserted into a reel and sealed before being packed.

The focus for this area were to determine the existing labor utilization, to identify the ideal man to machine ratio and to find the opportunities

to reduce or eliminate any non value added activities or wastes. Six Sigma DMAIC methodology was used to conduct the study.

4.1   Define

The final test area is where the units are separated from the lead frame and the legs of the units are shaped to the customer's specification using the trim and form equipment. The same equipment also is used to mark the units with the company logo and to test the units to meet the customer's electrical requirements. Table 2.0 summarizes the equipment allocation at the final test process.

Table 2.0: Final Test Process Equipment Allocation

Cells	Products	Equipment	Qty
Cell 1	SMB	T-16	6
Cell 2	SMB	T-16	3
	SMC	T-16	2
Cell 3	SMA	NT-16	1
	SMB	NT-16	2
Cell 4	SMB	NT-16	4
	SMC	NT-16	2
Cell 5	SMB	NT-16	2
	SOD123_FL	NT-16	4
Cell 6	SMA	NT-16	2
	Pmite	NT-16	2
Cell 7	Pmite	NT-16	3
		T-16	1

The first step is to define the product and equipment allocation at the final test area before detail capacity study can be done to define the unit per hour (UPH) and the lot cycle time to be used in the M2M study. From Table 2.0, the final test area consists of seven cells containing two different types of final test equipment; Ismeca T-16 which is very old technology final test equipment and Ismeca NT-16 which is the newer technology final test equipment. However, there is already a plan to phase out all the Ismeca T-16 and thus, for the purpose of the M2M study, the author is asked by the management to only focus on the NT-16 equipment.

The labor configuration in each cell at final test area is 1 operator handling 2 machines. The operators are designated to load and unload the materials, operate the machines, perform machine assist whenever minor stoppages occur, product inspection, transport materials and prepare required documentations.

4.2   Measure

The product and equipment information in the final test area such as the lot size and the units per hour (UPH) are then used to calculate the lot cycle time using the formula defined during the M2M method development. Since the equipment efficiency information is not available at the time of study, the management has agreed to standardize the use of 70% equipment efficiency for the purpose of calculating the lot cycle time. The summary of the lot cycle time used for the three M2M studies done at the final test area is presented in Table 3.0.

Table 3.0: M2M Study Lot Cycle Time

Cell	Product	Lot Cycle Time (min)
Cell 3	SMA/SMB	251.83
Cell 4	SMB/C/SOD	146.8
Cell 7	Powermite	164.93

With the lot cycle time to be used determined, the next step is to perform the mapping of the final test operator's detail activity study and measuring the time taken for each activity using the MOST predetermined time standards.

4.3   Analyze

Based on the analysis of the M2M result, the summary of the operator's utilization and man to machine ratio for the final test area is summarized in Table 4.0 below.

Table 4.0: Summary of the Final Test M2M result

Cell	Product	M2M(1)	M2M(2)	M2M(3)	M2M(4)	M2M(5)
3	NT 16 SMA/SMB	29.32%	54.97%	80.61%	106.26%	
4	NT 16 SMB/SMC/SOD	24.65%	45.12%	65.59%	86.06%	106.53%
7	NT 16 Powermite	30.57%	56.95%	83.34%	109.73%	

Referring to Table 4.0, the cell 3 operator's utilization who is only handling two machines is 54.97% and can be improved to 80.61% if another machine is allocated to the operator. Similarly, two more machines can be handled by the cell 4 operator and the utilization of the operator can be improved further to 86.06%. In addition, the operator handling the Powermite products can also take care of another equipment to improve the utilization to 83.34%.

The existing allocation of operators is three operators per each cell. However, if one operator has to handle 3 machines, there will be only 2 operators handling a cell and this will create a problem when one of the

operators go for break or had to attend to some other personal delays. This will result in 1 operator handling 6 machines and the operator's utilization will increase to beyond 100% and risking potential loss of valuable outputs if the operator is unable to perform critical functions such as machine assist, reel change and start new lot. Consequently, the alternative to reduce one operator from each cell will need to be delayed until waste elimination activities are implemented in the final test area.

4.4   Improve

From the three cells Final Test M2M study, the top three major wastes in the final test area are the machine assist, reel change and start new lot activities as illustrated in Figure 3.0 below and taking the cell 3 operator's M2M(1) data as an example. Although briefing also takes up the operator's valuable time, this activity is considered necessary to ensure the operators clearly understand what is required to be done at the beginning of every shift but efforts will need also need to be put in to reduce the time taken to conduct the briefing session.
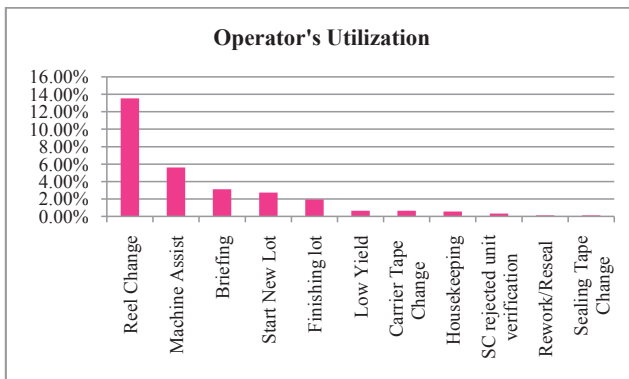

Figure 3.0: Cell 3 NT-16 Operator's Utilization

Referring to Figure 3.0, the reel change activity takes about 13.52% of the operator's total working time, machine assist activity consumes about 5.59% of the operator's total working time and start new lot activity acquire about 2.74% of the operator's total working time and. In order to identify the opportunities to reduce or eliminate waste, further analysis of the machine assist, reel change and start new lot activities are done.

4.4.1 Machine Assist

Machine assist is the activity of the operator needs to perform whenever the equipment suddenly come to a stop to reset the test program, units pick up problem or laser not marking issues. Whenever the operator has to perform machine assist activity, the operator will also need to walk to the Pridelink workstation where the information regarding the machine down time will need to be entered in the computer.

During the period of the study, there is only one Pride link system installed at each cell. This system is used to track the occurrence of machine breakdowns and the data taken from this system is used to determine the machine efficiency. Every time a machine is down, an operator had to walk at an average of 17 feet from the machine to the Pride link system to enter the machine down time loss code before walking back to the machine to assist the machine. As a result from the M2M study, the IT group has agreed to install another Pridelink workstation in every cell to reduce the operator's travelling waste.

4.4.2 Reel Change Activity

Based on further inspection of the Final Test process, the machine will stop for every 2500 tested SMB units for the operator to unload the completed reel and load it with a new reel. The operator will then do a 100% inspection on the completed reel of SSOVP (difficult SMB device) and about 25% on the completed reel on the rest of the devices. The inspection is done for every reel. Referring to Reel Change Activity Chart (Figure 4.0), it is clearly shown that the inspection activity has taken most of the time in the reel change category.
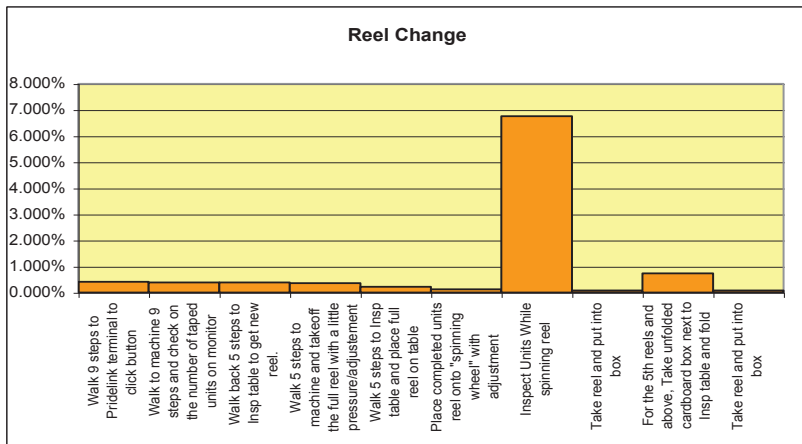

Figure4.0: Reel Change Activity Chart

Due to this, manufacturing has decided to change the inspection method. Instead of inspecting on every reel, the new procedure is to inspect only the first and the last reel of a lot. However, whenever a machine brakes down while processing a lot, the next completed reel is required to be inspected once the machine is fixed. In order to ensure the machine runs continuously and no major downtime occurs, one technician is assigned to each cell to maintain the efficiency of the machines.

4.4.3   Start New Lot

In order to reduce the frequency of lot start, manufacturing has also agreed to increase the standard lot size from 30000 to 60000 and this will help in reducing the frequency of the setup time. The Lot Start Activity Chart in Figure 5 shows that although each activity does not require too much time, there are still too many activities that the operator needs to perform when starting a new lot.
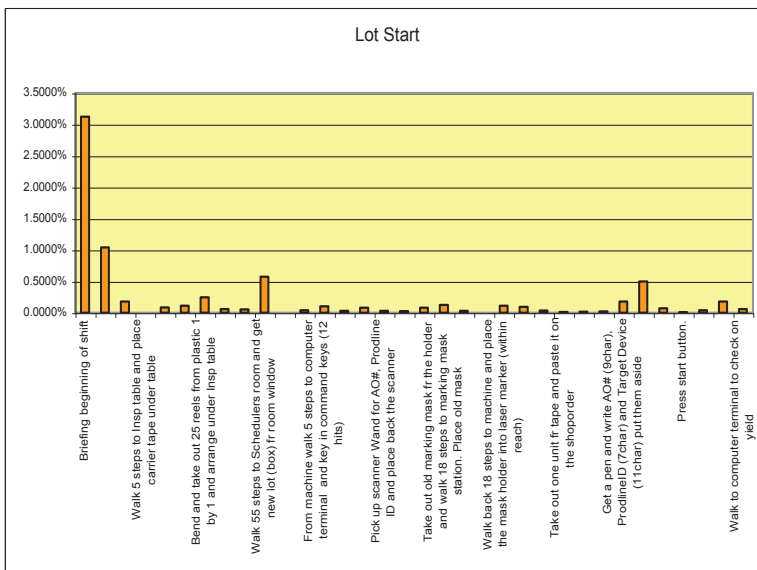

Figure5: Lot Start Activity Chart Analysis

To further improve the Final test machine capability and reduce the operator's reel change activities, equipment group had started on a new project to automate the reel change process. The machine will replace the operator's function to perform the reel loading and unloading. In addition, the new process will also include picking a new reel from a reel stacker and loading it to the machine. The group had already started working with external vendors and internal experts to implement this project.

In order to further improve the operator's utilization, the author also recommends to automate the current Pridelink system whereby the operator did not have to walk to the system anymore when assisting machines. In addition, detail study on the machine breakdown will need to be done to further reduce the Mean Time Between Assist (MTBA) time and improve the equipment capacity for the production line.

4.4.4   Control

The final test improvement team was required to report the progress of the implementation during the monthly team review and quarterly management review. This was to ensure that the lean efforts are given appropriate attention in order to continuously increase the productivity of the final test production line.

5.0   CONCLUSIONS

Productivity measure is important in any business organization and can be achieved through the production of higher output utilizing the minimum amount of inputs. Focusing on labor inputs provides the opportunity for a company to efficiently utilize the manpower needed especially at the critical operation to gain maximum output with minimum labor hours. Lean Six Sigma is a systematic technique that can be used to uncover the various types of wastes in the operator's activities in order to increase the efficiency of the workers.

The Man to Machine ratio (M2M) techniqueis an alternative technique that can be used to provide any work study practitioner with easy, fast, accurate, economic and flexible tool. By utilizing the M2M method, current and ideal labor utilization can be determined and various wastes can be uncovered to further improve labor productivity and reduce manufacturing cost.

The result of the improvement of the cycle time will contribute to the increase in the speed of delivery to the customers. Thus, the company will be able to confidently identify the actual number of employees they need to employ and can concentrate on the training to ensure each employee they hire provides high productivity and performance to the company. By employing the M2M method, human wastes such as motion and idling were able to be identified.

In addition, the data obtained from the work study can be used for designing work standards and operator cross training in order to

increase the production throughput and ensure balanced work load between operators. The work standards can also be used by the training department to perform job design, train the new operators and set realistic learning curves. Attractive incentive plans can also be set so as to boost the employee's morale. These activities will contribute to the overall improvements in the productivity of the production line and will help contribute to the reduction in cost and the increase in profit to the company. In the end, the company will be in the right track of its lean journey and towards achieving a high productivity, quality and safety of the employees.

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