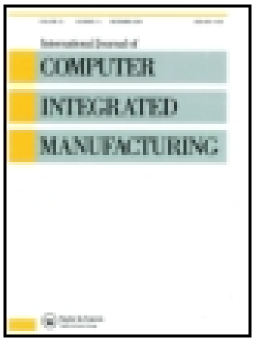

International Journal of Computer Integrated Manufacturing

ISSN: 0951-192X (Print) 1362-3052 (Online) Journal homepage: www.tandfonline.com/journals/tcim20

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To cite this article: J. O. Ajaefobi, R. H. Weston & K. A. Chatha (2006) Predicting the performance of candidate human systems within specific work contexts, International Journal of Computer Integrated Manufacturing, 19:7, 651-662, DOI: 10.1080/09511920600628764

To link to this article: https://doi.org/10.1080/09511920600628764

Published online: 19 Feb 2007.

International Journal of Computer Integrated Manufacturing, Vol. 19, No. 7, October–November 2006, 651 – 662

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Predicting the performance of candidate human systems within specific work contexts

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This paper describes concepts embedded into an 'enhanced multi process modelling' approach designed to capture and reuse coherent models of enterprise processes and human systems. Human systems are modelled in terms of the competencies and capacities they can bring as potential occupants of work roles. Multiple dependent enterprise processes (used by a specific 'manufacturing enterprise') are also modelled. The process modelling enables separable groupings of activities to be identified and designated as required work roles, to which competency and capacity requirements are associated. By coherently modelling role requirements and potential role occupants, and at needed abstraction levels, the enhanced multi-process modelling approach (i) supports human system selection (from among candidates), (ii) enables the development and testing of simulation models (that predict relative cost and lead-time performance of alternative role occupants) and (iii) enables the generation of workflow models (that support the runtime management and control of work through specified process and human resource system configurations). The current paper illustrates the use of the developed approach and observed benefits in respect to (i) and (ii). An example application of the approach is described that concerns the human resourcing of a machine design and build process currently used by a vendor of automotive production lines.

Keywords: Human systems modelling; Process modelling; Enterprise modelling; Simulation modelling; Organization design

1. On the need to model human systems

People are the prime resource of any manufacturing enterprise (ME). Van Assen (2000) suggests that enterprise competencies, capabilities, knowledge, culture and skills (which are essential to competitive advantage) are embedded largely in human systems. It is people who determine the ME's purpose, goals and objectives. It is people who conceive ME products and services and decide how and when product- and service-realizing processes and systems should be deployed. Further, people do many of the activities needed to realize products and services in conformance with plans. Salvendy (1992) and Pandya *et al.* (1997) explain separately that common classes and groupings of processes are deployed by MEs, as depicted by figure 1.

Some ME processes are required to conceive, specify, develop and change other processes. Other ME processes are concerned more directly with conceiving, specifying and developing new products; or planning and managing product realization. Some processes are directly concerned with selling, making and delivering products. Others realize support activities for some, possibly all other, ME processes. Whatever the process type, in general, responsibility for that process will be assigned to a person or group of people. Also human systems (be they individuals, groups or teams, and whether or not their work is enabled by technology) will play key roles in realizing all needed process instances during the lifetime of each process. For example a 'fulfil order process' may need to be executed many times, with or without variation in order to produce required quantities and mixes of product, on time and at

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International Journal of Computer Integrated Manufacturing
ISSN 0951-192X print/ISSN 1362-3052 online © 2006 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/09511920600628764

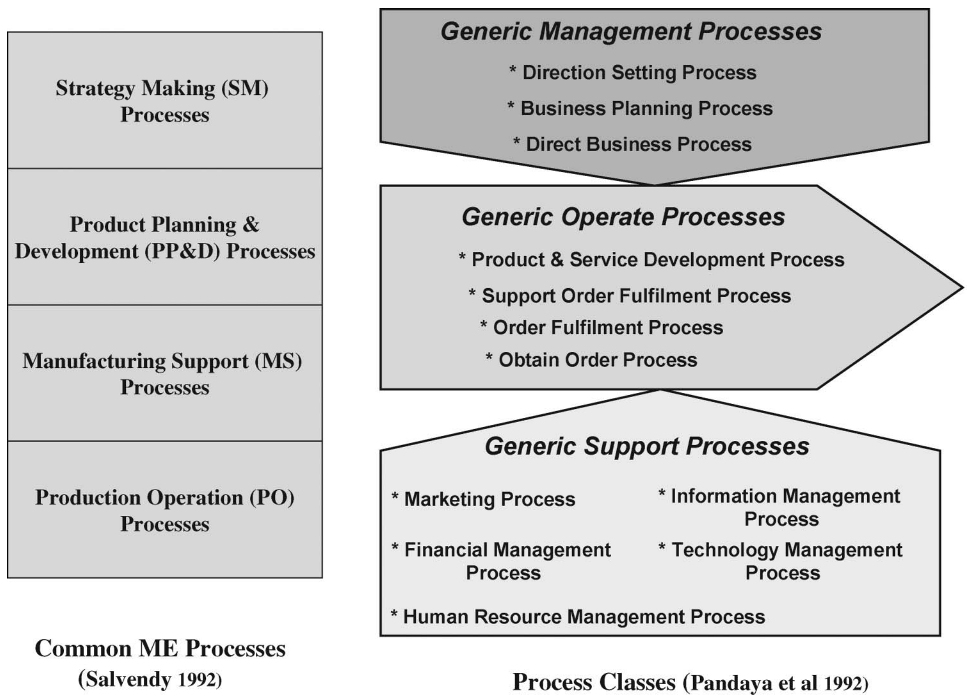

Figure 1. Common process types found in MEs.

the right price and cost, and with required qualities. This will require people to plan, schedule, manage, act, etc. in systematic (and possibly innovative) ways, probably on an ongoing basis. Other ME process instants may occur as projects are released to realize plans, or designs and so forth; and this will require people to fulfil designated roles while exercising various functional and behavioural competencies to realize project goals within defined constraints. Therefore we observe that the interworking of people needs to be systemized and coordinated so that any ME realizes multiple, dependent process instants and thereby generates (other) processes, products and services of suitable quality, in needed quantities (for internal and external customers) in a timely and cost-effective manner.

The foregoing, somewhat abstract description of ME properties and the attendant need to define, implement and change organizing structures on an ongoing basis, has fuelled a growing interest in *process thinking* and *process modelling*. In this context ME processes have been defined as '*organised sets of activities, that are realised by human and technical resources, such that outputs (products and services) of increased value are transformed from process inputs (material, information and knowledge)*' (Vernadat 1996, Weston 1999).

By thinking in terms of processes, people responsible for designing enterprise systems can envisage how time-dependent operations and interoperations should be structured and resourced, and how changes arising from outside or inside the enterprise might best be accommodated. Many process modelling techniques have been developed in recent decades to underpin process thinking, and the value of such tools lies in their ability to create graphical and/or computer executable models of ME activities which can be reused in support of process design and analysis, selection of resource systems, time-based prediction about process behaviours and performance (e.g. cost and lead times) and runtime management and control of workflows. Potentially therefore the reuse of process models is key when specifying, realizing and managing ME change.

It follows that process modelling tools have an important role to play in the context of ME organization design and change. However, the current process modelling tools have known deficiencies with respect to analysing and predicting the performance of alternative (candidate) human resource systems under different operating scenarios (Kosanke 2003). Therefore this paper reports some progress made towards overcoming that lack in modelling concept provision.

2. Modelling assumptions and background

People (human systems) can be modelled with respect to their work context, and more particularly in the context of a specific ME. For example work study has been a fruitful area of research over a number of decades (Owen 1968, Muhlemann *et al.* 1992). However despite significant advance in enterprise modelling, simulation modelling and workflow modelling technology it is not common practice in industry to use computer models of human systems to improve decision-making processes involved in ME design and change. In this paper, means of unifying the use of new human systems modelling concepts with established process modelling concepts are described. Previous research in the MSI Research Institute used CIMOSA (CIMOSA 1993, Kosanke 1995), to document formally the set of business processes used by the Ford Motor Company and their suppliers to conceive, specify and engineer a new family of (4 and 5 in-line cylinder) petrol engines (Monfared *et al.* 2002, Chatha *et al.* 2003). The process models created explicitly documented prime activities involved in Ford's (so-called) I4/I5 engineering programme; along with explicit descriptions of temporal and causal dependencies linking those activities, events, in terms of precedence relationships and associated material, information and knowledge flows. A primary focus of research attention was on creating computer-executable models of a subset of I4/I5 business processes. The process subset chosen is used by Ford and their preferred machine builders to conceive, specify, build and install production systems at a number of Ford plants around the globe. Participating systems of people have many different roles, responsibilities and concerns with respect to the full set of I4/I5 processes. However business process models created earlier by MSI researchers did not explicitly encode characteristic properties of roles that human systems should play or needed competencies and behaviours required from candidate human systems to effectively accomplish identified roles. Although it was understood early in I4/I5 process modelling work that process enactment properties will depend very largely upon the abilities and availabilities of people it was observed that CIMOSA (as with other public domain enterprise modelling approaches) provides very limited human systems modelling concepts. The research reported in this paper proposes modelling formalisms which can be used in a coherent fashion with established process modelling concepts to enhance and extend the industrial use of enterprise modelling.

First the paper describes the new human systems modelling concepts defined along with a rationale describing their intended purpose and key assumptions that had to be made. Subsequently the paper explains how use of the proposed human systems modelling concepts was enabled as part of new multi-process modelling (MPM) approach. This was advanced by defining general purpose human system modelling constructs and means of transforming enterprise models into computer executable simulation models. Finally the paper illustrates how the enhanced human systems modelling capability was initially tested by (i) creating an enhanced enterprise model which explicitly describes one segment of the full set of I4/I5 business processes and (ii) by transforming this enhanced enterprise model into a computer executable simulation model capable of assessing relative lead-time and cost properties of the modelled process segment when it is resourced by alternate human systems.

3. Founding concepts embedded into the enhanced multi-process modelling approach

Implicit in the developed modelling approach is an assertion that enterprise models can capture key information describing a specific work context, and that this context can be 'fleshed out' by attaching human-systems-related modelling requirements that are derived from the specific work place model. With this assertion in mind the enhanced modelling approach was developed based on the following assumptions.

1. Enterprise activities (EAs) can be modelled in the specific ME context in which they are to be realized, thereby providing a formal description of key structural and coordination aspects of processes that can readily be overlaid onto candidate human systems that need to work in association with other enterprise resource systems to realize defined goals.
2. Models of enterprise activities can be suitably grouped into largely separable work units. Also, these work units can be explicitly characterized with respect to needed roles and role dependencies and each role can usefully be defined (in part) by a competency requirement set.
3. Candidate human systems can be modelled with respect to their ability to occupy roles, and therefore their potential to bring to bear competency types and competency attributes that suitably match activity requirements.
4. Dynamic workloads (i.e. changing instances of project, product and service need) can be overlaid onto ME processes segments (i.e. groupings of activities that can meaningfully be modelled independently) so as to reflect an apportionment of workloads and thereby an attribution of workloads requirements to defined roles.
5. Candidate human systems can be modelled in terms of their ability to occupy time constrained roles by modelling their potential to cope with various types of workload.

Thus it was envisaged that current best practice in organization design and change decision making could be enhanced by explicitly and coherently representing models of (a) 'context-dependent processes' (b) 'candidate human systems' and (c) 'dynamic patterns of work'. By using these three model types in a unified manner it was presumed that the following beneficial outcomes would result:

(i) an ability (in any given ME context) to choose between alternative candidate human systems in terms of their ability to satisfy requirements of activities (individual or grouped) from both functional and workload points of view;

(ii) a systemic facilitation of aspects 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;
(iii) a systemic attribution of values (e.g. as part of a knowledge capitalization project) to processes and their elemental activities; by attributing them with (a) business metrics and (b) competency and capacity attributes of assigned human systems. Thereby potentially capital value can be placed upon human and structural assets of an enterprise.

4. Assessment of available modelling techniques

It was decided that a combination of enterprise modelling (EM) and simulation modelling (SM) techniques could be deployed to satisfy the modelling requirements listed under (1) through (5) in section 3. Table 1 lists known characteristic features of EM and SM. Here it was supposed that:

1. EM would be used to describe (at needed levels of abstraction and detail) specific ME workplaces, each as a network of dependent processes. Specific ME networks described via EM concepts and methods would only encode relatively enduring ME aspects, partly because current EM is not designed to represent and exercise system dynamics and partly not to overcomplicate the developed workplace models, and therefore reduce the cost and time involved in model creation, verification, updating and reuse. EM naturally generates multi-perspective (static) models of: 'enterprise requirements', expressed in the form of business process specifications; and 'enterprise systems', composed of (current and/or possible future) human and technical resources with 'abilities' to realize specified enterprise requirements. This inherent capability of EM would be used to provide a semantically rich (but static) workplace description, and particularly would facilitate an identification and description of required roles (of human systems and/or technical systems) in terms of the activities (and activity dependencies) forming each role and (material, information and logical) dependencies that link those roles.
2. As explained above, current generation EM is not designed to encode process and system dynamics, hence it is not suited to modelling the loading of process networks with time-dependent instances of project, product and service flows, nor therefore with mixes of those flows. Nor can EM naturally replicate or predict behaviours of alternative

Table 1. Complement of enterprise modelling and simulation modelling approaches.

	Common modelling capabilities	Primary modelling constraints
Enterprise modelling	• Can handle complexity. Formally decomposes process networks into process segments and their dependencies. • Formally enables attribution of multi-perspective model views to models of process segments. • Can represent (and help communicate/visualize) unified views of multiple stakeholder. • Generates common representation of ME processes and systems that can inform/support/unify various forms of decision making. • Has concepts related to lifecycle which coupled with formal decomposition concepts facilitates systems integration and interoperation. • Has abstraction and generalization concepts that facilitate the generalized reuse of models, such as when creating reference models of processes and resource systems.	• Resultant models are focused on relatively enduring aspects of MEs and do not encode time dependencies related to product flows, control flows, process instants, exception instances and time dependent causal effects. • Resultant models cannot replicate real ME behaviours, say in support of model validation. • Resultant models do not provide a basis for predicting future ME behaviours.
Simulation modelling	• Can concurrently model queues, stochastic events, product flows, process routes, resource utilization, breakdowns and absence, exception flows, etc. • Various simulation modelling techniques can be used such as numerical integration, discrete event simulation, event condition, action simulation, etc. that have relative strengths.	• Because multi-perspective static and dynamic system properties are modelled together (often in an ill-structured way) resultant simulation models have significant practical constraints if the model scope/detail/complexity grows. • If a simulation model of an isolated ME segment is created, this model cannot readily be interpreted in its context of intended use.

candidate human systems assigned to particular roles. Hence it was decided that the prime purpose of SM would be to 'exercise organization dynamics'; particularly with a view to replicating and predicting workload requirements associated with designated role (requirements). However it was understood that, if used for such a purpose, SM would need to encode both static and dynamic properties of process flows, process instances and resource system assignments. Consequently it was known that: (a) only relatively simple simulation models could be exercised in practice, therefore either the scope or depth of any SM would need to be systematically restricted; (b) in general SM creation should be well structured to reduce the time and effort involved in replicating real world behaviours (in support of model validation) and predicting the effect of candidate change to the real world.

To relieve modelling concerns connected with the lack of scalability of SMs, it was presumed that decomposition formalisms embedded into EM approaches naturally enable progressive detailing of targeted segments of ME processes, while retaining a sufficiently rich description of the context in which target segments must interoperate with other process segments. This presumption needed to be tested in practical situations. In theory, however, it was expected that the coherent use of EM and SM approaches would facilitate SM based analysis and thereby improved (i) design of process logic, resource systems and patterns of work attributed to process segments and (ii) interoperability between multiple SMs derived from a common EM.

It was observed however that the modelling approach conceived would require new EM concepts related to:

(i) modelling constructs and reusable methods for grouping activities into suitable descriptions of role requirements;
(ii) modelling constructs to describe sets of functional competency requirements that suitably characterise static aspects of role requirements and role dependencies;
(iii) modelling constructs to describe and attribute workload requirements to required roles and role dependencies.

In respect of (i), research of Chatha (2004) was observed to provide systematic means of modularizing processes into essentially decoupled modules of activity. Hence it was decided that empirical research would be conducted to test the viability of such an approach to identify roles and largely separable process segments that can be modelled largely in isolation using SM. This later notion was considered to be key to keeping simple, later stages of real system replication and prediction.

A significant body of previous literature was observed in regard to requirement (ii). Much has been written about human (system) competencies by authors affiliated to a number of disciplines (including human scientists, business schools, manufacturing sciences and IT and EM communities). A review of relevant literature can be found in Ajaefobi (2004). Also Harzallah and Vernadat (2002) and Hermosillo *et al.* (2002) have considered the static matching of people to activities by creating static models of required and available competencies. Hence the present authors decided to select and develop the use of a suitable set of competency modelling concepts based on an analysis of the previous literature. Section 5.1 describes how competency modelling concepts were selected and developed.

5. Competency and capacity modelling

5.1. Competency modelling

When specifying competency modelling constructs, it was presumed that MEs require three distinctive classes of enterprise activity to be resourced by human systems, namely: strategic, tactical and operational activity types. These classes of enterprise activity need to be appropriately resourced (by human and technical system elements) to: (i) decide *what* the enterprise should do; (ii) *how* to do what has been decided; and (iii) *do* the things that have been decided. Four-semi generic competency classes were proposed to characterize *what*, *how* and *do* enterprise activities commonly found in MEs. This characterization helped to classify those competencies that need to be possessed by human systems deployed by MEs, i.e. such that all ME activities can be executed effectively. The competency classes proposed were as follows: competency class one (CCL1), competency class two (CCL2), competency class three (CCL3) and competency class four (CCL4) (Ajaefobi and Weston, 2005). The competency classes designed correspond to generalized models of activity types, namely: (i) simple operations, (ii) skilled operations, (iii) tactical operations and (iv) strategic operations (see table 2). In a specific ME a number of candidate human systems may possess competencies corresponding to one or more of the four nominated competency classes. However at many industrial collaborator sites it was observed that candidates differ in terms of their measurable performance outputs when deployed separately to realize the same activity. It was considered likely that four prime variables could be used to characterize and measure output performance levels achieved by human systems belonging to the same competency class, namely: quality of output, defined as being the performance output achieved by a candidate human system measured against a set standard with respect to quality, quantity or lead time; autonomy,

Table 2. Competency class definitions.

Competency Class	Enterprise activity types
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.
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.
CCL3	Competency needed to translate abstract concepts into shared realities in the form of product designs, process specifications, operation procedures, budgeting and resource specifications
CCL4	Competency needed to formulating high-level business goals, mission, policies, strategies and innovative ideas

i.e. the ability of a candidate human system to work with limited supervision, taking its own decisions and initiatives when and where necessary; flexibility, i.e. the ability to do alternative activities or do the same activity in a different way as changing requirements and contexts dictate; and experience defined as accumulated expertise that can be brought into effect when solving problems emerging from an assigned activity.

To develop a characteristic model of performance variations exhibited by candidate human systems belonging to the same competency class, it was decided that each of the four competency classes proposed (namely CCL1, CCL2, CCL3 and CCL4) would be attributed with a performance level to reflect significant performance variations between candidates. It should be noted that various alternative approaches could have been conceived to characterize performance output levels that can be achieved in relation to activity types. However, the three performance levels chosen are defined as follows.

1. Level 1 (L1): people at this level are generally competent and active so that 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.
2. Level 2 (L2): 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. Furthermore, they are familiar with tools, operating procedures, and technology and therefore can be trusted to deliver expected output even under critical situation.
3. Level 3 (L3): people at this level have versatile experience and consequently are proactive, innovative and creative. They have confirmed experiences of solving problems and therefore can predict and effectively manage system behaviours in their area of expertise.

Further, it was determined that differentiation between candidate human systems could be drawn during enterprise modelling on grounds of (a) their relatively long enduring competencies (grouped within competency classes to naturally link them to enterprise activity types) and (b) performance levels associated with competency classes. (In different MEs the competencies and performance levels of available human systems may change at different rates, dependent for example on training regimes and/or rates of turnover of personnel.) Therefore a first stage matching of *competencies required by activities (grouped into roles) to functional competencies possessed by candidate human systems* was made by analysing process and resource aspects of static EMs to draw up a short list of viable candidates with needed competencies.

6. Illustrative case study application

Initial testing of E-MPM approach to modelling human systems in process-oriented work contexts was carried out in relation to a 'semi-generic' production machine design and build (PMDB) process utilized by an internationally prominent supplier of car engine production machines. Section 2 described in outline the I4/I5 engineering processes. This particular machine builder was one of three main suppliers of production systems during the early stages of the I4/I5 programme. The PMDB process used by this machine builder is semi-generic in the sense that this company uses a similar process (i.e. set of activities) to build production systems for many manufacturing companies (not just Ford).

Initial testing of E-MPM concerned one instance of the PMDB process needed to supply Ford with I4/I5 engine assembly systems. As with its predecessor MPM approach (Chatha *et al.* 2003), E-MPM was based on use of CIMOSA (CIMOSA 1993) EM modelling concepts, which after literature review and experience of its use was considered to provide state-of-the-art EM formalisms to which human systems modelling formalisms could be added. Initial testing of E-MPM began by creating CIMOSA modelling templates that described the PMDB process. Within the context of the full set of CIMOSA models of the I4/I5 engineering processes the PMDB process was designated Domain Process 23 (DP23). This sub-domain process was observe to comprise six, more elemental business processes (BPs) namely: 'Scheduling' (BP231), 'Machining' (BP232), 'Assembly' (BP233), 'Commissioning' (BP234), 'Control and Test' (BP235) and 'Services' BP236). A definition of the CIMOSA terms 'Domain Process', 'Business Process' and 'Enterprise Activity' can be found in (CIMOSA 1993). It was observed that the elemental business processes of DP23 had causal and temporal interdependencies, as they interact with each other within the context of their parent domain process. The CIMOSA EM technique was used to create 'context diagrams', 'interaction diagrams', 'structure diagrams' and 'activity diagrams' related to DP23. Once again the purpose of these CIMOSA diagrams is described in the notation. Because of space constraints only a representative selection of these diagrams can be included here to illustrate the way in which DP23 was modelled. (The reader should note that when creating the EM of DP23 many related 'context', 'structure', 'interaction' and 'activity' diagrams needed to be created at a number of levels of abstraction, so as to specify relative properties of the workplace pertaining to the BP (i.e. BP23) of focal interest.) Figure 2 shows, in the form of a high level (i.e. abstract) 'structure diagram', the full set of business processes (BPs) that constitute DP23. Figure 3 shows a much lower level activity diagram which describes in outline the timeframe over which activities constituting business process (BP233) need to be realized by suitable human and/or technical resource systems. When BP233 is executed its six constituent enterprise activities should be appropriately resourced by human or technical system elements, such that needed causal and temporal relationships are maintained between instances of parent processes, and their child processes and activities.

However to enable this to happen within needed timeframe, cost and other application constraints, the human and technical systems assigned to activities must possess appropriate competencies and capacities. The remainder of this section illustrates use of the proposed competency modelling constructs when resourcing BP233. Each activity comprising BP233 was analysed with respect to *required competencies*.

6.1. Competency requirements of BP233

From the CIMOSA activity diagram for BP233 (see figure 3) it is evident that this BP comprises six enterprise activities. It was observed that to execute these activities the *required competencies* were those summarized below:

(i) general technical knowledge about electromechanical assembly operations;
(ii) practical knowledge and ability to operate and manipulate specific tools and other resources needed for each activity;
(iii) procedural knowledge of the operations involved in each enterprise activity;
(iv) ability to communicate attributes of work in progress and to report problems and possible exceptions.

Bearing in mind the proposal in section 4.1 that competency requirements of activities can be classified within four

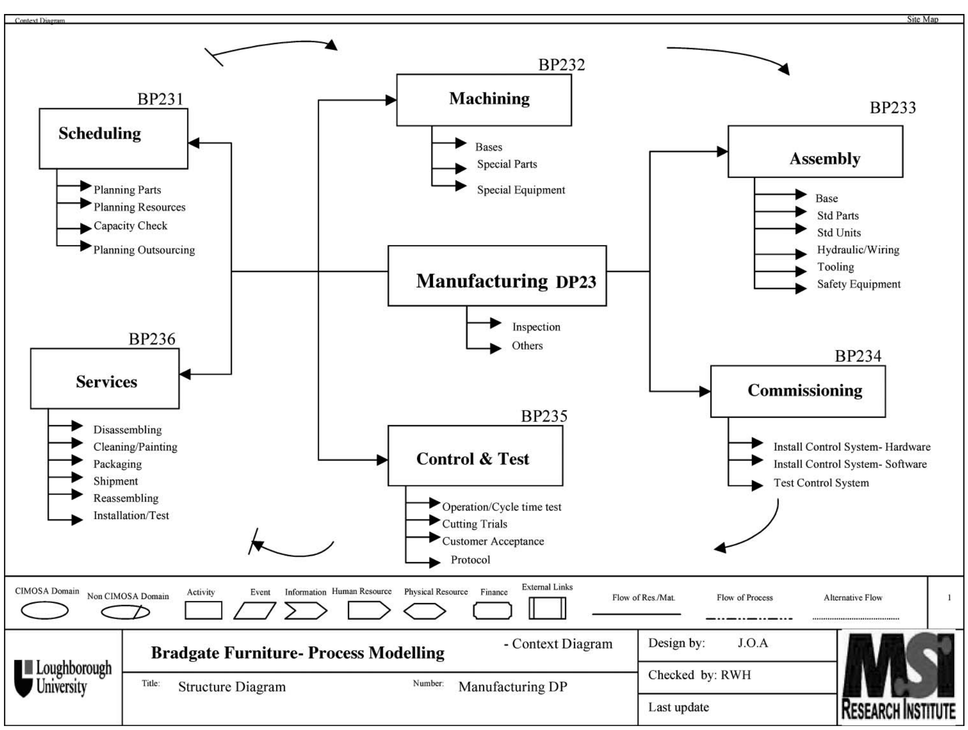

Figure 2. Decomposition of the manufacturing domain process (DP23).

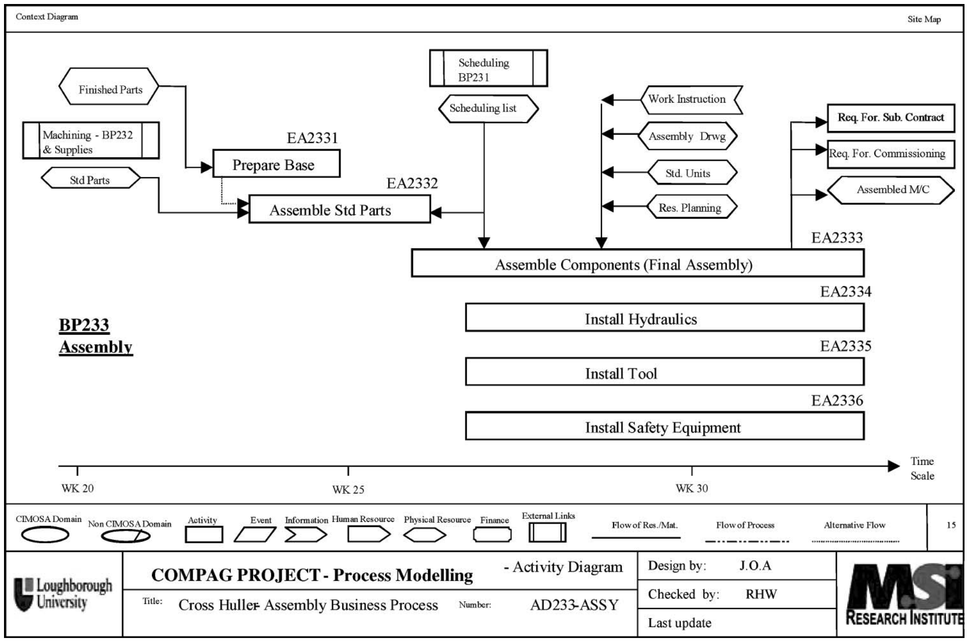

Figure 3. CIMOSA activity diagram for the assembly business process.

groupings, it was noted that BP233 is essentially an operational process. Hence it was observed that any viable candidate human system would need to belong to the CCL2 competency class. In this case, CCL2 competency is needed systematically to operationalize specified sets of enterprise activities that were previously strategically planned and tactically designed. In addition, however, specific CCL1 competencies are required to execute routine assembly operations and specialist CCL3 competencies are needed to provide supporting tactical expertise. Indeed CCL3 competent assembly system designers and developers were considered by the case study machine vendor to constitute a key asset, by offering support and expertise, especially where assembly operations are critical.

Thus a rather abstract, first stage analysis of the *required competencies* was carried out. In this case the specified prerequisite competency requirement, which needs to be possessed by any short-listed candidate human system, is that of a CCL2 competency. In addition however, some CCL1 and CCL3 competencies could lead to competitive behaviours when this assembly business process is realized.

7. Dynamic testing of enriched models

To facilitate modelling of dynamic aspects of processes, and their attributed human systems, it was observed that suitable computer-based simulation capabilities could be deployed. This was expected to enable predictions to be made about possible benefits and disbenefits arising from changing the way in which (i) activities are organized (or structured) and (ii) activities are resourced by alternative candidate human systems so as to meet defined performance constraints. This led to use of a proprietary dynamic systems simulation tool as a simulation engine. The tool selected provides various numerical integration capabilities to solve multiple, dependent differential equations. The tool enables dynamic models to be constructed in a graphical model creation environment by 'dragging' and 'dropping' and attributing parameters to a small number of standard and general purpose graphical modelling constructs, namely so called 'stock', 'flow', 'connector' and 'converter' modelling constructs which can readily be parameterized and linked to dynamic equations and equation solvers.

Implicit in the choice of this tool was a need to transform enriched but static process and human system models into useful dynamic models that can be run by the proprietary simulation environment. Because of space constraints this paper will not consider further the mapping process between EM and SM constructs. Rather, with a view to predicting process completion times when using alternative competent human resource systems, the aim here is simply to illustrate the use of the dynamic systems modelling tool to capture and represent the dynamics of enterprise activities associated with BP233. It was decided that such a simulation facility could usefully estimate relative activity and process lead-times and costs associated with an executing process, by processing encoded and executed knowledge of activity and resource completion times and resource type utilizations and costs.

When building the SM representing BP233, 'stock' constructs were used to represent the magnitude and complexity of relatively enduring enterprise activities. Also 'stock' constructs were used to model the outputs resultant upon activity completion. Further, 'stock' constructs were used to represent the growth of employees. Employee stock was considered to contain humans of different competency types, corresponding to the semi-generic competency classes described in this paper. 'Flow' modelling constructs were used to evaluate analytically collective impacts on system dynamics of key process variables, such as phenomena that influence the rate of arrival of employees, the rate of deployment of employees on activities, and thereby the rate of execution of enterprise activities. 'Converter' modelling constructs were used to hold constants, to define logic and equations and to transmit values to other converters or flows. For example a 'performance rating' converter was used to encode values that were use to classify human performances according to competency classes and their attributed performance levels. The 'performance rating converter' characterizes potential candidate human systems as follows:

(i) autonomy: ability to work independently, taking good initiatives, right decisions and actions;
(ii) output quality: the degree of excellence or quality of the output in comparison to the expected standard outcomes. The consistency of workers with respect to the requirements and policies for attaining the standard product outcomes;
(iii) flexibility: the extent to which a worker is able to adapt and react to alternative job requirements;
(iv) experience: how the experiences of a worker contribute to enhancing the work output with regards to quality, quantity and timeliness.

As stated earlier, it was observed that CCL2 competencies are needed to resource process BP233 and its component enterprise activities. Therefore, in the model developed, CCL2 was selected from the array of competency classes and human systems with competencies of this class were attributed performance levels encoded as L1, L2 and L3 as they execute BP233. BP233 was itself modelled in 'as is' and possible 'to be' ways having parallel and sequential arrangements of its enterprise activities. Completion times for each activity and the cumulative completion time of the entire process by the respective candidate systems, of CCL2 (L1, L2 and L3) were observed with respect to the parallel and sequential arrangement of BP233 activities. Further, the three CCL2 candidates (L1, L2 and L3) were grouped to form a prototype team called TeamCCL2, and this comparator candidate system was deployed in the simulation environment to resource the same BP233. The performance rating attributed to TeamCCL2 was defined as the average performance rating of the three individual candidate team members. The team development factor converter contains a numerical constant that slows down team performance at the beginning of team working when team members are getting to know each other, and begin to understand and share tasks amongst themselves. Details of team working and its attendant synergy are beyond the scope of this paper. However, the essence of TeamCCL2 was to capture and represent alternative resourcing of BP233 activities using a system of people with different performance ratings.

7.1. *Dynamic model simulations and observations*

Table 3 depicts a representative sample of simulation results obtained with respect to the concurrent execution of enterprise activities comprising the case study assembly business process BP233. The completion times obtained from the simulations for BP233 were observed to be 11.84 time units for a CCL2, L3 candidate system; 18.00 time units for a CCL2, L2 candidate system; and 28.85 time units for a CC2, L1 candidate system.

In contrast, TeamCCL2 which comprised three candidates as members, was predicted to be able to complete the same process in 6.10 h, i.e. approximately one working day. Simulation results (similar to table 3) were obtained for process completion times with a sequential arrangement of elemental activities of BP233. Table 4 presents a summary

Table 3. Simulation results for concurrent execution BP233 enterprise activities.

CCL2 candidates	Time	Enterprise activities					
		EA2331	EA2332	EA2333	EA2334	EA2335	EA2336
L3	Start	0.00	1.56	5.10	6.70	6.70	6.70
	End	2.58	6.66	7.69	9.02	10.81	**11.84**
	Duration	2.58	5.10	2.59	2.36	4.11	5.14
L2	Start	0.00	2.36	7.80	10.00	10.00	10.00
	End	3.95	10.16	11.76	13.60	16.44	**18.00**
	Duration	3.95	7.80	3.96	3.60	6.34	8.00
L1	Start	0.00	3.70	12.48	16.30	16.30	16.30
	End	6.28	16.29	18.83	21.95	26.34	**28.85**
	Duration	6.28	12.59	6.35	5.65	10.04	12.55

of completion times for the candidate systems for both sequential and parallel activity arrangements.

Potentially, therefore, dynamic models created using the new modelling formalisms can be deployed to capture and predict process lead times by deploying characterized models of human resource types in the context of parallel and or sequentially executing activity arrangements. When developing the example models of current and possible future (process and human resource) combinations, certain assumptions needed to be made so that numerical values could be attributed to model elements and variables. However, the combined enterprise and simulation models demonstrated an ability analytically and systematically to match candidate human systems to existing and possible future workplace arrangements without overly complex and time consuming experimentation. Unfortunately however the case data used in the example application given were not complete. Much of the workplace data used were accurate at a time some two years prior to the study reported in this paper when active Loughborough University collaboration was ongoing with the particular machine builder. Subsequently it did not prove possible to obtain updated workplace data or any case data on the performance of actual people employed in respect to BP233. Nevertheless, the authors argue that it is evident that SMs of similar form to the dynamic model of BP233 can usefully quantify relative behaviours of many different enterprise activities, precedence relationships linking activities, and human resource types and their competencies. Specific evidence supporting this view comes from table 4 which predicts relative process completion times for sequential and parallel activity ordering, where the latter corresponds to a past 'as is' arrangement used by the case study company and the former a possible 'could be' future arrangement. Figures 4 and 5 show example simulation results obtained, which predict a contrast in the completion times of the candidates, should they be used to execute BP233 activities in parallel and sequential ordering respectively.

8. Conclusions

Although the systematic use of human resources over time is critical to the success of any ME, previous process

Table 4. Process completion times.

Candidate systems	Sequential completion time	Time (h)	Approximate time (days)	Parallel completion time	Time (h)	Approximate time (days)
L3	21.88	21.88	3	11.84	11.84	2
L2	36.65	36.65	5	18.00	18.00	3
L1	40.91	40.91	7	28.85	28.85	4
TeamCCL2	11.94	11.94	2	6.10	6.10	1

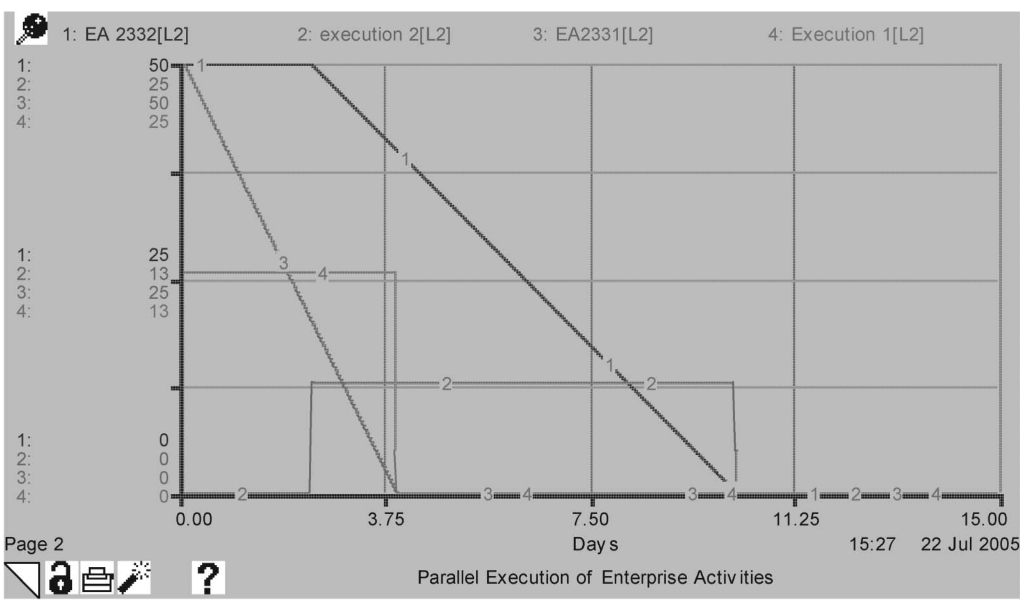

Figure 4. Concurrent execution of 'prepare base' (EA2331) and 'assemble standard parts' (EA2332) activities by a CCL2, level 2 (L2) candidate.

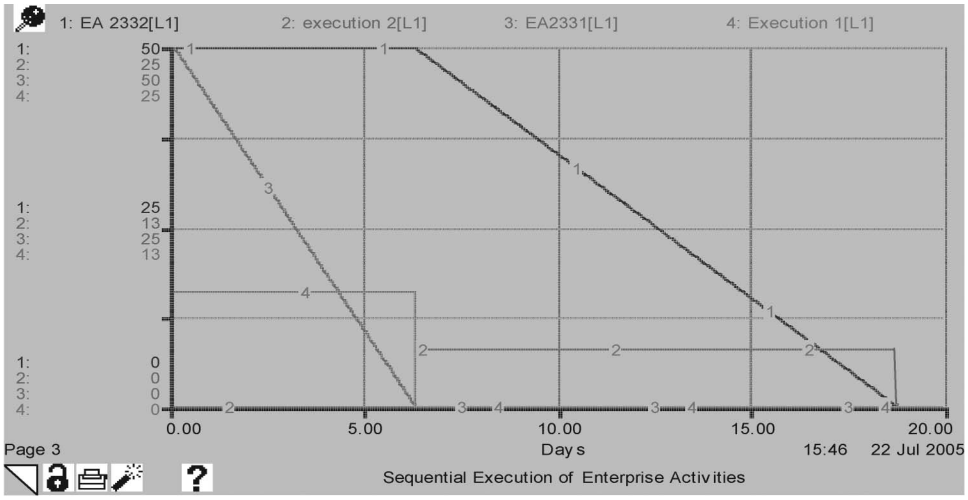

Figure 5. Sequential execution of 'assemble standard parts' (EA2332) and 'install hydraulics' (EA2333) activities by a CCL2, level 1 (L1) candidate.

modelling approaches provide only limited human systems engineering support. This motivated the conception and development of the context-dependent, human system models described in this paper. In principle these models have been shown to enable both long-term and short-term matching of competency and capacity attributes of human systems to workplace requirements. Also in principle such an approach has potential to systemize and support important aspects of organization design and change, by predicting alternative futures when structuring and co-ordinating the deployment of alternative human systems. Further, it promises process oriented means whereby (i) quantified values can be attributed to alternative human systems and (ii) quantified deficiencies in human systems provision can be analysed, predicted and improved upon.

The paper illustrates how enterprise and simulation models can be used to support different aspects of decision making involved in planning, resourcing and work loading of a case study process. An EM was created to explicitly decompose and represent work requirements, some of which are specific to the complex environment in which the case study process must operate. Here a well-proved EM technique was used to describe explicitly work requirements in terms of groupings of activities and relatively enduring structural dependencies linking activity groups. Essentially thereby complex work requirements were decomposed into largely separable process segments, explicit descriptions of which can be interpreted as role segments specifications. This can enable the identification and specification of viable roles of (human and technical) resource systems, to which suitable candidates can be assigned.

When subsequently building simulation models of role requirements and candidate human systems the need for distinct, well-defined roles was found to be of key importance; because the resultant confined scope of the SMs enables them to be created in sufficient detail yet be simple enough for them to be used as a viable and practical instrument in support of design and change decision making. Also by interpreting the results of simulation runs, within the context described by the EM benefits and disbenefits of changing design variables can be appropriately interpreted. This was considered to be of major importance because in common practice people have multiple roles to perform and because the local optimization of process segments (and roles) may not lead to overall ME performance enhancement.

The authors cannot be sure that their approach to 'modelling human resources in context' is widely applicable but its underlying systematic approach to decomposition, representation and model execution (derived from combining key strengths of EM and SM to operationalize state-of-the-art ideas on human competencies and workload behaviours) appears to be very promising. Hence the approach to modelling human systems in process-oriented contexts described in this paper is currently being tested in other companies, where new applications research is supported by the UK's Engineering and Physical Sciences Research Council, via 'responsive mode' funding. Parallel ongoing research of the authors is also investigating aspects of process modularization and role separation, and the impact that has on the simplicity, and needed granularity of EM and SM models; because these factors will directly influence the practicability and utility of resultant models.

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