A Methodology Development of Defining Productivity Rate and Losses Analysis in Screen Printing Processing Line

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Abstract— **Productivity reserves many different opinions and concept but in every way it connects through the idea of continuous improvement and lean manufacturing in order to have more capability. The productivity capability in a real situation needs to be measured and understandable to be interpreted by a manager in an industry which the methodology of approaching the measurement is through a mathematical modeling. Hence, the knowledge of productivity is very crucial for manufacturing department to ensure that they achieve their goals especially costing in a much higher competitive market nowadays. This study offers a readable results of diagram that shows the losses categories that the department can focus on which its production losses are shown to be improve and perform corrective actions against the highest losses area. At the same time, productivity indices with calculations also will be define inside to have a measure of capability from time to time, in the form of performance key indicator for the department itself. Productivity is reflected in many possible ways bringing many practices such as Kaizen, Kanban, Just In Time, Plan-Do-Check-Act cycle which the objective of the practices approach are going to the same agenda that is improving the productivity in overall forms. Mathematical modeling of productivity is very important to figure out the peak of productivity possible that is always based on the limitation of the technological processes or machine ability. Unrealized losses seems to haunt all Manufacturing Managers, Engineers, and also the Managements of the organization thus creates lost of focus in capturing the bigger image in the organization itself , the real bigger losses area regime. Hence, the knowledge of productivity concept is very important in manufacturing that each management has to learn and optimize the investment made that it can create a faster return of investment to gain in the business.**

Keywords– **Productivity Rate, Analysis and Screen Printing**

I. INTRODUCTION

The screen printing process consisting of an Ultraviolet (UV) etch resist ink is printed on top of the substrate layer to cover the design trace of the products. Basic screen printing is a printing technique that uses a woven mesh to support an ink-blocking stencil. The attached stencil forms open areas of mesh that transfer ink or other printable materials which can be pressed through the mesh as a sharp-edged image onto a substrate.

This is basically processed through a flat bed screen printing machine. It basically have a standard printing table that is flat, a printing head which contains a squeegee holder, a flood bar and a squeegee to press the ink going through the stencil. This stencil containing mesh is coated with an emulsion and already exposed to have its own antenna design pattern depending on the product. In printing, every print will produce certain quantity of products, which is depending on the drawing on its stencil. Only after finished printing it will be processed through a curing station or short named as Ultraviolet station , a station where the heat from the UV lamps in the station intensify the etch resist ink to be cured.

In printing process, the work time is the processing time. Thus, the ratio of total work time for one complete print cycle divided by no of 1 print is logically presented as the cycle time of 1 print in the printing process. In the printing cycle time, it is expresses into two that is work time and auxiliary time (or the delivery time). The equation of cyclic productivity can be formulated as:

$$Q = \frac{z}{\theta} = \frac{z}{\theta_w + \theta_i} \quad (1)$$

Where Q = Productivity, z = Units of products produced and Θ = time observed.

The total idle time of the screen printing process is are divided into several categories which are malfunction of UV station, visual defects issues, waiting quality inspection time and fail of measurement buyoffs which needs to be fine tune again. Hence, the total idle time is a non productive times. In a typical manufacturing industry, the reasons of idle time are separated into technical reasons and organizational and managerial reasons. Here in screen printing since the quality inspection is a critical must add on criteria, it will be counted as the third one with the defects issues, process issues and equipment issues are categorized under technical reasons.

Finally the actual productivity of the screen printing process after substituting all the defined losses into Eq. (1) is represented by the following equation:

$$Q = \frac{z}{\theta} = \frac{z}{\theta_w + \theta_i} = \frac{1}{\frac{\theta_w}{z} + \frac{\theta_i}{z}} = \frac{1}{T + \sum_{i=1}^{n} t_{tech} + \sum_{i=1}^{n} t_{ins} + \sum_{i=1}^{n} t_{set} + \sum_{i=1}^{n} t_{mgt}}$$

Formulation of new calculations is based on the reasons of losses found in the screen printing process through this study. The formulation will be different from any other industry and in summary will be only for the reference of similar industry of same technological /manufacturing process.

The idling times or stoppages in this screen printing line are divided into:

i) Stops and breaks due to technical issues (t_{tech})
ii) Stops and breaks due to management problems. (t_{mgt}) + (t_{logi})
iii) Stops and breaks due to inspection of quality (t_{ins})
iv) Stops and breaks due to machine setup (t_{set})

The calculation of productivity rate can be applied to any manufacturing types. The degree of calculation complexity depends on the production processes which relates to the product technology, manufacturing process natures and the structure of the manufacturing process flow. In align with this, the data that form the mathematical model need to cover all the formalization of productivity calculations to avoid high error percentages. This study aims to collect all necessaries data of productivity losses and present it into a readable diagram for more efficient and reliable results for decision. This screen printing section was chosen because it is the main bottleneck in the whole manufacturing systems. All data were recorded according to the proposed methodology.

For this productivity study data collection, the observation time of the screen printing was set to satisfy the minimum statistical requirements. In order to get the most reliable results in studying the screen printing productivity, the company's data of previous month which contains 24 shifts of work was used as the requirements data.

Each production shift works for 12 hours day and night and this type of production runs 24 hours and 7 days nonstop. There are no schedule stoppages that involve management decision such as planned shutdown during this study. The stoppages are divided into the average output of each shift production was taken and tabulate in a list. From this outputs, we calculate that mean cumulative average in each shifts should it be adding up until the average deviation is lower than 5% from the total average of outputs.

The data of statistic must show a gradually reducing trend of below 5 error % of outputs towards the shift accumulations. This shows reliable data of production outputs was taken for this study as a source for the analysis of productivity. From the output results of 24 shifts tabulate and after getting the average deviation of the outputs, it is found that the deviation should be no more than 5% from the average mean cumulative number.

Cycle time of screen printing is supposing the total elapsed time from material entrance to the print entrance and to the exit of print table that is including transport. The cycle time of print is included the print cycle, the squeegee Cycle time includes = UV (Curing Station) or Printing Head time which one is taking the longer time since in between the 2 stations have buffer. Cycle time in printing process will be calculated in way which we need to find the longest time taken to finish one single print in that particular area station in a machine.
In this printing machine, there are 5 stations which are:

i). Feed Station
ii). Printing Head
iii). Buffer 2
iv). Ultraviolet Curing (UV) station
v). Buffer 3

Method of time taken each station will be that one single line marking is presented in the material and stop watch starts as soon as it moves from start point of that station to the end of it. The results will determine which station is taking the longest time to reach the marking point. The results made from the time taken (Table I):

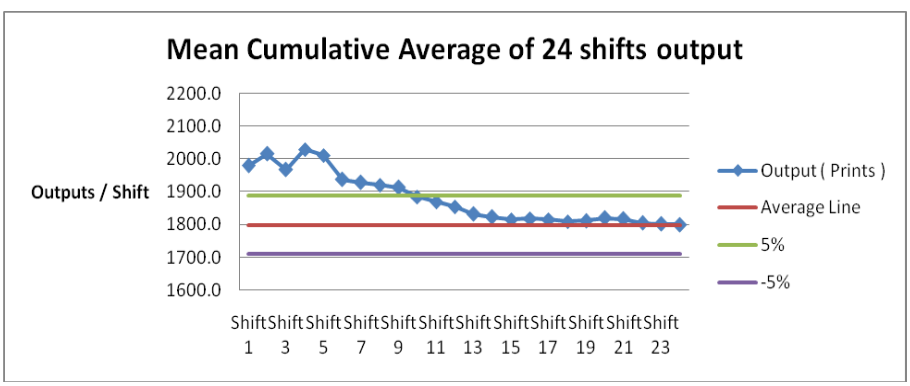

Fig. 1: Cumulative Average of prints output in 24 running shift previous month

Table I: Results Table

Per Print Time Validation (seconds)					
Station	Buffer 1	Printing Head	Buffer 2	UV Station	Buffer 3
Time 1	0	3.8	3.6	7.8	2.2
Time 2	0	4.2	4.1	8.4	2
Time 3	0	4.1	3.9	8.4	1.8
Time 4	0	4.1	4.2	8.2	2.3
Time 5	0	4	4.3	7.8	2
Average	0	4.04	4.02	8.12	2.06

Table II: Results for the events

Events	Elements of time distribution from observation time	Duration (hrs)
Stops and breaks due to technical issues and equipment (t_{tech})	1.UV light error 2.Smearing issues 3.Pitch between print cavity fails 4. Conveyor brake issue	2.2 10 6.1 2.5
Stops and breaks due to management problems. (t_{mgt} & t_{logi})	1.No staggering breaks, machine idle 2.Operator go to regrind squeegee 3.Waiting stencil readiness 1. Waiting spare parts 2. No material to run	1.25 0.5 1.5 1.0 3.0
Stops and breaks due to inspection of Quality. (t_{ins})	1.Quality operators + printing operator perform quality buyoff/inspection	29.2
Stops and breaks due to machine setups. (t_{set})	1.Machine setups and fine tune	10.9

II. CHRONOLOGY ANALYSIS IN SCREEN PRINTING

In printing line, only the working stations should be calculated as the work time which is the printing head and the UV station. Between this two station, the time taken at UV station is more longer than time taken printing head, therefore the design of the Buffer 2 is presented to compensate the UV delaying which the printing head always additional prints buffer before entering the UV station. The auxiliary motions in the printing line is identified as the Buffer 3 station only since this station is a point where it feeds the post UV treatment material into the output finished processed rolls.

In average the auxiliary motions in buffer stations calculated as few seconds per print. The Buffer 3 stations is the last point that all the printed and UV cured materials have to be feed until the end of the un winder rolling stations. To perform thorough calculations and identify the main losses to the productivity in the screen printing process, it is first to identify the bottleneck process in the partition station of the screen printing flow.

From the time taken results it is found that the UV conveyor is taking the maximum time to finished and from here we can conclude that this are the contributor for the delay in the whole serial stations of screen printing. These UV chambers used to cure and dry the ink after printing process and in a process results supposing the ink printed will not peeling off when going to in a roll form and to another process.

This auxiliary time is the time losses due to machine not running in the whole total 5 stations in the screen printing machine. These are all issues or problems that happen in the whole serial station which stops all the station together, means total unproductive time. The idle times in total was consuming 104.5 hours in total.

Hence, the results for the events that contribute to idling are (Table II):

III. DATA RESULTS

Time of total stops = 68.7 hours

Time of work = 288-68.7 = 219.3 hours

Time of observations = 24shifts x 12 hours = 288 hours

Cycle time = T = $t_w + t_{aux}$ = (4 sec+8 sec) + 6sec = 18 seconds = 0.3 minute,

Where t = printing head time + UV time.

Theoretical time of work at printing line is T*z = 0.3 * 43187 prints = 12956 mins/60 = 216 hours

$$\delta = \frac{\theta w.th - \theta w}{\theta w} * 100\% = \frac{219.3 - 216}{216} = 1.5\%$$

The deviation get from the results = 1.5% and is acceptable in mathematical statistics as it should not exceed 10 percent and from this the results of this study can be consider trustworthy with a probability of 98.5%.

The information obtained from the study enables us to calculate the technical data of the screen printing line and this information is used to calculate also the availability and real productivity of the printing line.

Firstly is to get the maximum limit that this line is able to produce in assumption that the machine is ideal and 100% efficient running condition without any auxiliary time factor in.

Defining Screen Printing Productivity Rate:

Limit of the printing line's productivity rate is, Q_L:

$$= \frac{1}{\theta w} = \frac{1}{0.2\sec s} = 5\,print/\min = 300\,print/hour$$

Where θw = the cycle time at printing head + UV station.

Secondly to understand the cyclic term that adds up differentiation of work time and auxiliary time but calculating it together to form cyclic productivity.

Theoretical Cyclic Productivity of the screen printing line is shown as:

$$Q_T = \frac{1}{\theta_w + \theta_{aux}} = \frac{1}{0.2 + 0.1} = 3.33 \text{ print/min} = 200 \text{ print/hour}$$

With additional auxiliary time (Buffer 2 + Buffer 3) = 0.1 minute.

Actual Productivity in the observed time for this study is:

$$Q_{act} = \frac{z}{\theta} = 43187 / 288 = 150 \text{ print / hour}$$

Where observed time = 288 hours and total output produced in 288 hours = 43187 units.

In determining the group of losses which are higher and the lower ones, the ratios of idle times are calculated as:

Productivity losses of the flat bed screen printing line due to defined reasons presented in the idle times list by categories are calculated by formula :-

$Q_i = Q_t - Q_a$ = 200-150 = 50 print /hour

Also other productivity losses of the screen printing line by the ratio of idle times with different reasons are as:

$\Theta_{tech} : \Theta_{mgt} : \Theta_{ins} : \Theta_{logi} : \Theta_{set}$ = 22.4 : 2.75 :29.2 : 3.4 : 10.9

ΔQ_{tech} = 16 print/hour (losses due to technical process and equipment issues)

ΔQ_{mgt} = 2.5 print/hour (losses due to management issues)

ΔQ_{ins} = 21 print/hour (losses due to quality inspection time)

ΔQ_{logi} = 2.5 print/hour (losses due to logistic issues)

ΔQ_{set} = 8 print/hour (losses due to machine setup and fine tune)

Where in total, $\Delta Q_{tech} + \Delta Q_{mgt} + \Delta Q_{ins} + \Delta Q_{logt} + \Delta Q_{set}$ = 50 print / hour

*Equivalent with total idling losses of 50 print /hour.

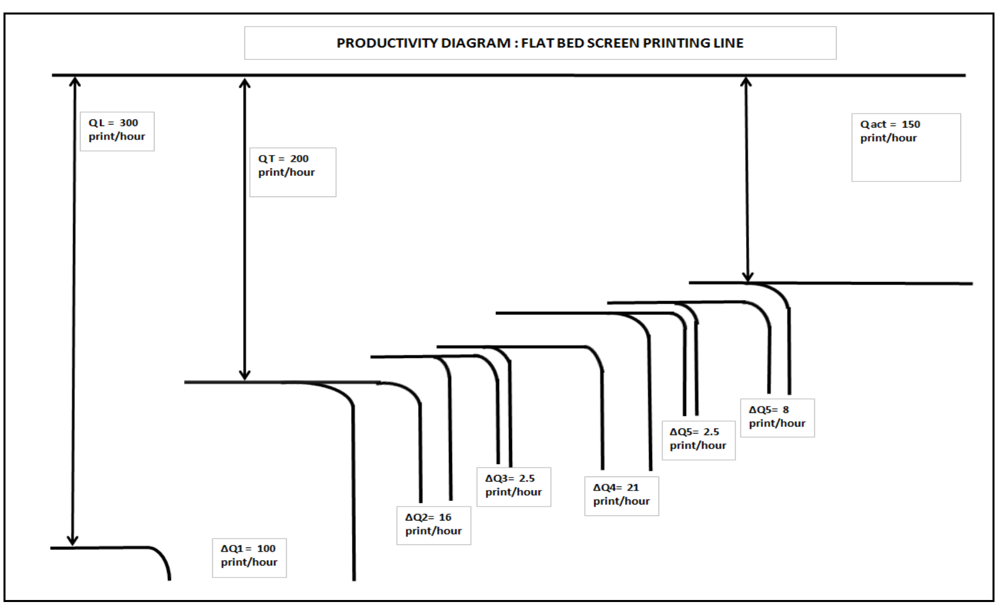

Fig. 2: Productivity Diagram of Flat Bed Screen Printing Line

This means also that the availability of this screen printing production line is:

$$A = \frac{1}{1+\left(\sum_{i=1}^{n} t_{idle}\right)/(t_w + t_{aux})} = \frac{1}{1+(\theta i/z)/(t_w + t_{aux}))} = \frac{1}{1+(68.7*60)/(43187*0.3)} = \frac{1}{1+0.318} = 0.758$$

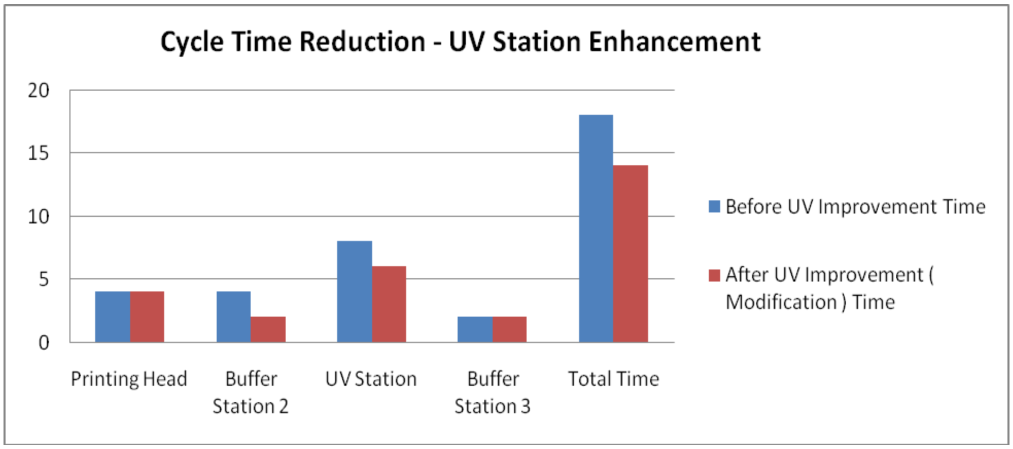

Fig. 3: Cycle Time Reduction

Table III: UV Improved Time

Situation/ Station	Printing Head	Buffer Station 2	UV Station	Buffer Station 3	Total Time
Before UV Improvement Time	4	4	8	2	18
After UV Improvement (Modification) Time	4	2	6	2	14

Considering the same idling losses factor in this diagram which is derived after the UV station improvement, it is observed that there is a clearly 50% total losses from this screen printing line which define from:

$Q_L - Q_{act}$= 300print/hour – 150 print/hour = 150 print/hour.

Thus, it is greatly recommended that this line must have a better productivity improvement plan to enhance the utilization making more profits and reduces wastages. In summary from this results, we clearly understands that the major losses is greatly taken from the auxiliary losses from the buffering station 2 and the UV station which both accumulates 12 seconds each prints.

Here to understand the percentage of impact from overall auxiliary delay is equivalent to:

= $t_{b2 + UV station} / t_{work + aux}$
=12 seconds / 18 seconds
= 66%

This 66% of time impact slows the overall process in the printing line especially when UV station takes 8 seconds longer than printing head thus creates a buffer station 2 which waits for this delay. The time variance may look only in seconds but if it multiplies over running time of 1 month, it creates a huge impact to the production delay. Therefore, the focus of the improvement must be in reducing the bottlenecks in this system which is the UV station (ink curing station from using the ultraviolet light).

IV. OPTIMIZATION OF BOTTLENECKS IN SCREEN PRINTING

Practically, the mathematical calculation between the theoretical and actual production is different but in a controlled deviations which is statistically accepted as verified by the previous data mean average accumulation. But, the results of this study shows significance of how the losses divisions are categorize making ways for the managers and engineers to start prioritizing which are losses to be improved. In the auxiliary time losses, it is found that the cycle time in UV station which is slower by 100% than the printing head cycle time 4 seconds per print comparing to 8 seconds per print. It shows that the UV station needs to be enhanced and optimize that the cycle time there is at least near similar to the printing head to avoid each time waiting time at the 2nd buffer station.

In the example of improvement made at the UV station and cycle time simulates improving by 25% faster, the assumed productivity after this improvement can be calculated to see overall productivity improvement indices.

Calculation after modification of lamps done and UV station improves 25%:

From the table above, it shows that both UV station and Buffer station 2 cycle time reduce from the modification of adding the new ultraviolet UV curing lamps into the stations to enhance the UV time. Thus, considering the same time observed and the same idling time results shows the changes in the productivity:

The loss in screen printing since it's a high volume manufacturing line type and the productions are needed for speed and low downtime which the mean time between repairs must be in low frequency. Combination of high speed processes and low idling time can benefits utmost to the production efficiency. The third factor important is the process yield, means that referring to the visual and measurement of pitch and gaps.

Productivity diagram in screen printing line as expected shows the inspection time also contribute to major idling times that reduce the productivity rate. Inspection in screen printing is a major contributor to the downtimes. The cavities produced by screen printing as in specification are always critical in tolerance. Thereby, the time taken here is an opportunity also to be improved to cut down the idling.

The productivity losses that are identified in this study should be a list of continuous improvement activities that are focused to reduce the major 2 losses in the top rank so that the overall losses will be reduced thus increasing the total productivity making it nearer to the cyclic productivity figure.

UV station enhancement of speed are an example of project that the manager and engineer should focus on bringing the UV station cycle time to be improved, with the intentions to eliminate the buffer station delaying function, which in the real case is unnecessary and considered as a loss. A testing of adding the UV lamps and source an alternative type of UV lamp in the UV station with the objective of bringing down the UV station cycle time will bring the benefit in the long run. Only that the stability of the reliability of the implementation is a major thing to monitored and revalidate to ensure long run stability without any spike on that particular failure which contribute high Mean Time Between Failure , MTBF and Mean Time To Repair , MTTR again after the implementation of improvement. Further arguments made in the area of manufacturing system should be based on the real production systems data base which connects directly to the basic of the technological disadvantages, technical disorders in the reliability field and manufacturing Thus, the real concept of manufacturing system in bottleneck area should be very rigid to the changes of improvements designs, processes and procedures to adapt to the future challenges.

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Nomenclature

t_{work} - work time

t_{aux} - auxiliary time

z - number of products produced per observation time

Δ – time losses due to different reasons of either management/ technical problems.

θ - observation time

Q_T – Cyclic productivity of a machine

Q_L – Limit of productivity of a machine

Q_{act} - Actual productivity of a machine

$\sum_{i=1}^{n} t_{tech}$ - total time losses referring to technical issues in screen printing line

$\sum_{i=1}^{n} t_{ins}$ - total time losses referring to inspection time in screen printing line

$\sum_{i=1}^{n} t_{set}$ - total time losses referring to the machine setup time in screen printing line.

$\sum_{i=1}^{n} t_{mgt}$ - total time losses referring to the management and logistics in screen printing line.