Human System Modeling for Optimum Labor Utilization and Man-Machine Configuration

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***Abstract*— Manufacturing organization with increased in the organizational complexity, is facing difficulty in measuring its performance. Various factors could affect manufacturing performance such as equipment performance, material planning and human resources. In this paper, focus was given primarily on the human resource which was considered as an important factor of the simulation model development to achieve optimum utilization and ensure efficient operator allocation to the machines. Static modeling was performed to capture all the critical factors contributing to the work such as the operator activity sequence, the time value for each activity and also the machine process time for each batch of product. A dynamic model was then developed to enable quantitative analysis in the optimization of human system performance. This paper illustrates the application of different modeling approaches to demonstrate advantages gained in the process of evaluating human system performance.**

***Index Term*— Human System Modeling, Simulation Modeling, Man-machine Configuration**

I. INTRODUCTION

The manufacturing operations have increased in complexity due to constant changes required to cater to unpredictable customer demands. Siemieniuch and Sinclair [1] stated that manufacturing is considered complex if various resources that interact with each other resulted in unpredictable organization performance. Global competitions are also putting pressures on the manufacturing companies to produce products cheaper and faster. Thus, manufacturing operations are urgently exploring methods to reduce the complexity and improve the efficiency in managing the resources.

Among the factor that is becoming critical to be considered in managing manufacturing complexity is the human resource. Human resources are required to fulfill orders such as in the areas of material processing, product assembly or component manufacturing [2]. Thus, the optimum utilization of the labor should be a serious consideration in order to minimize the operating cost in manufacturing [3].

This paper explores an alternative method to model human system in order to provide the manufacturing organization with an effective decision-support tool to efficiently manage human resource in the complex manufacturing environment. The two modeling approaches used in this study are:

Static Modeling – enables static spreadsheet analysis coupled with trial and error runs to experiment different sets of work activities and observing the impact of a selected decision on the operator utilization and man-machine configuration.

Dynamic Modeling – enables experimentations of the critical parameters in a virtual environment such as to predict the human resource performances. Some of human resource performances that can be predicted using this method are optimum labor utilization and man-machine configuration.

This paper describes the possibilities to dynamically model specifically human and machine resources to predict the behavior of the manufacturing operation performance. This technique can potentially be used as a basis of a more accurate decision support tool to efficiently assist production managers in optimizing the man-machine configuration.

This paper begins with literature reviews to support the various studies done in the area of human system modeling and simulation modeling. Next, it will explain the development of the static model and also the use of dynamic model to mimic the actual production case of the back-end semiconductor manufacturing facility.

II. HUMAN SYSTEM MODELING

Manufacturing efficiency is highly dependent on how well resources such as equipment, human and material are being managed. Due to continuous rise in labor cost, effort has been focused on human system modeling in order to address the issues and support the manufacturing operations in the quest to achieve better competitive advantage.

Model such as CIMOSA can be used to analyze key aspects of human systems using enterprise (static) and simulation (dynamic) to deploy human systematically in manufacturing [4]. In modeling human system, static model via CIMOSA modeling technique is used first to model static human system model in manufacturing plant which is later used as reference to create dynamic model i.e. simulation model to quantify human performance and efficiency values and to observe the effect of these variables on the production performance i.e. the throughput and takt time [4].

Zulch [5] on the other hand stated that there are still few studies done to simultaneously plan machine and personnel. Thus, his team developed ESPE-IP which started with a static procedure that took into consideration the personnel (both technical and operators) quantity and qualification in an operation-resource-matrix and function-equipment-matrix. These input combined with product demand and machine information were dynamically modeled using simulation aimed to eliminate personnel bottlenecks by realigning their structure.

Both CIMOSA and ESPE-IP combined static and dynamic modeling to evaluate the manufacturing operation. Simulation has grown in popularity due to the ability to analyze and optimize the production line in a digital environment without having to disturb the actual production process [5]. Consequently, simulation tool is perceived to provide an advantage to model alternative combinations of humans and machines for optimum resources configurations [6,7].

In both CIMOSA and ESPE-IP, the time values of the human's detail work activities are just based on estimation in the form of either efficiency percentage or qualification matrix. Thus, accurate utilization values of the workers are not able to be provided. Baines et.al. [8] explained due to failure in relating workers performance with the critical factors impacting them has caused processes to be poorly modeled. Therefore, this study aims to design a method to measure operators utilization based on the detail work activities and determine the optimum the man-machine configuration using simulation for the manufacturing operation.

III. M2M STATIC MODELING

Man-to-Machine (M2M) modeling refers to a static spreadsheet analysis to observe the result of detailed work study on the operator's activity on the overall operator's utilization and man-machine configuration. Using a case study of the back-end semiconductor process, a M2M template was designed to capture the worker's activities. Next, Maynard Operational Sequence Technique (MOST) predetermined time standard times were assigned to each work activities to achieve an accurate time values. The time measurement unit (TMU) value in MOST was then converted to the activity time in minutes for the semiconductor process under study. Other information including the frequency of the same work activity being repeated and also equipment information are also incorporated in the model. An algorithm to determine the M2M value was then developed and captured in the M2M column of the M2M template [9]. For example in Table 1, the bottom value in the M2M(1) column refers to the operator's utilization percentage if assigned with one machine or M2M ratio of 1:1. Similarly, the next column of M2M(2) shows the percentage utilization of the operators if assigned with two machines thus M2M ratio of 1:2.

Table I

Template for M2M Static Analysis

No.	Start New Lot	Activities Sequence	TOTAL TMU	Time (min)	Frequency	Time per lot (min)	Lot Cycle Time	M2M(1)	M2M(2)
1	Briefing beginning of shift		25000	15	1.3146	19.72	631.03	3.1250%	3.133%
2	Housekeeping		8333	4.9998	1.3146	6.5729	631.03	1.042%	1.044%
3	Walk 34 steps to Ministore and get 2 carrier taped reels and walk back to machine . Twice per shift (2 reels/2 mch/1time)	A67 B0 G3 A67 B6 P1 A0	1440	0.864	1.3146	1.1358	631.03	0.180%	0.360%
4	Walk 5 steps to Insp table and place carrier tape under table								
5	Walk 34+5 steps to store and get unfolded cardboard box and walk back to Insp table and place next to it (Once per 2 shifts)	A67 B0 G3 A67 B0 P1 A0	1380	0.828	0.6573	0.5443	631.03	0.086%	0.173%
6	Walk 34+5 steps to store, bend and takeout plastic of reels and walk 8 steps to housekeeping area place box and walk to Insp table 39 steps	A67 B6 G1 A16 B0 P1 A0	910	0.546	1.3146	0.7178	631.03	0.114%	0.228%
7	Bend and take out 25 reels from plastic 1 by 1 and arrange under Insp table	A67 B6 (G1 A1 B0 P3) A0	1980	1.188	1.3146	1.5618	631.03	0.248%	0.495%
8	Walk 34+5 steps to store to get a box of sealing tape and walk back to Insp table (Once per day)	A67 B0 G1 A67 B0 P1 A0	1360	0.816	0.4382	0.3576	631.03	0.057%	0.113%
9	Walk 9 steps to Pridelink station fr machine and click Lot Starting button	A16 B0 G1 M1 X0 I0 A0	180	0.108	1	0.108	631.03	0.017%	0.034%
10	Walk 55 steps to Schedulers room and get new lot (box) fr room window	A96 B0 G1 A96 B0 P1 A0	1940	1.164	1	1.164	631.03	0.184%	0.369%
	TOTAL		**84884.87**	**51.00**				**14.95%**	**25.74%**

IV. M2M DYNAMIC MODELING

Discrete event system simulation was applied in the production process modeling using WITNESS simulation software package. Our simulation model consists of three parts: (A) the first part is the modeling of the production process to mimic the current condition before line balancing technique is applied in order to determine the optimum numbers of equipment required. (B) The second part of the simulation model realizes the aim of the study which is to determine the optimum man-machine configuration of the production line without jeopardizing the production line throughput and cycle time. (C) This final part includes the model experimentations to achieve the optimum operator utilization and also man-machine configuration.

A. Equipment Capacity Modeling and Line Balancing

Before the simulation model can be developed, a conceptual model needed to be designed. Figure 1 illustrates the inputs and outputs of the simulation model framework.

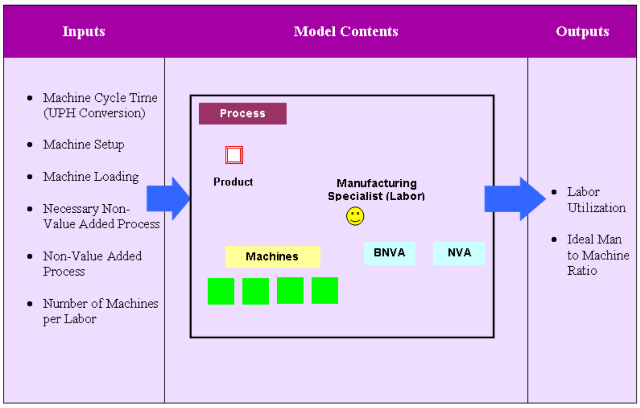


Fig. 1. M2M Simulation Model Framework

The critical part of simulation model development is the model verification and model validation. Verification is the process of making sure the simulation model behaves as planned. Verification process can start once the entire model is completely ready. On the other hand, validation is a process to ensure that there are no significant differences between the conceptual model and the real production line. In this study, verification was done by comparing the simulation output to the manual calculation of a given production scenario. Validation was carried out by comparing the simulation results with the actual system data.

Table II
Validation of Simulation Model

Process	Actual Production (units/shift)	Simulation Results (units/shift)	Delta (%)
Die Clip Bond	958000	967740	1.02%
Mold	347000	357096	2.09%
Trim and Form	1807000	1935480	7.11%
Test	189000	193548	2.41%

Based on the validation result in Table 2, the difference (delta) between simulation and actual production data is within the acceptance level of 10%. Therefore, the developed simulation model can be used for further studies to understand the system under consideration. The first part of the simulation analysis is to determine the production line bottleneck thus; the simulation model was run for one shift (480 minutes). The throughput (capacity) was observed for each process and then compared with the actual declared capacity per shift of all processes. From the simulation model runs, the bottleneck area was also identified based on the throughput results. Figure 2 shows that the bottleneck occurred at the test process where the throughput value is the lowest.

The validated model was used to simulate production scenario that balance the equipment capacity for each critical process. Masood [10] explained that assembly line balancing is used to determine optimum allocation of operations at the workstations so as to minimize the cycle time of the line for a given number of workstations, or to minimize the number of workstations for a given cycle time, by equalizing the loads on the workstations.

The graph on the right of Figure 2 shows the result of a more balanced production process by manipulating the equipment assignment and product load. This step is important in order to determine the optimum number of equipment required to meet the required customer demands before an optimum number of operators can be assigned to the equipment in the next part of the simulation modeling.

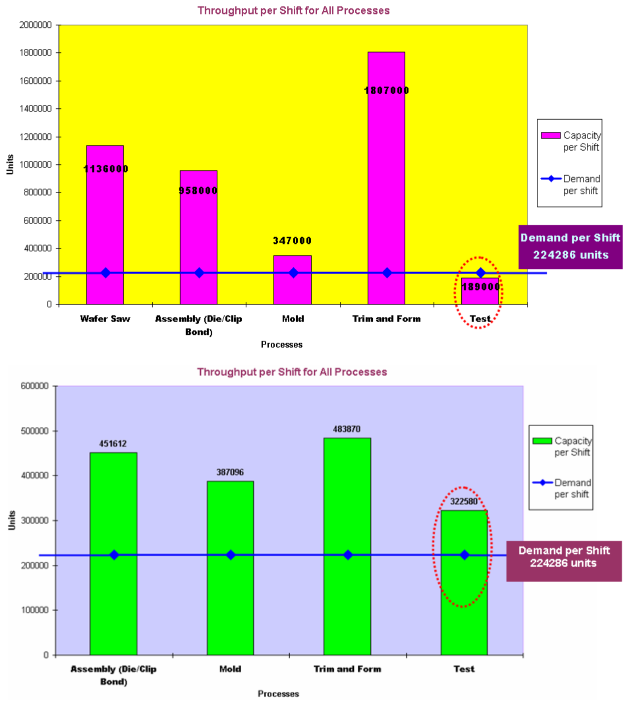
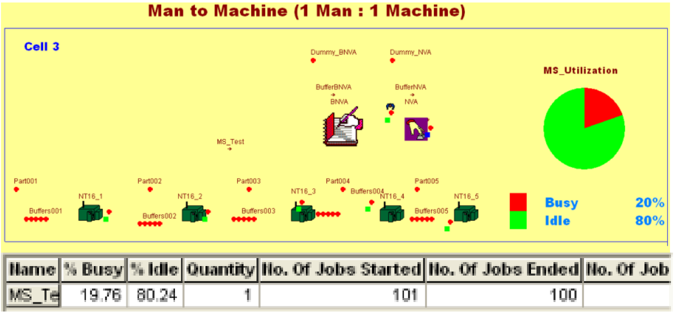


Fig. 2. Equipment Capacity before (above) and After Line Balancing (bottom)

B. Human Modeling and Optimizing the Resources

The second part of the simulation involves modelling the labour activity. The labour value added activities were categorized in the machine setup, loading or part change where the labor or the term used in the production line as the operators will attend to it. Meanwhile, necessary non-value added (e.g. transportation, inspection) as well as non-value added activities (e.g. delays, storage) were modelled as non-productive task using dummy machines. The model was intended to determine the ideal man to machine ratio that is not more than 85% of busy time of the labour. Figure 3 shows the simulation model developed for this study.



Name	% Busy	% Idle	Quantity	No. Of Jobs Started	No. Of Jobs Ended	No. Of Job
MS_Te	19.76	80.24	1	101	100	

Fig. 3. Man-Machine Configuration Simulation Model

From Figure 3 simulation model, the percentage labour utilisation for 1 Man to 1 machine is found to be at 19.76%. This result was compared with the result computed using M-to-M technique using the M2M static modeling and was found to be the same. Therefore, we concluded that second part of the simulation model is validated and can be used for improvement studies.

C. Experimental Runs

This simulation run takes into consideration product A package of the back end semiconductor production line under study as an example. It aims to improve the current production run by re-adjusting the number of equipment available for processing product A. This is to ensure a balanced line and to reduce the Work in Process (WIP) buildup of the bottleneck operations. To achieve this, the die clip bond equipment is first reduced from 15 units to 7 units since running 15 units will cause overproduction of units. As for the mold equipment, there is only one mold equipment and as a result, there is no need for adjustment for this process. The Trim/Form is another process found overproducing products so the equipment is reduced from existing 4 units to only 1 unit.

The second experimental run involves the computations of optimum M2M ratio. The Test area was selected and the summary of the model results is shown in Figure 4. The experiment results show that the optimum M2M ratio for the test operation is 1 operator to 4 machines with utilisation of 78.22%. Improving the operators' workload is a complicated task in real life industrial situation and in most cases is not done with the required accuracy since it is an issue which is hard to compute. Approach introduced in this study allows the user to overcome this problem. Analysis done using the M2M method indicates that there are plenty of opportunities to improve the operators' current work load.

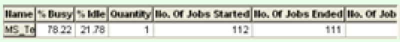
Scenario	**Simulation using WITNESS**	**Results (Labor's Utilization)**
1 (1 Man: 2 Machines	 Name, % Busy, % Idle, Quantity, No. Of Jobs Started, No. Of Jobs Ended, No. Of Job MS_Te 39.53 60.47 1 105 104	39.53%
2 (1 Man: 3 Machines)	 Name, % Busy, % Idle, Quantity, No. Of Jobs Started, No. Of Jobs Ended, No. Of Job MS_Te 59.29 40.71 1 109 108	59.29%
3 (1 Man: 4 Machines)	 Name, % Busy, % Idle, Quantity, No. Of Jobs Started, No. Of Jobs Ended, No. Of Job MS_Te 78.22 21.78 1 112 111	**78.22% (<85%)**
4 (1 Man: 5 Machines)	 Name, % Busy, % Idle, Quantity, No. Of Jobs Started, No. Of Jobs Ended, No. Of Job MS_Te 97.99 2.01 1 116 115	97.99% (>85%)

Fig. 4. Man-to-Machine simulation model

In addition to the labor utilization and M2M ratio information, this study also enables the authors to perform lean waste analysis on the operator's work activities in order to continuously improve the man-machine configuration for the manufacturing operation. The lean waste analysis information of the operator's current workload shown in Figure 5 provides the production line management with critical information on the area to focus in order to further improve the labour utilisation at this area. As it could be seen from Figure 5, the operator's efficiency can be further improved if the activity time at the reel change, start new lot and machine assist can be reduced.

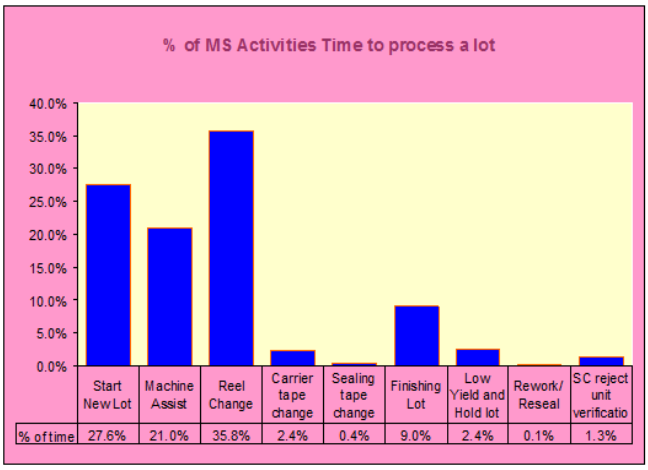


Fig. 5. Lean Waste Analysis on Manufacturing Specialist (MS) or Labor Activity Distribution

V. SUMMARY AND CONCLUSION

In this study, the ultimate objectives of optimizing the operator utilization and the man-machine configuration through a balanced production line were achieved. Static M2M modeling complemented with dynamic simulation has proven to be an effective tool to perform production line evaluation and was successfully used in this study. Static M2M was useful in providing detail information on the operator's work activities using inventive work study technique. Thus, the authors were able to acquire an accurate input to the simulation model and also perform lean waste analysis to identify opportunities for further efficiency improvements.

Simulation proved to be a faster alternative for experimental runs to gain information on improved operator utilisation and optimum man to machine ratio. With the production line equipment and labour simulation models, the semiconductor company's management now has an effective method to determine the best production line configuration to minimize the operation cost and at the same time meeting the customer expectations.

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