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Integrated approach to Modelling Human Systems as reuseable components of Manufacturing Workplaces

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Abstract

A new approach to modelling human systems as reusable components of manufacturing workplaces is described. Graphical and computer executable models of people competences and behaviours are created which are qualitatively and quantitatively matched to equivalent models of process networks, decomposed into roles and dependencies between roles. To enable model creation and reuse, coherent sets of role, competence and dynamic producer unit (DPU) modelling concepts have been defined and instrumented using Enterprise Modelling (EM), Simulation Modelling (SM) and Causal Loop Modelling (CLM) techniques. This paper reports on an application of the modelling approach to create related models of 'process oriented roles' and 'candidate human systems' so as to systemise matching of role requirements to resource systems attributes and to inform aspects of strategic and tactical decision making in an SME making composite bearings.

Keywords: *Enterprise Modelling, Simulation Modelling, Process Modelling Human Systems Modelling & Dynamic Producer Unit*

1.0 Introduction

Manufacturing Enterprises (MEs) are designed and engineered by people to achieve a wide range of goals. Normally, MEs comprise structured and technology enabled systems of people who process physical and informational workflows to add value to specific products in timely and cost effective ways. Globalisation of product markets, product customisation and shortening product lifetimes all impact in terms of increased and more frequent customer requirement changes [Krappe, et al, 2006]. To cope with customer and other environmentally induced product dynamics, MEs operating in most industry sectors require enhanced competences (provided by human

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systems) and improved capabilities (from technical systems) to realise their process-oriented roles effectively and in a timely manner. Generally, in MEs, people have collective and ongoing responsibility for: (1) deciding what an enterprise should do, (2) deciding how the enterprise should be structured and use available supporting technology to achieve those desired goals and constrain unwanted behaviours and (3) do most of those product realising activities in a structured and technically-supported way as defined by (1) & (2) [Weston, et al 2004.]. Essentially, people centred organisations like MEs are complex in terms of their composition, structures and operations. Consequently, effective and timely realisation of value adding activities requires selection and matching of appropriate resource system competences and capabilities to ME requirements, and ongoing basis, to change resource system solutions as ME requirement changes [Swarz & DeRosa, (2006), Skyttner, (2005)]. To achieve desired responses to ME requirement changes, enterprise systems and their human and technical components are often recomposed, reconfigured and reprogrammed. As necessary, enterprise system change can give rise to emergent behaviours in MEs with resultant changes in operational scope and role requirements for people and their supporting technical systems. To remain competitive however, MEs need constantly to develop their (human and technical) systems so that their competences, capabilities and capacities remain aligned to emergent business and environmental requirements. With increased business fluidity comes a growing need for change capable manufacturing organisations, namely organisation that possess an ability to 'recompose', 'reconfigure' and 'reprogram' their system components rapidly and effectively. In turn this requires improved understandings about how business and environmental change can be realised via suitable change to process structures and how this is related to required resource systems structures, attributes & behaviours [Weston et al 2007, Zhen & Weston, 2006]. Such understandings can be gained by studying ME 'requirements' and related 'resource components and their configurations' in model views. Models of MEs and their component parts can be captured in different views, at different levels of granularity, via alternative methods and by deploying appropriate modelling tools and modelling languages; thereby making it easier to represent, visualise, analyse, understand and possibly predict behaviours of viable configurations of enterprise components and to inform management decisions.

Many 'method-based' approaches to engineering change in MEs have been conceived and are becoming widely adopted by industry including: Just in Time and Lean Manufacture, Agile Manufacturing and Postponement and Mass Customisation [Womack & Jones, 2003, Womack, et al, 1990]. However, it is observed that typically in industry the application of these change methods:

- (i) is ad hoc, constrained and piecemeal;
- (ii) supports qualitative, rather than quantitative analysis;
- (iii) does not facilitate an ongoing externalisation and reuse of organisational knowledge and data
- (iv) is techno-centric, with limited characterisation of impacts of people system roles, competences, behaviours and cultures.

Hence the present authors propose the use of model-based approach to underpinning manufacturing organisation design and change. In conjunction with Enterprise Modelling (EM), Causal Loop Modelling (CLM) and Simulation Modelling (SM) can usefully be deployed to achieve ME requirements specifications and capture, resource systems (solution) design, and the ongoing matching of emerging requirements to changes in solution design. Since early 2000, the authors modelling research have specified developed and case tested systematic uses of state of the art EM, CLM and SM technologies to develop virtual models of large and small scale manufacturing systems. Essentially, their approach unifies the use of: (a) decomposition principles defined by public domain EM methodologies especially CIMOSA, (b) causal and temporal relationship modelling notations, provided by CLM technologies, (c) discrete event and continuous SM tools to computer exercise behaviours of selected configurations of work loaded process segments and their underpinning resource systems and (d) mixed reality modelling based on the use of workflow modelling techniques that enable interaction and information interchange between simulation models and real resource systems. In that context, this paper reports on progress made with respect to developing models of people in their manufacturing work places for the purpose of realising enhanced enterprise behaviours and performances that continue to match explicitly defined but changing ME requirements.

2.0 ‘Modelling People at Work’ in MEs

Evidently it is difficult for humans to model themselves for a number of reasons which include the following:

- (1) People are complex entities that generate various (individual and collective) behaviours that are often context dependent [Ajaefobi, et al, 2006]
- (2) People acting as modellers often have constrained understanding, knowledge and data about themselves, about the modelling context and about related causal impacts.

However every day we all generate and use simple models of ourselves, our fellows, colleagues, companions, etc and of related situational impacts. Research reported in this paper is concerned with understanding and characterising problems and constraints associated with modelling people in ME workplaces. Definitive foci of reporting is on creating and using models of ‘human systems’ in relationship to common roles performed in MEs. Here the term ‘human systems’ is used to infer either: competent individuals working systematically; loosely affiliated ‘workgroups’; or closely coupled teams of people deployed to interact in a structured work environment. Generally though, resourcing value adding roles in MEs involves the use of (a) systems of competent people, (b) suitable technical systems and (c) combination of (a) & (b). The choice and deployment of the above resource system types depends on the nature of the requirements, i.e. the nature of the work to be done, which often dictates the extent of human involvement & possible extent of automation, the costs of deploying particular resource system types and the nature of expected outcomes. To enable human systems to function effectively in MEs, various organising structures that impact on their actions and behaviours are commonly deployed including: *human organising structures* (like hierarchy, roles, responsibilities and authority) [Hendrick, 1997, Ashkenas, 1995], *work organising structures* (such as processing routes, batching and prioritising rules and ‘job’ and ‘task’ assignments) [Vernadat, 1996, Benis, 1996, & Medsker & Campion, 1997] and *enterprise cultures* (including corporate beliefs and values).

Previous research findings by the present authors had observed a key differentiation between human and their technical system counterparts which centre on a common human ability to reflect on job performance outcomes and thereby as necessary to (1) develop new competences and/or (2) develop new structures; thereby modifying their

behaviours and the behaviour of the entire system leading to improved performance [Weston, et al 2003]. People are therefore more flexible than most technical systems because they have the ability to reflect on (and develop) what they do, their work patterns and behavioural relationships.

To realise a prime objective of this research (i. e. to systemise and support with models aspects of matching people to roles in the context of specific and changing ME work places), it is assumed that people and technical systems and the process-oriented roles they realise in manufacturing workplaces need to be modelled in a coherent manner. Also it is assumed that in conformance with established general systems engineering practice, flexible 'interconnection' is required between developed models of process-oriented roles (that explicitly define work requirements) and developed models of solution configurations of human and technical resource components. To identify common ME requirements (things MEs do to create values for their customers), the authors have adopted a process view of MEs thereby modelling specific ME requirements as a specific network of dependent processes and their derivative roles. Previous authors have classified and characterised processes commonly found in most MEs [Pandya, 1997, Chatha et al, 2006]. A consensus view is that MEs typically deploy people and technical systems to realise the following process types:

- (2) processes that realise products and services for customers
- (2) processes that ensure that those product and service realisations are well managed, such that they remains aligned to established business and manufacturing policies and strategic goals of the ME, and
- (2) processes that structure and enable ongoing change as the ME systematically renews and reconfigures itself, developing and implementing new strategies, policies and processes in response to external change.

While conceiving, specifying, developing, realizing and changing enterprise processes; people exercise different role types, namely *interpersonal*, *informational*, *decisional* and *operational* roles [Mintzberg, 1989 & Steers & Black, 1994]. The term role can further be described as: functions (tasks or activities) that need to be performed by role incumbents; identity created (or positions occupied) by incumbents in a social structure while performing the role and behaviours that people or

stereotypical people can/will bring to roles and the management of role dependencies [Ashfort, 2000, Wagner & Hohenbeck, 1992, and Steers & Black, 1994]. The focus of this paper is on *functional roles*; which represent sets of functional activities and operations that are resourced by people and their supporting technology during product (service) realisation [Zaidat, et al 2004]. To effectively satisfy role requirements i.e. attainment of specific results required by the role through specific actions while maintaining or being consistent with the policies, procedures and conditions of the organisational environment [Boyatzis, 1982], role incumbents need to bring to bear upon assigned roles work related attributes especially competences. The term competence is presume to mean those work related attributes, including: natural traits (underlying attributes), acquired traits (knowledge, skills, education, training, experience, etc) and consistent performance outcomes for which a given resource system is known. It follows that in resourcing ME roles, two types of competences are evident: (1) competences required by roles and (2) available competences possessed by potential role incumbents [Harzallah & Vernadat, 2002]. Selection and matching of people to roles involves 'mapping' between available competences and required competences. Any such mapping is naturally constrained by factors like:

- (a) does the selected candidate system (person or people) have all the competences required by the role(s)?
- (b) if the answer to (a) is affirmative, what is the capacity i.e. (how much in case of quantifiable outcomes) will the system deliver in a given time frame?
- (c) can the selected candidate system cope with changing workload requirements, including changes related to production volumes and product variances?
- (d) What aspects of the required competences are lacking in the solution provision?
- (e) Can such deficiencies (as identified in (d)) be remedied by training or upgrading the supporting technology so as to enhance achievable performance of the deployed candidate system?

Addressing the above questions requires modelling concepts with analytical and dynamic features to support data capture on requirements, representation and analysis of the available and required competences. In subsequent sections, data capture and modelling of requirements from such captured data, modelling of candidate solution

and how simulation modelling can be used to match specified requirements to alternative solutions in both structural and dynamic behavioural terms are discussed.

3.0 Need for New Modelling Concepts

To develop an approach to modelling human systems as reusable components of MEs, it was observed to be necessary to realise the specification and selection of a modelling method with capabilities to:

- (a) represent and abstract generic and specific ME requirements, in terms of the required network of processes used by any specific ME to realise products and common workflows through different segments of that process network. Here it was envisaged that such a modelling method would facilitate and systemise the decomposition of process-oriented requirements (explicitly modelled as process segments and their needed workflows) into well defined roles that are themselves can be decomposed to enable their explicit modelling at different levels of granularity; so that later the roles defined can be flexibly matched to 'work centres' that can be physically realised by suitable (human and technical) resource systems
- (b) represent, decompose, abstract and structure models of human systems and their component elements in terms of work related attributes, and especially functional competences
- (c) facilitate qualitative and flexible matching between models of people (competences) and models of process oriented roles.
- (d) enable the selection and testing of alternative role-people 'couplings' in a simulation environment, so that quantitative comparisons can be made between the behaviours of alternative candidate role-people couples when they are subjected to historical and/or possible future changing ME requirements

To satisfy the modelling requirements listed and to achieve the envisaged benefits, a suitable modelling approach needed to be specified and selected. In principle, any of the state of the art EM methods that have been successfully tested and usefully applied in industry (such as CIMOSA, IDEF, PERA and ARIS) could have been chosen as the foundation modelling method. However, the authors chose to deploy the open system architecture for computer integrated manufacturing (CIMOSA) [Vernadat, 1996, Kosanke, 1995, Zelm et al, 1995]. In spite of its known modelling

strengths, CIMOSA has some notably weaknesses including (a) models developed using CIMOSA are essentially static and hence cannot be used to reason about changing requirements and the impact of such changes on selected & alternative resource systems and (b) CIMOSA does not have specific modelling constructs to represent human systems competences. To address the limitations observed, a modelling framework incorporating role modelling concepts, competence modelling concepts and the use of SM modelling tools to instrument role-people couplings was proposed. The unified modelling framework proposed uses CIMOSA as the main modelling foundation but it has extended the modelling capabilities of CIMOSA (by exploiting its eclectic nature) to incorporate competence and SM modelling concepts. Furthermore, to reflect the fact that human systems execute assigned roles while being supported by technical systems, the dynamic producer unit (DPU) concept previously proposed by the authors and their research colleges was employed to further systemise human systems modelling. DPU modelling construct was proposed for the purpose of abstract description of *enterprise resource units comprising people, machines, computers and or a structured combination of those; that is a reconfigurable, reusable and interoperable component of complex organisations such as a manufacturing enterprise* [Weston, et al 2009].

4.0 Modelling Methodology Conceived

The modelling framework shown in Table 1 was proposed and developed to enable the capture of coherent models of ‘process-oriented roles’ and ‘human systems commonly found in specific manufacturing work contexts’. Section 5 of this paper describes a case study application of this *integrated approach to modelling human systems, as reusable components of manufacturing workplaces*.

[Insert Table 1 about here]

5.0 The Case Study Company and its Modelling Requirements

5.1 *Company Background*

A composite bearing manufacturing company which makes to order a wide range of composite bearing products was chosen as the subject of a case study. For reasons of confidentiality the authors will refer to the company as ComBear Ltd. ComBear Ltd is a rapidly growing UK based SME with a customer base which extends beyond Europe. ComBear manufactures different composite bearing products suitable for agricultural, marine, mechanical, pharmaceutical and food processing applications. Essentially, all ComBear products are manufactured from reinforced plastic laminates composed of synthetic fabrics impregnated with resins and lubricant fillers. Final products are delivered to customers in tube and sheet forms as well as fully finished components such as structural bearings, washers, wear rings, sphericals, wear pads, wear strips, rollers, and bushes. Figure 1 shows some of ComBear's current product range.

[Insert Figure 1 about here]

5.2 *Reasons for Modelling*

The objectives of the research funded by the UK's EPSRC are described in detail in the EPSRC case for support [Weston, 2005]. In the ComBear case more specific modelling goals were agreed with the company management and are listed as follows:

- (1) to formally document ComBear's current network of processes, identifying *who* does *what* and *with what* and at *what time*;
- (2) for selected segments of ComBear's current network of processes, to create computer executable models that predict dynamic impacts on (current and possible future) process performances (e.g. lead-times,

- throughput, bottlenecks, inventory, value generation and processing costs) of alternative work patterns and workloads;
- (3) use documented and computer executable models to suggest potential beneficial changes to organisational structures, management philosophies and culture;
 - (4) use integrated models to identify where processes can become more lean or agile so that the firm can gain business benefits;
 - (5) use integrated models to suggest ways of improving the deployment and performance of (human and technical) resources;
 - (6) use integrated models to improve the planning, scheduling and control of workloads placed on primary 'operational' process segments.

To realise the stated modelling goals, the present authors adopted use of the *integrated approach to modelling human systems, as reusable components of manufacturing workplaces; the modelling stages of which are* described by Table 1.

5.3 Formal Documentation of ComBear's Process Network

Stage 1 of the integrated modelling approach involves the capture of a specific CIMOSA conformant ComBear's enterprise model. The main purposes here were to:

- (a) provide the university team with means of externalising and reusing knowledge (formerly only distributed amongst the minds of various personnel) about the firm's 'operational' (day to day), 'tactical' (sometimes daily or weekly and sometimes episodic) and 'strategic' (longer term) activity flows;
- (b) understand how ComBear's operational activity flows enable the company to generate short term values and profit, whilst remaining competitive in the medium and longer term;
- (c) assist ComBear management and workforce to develop a big picture of the firm's activity flows, so that individuals can identify impacts of their roles on the business performance of the company; and
- (d) enable the University team (as directed by ComBear managers) to use the knowledge externalised as base level of company specific data which enables the development of reusable computer executable models of selected activity flows (so as to realise goals (2) to (6)).

Before embarking on CIMOSA modelling the present authors spent approximately 5 man days (i) discussing activity flows with its managers and (ii) observing technical and manufacturing personnel perform their various roles. Figure 2 provides an overview of the full range of ComBear processes identified, namely:

- *Strategic processes* that operate as required to envision, conceive and realise improved competitiveness through day to day management, leadership, financial and fiscal policy management and control, and adapting business rules and manufacturing policies in response to changing customer requirements, environmental and government regulations
- *Tactical processes* resourced by 'technical and mid-management teams' that : (1) obtain and process customer orders, (2) develop process plans and job cards for product manufacture, (3) design new products or improve the design of existing products, (4) control and manage production materials, and (5) plan, schedule and control production operations
- *Operate processes* that produce and deliver composite bearings and other products manufactured in three shops located within the production facility namely: (a) raw material processing shop, (b) sand & saw shop and (c) machine shop

[Insert Figure 2 about here]

Although causal, temporal and structural links were observed between most of the key processes, the chosen focus of case study modelling was on the 'operate processes'; instances of which need to regularly be resourced by human and technical resources, so that products are realised for customers and ComBear profit is generated. Four types of modelling template were used to describe ComBear's EM in a graphical form, namely: context diagrams, interaction diagrams, structure diagrams and activity diagrams

Context Diagram: describe in overview how various 'domain actors' (i.e. departmental sections and their supply chain partners) work together within the business context under study. In this case the context modelled was the day to day

production of composite bearings, of types and in quantities needed to satisfy orders from a variety of customers. Figure 3 shows an example context diagram captured in respect of ComBear.

[Insert Figure 3 about here]

Interaction Diagrams: describe various (relatively enduring) entity flows between processes (which in CIMOSA terms are modelled as Domain Processes [DPs] and their elemental Business Processes [BPs], Enterprise Activities [EAs] and Functional Operations [FOs]).

Structure Diagrams: depict relatively enduring structural relationships between DPs, BPs and EAs. This class of diagram is designed to code specific process decompositions consisting of ordered set of activities linked by precedence relationships, execution of which is triggered by events such as arrival of customer's orders.

[Insert Figure 4 about here]

[Insert Figure 5 about here]

Activity Diagrams: are used to depict specific process segments of concern, in terms of standard activity flows needed to create products. Activity flows were represented for each product family manufactured by ComBear. Figures 4 & 5 are examples of structure and activity diagrams.

Other kinds of modelled entity (such as events, information flows and precedence relationships) can be attributed to activity flows. In Figure 5, the activity flows illustrated explicitly depict processing activities carried out in ComBear's raw materials processing shop to create so called 'round products'.

5.4. Roles Identification & Specification

Having represented ComBear production processes using standard CIMOSA formalisms: domain processes (DPs), business processes (BPs), enterprise activities (EAs), and functional operations (FOs) (see Figures 3-5 (section 5)), step 2 of the integrated modelling method was implemented by specifying and defining viable roles executed by ComBear resource system elements at various work centres. The term role was used to refer to functions performed by role incumbents. Three classes of role were identified in ComBear namely: (1) management roles representing those management and coordination functions, (b) technical/support roles that realise functions such as specifying process plans and procedures for products manufacture, planning and controlling production, designing new products; etc, and (c) operational roles, which represent direct products realising functions. Matching human systems to operational roles is the focus of this paper and those roles in ComBear comprised: (1) raw material processing related roles; that produced materials for making different ComBear products, (2) machining roles; that shape processed materials into components and where applicable assemble them into products, (3) sanding roles; that put finishing touches to outputs from machining roles and (4) packaging and delivery roles. Figure 6 shows some roles identified in raw materials processing and sanding operations. In satisfying the raw materials processing functions for instance, five different roles (R1.11 – R1.15), which are groupings of operations executed at different work centres, were identified. When grouping operations into roles, considerations were made about:

1. precedence relationships between activities and their functional operations (bearing in mind closely coupled and non-separable activities)
2. dependencies between possible candidate 'as-is' and possible 'to-be' role incumbents (e.g. availability of people and supporting machine resources).

In general, roles specified were explicitly defined in terms of functional competences that potential candidate solutions need to bring to realise those roles. It was observed that ComBear's operators perform different roles while realising specified activity instances. Roles performed during activity instances depend on the product types passing through the process structure. In the RMP shop for instance, the roles played

by operators depend on whether a particular operator is processing round, flat or strip materials and their variants.

[Insert Figure 6 about here]

Subsequent sections of this paper describe how ComBear's process-role oriented models (exemplified by the templates shown in Figures 11) were successively reused (and as needed further detailed and modified) as an explicit big picture of ComBear processing requirements that needed to be resourced by suitable human and technical systems.

6.0 ComBear Human Systems Modelling

To realise step 3 of the modelling methodology depicted by Table 1, actual ('as is') shop floor operators' data were elicited and collected in terms of numbers of people deployed to specific operation areas, roles assigned to such groupings of people and their individual known skills. The aim of so doing was to (re)use this employee data to facilitate an ongoing matching of available human resources to specified instances of ComBear product realising processes. While collecting the operators' data, it was observed that most shop floor operations performed by ComBear personnel have no formalised written standard operating procedures. Rather it is left to supervisors and operators to flexibly prioritise and execute their work. Hence performance outcomes vary amongst individual operators with respect to quality ('fitness for purpose'), quantity of work done and the rate of achieving specified quantity of work within acceptable quality standards. It follows therefore that ComBear management depend heavily on the commitment (related to behavioural, 'will do' competences) and work related (functional, can do) competences of its workforce to achieve its overall business goals.

To enable the capture and conceptual representation of the competences available amongst ComBear employees, currently deployed in the production shop, the following assumptions were made:

- to realise the ‘make bearings to order’ process segment, competent people supported by suitable technical systems need to realise roles associated with ordered sets of processes that relate to each product type manufactured by ComBear. Essentially when customer orders are received for each product type the realisation of the related roles will constitute different (multiple) value streams.
- a suitable match needs to be realised and maintained between *required competences* (explicitly defined by descriptions of competency requirements that can be associated to each role) and *available competences* (that people and supporting technology can bring to bear on specified roles) to ensure that prescribed work outcomes are not compromised nor that the people deployed will be stressed.
- ‘unlike technical systems, human systems can reflect upon their task and job performance outcomes and thereby as necessary (1) *develop new competences* or (2) *develop new structures* (and possibly behaviours) that can enhance future performance outcomes.

Bearing in mind the key process groupings identified in ComBear, namely; (a) strategic, (b) tactical and (c) operational process types, a competence classification previously proposed [Ajaefobi, 2004, Ajaefobi, et al 2003] was deployed. However a relatively minor adaptation of this classification was needed to encompass all ComBear workforce roles identified in relation to the firm’s processes. The classification presumes that when models of ‘requirements i.e. roles’ are specified they can be compared with ‘coherently defined models’ of candidate solution systems (people and their competences organised by suitable structures) to draw up a first stage selection of suitable candidate solutions thereby satisfying step 3 of the **‘integrated approach to modelling human systems’** outlined in Table 1. Thus with respect to the specific ComBear process network defined during stage 1 of the modelling approach and described in outline in sections 5.3 & 5.4, it was necessary to observe and characterise strategic, tactical and operational competence types that personnel should possess to satisfy specific roles (and their elemental activities). Furthermore, it was observed that current (‘as-is’) human systems at ComBear (and in a number of other industry partners doing collaborative research with the authors) are structured into a three level hierarchy, namely: (a) management group, (b) technical

group (c) and shop floor operational group. These three groupings of workers interact (in a combined top-down and bottom-up manner) so that collectively they execute all strategic, tactical and operational aspects of processes. Figure 7 is a simple conceptual representation of the processes required and corresponding competences possessed by ComBear personnel.

As mentioned previously the major focus (in this case study) was on 'operate processes' and the competences they required for their realisation from people. In the ComBear raw material processing shop(RMP), the following 'general competences' were identified through detailed discussions between ComBear managers and the present authors as being needed by operators for them to be considered competent:

- ability to read, interpret, and execute working and technical drawings and to follow job card instructions to produce required parts or products
- ability to set up and operate available machine tools
- ability to identify, measure and mix appropriate chemicals required for specified composite manufacture
- being quality conscious and able to get assigned jobs right during their first attempt and where necessary being able to fix up minor defects on completed products thereby restoring them to acceptable quality standards (fit for purpose)
- ability to work under stress (if need be) to meet deadlines
- demonstrate commitment in relation to assigned roles, prioritising actions and being flexibly ready to work on related jobs within his/her competence area
- ability to demonstrate an understanding of industry safety rules

[Insert Figure 7 about here]

In 'specific roles' and for 'their product type variances' the specific nature and importance of these general competences was known to vary. Therefore to resource

value streams that realise different ComBear products in the RMP shop, combinations of these competences (possessed by particular operators) need to be selected and matched to required competences of the roles. Also such a match must be maintained and changed as requirements change. Selecting and maintaining an appropriate match between required and available competences is therefore an ongoing tactical task so that neither prescribed outcomes with respect to product quality, quantity, lead time, operating procedures, etc are compromised nor are assigned operators are overly stressed. In addition to possessing one or more of the general competences in varying degrees, operators were observed to differ in their experiences and in their potential to deploy so called tacit knowledge, which enables some operators to (1) flexibly adapt to changing work requirements, (2) re-set machine tools to meet changes in job requirements and (3) deliver promptly in regard to assigned jobs keeping to quality and quantity demands in comparison with their peers. In view of the observed competence variations, operators were grouped into three categories, namely: (a) experts, (b) practitioners and (c) trainees. The observed competence variations were found later to provide a logical thread of reasoning to underpin role assignment when matching alternative groupings of activities to operators and/or groupings of operators. In the case instance being reported, i.e. in the RMP shop, operators were rated in three key competence areas with respect to their: (a) abilities to set up and use relevant machines and related tools in the shop, (b) procedural knowledge of operations, and (c) actual process execution and average processing time on assigned job. Numerical values of 1, 2 & 3 (corresponding to trainee, practitioner and expert operators respectively) were used to rate the Operators according to their performances in relation to specified reachable states. Table 2 shows ratings assigned to one of the expert operators.

[Insert Table 2 about here]

7.0. Enhancing the Re-Usability of ComBear Models using DPU and Role Modelling Concepts

Previous sections have described how CIMOSA and competence modelling concepts were used to capture and represent processes and human systems deployed at ComBear. This section discusses how the models developed were semantically further

enriched via the use of DPU and role modelling concepts. Essentially, DPUs are viewed as component entities that can be configured to form MEs via engineering processes that include selection, structural and temporal configuration, programming and run-time interaction and interoperation thereby producing desired outcomes. Notions about DPUs presume that at some level of abstraction, enterprise components can be considered to be ME modules. However linked to this notion is the fact that some ME components can be decomposed into DPU subsystem units, so that their modular units can be recomposed differently to realise (changing) targeted behaviours; and by so doing organisation design and change can be engineered in a model driven manner. Another way of viewing ME components is that they have the ability to act individually and to interact collectively as building blocks (whether they are machines or modular units of machines, IT systems and/or human resource systems) to achieve desired behaviours and therefore desired goals. Suitable ME components (resource system elements) with potential to generate high performances when matched to a specific network of processes constitutes a viable candidate DPU. Modelling ME components can enhance understandings about their characters, behaviours, applications and change. The DPU concept was proposed by the present authors and their colleges as a modelling construct which can be re-used in a virtual environment to enable enterprise components (especially active resource systems: namely humans, machines and IT which can realise specified roles) to be described coherently and explicitly as 'reusable', 'change capable' 'components' of MEs. Thus, DPU characterisation is designed to facilitate: (1) **graphical representation** of resource systems, (2) **explicit specification** of resource systems and (3) **implementation description** of resource systems, such that DPU's can be computer executed within simulation modelling environments (Weston, et al 2009). It is assumed that (1) DPUs can function individually as a holder of one or more assigned roles and (2) configurations of multiple DPUs will interoperate so as to function collectively as holders of one or more higher level (more abstract) roles (i.e. roles composed of lower level roles). Further, depending on their working context, DPUs are expected to be explicitly defined in terms of recognisable work related attributes: i.e. various types of competences (for human systems) and/or capabilities (for machine and computer systems). Consequently, depending on specifics of any work context and the nature of work deliverables, viable candidate DPUs should possess the abilities to produce identifiable, measurable and observable outputs; so that for

example a DPU comprising of an operator and machine can realise both product X and Y in specified quantities, and with specified quality levels within specified cost and time constraints. Furthermore, for DPUs to possess the competences and capabilities to cater for changing work contexts and work deliverables, they must also possess a competence to be re-programme and/or re-configured as needed. It follows that DPUs have dynamic nature, which means that DPUs need to be modelled in terms of both relatively enduring structures and time dependent behaviours; so that their model parameters can be adjusted to judge in simulation environments their potential performances in 'Key Performance Indicator (KPI)' terms such as lead time, efficiency, utilisation, throughput and operational flexibility.

From the above description of DPU concepts, it was decided that ComBear human operators and their supporting tools and technology would be modelled as DPUs. To represent ComBear resource system configurations (using DPU concepts) in the process-oriented roles they must realise, use of the CIMOSA EM framework proved effective via its inherent separation of 'process-oriented requirements capture' from 'DPU-based conceptual designs of resource system solutions'. By so doing ComBear resource systems were modelled separately as solution units that on an on-going basis can be matched to previously modelled process-oriented roles. To facilitate formal capture, documentation, modelling and matching of DPUs to process-oriented roles, the Unified Modelling Language (UML) was deployed. UML was used to encode (1) DPU attributes and (2) process oriented roles. This enables reuse of information structures and information entities related to the decomposition of specific networks of processes. Furthermore, the use of UML provided a flexible means of representing and structuring groupings of ComBear resource system components, modelled in terms of DPUs and groupings of DPUs. When creating models of the 'as-is' ComBear resource systems in UML, the entire ComBear workforce was modelled as a high level 'DPU class' which is referred to as a 'Human Systems Model DPU'. This DPU class is comprise of three subclasses; respectively representing ComBear employee groupings that possess the kinds of competences needed to execute one of the identified key processes, namely:

- DPU1 representing the management and day to day administrative group
- DPU2 representing the mid-management and technical group

- DPU3 representing the entirety of ComBear production operatives

Instances and objects that constitute the above DPU subclasses were further modelled and their attributes documented. Figure 8 is a detail illustration of DPU3; which encodes ComBear's employees classes and their instances responsible for executing the 'produce composite bearing products to order' processes and its derivative roles.

[Insert Figure 8 about here]

The use of UML formalisms semantically enriched the graphical representation and detailed structural documentation of ComBear's DPUs, their work related attributes and relationships between those attributes. Furthermore, the previously identified production processes modelled in terms of roles; (where roles denote related operations and groupings of operations that are executed at distinct work centres by one or more DPUs) were also documented using UML formalism. Here UML conformant 'use case diagrams' were created to document and depict process-oriented roles and corresponding DPUs executing them. DPUs were modelled as 'Business Workers' (a role-based concept in UML use to capture and denote groupings of employees that perform roles specified in the 'use cases') along with the responsibilities of the workers and the competences they bring to those roles. Figure 9 shows one of the use case diagrams for a segment of ComBear production processes; this flexibly links role 1 (modelled as an exemplary activity flow diagram) for the 'process raw material' use case.

[Insert Figure 9 about here]

By means UML modelling constructs, elicited work related attributes of candidate human resources were formally documented; in terms of competency descriptions of individual and groups of DPUs and their associated performance levels, as experts,

practitioners or trainees. Similarly, roles were explicitly defined in terms of required competences, i.e. competences that viable candidate operators need to possess to satisfy role requirements. By so doing, explicit descriptions of viable resource systems were matched to explicit descriptions of roles, thereby forming different Role-DPU couplings.

However, it was observed that the dynamics of work item flows have very significant impact on needed competences and capabilities of DPUs; and therefore on how these might best be configured to realise required product outputs on time and at an acceptable cost. Furthermore, at this stage it was also observed that selected configurations of Role-DPU couples were static; in the sense that they only describe relatively enduring relationships between ‘work types and work flows’ and ‘potential workers’. It follows that at this stage (of modelling), the likely performances of Role-DPU couples under varying work conditions (changing product volumes and variance) were yet to be established.

In the reality, however, customers’ changing requirements impact significantly (in terms of reflected workloads placed) on roles and competences needed to fulfil such roles. In principle also, human performance (be they competent individuals, groups or teams of people deployed to realise predictable outcomes) can be measured in quantitative terms in order to characterise and rank impacts of (average or stochastic) system behaviours, like lead time, quantity & quality of work, costs, etc. Hence it was decided that the static competence model that encodes operators as experts, practitioners and trainees and their assigned roles needed to be computer exercised via a simulation modelling tool to replicate existing and when resultant models have been validated to re-use them to predict possible future performance outcomes when deploying different operators under changing requirements.

8.0. ComBear Simulation Models: Dynamic Views

8.1. Causal Loop Models (CLMs)

As a precursor to building dynamic models of ComBear’s operational processes, the authors had a brain storming session with ComBear management during which causal

and temporal dependencies between ME components and subsequently modelled. The brain storming exercise was facilitated using CLM diagrams which were designed to enhance the understanding of causal relationships, and resultant behaviours, amongst common deployed ME system components. Figure 10 shows one of the causal loop models created for this purpose depicting causal effects on the rate of doing work; including expected impacts of increased competences and capabilities from deployed resource systems.

Insert Figure 10 about here]

Conventionally though, CLMs have been used as a front end to the use of continuous simulation technologies as they naturally provide a systemic way of creating ‘stocks’ and ‘flows’ modelled in SMs of this type. But in the ComBear case, the authors chose to use CLM to enable ‘front end’ thinking prior to use of a discrete event simulator. This choice of discrete event simulation was made on technical grounds in that the ComBear problem under study concerned multiple value flows with dynamic production volumes and mixes. This necessitated the use of time dependent models of processing operations and related processing operators and machine configurations, and related bottleneck and inventory analysis. The need to model individual and mixes of product flows, subject to probability was paramount. Also it was necessary to evaluate key performance measures like production lead-times, resource utilisation, inventory levels, pricing, costs and value generation. These and other parameters needed to be predicted with differentiation made when alternative resource configurations are deployed and when different value flows are being generated. Therefore, a conscious choice was made to deploy proven and proprietary simulation technology (rather than research prototypes) with a view to suggesting in the longer term decision support tools that large and small companies can practically deploy.

8.2. Dynamic Modelling of Selected ComBear Processes

Having developed static models of ComBear processes, and considered the static matching of candidate human systems to role requirements and discussed the nature of casual interactions between different ME components, the next step taken was to

analyse the behaviours of alternative human system configurations under differing workload conditions. This corresponds to stage 4 of modelling approach outlined by Table 1. The purpose of simulation modelling (SM) was (1) to replicate historical behaviours of the RMP section of the production shop, so as to verify the correct operation of the models created and to gain new insights in the current operations performed in the RMP section and (2) to predict possible future behaviours of alternative Role-DPU configurations and (3) make suggestions about possible future re-configurations of (human and technical) resource systems, so as systemise and quantify possible future outcomes should the changed configurations be adopted.

To help structure the design of the SMs, stakeholders knowledge, structural relationships and data previously coded into ComBear's EM and current DPU-Role couplings were reused. Also understandings generated from the CLMs were used to determine which parameters of the SM needed to be experimental variables when modelling from alternative points of view. Based on all these understandings, discrete event simulation models of ComBear's RMP shop were designed and created using Simul8®.

With a view to realising specific ComBear modelling objectives listed in section 5.2, the RMP activities (for each of the identified value streams) were coded as elements of work to be realised at work centres of the simulation models. One key purpose of so doing was to observe behavioural implications of interactions between the value streams and thereby key impacts of sharing resource systems (i.e. lower level DPUs); so as to predict resultant throughputs and DPUs utilisations as a result of such interactions and overall impacts on downstream 'Sanding & Machine' shops; where further value adding operations are carried out. Initial objective use of the simulation model was to investigate capacity constraints of the RMP shop DPUs, as a timely supplier of requirements of its downstream shops (Sanding & Machine shops). Throughputs in the RMP shop were observed to be a largely predictable function of the operators' competences, including rate of working, flexibility and use of tacit knowledge. Furthermore, apart from the 'mixing booths' (there are two booths in the shop that are shared with other operators needing them) no other significant bottle necks were observed; as regards to the availability of work centres to be used by the operators as they move from one processing stage to another along the value streams. The modelling results predicted that with the 'as-is' process and resource system

configurations and their workloads, an average operator can make 4 or 5 flat sheets per day. Similarly for strip sheet and round products, daily operator's outputs were predicted to be 3 to 4 strip sheets and 65 tubes per day respectively. In terms of average operator utilisation, it was observed from the model that operators had a 85 % utilisation for flat sheet making, a 67% utilisation for strip sheet production and a 94% utilisation for round products. Here the percentage utilisation indicates the actual availability of that resource for the work. In the case being reported, it implies for instance that the operator was available for only 85% of the total value adding time.

[Insert Figure 11 about here]

Bearing in mind that useful value adding time (in ComBear) is 426 minutes per day, it follows that on average; an operator spends more than 1hr on non-value adding operations per day, which other things being equal, can be interpreted as waste. To account for the non value adding times observed, further investigation sought to determine non value adding times for:

- [i] Changeovers
- [ii] Late delivery from upstream to down stream processes
- [iii] Material irregularities
- [iv] Breakdowns
- [v] Sharing of people on other activities
- [vi] Operators doing just the volume of job planned for the day i.e. planned job is less than operators' capacity

It was observed that only factors (v & vi) above impacted on the daily throughput of the operators and none of (i - iv) really applied. Most of the value adding operations in raw material processing are essentially manual, executed on 'benches and work benches', hence changeovers with respect to tools do not necessarily apply. The distance travelled by operators was considered negligible because the work centres were basically adjacent to one another. Further, materials were promptly delivered and were readily accessible and no breakdown of work centres was observed during the investigation. This leaves process improvements (including lead time reduction,

shortening of Takt time, increasing throughput, and quality of work done) or improving operators' competences, including aspects of competences like flexibility, working speed, tacit knowledge, etc that impact on performance outcomes.

The authors considered ways to rectify the observed short comings in throughput and operator utilisation by constructing possible 'to be' scenarios of improved performances. To achieve this, the roles that constitute the identified value streams in RMP shop were regrouped and then simulated under two different conditions: (a) with increased work entrance and (b) using the cycle times of the expert operators, instead of the average operators' cycle times. The resultant outcomes showed an improvement in both throughputs and in the operators' utilisations. Throughput by an average operator was raised from 5 to 8 units of flat sheet per day and the operator's utilisation increased to 94%. Similar improvements were observed with respect to strip sheets and round products value streams. It follows that the simulation experiments predicted that training the operators to improve on their competences (thereby acquiring the so called 'expert competences'), can improve the production system performance.

Furthermore, to illustrate the impact of improved available competences on throughput and timeliness of ComBear products, a second dynamic model was created. The CLM of figure 10 illustrates how increase in the number of competent operators will naturally increase available competences, which other things being equal will trigger increased rates of doing work, improved operational flexibility, economies of scale and increased value generation. These features were demonstrated by the second simulation model using the RMP shop as a case instance. It was observed that apart from the 'expert' operators, (supervisors) who can flexibly do any job realised by ComBear, other operators were narrow in their competence scope, being unable to work outside their operational areas. The implication is that operators cannot flexibly be deployed to areas of bottleneck outside their core competence area. In the second simulation model, assumption made was that all the operators can flexibly pick any job from the three identified value streams and competently deliver the prescribed out come effectively and on time. Based on this assumption, the average cycle times taken by the experts (supervisors) to execute value adding activities were measured for any of the three value streams. The expert cycle times were then presumed to be standard operation times for all RMP roles. The purpose of

doing so was to observe and compare the differences in outputs when two different operation times i.e standard operation times (based on the performance of average operators) and the experts' operations times are used in the model. The results obtained by running the model showed: (i) improved lead times, (ii) increased throughputs and (iii) higher operators utilisations when compared with the 'as is' scenario; whereby all the operators work in their areas of speciality and with their existing competences and performance levels. In making raw materials for the flat sheet products for instance, the throughput showed an increase of 30% while operator's utilisation (which was previously 85%) rose to 100%. Furthermore, job waiting times were reduced and jobs in the queue also reduced by 32%. It follows that in non high tech production system like ComBear, investing on people to improve their competences and so called tacit knowledge will' other things being equal' significantly improve the over all system performance. Table 3 shows a performance comparison of two operator types in an 'as-is' and one of the possible 'to-be' scenarios while figure 12 is a screen shot of 'as-is' flat sheet materials making operations in the RMP shop

[Insert Table 3 about here]

[Insert Figure12 about here]

Another factor that impacted on the throughput and thereby the utilisation of the operators was the capacity of the press (oven) and the minimum time a work item spends during curing (in the oven) before it is released. The oven has a capacity of 6 flat sheets and a processing time of 90 to 120 minutes. However, the simulation view predicted that some work items spend more than 2 hours during curing. Though this does not affect the quality of the job, it will have some impact on the daily throughput. When a minimum curing time was set at 90 minutes, a predicted throughput of 7 to 8 sheets per day per operator was obtained while maintaining an average of 110 minutes oven curing time. From the foregoing discussions, it follows that the weekly throughput of processed flat sheets materials can in theory be

increased to a weekly average of 30 to 40 units per operator contrary to the current observed 20 to 25 units. Though currently, the operators can be said to be performing below their capacities, as evidenced by the non value adding times observed especially with respect to strip and flat sheets making operations, it was observed that the down stream shops were not in short of strips and flat sheets supplies because of the *defacto* practice in ComBear which allows the build up of much stock and large WIP. This practice carries with it extra production costs, risks associated with large WIP and general shop floor untidiness. In the short term, an approach using 5S principles to cutting down wastes and improving shop floor orderliness developed by the authors is being tested in ComBear while in the long term, a full lean manufacturing implementation has been proposed.

9.0 Conclusions and Ongoing Research

ME managers and developers require much improved analytical means of deploying key and scarce resources including people, IT systems and machines. This need is growing because of increasing workplace dynamics. Generally also state of the art enterprise engineering methods are techno centric and do not account for significant behavioural differences between human and technical resources. This paper introduces an approach to modelling human and technical resources coherently but distinctively, which builds upon a unification of best in class EM and SM frameworks, methods and tools. This unification has been achieved by defining and developing the use of integrating modelling concepts, centred on 'role', 'DPU' and 'competence' modelling. This first part of this paper explains how the unifying concepts chosen have built upon a complementary use of CIMOSA enterprise modelling principles. Subsequent paper parts describe a case study application in an SME and the lessons learned.

The authors observed that great benefit was obtained from combining the use of EM, SM and CLM to conceive and analyse alternative futures for ComBear. Use of EM has benefited as follows.

- (i) It has organised the capture of complex knowledge about ComBear processes, structures, resources and workflows in a virtual manner which

ComBear managers can readily understand and verify as being representative of how the firm actually operates.

- (ii) The same EM has provided a 'static' (process oriented) big picture of the company and its supply chain which has been reused many times and updated and developed as new understandings about ComBear were developed. Via use of the embedded EM decomposition technique it has broken down ComBear's big picture into sets of lower level (more detailed) requirements descriptions for operations (job, tasks and activities) that need to be performed by that firm. Also key temporal and causal relationships between the decomposed process segments have been explicitly modelled.
- (iii) Multiple value flows have been overlapped onto the big picture of ComBear provided by the EM. This has allowed differentiation between different product classes to be established. Also it has enabled reasoning about alternative flow rates for different value streams and the loads they place on different operational sequences (or process segments).
- (iv) ComBear's EM also provides an overarching structural framework and pool of reusable knowledge and data which supports the design and development of any number of lower level, more focused SMs. In this way the context of simulation modelling is explicitly defined in terms of static requirements and alternative viable resource system candidates.
- (v) The structural framework provided by ComBear's EM is currently being used to organise alternative viable configurations of SMs, so that their combined interoperation and performances (as a configuration of DPUs) can be judged in the light of context dependent and dynamic business and environment requirements faced by ComBear today and possibly into their future.

Because of space limitations and the focus of concerns herein, beneficial use of the CLMs has not really been illustrated in this paper. However significant benefit has been gained by using the EM in combination with various CLMs to (a) consider how changes in product dynamics (e.g. product orders, production volume variation and production mix variation) impact on production system performance requirements, and thereby on human resourcing requirements and (b) as a front end for designing SM experiments, by helping to identify possible control, controlled and likely causal

impacted variables in different ComBear production shops, and thereby enabling the construction of well engineered simulation experiments. The systematic method proposed has many potential uses in Enterprises that are subject to ongoing change in product types and quantities realised. Particularly it can help to avoid inappropriate and risky change engineering such as by supporting: short and medium term planning; production system value and cost analysis; production due date and cost estimation; the management of information about human competences possessed by specific Enterprise; new manufacturing paradigm selection and analytical design; and factory design and investment planning. However within a single paper and for a single case study only limited illustration of these purposes has been possible. Other purposes will be reported in subsequent journal papers.

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Figures



Figure 1: ComBear product samples

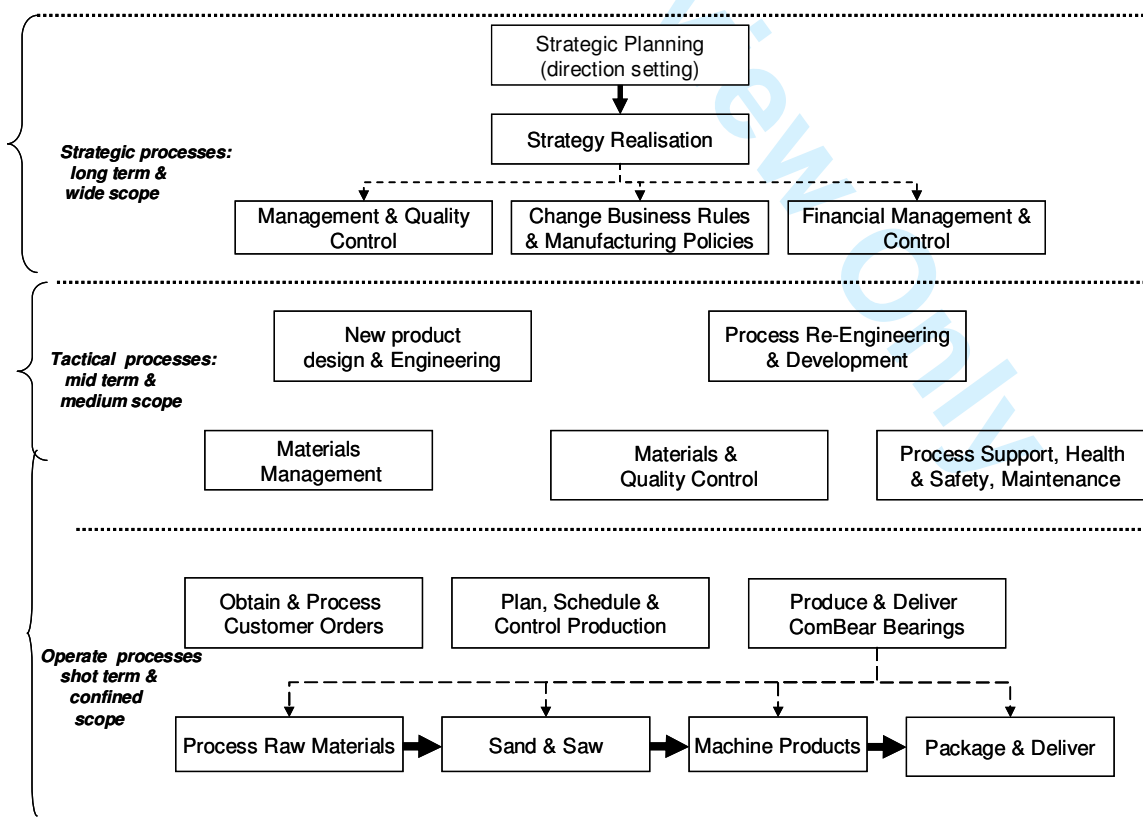


Figure 2: Key Processes identified in ComBear

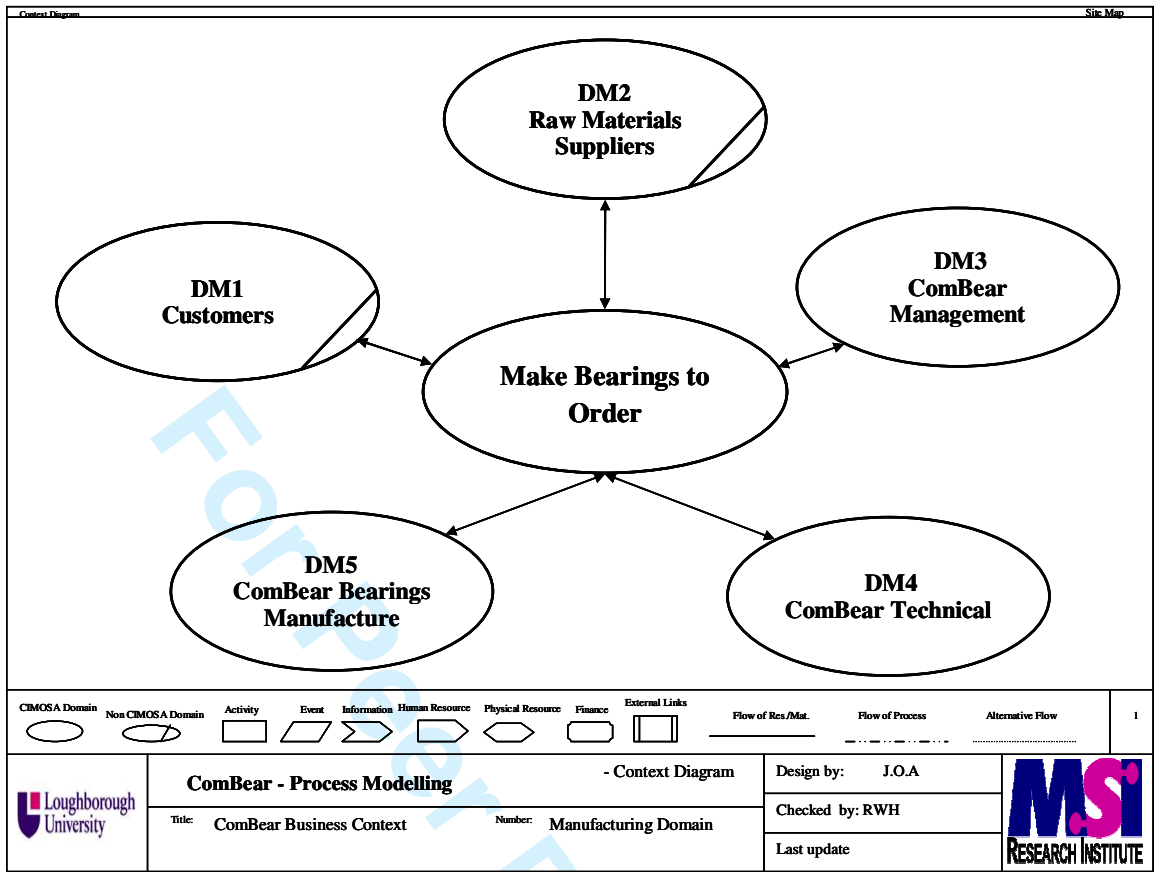


Figure 3: ComBear top-level context diagram

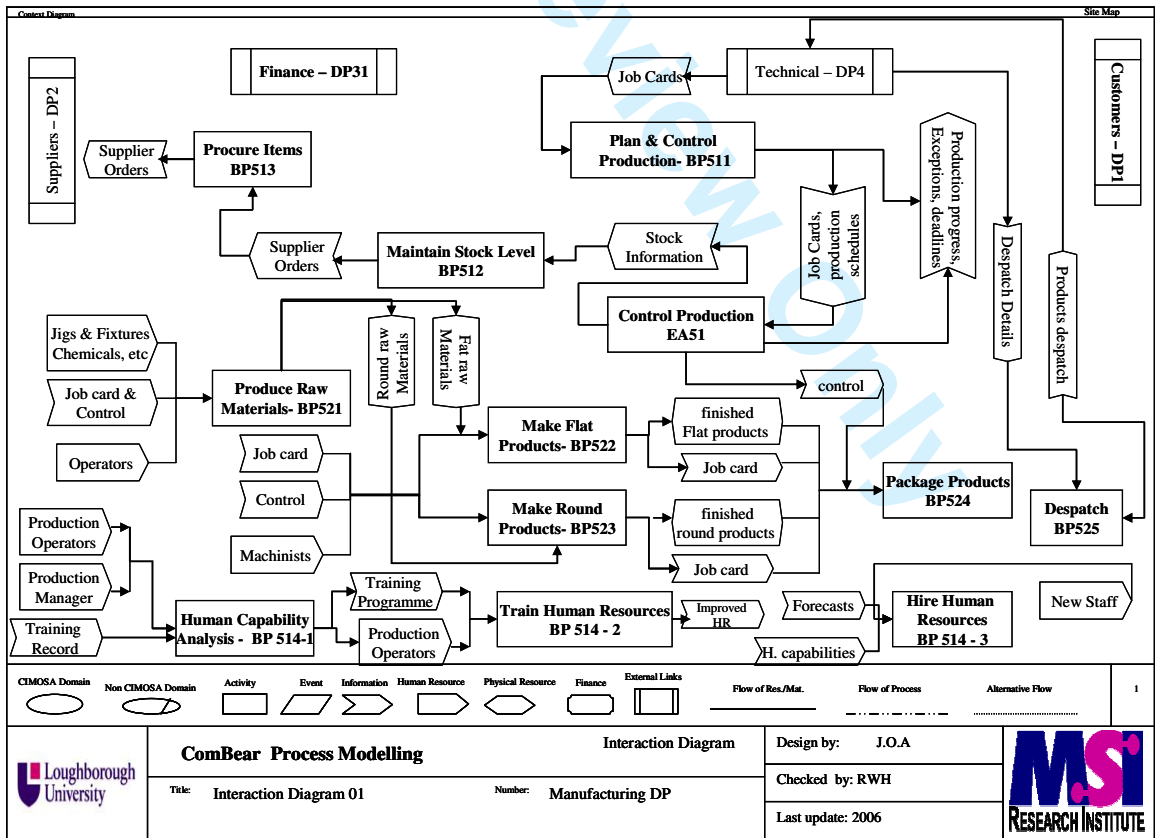


Figure 4: ComBear Interaction Diagram

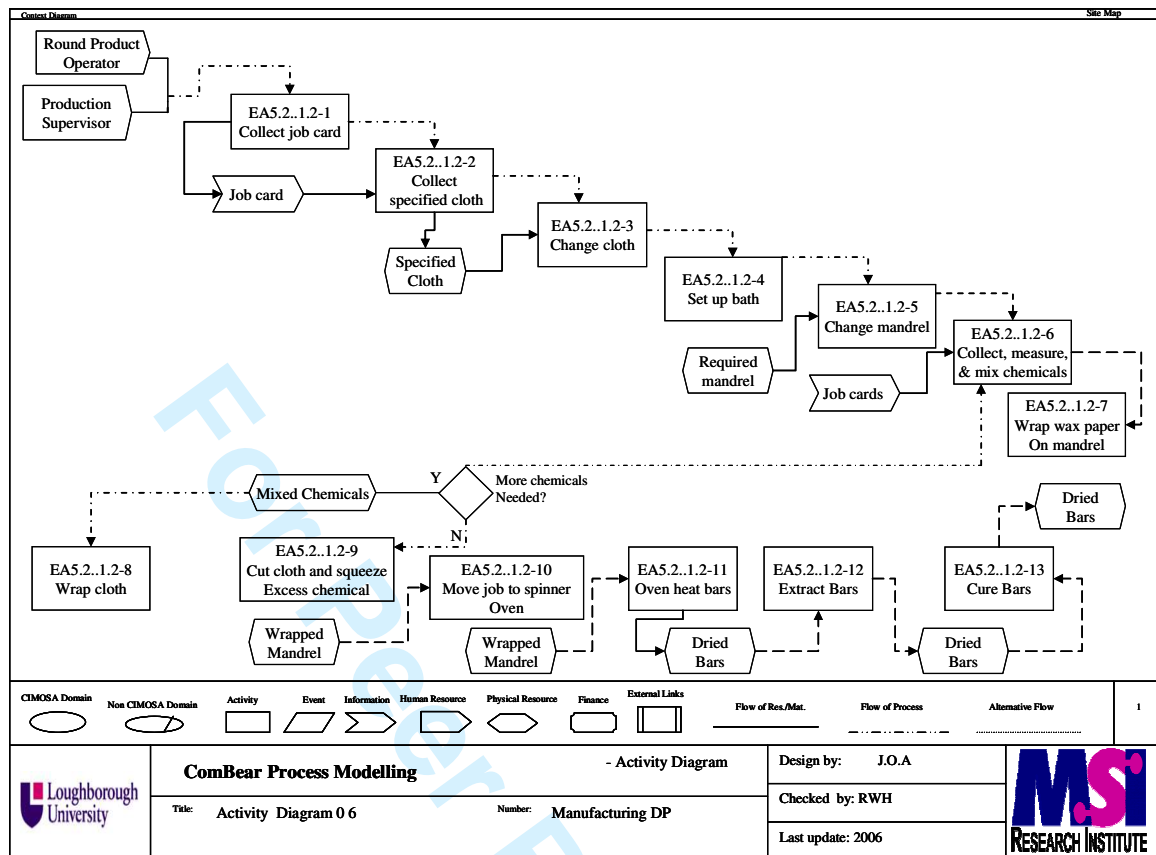


Figure 5: Activity Diagram for making materials for round products

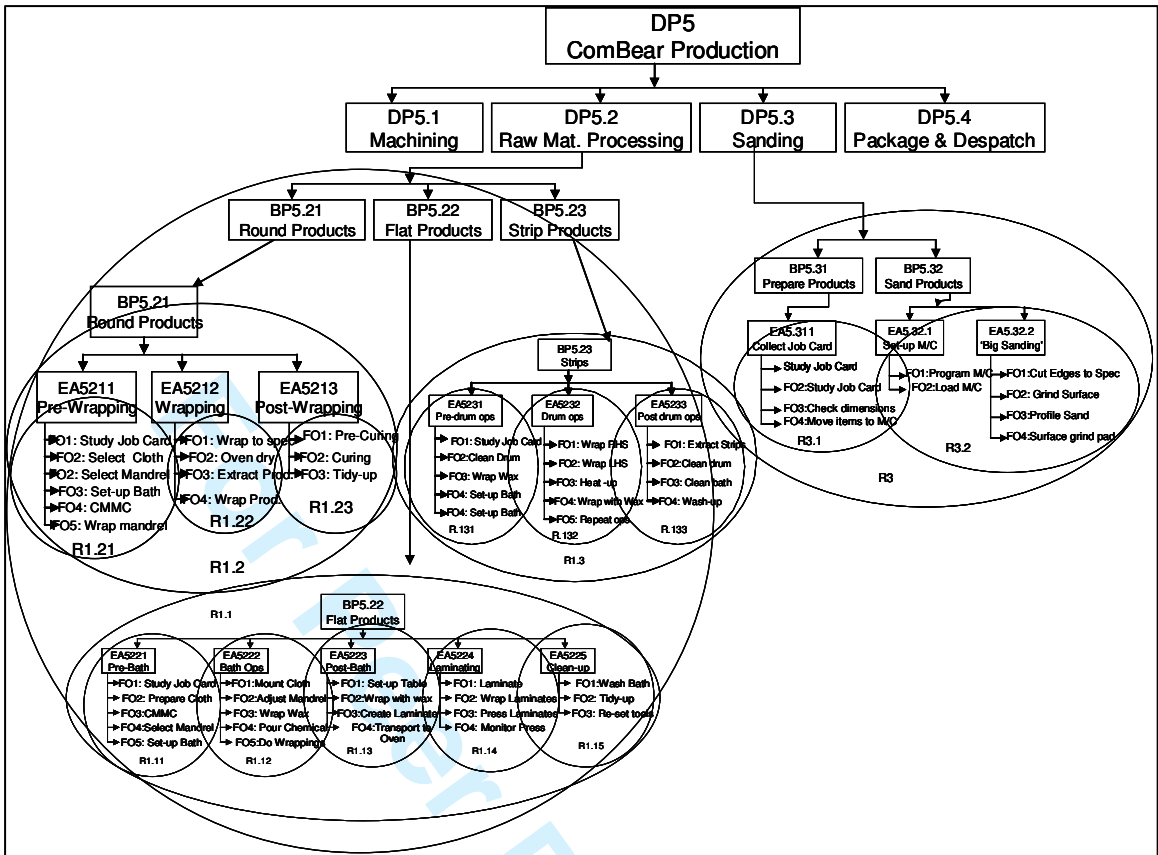


Figure 6: Combined Use of CIMOSA and Role-Modelling Constructs to represent ComBear Processes

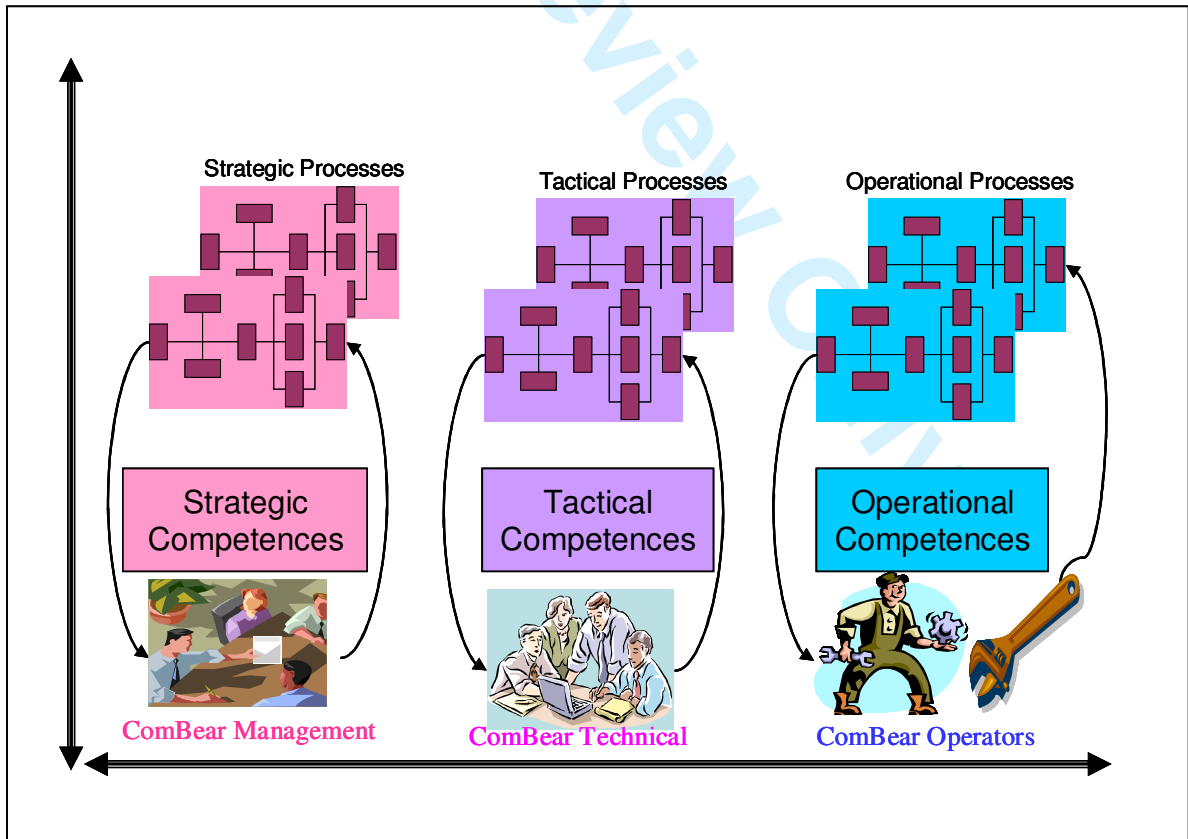


Figure 7: Conceptual representation of required and available competences

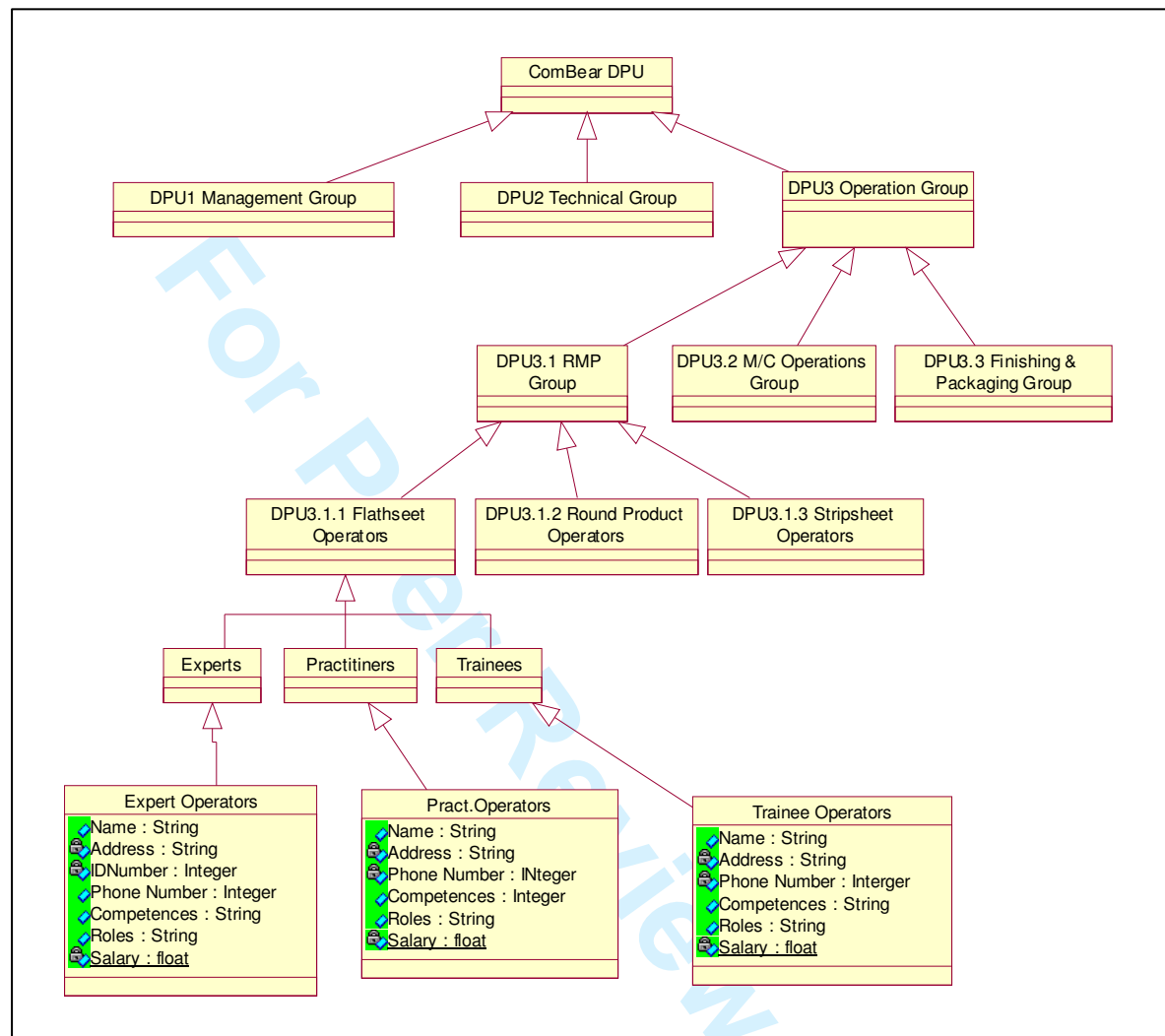


Figure 8: Using UML Constructs to represent ComBear's DPUs

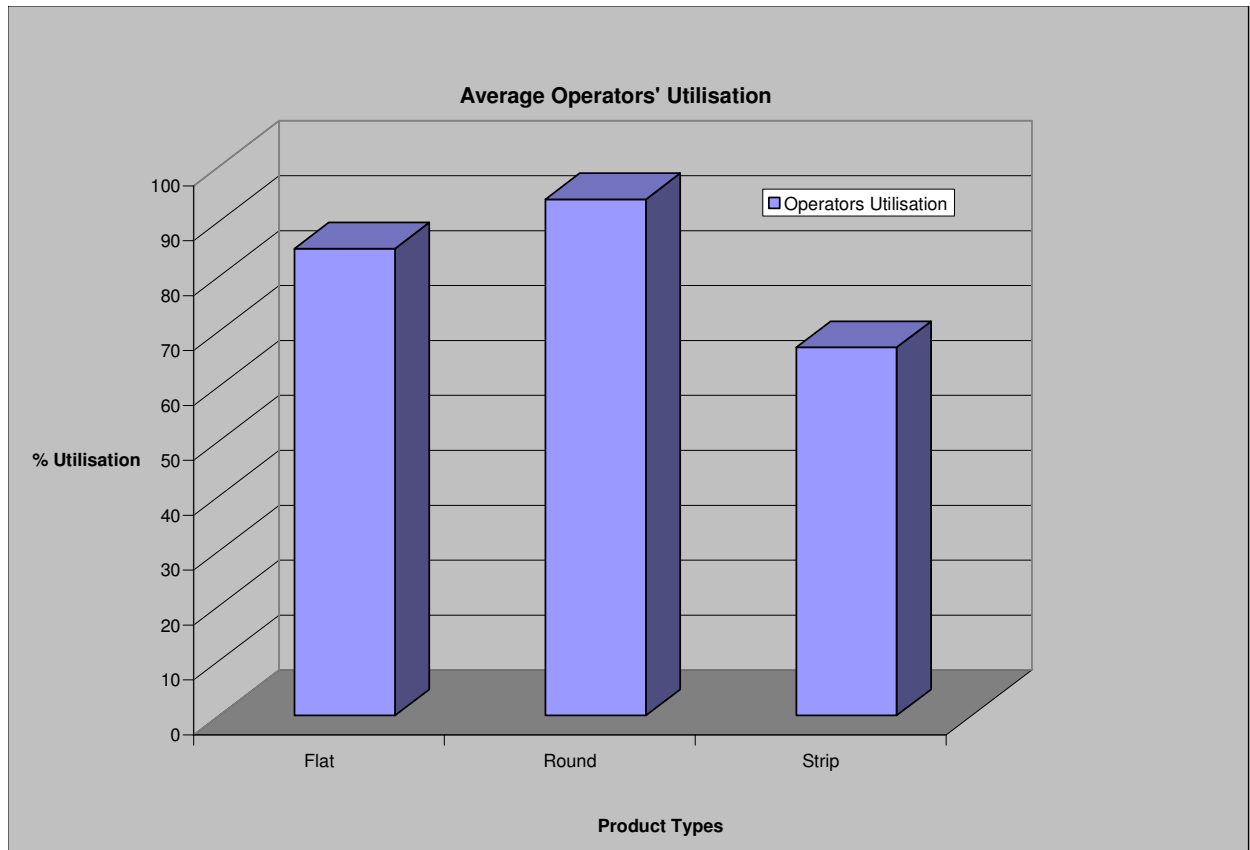


Figure 11: 'AS-IS' Average Operators' utilisation

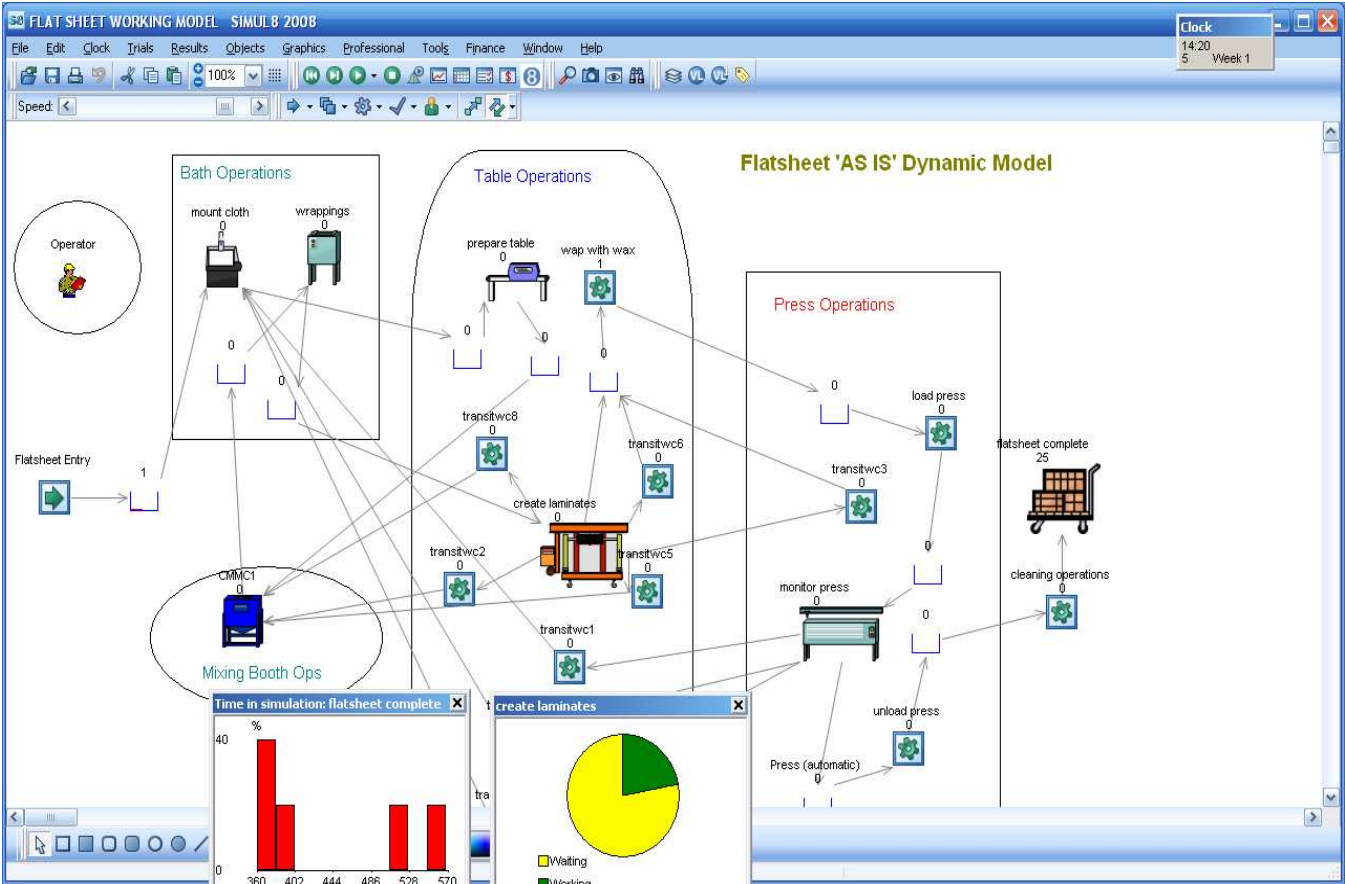


Figure 12: Screen shot of ‘as-is’ flat sheet materials making operations

Tables

Stage	Purpose of each modelling stage and the approach to modelling adopted		Example Entries Modelled
Stage 'Context Modelling'	1:	Enterprise Modelling is used at this stage to decompose and graphically represent relatively enduring aspects of the specific network of Business Processes (BPs) used by the ME under study. Stage 1 modelling is focused on characterising properties of the process logic currently used by the subject ME.	<ul style="list-style-type: none"> • Network of BPs – used to realise products & services. • Segments of the process network – that must be resourced by suitable human (& technical) systems. • Process segments are modelled in terms of activity, information, material, control & exception flows.
Stage 'Role Specification'	2:	Various groupings of enterprise activities (that constitute specific process segments and realise dependencies between process segments) are analysed with respect to their 'functional' & 'behavioural' requirements. Various grouping rules (based on research findings from work design, human science and the process modularisation literature) are used to: identify & specify viable roles & role relationships for human systems.	<ul style="list-style-type: none"> • Required 'functional operations' & 'functional entities'. • Viable role behaviours & role relationships. • Functional & behavioural specifications for viable roles.
Stage 'Shortlisting of Candidate Systems'	3:	A shortlist of candidate (human & technical or DPUs) resource system designs is established in terms of their potential to match: (1) competences & characters possessed by candidate human systems to (2) required functions & behaviours of viable roles & role relationships defined during stage 2.	<ul style="list-style-type: none"> • Relative performance levels & costs of resources are tabulated. • A short list of candidate resource systems – with potential to realise specified roles.
Stage 'Modelling Dynamic Behaviours'	4:	Dynamic behaviour of process segments resourced by viable candidate human systems are modelled using CLM & SM technologies in a unified way. The computer executable SMs so produced reuse specific structures & data about the business content and ME process network defined previously by the EM during stage 1 modelling. Thereby the SMs encode: (1) specific process logic (& embedded role requirements); (2) alternative attributions of short listed resource systems (to embedded roles & roles relationships) & (3) ME specific workflows through viable [process logic – resource systems] couples. The purpose of so doing is to optimise the choice of resource system & methods of achieving workflow control based mainly on cost & lead-time criteria.	<ul style="list-style-type: none"> • Process routes, embedded roles, op times, etc. • Alternative assignments & organisational groupings of human resources to roles. • Work entry points, inter-arrival times, workflow controls. • Relative process segment behaviours.
Stage 'Overall Function & Behaviour Modelling'	5:	The predicted functional & behavioural properties of specific process segment-resource system couples are reviewed with reference to (needed and achievable) overall (functional & behavioural) properties of the ME. Various measures from the literature on process performance & motivation can be utilised.	<ul style="list-style-type: none"> • Comparative quality measures. • Motivational factors and measures. • Overall throughput, value stream & cost measures.

Table 1: The Modelling Stages of the ‘integrated approach to modelling human systems’

Operator's identity	Operations/ Work Centres	Operators Competence Rating			Potential Competence Efficiency(PCE)
		Basic (1)	Practitioners (2)	Experts(3)	
xxxxxxxx	Bath operations & Wrappings			3	$15/18 * 100$ $= 83\%$
	Mixings			3	
	Laminating			3	
	Electric Saw			0	
	100 ton Press			3	
	Tube Extraction			3	

Table 2: An Expert Operator's rating

‘AS-IS’ Scenario				Possible ‘To-Be’ Scenario 1			
Operator Type	Product Types	Average Daily output	Operators Utilisation %	Operator Type	Product Types	Average Daily output	Operators Utilisation %
Average Operators (standard cycle times)	Flat sheets	5	85	Expert Operators (expert cycle times)	Flat sheet	8	100
	Strip sheets	4	67		Strip sheets	7	93
	Round (tubes)	13	94		Round (tubes)	15	100

Table 3: Performance comparison between average and expert operators