12. Coherent Models of Processes and Human Systems

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Enterprise processes are characterised to specify a conceptual model of MEs. The model is developed, with reference to processes classes, resource system types, product flows, and organisational views, so as to exemplify general interoperability needs and to highlight deficiencies in current EM and EI provision. One significant deficiency relates to modelling human resources. Hence ME enhancements are proposed centred on the coherent modeling of human systems and enterprise processes.

1. INTRODUCTION

The need for coherent models of enterprise processes and human resource systems is described with reference to a characterization of processes found in most Manufacturing Enterprises (MEs). Subsequently this characterization is used to identify means of overcoming observed deficiencies in the existing EM (Enterprise Modeling) provision.

2. CHARACTERISATION OF ME PROCESSES

2.1 Definition of Terms

According to Vernadat (1996): "processes represent the flow of control in an enterprise"; they constitute "a sequence of enterprise activities, execution of which is triggered by some event"; "most processes have a supplier of inputs and all have a customer using outputs". Scheer (1992) emphasised the dynamic nature of decision and action making about processes, with respect to (i) the need to transform material (physical) and informational (logical) entities, and (ii) resource allocation and the design of information systems. Processes are a conceptualisation of reality, not reality itself and exist over finite lifetimes; although multiple, similar process instants may be realised (Poli, 1996). Weston (1999) further explained that process models naturally define enterprise activity requirements in a reusable form; and that resource systems are needed to 'realise' those requirements within time, cost, flexibility and robustness constraints.

It follows that resource systems must possess functional abilities needed to realise instances of processes assigned to them. Functional abilities of technical resource systems (i.e. machines and software) are often referred to as 'capabilities'. Whilst functional abilities of human systems (i.e. teams, groups of people or individuals) are normally termed 'competences' (Ajaefobi 2004). Resource system organisation is achieved via both relatively enduring and short-lived structures such as methods, project plans, procedures, product structures, business rules, communication rules, role descriptions, workflow specifications, process routes, work to lists, state transition descriptions and the like.

Significant benefit can be gained by developing and reusing separate models of (1) processes and (2) candidate resource systems, with abilities to realise processes (Vernadat, 1996). Figure 1 conceptualises such a separation which is important in MEs where processes and resource systems often have distinctive life times and change requirements. For example the introduction of a new production philosophy may require a once only restructuring and re-engineering of enterprise activities, but various alternative resource systems may need to be deployed during the useful lifetime of the restructured process.

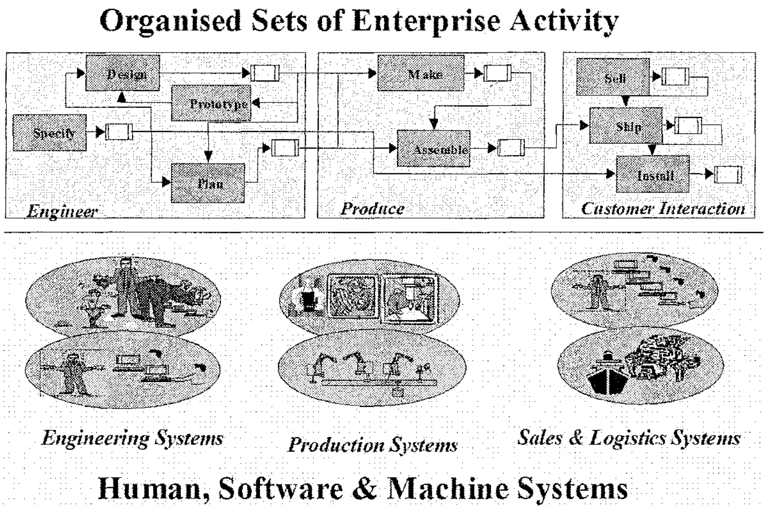

Figure 1 Resourcing Processes in an Engineer-to-Order Manufacturing Enterprise (Source: Weston 2003)

2.2 The Nature of ME Processes and Instances of ME Processes

Figure 2 shows conceptually how many MEs organise product realisation (Weston *et al* 2001). Implicit in this graphical representation are causal dependencies between products realised, processes needed, roles of resource systems and organisational boundaries

Assume that distinctive product families are realised by the alternative process flows depicted (i.e. by sequences of value adding activities) that need to be resourced for finite periods of time as needs for multiple process instants may arise. In a given ME: A1 might be a 'materials procurement' activity; A2 a 'sales order entry' activity; A8 a 'turn shaft' activity; A12 an 'assemble gear' activity; etc. Therefore with respect to individual process flows, opportunities arise to mass produce products, i.e. by involving multiple, sequential instances of the same (or a similar) process flow to produce large numbers of (similar) products. This can give rise to economies of scale, because the elemental activities that constitute a process, and their interrelationships, can over time be developed to (a) be effective and robust and (b) so that optimal resource utilisation can be achieved. It may also prove possible to invoke multiple, sequential instances of a single process flow to realise different batches of customised products, thereby giving rise to both *economies of scope* and *economies of scale*. Economies of scope may arise for similar reasons to those outlined for economies of scale but normally increased process flexibility (in terms of ability to cope with needed variations in product applications) will be needed and this can induce lead-time and cost penalties.

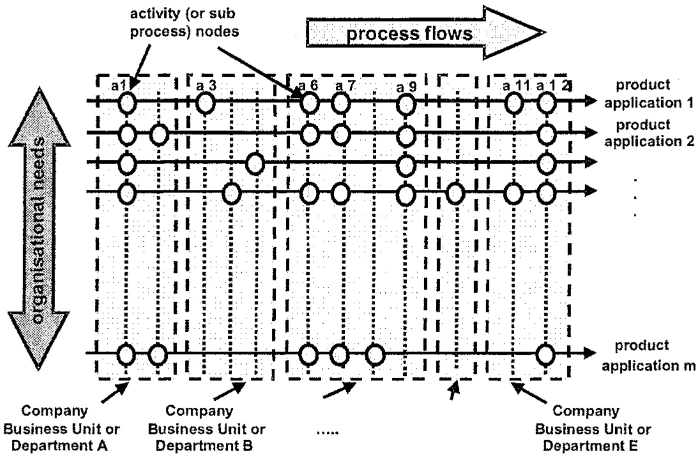

Figure 2 Process and Organisation Streams

Where products have significantly distinctive processing requirements, then distinct process flows may need to be created, also illustrated by Figure 2. New and existing process flows may share common product realising activity, but to meet differing product realisation requirements these activities may need to be linked differently, e.g. via distinctive 'physical flows' (e.g. of materials and products) and 'logical flows' (e.g. of information and control). Essentially this kind of organisation structure is both process and product oriented, so that a variety of product applications can be realised in quantities, and by due dates, required by customers. *Economies of scope* may come primarily from using a common resource set to realise sequential and concurrent instances of multiple process flows; as this increases opportunities to cost-effectively utilise available resource system capacity. But whether it arises in respect of having one or more distinctive process flows the down side is that it introduces organisational concerns: as indicated indirectly in Figure 2 by the introduction of dotted organisational boundaries. Aspects of those organisational concerns are discussed in the following.

We return to the earlier point that the notion of having process flows may constitute no more than abstract thought (Poli 2004). But real physical things (like a person supported by an order entry system; or a combination of machine operator, CNC machine, jigs and fixtures) are needed to do activities. Also real materials, sub products and products require physical movement, whilst logical entities like information need to be processed and physically moved to points of use. The human and technical resources deployed to realise activities must therefore have abilities required to do activities assigned to them. Also they must have the *capacity,* and be *available* and *willing,* to do the activities assigned to them within timeframes over which relevant process stream instances occur (Ajaefobi 2004). Indeed process flow specifications provide a time dependent organisational structure which can be referenced when synchronising individual and group resource behaviours within given time frames.

On considering the need to resource activities related to multiple process flows (and multiple instances of those processes) it becomes clear that some form of organisational boundary may be necessary to manage high levels of operational complexity, and to decide how to make both short and long term changes to processes and product applications. Clearly the size of MEs, product complexity, product variants, product volatility, production numbers, etc will determine how this might best be done, such as by forming company partnerships, business units, departments, manufacturing cells, production lines and so forth. But in general any such boundary is likely to impact (mainly for social but also for technical reasons) on process lead-times, costs, flexibility and robustness.

In many MEs a functional organisational paradigm is deployed, where cognate resource capabilities are grouped and assigned to similar activities. For example a sales office will be able to develop relevant (I) functional capabilities with regard to the human and technical resources it owns and (II) structural/organisational capabilities, in respect to the way in which it deploys its resources. By such means, for example, it will be able to schedule and seek to optimise the use of the resources it owns, so as to contribute collaboratively along with other organisational units to the execution of one or more process streams that constitute a specific ME.

Figure 2 is a simplification of the reality in actual MEs, but it does show process thinking in action: such as by conceptually defining how value is added by activities and providing a framework on which to 'anchor' specifications about needed resource capabilities, capacities and availabilities, as well as synchronisation needs, and related resource behaviours. Further cost, lead-time and other metrics can be attributed to process and product flows so as to calculate and predict revenues, etc. This in turn can lead to resource costing and efficiency calculations and help apportion appropriate budgets, costs and rewards to organisational units, or even individuals.

Over many decades the established process industry sector (populated for example by steel, petrochemical and pharmaceutical companies) has commonly organised its product realisation in a fashion characterised by Figure 2. In fact commonly they have done this from both 'logical' and 'physical' standpoints70: primarily because in this industry relatively large quantities of product need to be realised, with relatively little variation over relatively long time frames. In such a case it is appropriate to physically organise resource systems along process-oriented lines, as it can lead to robust, high quality, cost effective and short lead-time production and can much simplify organisational concerns. But intuitively one might expect that this kind of physical resource organisation can only be competitively applied where product variety and product volatility is relatively low.

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[70] Here distinction is made between 'conceptualised' and 'physically realised' aspects, because in general ME processes and their underpinning resources may not adhere to both of these viewpoints.

Historically most (but by no means all) other industry sectors have preferred to physically organise their resources in (cognate) functional groupings, such as in engineering, financial, sales, machining, assembly, testing, packaging departments, sections, sub groups and teams. Despite this fact, recent literature reports how many (if not most) industries have become aware about potential benefits from process thinking. These benefits arise because a 'logical overlay' of product and process streams can be conceived, designed and mapped onto functionally organised groups of physical resources (be they people or machines). In fact the time-dependant usage of resources can then be driven largely by a logical overlay of control, data and material flows (conveyed by process thinking) despite actual resources being physically located into cognate functional groupings.

Naturally one might expect the choice of physical organisational structures in a specific ME to be influenced by (a) the stability, longevity, complexity, variability and robustness of the products and services currently realised and (b) the product and service realisation processes the ME has chosen to deploy to achieve product and service realisation. Such a theoretical stance is taken here because it is presumed that these (and possibly other) key factors will impact upon the rate at which existing and new processes need to (or have ability to) start and end, be resourced by suitable systems and be managed, maintained and changed (i.e. be reconfigured, improved, developed and/or replaced). Bearing these kinds of organisational concerns in mind, the next sub section brings out distinctions between common types of process found in MEs.

2.3 Common ME Process Types

A number of authors have classified ME processes. Table 1 compares and contrasts three such classifications developed independently by Salvendy (1992), Pandya *et al* (1997) and Chatha (2004). All three describe ME processes at a high level of abstraction.

Contrast for example MEs making computer products as opposed to MEs making roller bearing products. Clearly specific properties of instances of 'product development' and 'order fulfilment' processes needed to realise bearings will be very different to instances of the same process type used to produce computers. Whereas both ME types may usefully deploy fairly similar instances of 'business planning', 'obtain an order', and 'information management processes'. It should also be noted that the manufacturing strategies adopted by MEs will influence the nature of dependencies between process classes. For example a Make to Stock (MTS) ME is likely to have well decoupled instances of 'obtain an order', 'order fulfilment' and 'product and service development processes', each having different start times, cycle times, frequency of occurrence, etc. Whereas Engineer to Order (ETO) MEs will require occurrences of these three process types to be well synchronised.

It follows therefore that process type descriptions listed in Table 1 enable similarities and differences to be drawn between MEs. However all MEs are unique in that they:

- differently decompose process segments into organisational units
- resource processes and process segments differently

- have very different numbers and patterns of process instances, so that they can: realise large or small batches of products for customers; achieve lean, as opposed to agile manufacturing; and so forth.

Another important observation that can be drawn with reference to Table 1 is that 'operational processes' comprise those activities that should be repeated to realise products and services for customers. Whereas 'strategic processes' and 'tactical processes' should collectively ensure that all needed operational processes are specified, designed, implemented, resourced, managed, monitored, maintained, developed and changed through their lifetime, such that they continue to realise products and services of quality, on time and at an appropriate price for customers; whilst also ensuring that the ME achieves its defined purposes for stakeholders.

Table 1- Common ME Process Type Descriptions – from various authors

<table>
<tr><th>Salvendy (1992) Process Classification</th><th>Pandya et al (1997) Process Classification</th><th>Chatha (2004) Process and Activity Classification</th></tr>
<tr><td>Strategy Making Process</td><td rowspan="4">Generic Management Process Group, includes:

'Direction setting process'
'Business planning process'
'Direct business process'</td><td rowspan="2">Strategic Process: predominantly "what activities": that decide what the ME should do and develop business goals and plans to achieve the ME purposes defined</td></tr>
<tr><td rowspan="2">Product Planning & Development Process</td></tr>
<tr><td rowspan="3">Tactical Process: predominantly 'how activities': that decide how segments of the business plan might best be achieved and as required specifying, designing, developing new products, processes & systems with ability to achieve business plans.</td></tr>
<tr><td rowspan="3">Manufacturing Support Process</td></tr>
<tr><td rowspan="3">Generic Operate Process Group, includes:

'Obtain an order process'
'Product and service development process'
'Order fulfilment process'
'Support fulfilment process'</td></tr>
<tr><td rowspan="2">Operational Process: predominantly 'do activities' that repetitively create products and services for customers, and thereby realise business objectives and goals</td></tr>
<tr><td>Production Operation Process</td></tr>
<tr><td></td><td>Generic Support Process Group, includes:

'Human resource management process'
'Financial management process'
'Information management process'
'Marketing process'
'Technology management process'</td><td></td></tr>
</table>

Pandya *et al*'s (1997) process classification separates out a support process group, that is 'infrastructural' in nature, i.e. the purpose of this support group is to enable other process groups, rather than control or directly contribute to strategy, process, system, product or service realisation. Such a conceptual separation promotes separated execution and (re-)engineering of processes over appropriate timeframes.

Many similar, concurrent and/or sequential, instances of processes within Pandya (1997) 'generic operate group' may be required to satisfy customer demands. However the adoption of alternative manufacturing policies (such as 'make to stock', rather than 'assemble to order') and the deployment of different scheduling policies and resource configurations (such as by deploying 'synchronous dedicated production lines' as opposed to 'flexible manufacturing cells') will determine the frequency with which these processes must repeat and the variance needed between process instants so that necessary product customisation can be realised. As mentioned previously though, if similar process instances frequently occur then increased opportunity arises to continuously improve process repeatability, robustness and utilisation of resources which in turn can improve product quality, cost and lead-times. Also if the variance between process instants is well understood, and many process instants are likely to arise, then it may become appropriate to automate some (or even all) of the enterprise activities that constitute the process.

In most, possibly all MEs, it is probable that processes within Pandya *et al*'s (1997) 'generic management group' will not repeat often and will have significant variance between process instants. Indeed typically these process instants define and realise strategy making and tactical changes on project by project basis. 'Direction setting' and 'business planning' process instants may repeat annually (or possibly episodically in response to a new business threat or opportunity) but generally their constituent activities will require insight, analysis, prediction and innovative human-centred thought with respect to a new set of circumstances. Consequently opportunities to automate or continuously improve direction setting and business planning processes may not occur. Rather it will be important to ensure that the purpose, overall structural decomposition and means of managing these process types is well defined and possibly even more importantly that competent people (and teams) with sufficient motivation and time, are assigned suitable roles for enterprise activities that comprise generic management process instants. It is probable, for example, that only large-grained enterprise activity definitions can be specified and deployed, in relation to process instants of this type, and that the realisation of some of these activities will require the invocation of various 'child process instants' to which suitable human and technical resources are assigned. It follows that processes within the 'generic management group' may be recursive in nature, in as much that instances of high level processes may invoke multiple reporting instances of lower level process, but that outputs from these lower level process instances may significantly impact on the flow of higher level process instants.

In most MEs, except probably for 'technology management' process instants, instants of Pandya *et al*'s (1997) 'support process group' are likely to occur with predictable frequency and variance; albeit that they may require complex decision making and access to different data sets. Consequently multiple instants of these processes may best be realised by competent and capable resource systems comprising people whose activities are well structured by group productivity tools and well supported by personal productivity tools. Further, and possibly except for the 'technology management' process instants, support processes can be continuously improved so that they become robust, even standard.

2.4 The Need for Change Processes

Implicit within foregoing discussion is the notion that realising any change to ME processes and resource systems itself requires a process, i.e. a set of enterprise engineering activities that add value to the ME and need to be resourced by suitable human and technical resource systems. Such a *change process* can take many forms but many instants of change processes will be needed during the lifetime of any specific ME: because the environment in which it operates will change and because it will need to change itself to continue to operate competitively. At one extreme a complex change process may be needed following a merger or acquisition, which may comprise many lower level change processes, each comprising organised sets of enterprise activities. At another extreme a change process may be required to: program a production machine so that it can machine a new product; set up a production facility, so that it can manufacture a different batch of products; or deal with a known exception type and condition, e.g. as a customer modifies an order. Thus instances of change processes will range significantly as they may require large-scale, complex programmes, projects, processes and resource systems or alternatively, simple and predictable processes and resource systems. This is as one might expect because instances of all classes of process illustrated by Table 1 may need to be changed during the lifetime of MEs. We can deduce that change processes need to re-engineer fragments (or all) of MEs for some purpose and that in so doing they will require suitable: (1) change actors operating as part of an underpinning resource system and (2) models of the ME, focused primarily on issues of concern to the change actors used to realise change processes. However notwithstanding the specific aspects of concern that need to be modelled, it is important that these sub-models be appropriately positioned within the specific ME context, otherwise the changes specified, designed, implemented and maintained may not suit their intended purpose. Bearing in mind the forgoing observations about common ME process types, and the need for various change processes, in the next section common enterprise modelling and integration requirements are considered.

3. IMPLIED EM, EI AND INTEROPERABILITY REQUIREMENT

Previous sections characterise MEs from a process oriented viewpoint. However necessarily the discussion considered other viewpoints, including resource system, product flow, organisation and lifecycle views. Multi-perspective considerations were needed to cater for the high levels of complexity involved. The use of decomposition techniques and multi-perspectives is a common practice in MEs; as means of simplifying problem understanding and solution generation. Figure 3 has been constructed to illustrate common perspectives and decompositions deployed.

A process-oriented perspective usefully segments concerns about what the ME should do, by when. Day-to-day processes should add value (to materials, components and systems received from suppliers) in order to generate products and services for customers and benefits and profits for stakeholders. Whilst strategic and tactical processes should periodically plan, manage and support product and service realisation so as to renew the MEs purpose, structures, composition and behaviours over time. Such a process decomposition enables common understandings to be conceptualised and shared but as explained in section 2, in reality causal dependencies exist between process segments which will be ME specific and much complicate process interoperation and ongoing ME development and change.

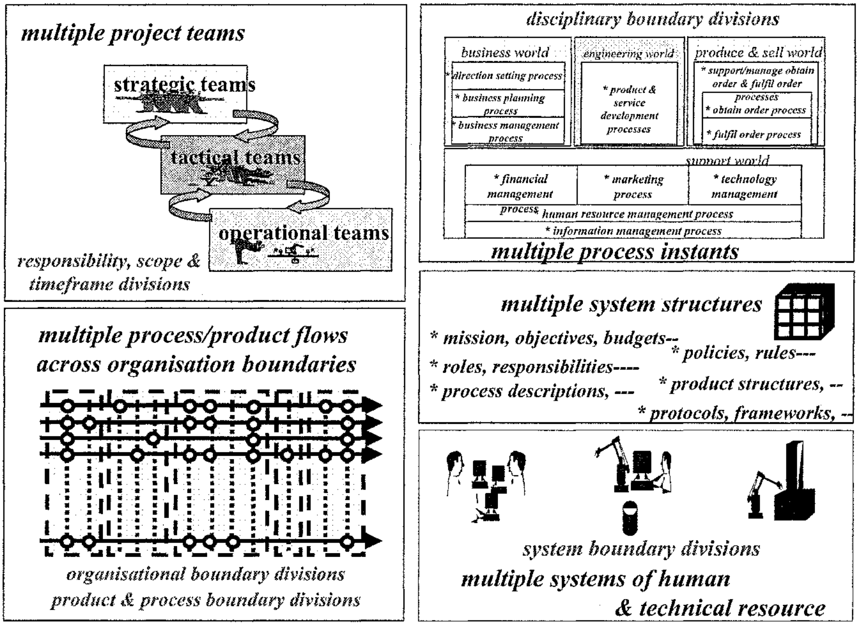

Figure 3 Conceptual Need for Integration (& Inter-Working) Across Multiple Boundaries

The reality is that various system structures need to be deployed to ensure that (human and technical) resource systems realise all ME activity requirements effectively and on time. In specific MEs structural decompositions can take various forms. Some structural elements may be: implicit within an organisational culture; be implicitly imported as part of a technical system (such as an ERP package); or be explicitly defined as part of a role, rule or procedure. The result of deploying various combinations of structural elements should be that those resources selected and assigned to enterprise activities should interoperate to realise ME goals and objectives, over both short and long time frames. It is important to stress once more the high levels of complexity involved here, one dimension of which is illustrated by the product decomposition in Figure 3. Section 2 explained the need to share a finite set of resource systems, so as to realise economies of scale and scope. It also described a common need for additional organisational decompositions to cope with product, process and system complexity and change, such as by overlaying departmental, business and company boundaries or by deploying project based organisational structures and teams.

Much of the complexity and change issues discussed in the foregoing can lie within the scope and control of a specific ME. However other issues do not. Clearly MEs must also suitably fit their environmental context which itself will change; possibly because of competitor, customer, supplier, stakeholder, legislative or political actions. Hence strategic and tactical processes and resource systems (such as teams) must operate accordingly. One general set of tactical problems can arise because proprietary technical resource systems may not readily or adequately interoperate with existing (legacy) technical systems to enable and support appropriate interoperation of human resources. To date much of the focus of the IT community has centred on: overcoming technical systems interoperation problems faced by industry; or alleviating some of those problems by improving upon the *status quo* in terms of technical system decomposition and implementations.

The author observes that the general enterprise integration (EI) and interoperation problem is extremely complex, and is far more complex than simply realising technical systems interoperation. Rather as illustrated by Figure 3, in reality also required is: process interoperation; product integration; human (including team) systems interoperation; and structural and organisational integration. Further that interoperation needs to be developed, maintained and changed through the lifetime of specific MEs as they interoperate with other MEs and complex systems in their specific environment.

It follows, with respect to interoperation in MEs, that enterprise modelling (EM) and enterprise integration (EI) methodologies and technologies have a key role to play, now and in the future. In principle EM can be used to specify how needed multi-perspective interoperation can be realised, and can be used to determine and formally document improved decompositions (in both performance and reuse terms). Also EI technologies can provide needed underpinning distribution, communication, and information and knowledge sharing mechanisms, organised into various forms that provide reusable infrastructural services.

From experience of modelling various ME process types, with reference to Figure 3 the author observes certain limitations of state of the EM and EI. Current EM methods do provide a plethora of multi-perspective modelling concepts but currently they do not adequately support the reuse of models of (i) functional, behavioural and structural aspects of human systems, (ii) causal dependencies between multiple processes and (iii) products and product instances, and organisational boundaries, and their mapping onto multiple process instants. It follows that improved EM tools are required to support the lifecycle engineering of multiple processes and associated product and resource systems; particularly with respect to enabling context dependent simulation and model enactment. The capabilities of current EI technologies have also advanced significantly in recent decades. However improved concepts, methods, architectures and tools are still needed to (1) facilitate component-based enterprise engineering and (2) enable the development of much improved infrastructural support (e.g. knowledge management, human resource management, technology management and financial management support services).

4. ON MODELLING HUMAN SYSTEMS

4.1 The Need to Model Human Systems

People are the prime resource of any ME. It is people who determine the ME's purpose, goals and objectives. It is people who conceive ME products and services and decide what, how and when product and service realising processes and systems should be deployed. People also make decisions and do many of the activities needed to realise products and services in conformance with plans. Therefore it is vital that the interoperation of ME personnel is suitably systemised and co-ordinated.

Different enterprises will vary significantly in the number of people they deploy and the roles those people play but the need for their systematic and co-ordinated working transcends the vast number of ME instances in operation globally. The high levels of complexity involved in satisfying this need necessitates the use of systemic problem decomposition, so that well structured solution realisation can be achieved. But that systemisation must be cognitive of factors that impact on people motivation, innovation and the like. Co-ordination is needed because of the time invariant nature of ME activities and the need to for interoperability amongst many resource systems used to realise ME activities. Some MEs and their operating environments may be subject to frequent change, e.g. to products and product realising processes. This in turn can require frequent change to the assignment of people roles, and dependencies between people roles.

Evidently therefore there is a general requirement within MEs to develop models of human resource systems (be they models of individuals, groups of people or teams of people) so that they can be used coherently in conjunction with developed models of ME processes to specify, implement and maintain timely and cost effective interworking of human resources through the lifetime of specific MEs. However, it is known that developing general purpose models of people (and systems of people) *per se* is impossible to achieve. Consequently before embarking on such a task the purpose for which human resource models will be used needs to be well specified; and even then it is understood that care needs to be exercised in respect to the use of derived models because of complex behavioural, motivational and cultural factors that impact on humans in the workplace.

4.2 Common Uses and Needed Attributes of Human System Models

Kosanke (2003) and Noran (2003) argue that in spite of progress made by ISO, IEC and CEN in regard to Enterprise Modelling (EM) more work is needed; especially on human related aspects like model representation of human roles, skills and their organisational authorities and responsibilities. With a view to addressing this need, Weston *et al* (2001), Ajaefobi and Weston (2003) and Ajaefobi (2004) built upon findings from previous human systems modelling studies to determine ways of classifying and modelling human competencies, (workload) capacities and the assignment of human roles and responsibilities. Bearing in mind the need to utilise human systems to resource multiple, dependent instances of the ME process types characterised by Table 1, the following generic modelling requirements were observed:

- Enterprise Activities (EAs) need to be modelled in the context in which they are to be realised, thereby providing a formal description of key structural and co-ordination aspects of processes that can readily be overlaid onto candidate human systems that need to interoperate with other enterprise resource systems to realise defined goals.
- Models of enterprise activities need to be explicitly characterised in terms of competency, capability and capacity requirements that must be satisfied by candidate systems of (human and technical) resource.
- Candidate human systems need to be modelled with respect to their potential to bring to bear competency types and competency attributes that suitably match activity requirements.
- Both long lived (static) and short lived (dynamic) structural aspects of human systems need to be modelled, including descriptions of: functional roles and responsibilities for groups of enterprise activities; and related causal dependencies between activity groupings and their associated information, material, product and control flows.
- Key behavioural aspects (such as reachable states and state transitions and associated performance levels) of unified process and human system models need to be usefully represented so that the operation and interoperation of candidate human and technical resource systems can be: simulated, and their performance predicted with respect to lead-time, cost and robustness; and enacted, via the use of suitable workflow technology.

Thus the need for separate but coherent models of context dependent processes and candidate human systems was observed as being needed to realise the following benefits:

- Ability in a given ME context to choose between alternative candidate human systems that satisfy requirements of activities (individual or grouped) from a functional viewpoint, namely in terms of their relative (a) competencies and (b) workload capacities.
- A systemic facilitation of process design, redesign and ongoing improvement (with reference to suitable candidate human systems) either at process, sub process or activity levels of granularity based on dual criteria of (a) performance lead times and (b) labour costs.
- The systemic attribution of values (e.g. as part of a knowledge capitalisation project) to processes and their elemental activities; here capital value can be placed upon human and structural assets of an enterprise by attributing to them (1) competency, capacity and structural attributes of assigned human systems and (2) appropriate business metrics.

4.3 Enhanced MPM Enabled Modelling of Human Systems

Suitable means of realising the modelling requirements described in 3.2 needed to be determined. Here the Multi-Process Modelling (MPM) method (Monfared *et al*, 2002) and its EM constructs and tools was selected as a baseline. MPM itself extends the use of CIMOSA modelling constructs and targets CIMOSA model enactment on (1) dynamic systems modelling and simulation and (2) workflow modelling, control and management. However by developing and incorporating into MPM a suitable set of human systems modelling tools an Enhanced Multi-Process

Modelling (Enhanced MPM) method was created and its development is reported in the PhD thesis of Ajaefobi (2004).

'Enhanced MPM' development centred on conceiving and testing a generalised methodology for selecting from amongst candidate human systems (namely individuals, groups of people and teams possibly supported by technical system elements); such that selected systems possess needed abilities to realise specific cases of the process types described in section 2. Here it was presumed that an initial match should be made between (i) *competency requirements* (identified as being necessary to realise a specific process and its elemental activities) and (ii) *competencies possessed* by alternative human systems. It was also presumed that a secondary matching would be necessary between (a) *capacity requirements* (identified in respect of specific processes) and (b) *capacity availability* vested in alternative human systems. Here it was understood that more than one viable candidate human system might possess competencies needed (to realise a specific enterprise activity or group of enterprise activities) but that the achievable performance of viable alternatives might differ significantly and/or they may vary significantly in their susceptibility to mental and/or physical workload stressors.

If those presumptions hold true then implicitly there is a need to achieve both a static and dynamic match between coherent models of processes and human systems. Here static competency matching should enable selection on the basis of relatively enduring abilities of candidates, which might be 'functional', 'behavioural' or 'organisational' in nature. Whereas the time variant (dynamic) nature of processes, process instants and process loading (in terms of product flows, information flows and the like) will in general impose workload variations on viable candidates (who pass static matching criteria) and their relative ability to cope with predicted load variations should usefully inform human system selection; as this choice could have process performance implications, e.g. on process lead-times, cost, repeatability, robustness and flexibility.

Hence to facilitate 'Enhanced MPM' development a set of generic and semi-generic 'competency', 'performance' and 'workload' modelling constructs was defined that can coherently be attributed to static and dynamic models of enterprise processes and candidate human (resource) systems. Figure 4 shows conceptually how such an attribution was designed to semantically enrich process and resource system models, related properties of which can be analysed to achieve static and dynamic matching of human systems to specified segments of processes. Thereby process costs, lead-times, etc, can be predicted before actual processes and process instants are implemented and run (so as to avoid future process loading problems. Further it was intended that the semantically enriched process and human resource system models would be mapped onto computer executable workflow models (run in proprietary workflow management tools) so as to support aspects of workflow design, execution and performance monitoring.

It was observed that competencies of human systems can be modelled at alternative levels of 'genericity', namely by defining: (1) generic competency classes pertaining to different process types discussed in Chapter 2; (2) semi-generic competency types, pertaining to common functional, behavioural or organisational competencies needed by processes operating in different domains (such as sales order processing, product engineering, manufacturing, logistical and project engineering domains); and (3) particular (functional, behavioural and organisational) competencies needed in respect of specific processes and process instants. To facilitate the application of Enhanced MPM, generic competency classes were defined to enable their use as reference models which can be particularised (in domain or specific cases) and incorporated into semantically enriched process and resource system models. Table 2 lists four generic competency classes so defined. This table also shows three generic performance classifications developed, which can also be particularised and attributed to (domain and specific) process and resource models. The use of these generic performance classes has proven useful in industrial case testing and has supported the second stage human systems selection, where process behaviours and performance are predicted should alternative viable human resource systems be deployed.

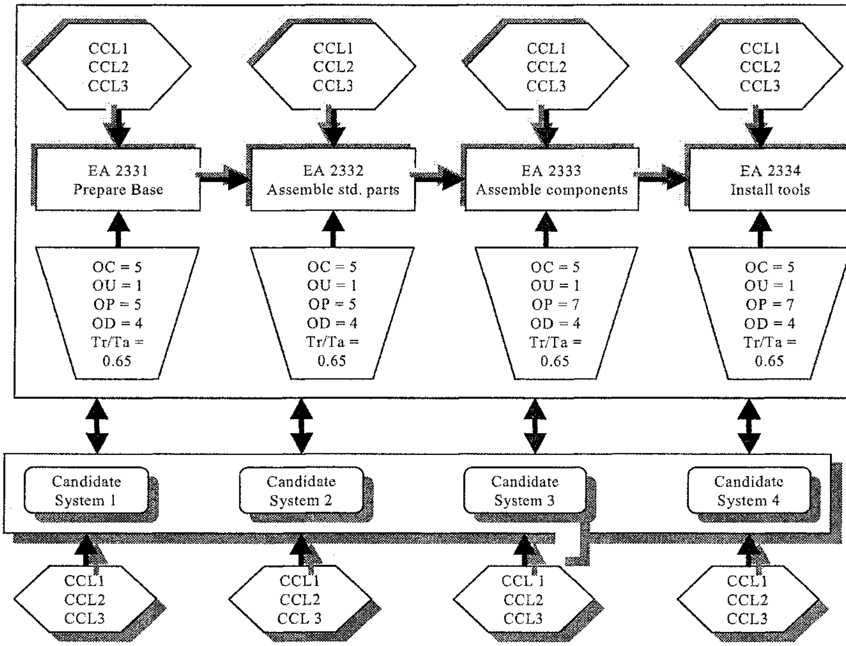

Figure 4 Example *Semantically Enriched Process Model Segment*

Existing human factors literature on workload stresses was reviewed to determine suitable means of modelling capacity attributes of processes and human (resource) systems. Here, in relation to human executors, it was observed that enterprise activities can generally be associated with some prerequisite level of workload that must be satisfied to guarantee adequate performance.

Workload was also observed to be multifaceted, involving mental, physical and organisational aspects. Because industry research sponsor interest was so oriented, emphasis during Enhanced MPM development was on mental aspects of workload. Another simplifying assumption made was that workload stressors lead mainly to two dimensional effects on people (assigned to execute enterprise activities); namely in terms of time stress and sensory modalities/effectors. The PhD thesis of Ajaefobi

(2004) describes the rationale, development and initial testing of Enhanced MPM workload modelling, while Table 2 lists some of the workload modelling construct conceived that were found to be particularly useful in support of human systems selection and process behaviours and performance prediction.

Table 2 Example Enhanced MPM constructs defined and used to match human systems to enterprise processes and to predict process performance

Generic Competency Classes (used as a reference)	Generic Performance Classes (used as a reference)	Mental Workload Modelling Constructs (common constructs used during Enhanced MPM simulation modelling)
CCL1: Competency to execute defined set of general operations based on specified methods, procedures and order. Here activities are essentially routine and results are predictable.	Level 1: People at this level are generally competent and active so they achieve satisfactory quality and timeliness of performance but have low degree of autonomy, low level of flexibility and are not conversant with the operational environment.	Operation Criticality (OC) Operational Uncertainty (OU) Operation Precision (OP) Time Ration (Tr/Ta): where Tr is the time required and TA is the time available. Auditory Demand (AD) Visual Demand (VD) Cognitive Demand (CD) Psychomotor Demand (PD) Note: During Enhanced MPM simulations, typically these constructs are assigned integer values in the range 1 (low) to 7 (high).
CCL2: Competency to understand, interpret and implement concepts, designs, and operation plans linked to specific product realization and to apply them in solving practical problems e.g. system installation, operation and maintenance.	Level 2: People at this level are competent, resourceful, 'reflective', with a higher degree of autonomy and flexibility and hence can do things alternatively if need be. Further more, they are amiliar with tools, operating procedures, and technology and therefore can be trusted to deliver expected output even under critical situation.	
CCL3: Competency needed to translate abstract concepts into shared realities in the form of product designs, process specifications, operation procedures, budgeting and resource specifications	Level 3: People at this level have versatile experience and consequently are very proactive, innovative and creative. They have long outstanding years of confirmed experiences in solving problems in their areas and therefore can predict and effectively manage system behaviours in their area of expertise.	
CCL4: Competency needed to formulating high level business goals, mission, policies, strategies and innovative ideas		

During subsequent simulation studies it was observed that an ordinal scale of 1 to 7 can usefully quantify those workflow constructs attributed. Also usefully incorporated into human systems selection methods has been sensory modality conflict theory of North *et al* (1989) and visual, auditory, cognitive and psychomotor (VACP) workload models proposed by Aldrich *et al* (1989).

The human resource modelling constructs developed to underpin the realisation of Enhanced MPM methodologies can also be used to formally describe important organisationally related attributes of human systems. For example 'role' modelling constructs have been defined to explicitly attribute to human systems, various responsibilities for process segments and process instants. By combining role and process definitions, key structural aspects of human systems can be formally specified from both individual and collective viewpoints.

Another thread of ongoing MSI research into human systems modelling concerns that of modelling behavioural competencies of human systems, and more particularly formally describing, predicting and monitoring key aspects of 'team member selection' and 'team working development'. Here it was observed that improved synergy and performance in teams is key in many MEs and commonly emerges from behavioural interaction between team members. Often also this behavioural interaction occurs in parallel with task execution, and constitutes a reflective process that leads to (a) improved team performance (in terms of task realisation) and (b) ongoing change in team roles, and hence team organisation. Thus Enhanced MPM modelling constructs were conceived and deployed that formally describe and predict the impact of team working behaviours {Byer 2004).

Thus it is concluded that the modelling of human systems, as executors of enterprise processes, is a fruitful area of research study which requires significant new efforts from enterprise modellers so as to meet industry needs and further the utility and applicability of state-of-the-art EM and EI.

5. CONCLUSION

General deficiencies in current EM and EI provision have been identified which point to a current unsatisfied need for:

- Enriched understanding about: ME process types; long and short lived dependencies between those process types, and between their derivative process instances and related physical and logical flows; long and short lived operation and interoperation requirements of resource systems that collectively have capabilities to realise ME goals within defined constraints.
- Improved means of developing and reusing coherent and context dependent models of ME processes and resource systems in support of large and small scale enterprise (re)design, engineering and change. The reader is referred to the PhD thesis of Chatha (2004) for a detailed description of this research need.
- New human systems modelling concepts that: usefully underpin the attribution of individuals, and groups and teams of people, to activity elements of ME processes; provide means of analysing the performance of alternative candidate systems; and provide a basis for capitalising intellectual capital in MEs. This research need is reported in detail in PhD theses of Ajaefobi (2004) and Byer (2004).

This paper reports some progress towards addressing these needs, with particular emphasis on human systems modelling. New modelling concepts reported in this paper have been partially tested in support of the lifecycle of selected processes and human systems used by a global consortium of companies operating in the automotive sector. However a much broader base of industrial evaluation work is ongoing which is jointly funded by the UK government and by small and medium sized MEs operating in furniture, leisure, electronics and aerospace industry sectors.

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