DEVELOPMENT OF ENTERPRISE HUMAN SYSTEM MODELLING FRAMEWORK IN SUPPORT OF CELLULAR MANUFACTURING LEAN OPERATION

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ABSTRACT: Static or enterprise model stems from the need to understand the potential effect of certain parameters on the system performance. This paper describes the development of the human system framework focusing on the aspects of human attributes and human dynamics in the effort to achieve a leaner operation in the cellular manufacturing operation. The aim of this study is to propose a model to improve the accuracy in modelling human workload and competency based on the theoretical frameworks. Existing frameworks and models were reviewed and two models (M2M mathematical model and CIMOSA) were identified as the theoretical framework for this study. A new human system framework was designed with the improvement on the operator competency accuracy using Maynard Operational Sequence Technique. The new framework was also primarily designed to suit the cellular manufacturing environment through the inclusion of the equipment competency. As a result, company's management is expected to be better informed on operator utilisation, man-machine configuration and operator non-value added activities.

KEYWORDS: *Human System Modeling; Human Performance; Human System Framework*

1.0 INTRODUCTION

The challenging economic environment prompted industries to react aggressively to improve the organizational operational process and to boost performance. Thus, the integration of productivity, quality and flexibility were identified to be the critical key measures to total manufacturing performance [1-2]. Productivity level of not only a company but even a country indicates the economic condition and how resources are properly optimized to increase production output. Thus, labour productivity is the common determinant being used to compare different company's or country's productivity level and is measured by output quantity per worker or per hour worked [3-4].
Various strategies and methodologies were developed over the years to improve the manufacturing productivity loss. Among the strategies are Total Preventive Maintenance (TPM), Total Quality Management (TQM), Toyota Production System (TPS), Theory of Constraints (TOC) and Business Process Reengineering (BPR) and Six Sigma [5]. The concept of Lean Thinking (LT) was originated from TPS through categorizing activities into value-added and non-value added or wastes [6]. The LT concept has become widely accepted and has been successfully implemented in various sectors including automotive, electronics and consumer product manufacturing [7]. The outcomes include a significant reduction in inventory and lead time, improved delivery performance, better space and resource utilization and enhanced product quality [8].

With the strong emphasis on improving the labour productivity, there arises a need to focus on human performance and the various human aspects that affect labour productivity. Pew and Baron [9] stated that study of human performance requires a model or representation of the system and environment with which the people are to function. Meanwhile, Allender [10] emphasized the importance to model human performance early in the design phase to proactively assess the impact on system performance and cost due to the 'noisiest' and highly variable nature of the human component. The human performance model is an integral part of bigger system architecture or an interactive simulation system and is significant to designing an efficient system.

Due to the importance to optimize human workload and competencies, there is a need address the gap in a quantitative study on the effect of the human component and its constraints on cellular manufacturing performance. Therefore, the aim of this study is to propose a model to improve the accuracy in modelling human workload and competency based on the theoretical frameworks.

2.0 HUMAN SYSTEM FRAMEWORK

Many studies have been done in the area of modelling and simulation that mainly focusing on the equipment and process in tackling the issues of the cellular manufacturing complexity. Although human resource also significantly impacts company's productivity [11] and deserves proper attention, the lack of study in this area is attributed to the difficulty in modelling human's behaviour [12]. Various approaches being used also have overlooked the importance of skill to task and skill to worker relationship [13]. Although system designers recognized the need to factor in the human attributes in ensuring the manufacturing competitiveness, they very often overestimated the value of the human contribution to the system due to a poor understanding of the effects of human constraints [14]. During the initial cellular manufacturing system design, human capacity is normally the last factor to be considered after machine, part, process and technology. This is despite the fact that without human's role, it is impossible for to perform any production activities. The dynamic and complex manufacturing structure prompted the importance to characterize human competencies, capabilities and capacities to ensure better understanding and for fast response for any business conditions. Thus, extensive studies were done in the development of human theoretical framework resulting in a general guiding theoretical framework for researchers to identify potential variables relevant to the area of study [15]. These studies include:

i. the general theory to specify relevant factors affecting the outcomes of work organization and
ii. the empirical study that analyses the rational of focusing on a certain variable.

Therefore, the first step in the design of the human system and exploring job performance is to determine the theoretical framework that links the key human factors to manufacturing activities which impacts manufacturing performance [16]. Engineers need to understand the impact that human factors have on their process designs from the early stage since many factors can be easily and inexpensively included in the model at this stage. Thus, abstract representation of the scenario states under study needs to be developed using static, dynamic or interactive modelling approach [17-18]. Table 1 summarizes the approaches to human system framework used by researchers to study human component in a manufacturing environment.

Table 1: Review of Human System Framework

Author	Framework	Synopsis	Application
[19-20]	Human system engineering - CIMOSA	Identify human potential roles, competency and capability. Explore the use of simulation for decision making.	Small Medium Enterprise (SME), automotive industry, furniture manufacturer
[21]	Human decision-making model – ESPE-IP	Concepts of modelling technical structure for human decision making in manufacturing. Explore the use of simulation in decision making	Mechanical part manufacturing
[22]	Indirect workforce (re)allocation framework	non-parametric frontier approach for planning and assigning of indirect workforce	Semiconductor wafer fabrication facility
[23]	Digital human model (DHM) framework	Ergonomics motion study using MOST for manual work design	General research/practices
[24]	Event-Discrete Process Framework	Human guidance/ supervision to study human-automation system interaction	mould semi-auto manufacturing process

From the extensive literature reviews, CIMOSA Human System model and ESPE-IP [19-21] were narrowed down for further investigation. CIMOSA was chosen as the theoretical framework for this study due to the exemplary approach to decompose human aspects into specific views to reduce modelling complexity. However, this model can still be further improved in the aspect of human workload and competency data accuracy. Nonetheless, both CIMOSA Enterprise model and ESPE-IP are integrated with the simulation modelling to study the effect of the human component on manufacturing performance. The proposed new model is also needed to be suited to the cellular manufacturing worker assignment environment.

3.0 M2M HUMAN SYSTEM MODEL

CIMOSA stands for the integrated approach to modelling human system through enterprise modelling (EM) using for Open System Architecture for CIM and enterprise integration (EI) using simulation [25]. The decomposed enterprise activities are represented using the lowest granular process and resource requirement to be executed by an actor (operator). Thus, humans are the roles holders constrained by the capability set and competency level required in performing production activities to execute the role as described in the process elements. A simulation modelling solution is then used to enable visual observation of the dynamic behaviour of the complex interaction among the process and the resource elements to fulfil customer requirement. The dynamic model not only mimics the actual behaviour of the system but also works as a platform to aid the integration of the segregated elements in the static model. The EI is also capable of performing multiple scenario experiments from the 'as-is' scenario by exploring the 'what-if' analysis to predict the optimized performance of the manufacturing system.

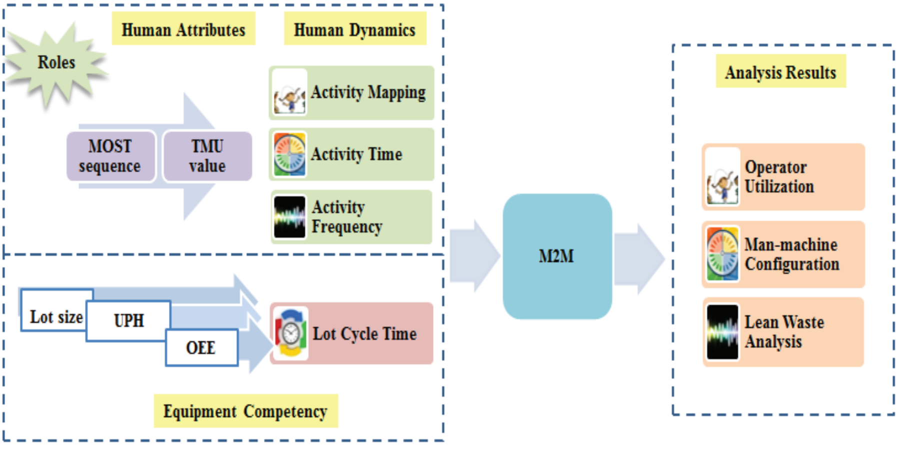

Figure 1: M2M HSM Framework

The proposed Enterprise M2M HSM model is designed to approach the human attributes (competency, flexibility, skills) and human dynamics (performance, workload, lead time) in a more detailed manner using predetermined time standards (PTS) incorporated in an Experts System (ES) to improve model input accuracy and to simplify the complexity of data gathering and analysing. Thus, the M2M model is able to provide a more detailed evaluation of the worker's workload (activity and frequency) with specific task time measurement. Moreover, the new framework is also able to provide detail operator utilization and propose optimum man-machine configuration which is amongst the vital information for the training department to develop Standard Operating Procedure (SOP) and for new operator training.

Figure 1 illustrates the conceptual M2M Human System framework using the elements that are already identified in the previously developed M2M heuristic mathematical model [26] and expanding on the theoretical CIMOSA resource view framework.

Components of the Enterprise M2M include:

i. Human Competency

The primary function of the roles holder (operators) and their roles are defined before the activity-mapping can be detailed out. The previous approaches to model human systems required the researchers to also include the human competency factor in the model [27-28]. However, the new M2M enterprise human system model uses the established Maynard Operational Sequence Technique (MOST) predetermined time standard (PTS) to measure operator utilization and man-machine configuration [23].

ii. Human Capability

Human attribute and dynamics are further refined into individual task's activity, frequency and time measurement. The detailed information provides the opportunity to categorize these activities into value-added and not value added for lean waste analysis and lean improvement opportunity.

iii. Equipment Competency

To suit the cellular manufacturing environment with an operator commonly assigned to more than one machine, the equipment competency factor need to be included in the model. The utilization of the operator will be compared to the utilization of the machine processing a batch of a production unit or a lot cycle time. The information required to compute the lot cycle time include the batch or lot size, the unit of product produced in one hour (UPH) and the overall equipment efficiency (OEE).

iv. M2M Mathematical Formulation

Equation (1) shows the mathematical model developed in an earlier study by the authors [29-31] based on the analysis of the critical human factors used in the traditional Process Mapping and Man-Machine Chart.

$$M2M = \sum_{i=1}^{n} \frac{t_i \times F_i}{T} \times 100\% \tag{1}$$

where

Activity Time (t) = time taken by an operator to perform a task;
Frequency (F) = rate of recurrence of an activity;
Lot Cycle Time = T;
i = number of activity time and the frequency;
n = total number of activity time and the frequency.

v. Result and Analysis

The new M2M model is capable of producing information such as the operator utilization value and the ideal quantity of machine to be allocated to one operator or man-machine configuration. In addition, the model can also generate information on the non-value added activities that can be used to identify activities that should be eliminated or reduced.

4.0 CONCLUSION

The human dynamics and attributes are integral aspects to resolve the manufacturing system's complexity and were the focus for the development of the improved HSM framework. HSM has great benefit in assisting management decision making by providing detailed information regarding individual critical resource behaviour and how it affects the overall manufacturing system performance. The Seminal CIMOSA framework was used as the basis of the new improved human system model due to the established human roles, competency and performance aspects. Further, the use of Maynard's predetermined time standards (PTS) work measurement approach eliminates the need to characterize competency levels of the operators with a higher degree of accuracy when modelling human performance. Further, the previously developed heuristic M2M mathematical model provided the opportunity to better suit the new framework in the cellular manufacturing operation through the inclusion of equipment competency aspect. Consequently, the new framework is expected to allow company's management to efficiently manage the manufacturing assets using information on labour utilisation, man-machine configuration and lean waste analysis. Future works include the use of actual data from manufacturing to capture the operator workload, measure the activity time using PTS and integrate all the components into a simulation model to evaluate the dynamic impact of all the system components (material, machine, man) on the overall manufacturing performance. The newly developed HSM will also be tested in the semiconductor assembly and test (SAT) cellular manufacturing environment where there is lack of published study on the application of human system modelling in this area.

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