People at Work: Modelling Human Performance in Shop Floor for Process Improvement in Manufacturing Enterprises

Siti Nurhaida Khalil, R.H. Weston, and J.O. Ajaefobi

MSI (Manufacturing System Integration Institute), Loughborough University
Leicestershire, UK, LE11 3TU
s.n.khalil@lboro.ac.uk, r.h.weston@lboro.ac.uk,
j.o.Ajaefobi@lboro.ac.uk

Abstract. Predicting actual human performance in manufacturing plants is difficult and not a straightforward task. This motivates further investigation of ways of modelling, measuring and predicting behaviours of people working in production systems. People can be modelled in terms of their competences in relation to the roles they play in realising enterprise activities. This research introduces a combined application of Enterprise Modelling (EM) and Simulation Modelling (SM) to investigate and understand how people systems can be matched to process-oriented roles in production situations. EM facilitates the development of static models of structural aspects of people system from both top-down and bottom-up points of view. It can also provide organisational models in terms of roles and role relationships. Developed versions of EMs can also explicitly define key attributes of current and possible future 'work contexts in which productions systems' are used. In this way any given EM can underpin the creation of multiple SMs that characterise important structural and dynamic aspects of production systems (in terms of human configuration, performance, flexibility, etc), and production throughput within specific contexts of use. The research methods are illustrated via the use of case studies in which roles that people play in the production systems of an international company were studied and modelled. The findings of related SM experiments have generated useful insights for industrialist and academics.

Keywords: Enterprise Modelling, Simulation Modelling, Competency.

1 Introduction

As designers and managers of Manufacturing Enterprises (MEs), assigned person's need, 'abilities' and 'tools' to help them systematically determine appropriate 'roles' for other groups of people, i.e. 'human systems' that can appropriately resource role sets determined by responsible designers and managers. But ME design and management is in general very complex, not least because competent human resources will be limited and costly and will themselves be complex. Recently there has been increased interest in the study of human systems and human systems integration with MEs. This

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growing interest is beginning to lead to new strategies for coping with human system complexity (behavioural, psychological, culture, attributes etc).

Previous literature reviews show that ME's are subjected to increasing dynamic impacts arising in the business environment in which they operate. To address this kind of concern, manufacturing philosophies like Agile Manufacturing Group Technology [1] Reconfigurable Manufacturing Systems (RMS), Mass Customization & Postponement and Holonic Manufacture[2-4] have emerged to inform ME managers and designers about how to achieve increased flexibility and responsiveness. However, on general these philosophies are only supported by limited implementation tools to quantify relative benefits of choosing alternative philosophies; and more particularly in the context of this research paper, to relative quantify benefits of alternative ways of resourcing process oriented roles in accordance with selected philosophy. Also observed is that despite significant advance in best practice complex systems engineering, as yet in industry there is neither model nor coherent means of modeling organizational structures and related time based behaviors of the human and technical (machine and IT system) resources. On the other hand, various modeling techniques have been developed to characterize machines (and their competencies and behaviors) and these techniques are becoming commonly implemented using virtual engineering and simulation of NC and robot systems. But generally because ME modeling plant's human system is so complex their software support tools are somewhat special purpose model kinematic and ergonomic characteristics.

2 Paper Scope and Focus

This paper addresses the question: given a well-defined set of process-oriented roles how best should work roles be resourced? In this respect it is assumed that either (1) people or (2) some form of machine or IT system or (3) some combination of (1) and (2) will prove most effective; and that generally these kinds of 'active' resource'; will be constrained in terms of their availability short and long term. Also assumed is that (a) the nature of roles and (b) the works loads placed on the roles will determine the most effective match of 'role holders' to 'the defined set of process oriented role.' Furthermore it is assumed that because the work loads in MEs are typically determined by customers and related factors in the ME's environment then these workloads will frequently change. This provides a baseline rationale thus benefits manufacturing enterprise for better human resources allocation. This study includes the competency requirements for an operator should have to perform manufacturing processes and study for an improved systematic method, and supporting modeling tools needed to compare the match of different choices of candidate human and technical (active) resources to process oriented roles and their workloads; and also that the developed method and tools should enable short term planning of resource deployment as well as longer term strategic decision making.

Figure 1 illustrates the systematic modelling approach under development by the authors. The underlying idea is to create multi-perspective models using enterprise models (EM's) technique i.e. CIMOSA that can be computer executed in the form of simulation models (SMs); such that they provide a computer tool to inform 'ongoing planning' and 'longer term investment' decision making leading to effective use of human and technical resources. Here specific ME models related to perspective P1 are created using an EM technique which is geared toward specifying sets of ordered activities (or process models) that can be decomposed into explicitly defined roles. These roles and role relationships specify a process oriented relatively enduring structure for any ME being modelled. A second dynamic workload perspective P2 is derived from (a) analysis of historical patterns of work that previously have passed through the defined roles and/or (b) a forecast or prediction of likely future workloads. The third perspective P3 relates to candidate role holders in the form both of stereotypical and actual human and technical resources. Here modelling can be with respect to (i) known competencies (of people) and capabilities (of machines), (ii) capacities and/or performance levels (of both resource types) and (iii) psychological behaviours (of people).

This multi-perspective modelling approach is designed to enable: (I) independent change to the three perspectives P1, P2 and P3; (II) reuse of models of MEs in the form of process and enterprise models; and (III) ongoing systematic reuse of models belonging to those three viewpoints, as required in support of short, medium and longer term ME decision making.

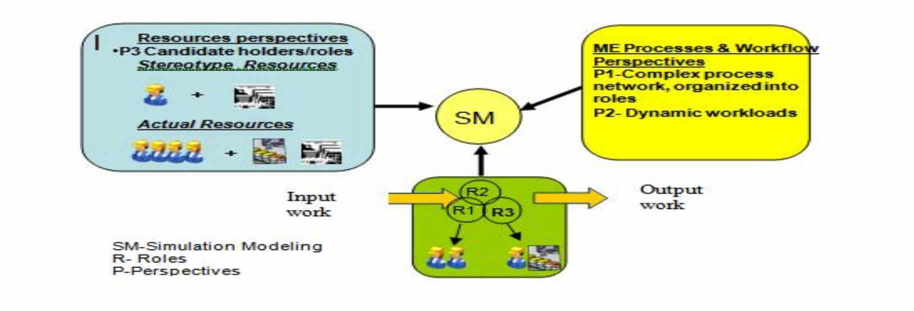


Fig. 1. Human System Modeling in ME

3 Modelling Concepts and Research Methodology

MSI researchers for some time have been using enterprise engineering and simulation modelling technique to aid decision making. Enterprise modelling is used primarily to (1) externalizing enterprise knowledge about case study MEs, and can add value to the enterprise by enabling knowledge sharing and (2) provide a process-oriented decomposition mechanism, so that high levels of complexity can be handled so that it becomes possible to break down the barriers in organization that hinder productivity by synergizing the enterprise to achieved better understandings about how business goals can be achieved in an efficient and productive way.

The enterprise modelling (EM) technique [5] used in this study is known as CIMOSA (refer Figure 4). CIMOSA is an acronym derived from CIM Open System Architecture and this acronym was introduced by the AMICE consortium. In CIMOSA the user representation and system representation, and related function information and control perspectives are decomposed. The associated decomposition and isolation of different modelling concepts and viewpoints enables an organization to be represented in a flexible fashion, so as to realise changing requirements for functional and facilities integration.

CIMOSA modelling enables ME decomposition into the following:

- **Domains (DM)**
- **Domain Processes (DP)**
- **Business Processes (BP)**
- **Enterprise Activities(EA)**
- **Functional Operators (FO)**
- **Functional Entities (FE)**

Graphical representation of CIMOSA models is shown in generic form in Figure 2.

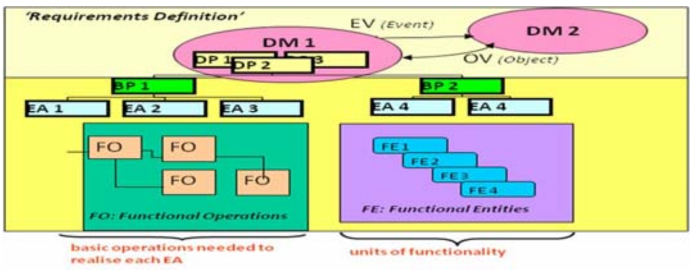


Fig. 2. CIMOSA static model

Case study modelling is also supported by simulation models (dynamic models) that are in part, derived from (and hence are consistent with) selected segments of the CIMOSA static model. EM using CIMOSA offers mechanism to systematically modelling common processes and relatively enduring structures that governs the way ME operates[6]. CIMOSA graphical models are static in the sense that they only encode relatively enduring properties of ME's and cannot be computer executed to show ME behaviours over time. The simulation models are capable of modelling queues, stochastic events, product flows, process routes, resource utilisation, breakdowns and absence and exception flows.

Enterprise and simulation modelling techniques can mutually support analysis of human system roles in a manufacturing enterprise. First EM enables modelling via systematic decomposition of processes into enterprise activities and second these models could be computer exercised, via a selected simulation tool to enable experiments to be carried out which predict behaviour outcomes if human systems are deployed in different ways. The simulation software used for this case study is Teknomatix Plant Simulation software, a discrete event, object-based simulation software that offers simple and user friendly application and also provides better flexibility to human system modelling as compared to other familiar software in MSI (Manufacturing System Integration Institute Loughborough University) such as Simul8 etc.

4 Choice of Study Domain

The Case Study chosen was an international based 'point of purchase' (POP) manufacturing company ABC. The 'produce and deliver' domain of the company is studied in this research where this includes all the activities involved in its production section including its assembly section. The majority of the parts are fabricated in the production plant i.e. in sections called 'Vacforming', 'Woodworking', 'Printing' and 'Injection Moulding'. But some are outsourced to external suppliers. The assembly work is currently carried out in two working units, namely: the batch assembly and lean cell assembly. Currently, on average, lean cells take over 20% of the overall assembly jobs. Lean Cells had recently been introduced to overcome the WIP problems, which were costing a high fraction of the company's stake. However key aspects of people working in both lean cell and batch assembly have not been studied in detail because the management assumed the assembly job can be performed by anyone without any training nor experience. In general assembly operators are temporary workers that are hired through an agency. This case study was conceived to investigate effects of workers performance based on their competency: here by batch and lean assembly lines are studied in terms of achievable Takt times and throughput.

Assumptions: Relationships connecting performance, speed and efficiency were assumed to be as follows. **P**(performance) is some function of **A**(accuracy) and **S**(speed); where accuracy may typically be expressed as a percentage of successful job completions and speed can be expressed as measure of the rate of job completions. Efficiency is expressed as workers ability to perform their work with accuracy. Also assumed is that **A** can be viewed as being a measure of the **C1** (competency) of an individual or a group or team of people. S can be viewed as being a measure of the **C2** (capacity) of an individual or a group or team of people.In many manufacturing situations it was also assumed that P=**C1 times C2** = **A** (accuracy) multiplied by **S** (speed) that can be written as:

$$P = C1 \times C2 = A \times S \quad (1)$$

The justification: for these assumptions was that workers performance is actually the multiplication of worker's accuracy of working and speed of working. This is because the worker's performance increases when workers ability to perform their work with accuracy as well as by worker's ability to work at higher rate (speed). Thus performance is assumed to be a multiplication of C1 and C2 of workers working in a unit of process, or role or workstation. The enterprise model (EM) was built using CIMOSA decomposition and modelling constructs. This EM explicitly mapped the ordered set of activities of the network of business processes used by the case company to realise products. This state-of-the-art method leads to top-down abstraction of the processes and these can be seen in Figure 3 and Figure 4. The assembly functions form a more definitive focus for simulation modelling as the case company wanted to understand what assembly paradigms might best suit its production situations. The static models EM's were therefore transformed into equivalent dynamic models (i.e. simulation models to understand assembly process dynamics). The actual historical order rates of the company were used as input to the SM. In the SM, five simulation trials have been exercised for which relationships connecting worker's accuracy and worker's speed has been changed and tested systematically. These models have been run at slow speed for specific time to show the behavior of work movement through different entities of the systems with respect to time. The model is verified because it is similar to the real system behavior. The simulation model from both batch assembly line and lean assembly cell configurations are recorded in Figure 5.

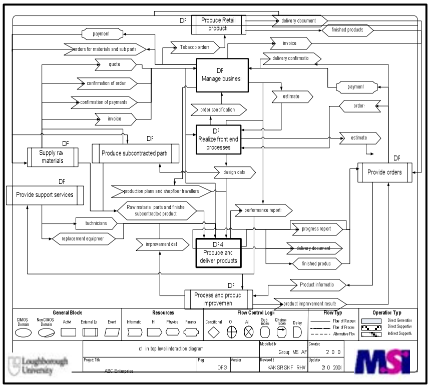


Fig. 3. Business Domain of ABC Company

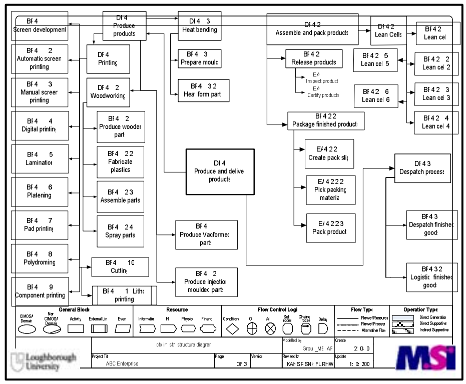


Fig. 4. Produce and Deliver activities

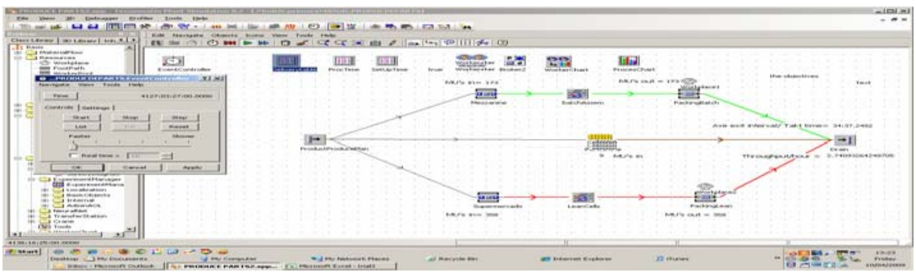
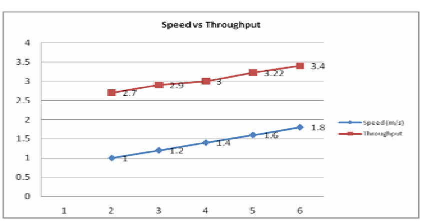


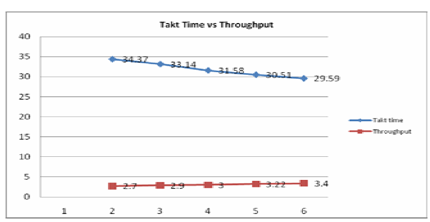
Fig. 5. Simulation Model

5 Results and Discussion

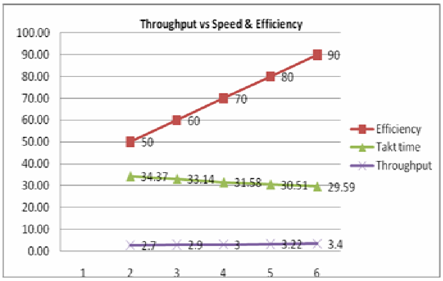
The results obtained from the simulation models are the used to populated graphs that show the relationships between worker's accuracy, worker's speed, takt time and production throughput. Graph 1 portrays relationships between worker's speed and throughput; Graph 2 co-relates takt time against throughput; Graph 3 shows the relationship between takt time, speed and accuracy; and Graph 4 depicts the relationship between throughput, speed and efficiency.



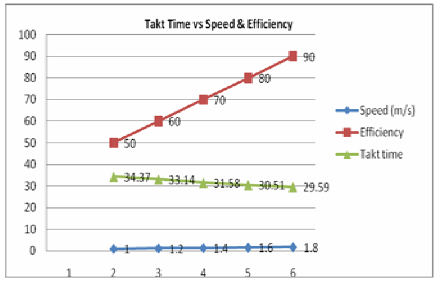
Graph 1. Worker's Speed vs Throughput



Graph 2. Takt Time vs Throughput



Graph 3. Throughput, Speed & Efficiency



Graph 4. Takt Time, Speed and Efficiency

The first graph shows positive relationship between speed and throughput. As the speed of the worker increases in the simulation model, the total production throughput increases. In Graph 2, as the efficiency and speed of the worker increases, the Takt time decreases. However the throughput increases. This can be explained as the time taken to produce one assembly is reduced when the worker's performance increases; thus resulting higher throughput in the assembly line. These graphs show that increase in C1 and C2, increases the throughput of the production line and therefore decreases the Takt time of the assembly line. Thus the relationship can be mathematically portrayed as follows:

Takt time (Tt) decreases as competency (C1) and capacity (C2) increases

$$\text{Thus } Tt/(C1.C2) = \infty, \text{ and therefore } Tt = C \qquad (2)$$

Hence the worker's performance is directly related to the overall takt time of the assembly line. Graph 3 and Graph 4 portrays that when speed and efficiency of workers increases, the production throughput increases and takt time decreases. Thus by improving worker's performance in the production line, process performance in the shop floor can improved. However, these parameters (accuracy and speed) are not the only factors that influenced the process performance in the shop floor, this also includes organization structure i.e. team, group, motivation, ergonomics and work organization etc.

6 Conclusion

This research illustrates how simulation models can be used to predict production systems performance in terms of people performance factors (competency and capacity). This is achieved by:

1. Linking the static modeling approach-time independent (EM) and dynamic modelling approach-time dependent (SM) tools. This enables prediction of the system behaviour systematically.
2. SM tool enable quantification of the effects of the observed issues i.e. competency on system performance thus objectively predicts the system behaviour.

3. The combination or EM and SM provides 'as-is' systems performance, also enables possible opportunity to evaluate different working scenarios that allows prediction of future system behaviour and performance.

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