International Journal of Production Research

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tprs20

Enriched multi-process modelling in support of the life cycle engineering of Business Processes

K. A. Chatha, J. O. Ajaefobi & R. H. Weston

To cite this article: K. A. Chatha, J. O. Ajaefobi & R. H. Weston (2007) Enriched multi-process modelling in support of the life cycle engineering of Business Processes, International Journal of Production Research, 45:1, 103-141, DOI: 10.1080/00207540600607150

To link to this article: https://doi.org/10.1080/00207540600607150

International Journal of Production Research,
Vol. 45, No. 1, 1 January 2007, 103–141

Taylor & Francis
Taylor & Francis Group

Enriched multi-process modelling in support of the life cycle engineering of Business Processes

K. A. CHATHA, J. O. AJAEFOBI and R. H. WESTON*

MSI Research Institute, Loughborough University, Loughborough LE11 3TU, UK

(*Received December 2005*)

A new approach to enterprise modelling is described that facilitates the reuse of multi-perspective models of Business Process networks. The approach has been designed to advance current best practice when engineering change to interdependent Business Processes of types commonly deployed within Manufacturing Enterprises. The approach is unique in the way it maintains coherence between (1) conventional enterprise models, used primarily to represent graphically (at multiple levels of abstraction) relatively enduring properties of Business Process networks; and (2) dynamic models of selected segments of a parent Business Process network, which can be computer-executed via conventional simulation modelling and workflow modelling technology. Thereby, context-dependent dynamic models can be used to replicate and analyse historical patterns of enterprise behaviour, and predict and analyse possible future patterns of enterprise behaviour, should selected elements and parameters of the modelled Business Process network be changed. The paper also considers 'needed decision support capabilities' during Business Process Reengineering and Business Process improvement projects. In so doing, it collates those decision support requirements identified into a generalized description of the life phases of such projects. This generalized description was used to help structure the design of the new enterprise modelling approach. Furthermore, it is used to help illustrate an example application of the new modelling approach.

Keywords: Multi-process modelling; CIMOSA; ME processes; Enterprise modelling; Simulation modelling; Workflow modelling; Life cycle of business processes

1. Introduction

1.1 *Process orientation in manufacturing organizations*

Manufacturing Enterprises (MEs) are man-made organizations composed of people and technical resource systems. Through their lifetime, MEs are designed (and changed), and this requires complex decision-making. Most MEs face uncertain competitor impacts: as new and old competitor MEs improve the functionality and aesthetics of products, reduce product costs and improve their (temporal and spatial) availability. Customer requirements may change unpredictably, as can

*Corresponding author. Email: R.H.Weston@lboro.ac.uk

International Journal of Production Research
ISSN 0020–7543 print/ISSN 1366–588X online
http://www.tandf.co.uk/journals
DOI: 10.1080/00207540600607150

change in enabling technology and political, economic and environmental conditions.

It follows that most MEs must deploy a complex, interdependent set of processes underpinned by a finite set of interoperating human and technical resources to do the following:

- Over short time-frames, repeatedly realize existing products, whilst generating values.
- In the medium-term, innovatively develop new products.
- Renew the ME's purpose and composition (including its processes and resources) so that it continues to behave competitively longer-term.

But there are at least two complementary schools of thought about processes. One perception common in business schools and frequently assumed in industry, is that the term 'process' implicitly embraces: (1) 'what needs to be done' and (2) 'those human and technical resources necessary to realize what needs to be done'. This first school of thought has generated notions about 'Business Processes', instances of which generate measurable business value and (by consuming resources) incur identifiable cost. Notions about 'Business Processes' naturally lead to derivative concepts such as: Business Process Engineering (Hammer and Champy 1993) and Continuous Process Improvement (Davenport 1998); and related manufacturing strategies, such as Lean Manufacturing (Womak *et al.* 1990) and Supply Chain Management (Tayur *et al.* 1999). A second school of thought about processes is adopted by Manufacturing Systems and Information Technology Systems research and vendor communities. This alternative process characterization assumes that all process types (e.g. accounting processes, welding processes, arithmetic processes, etc.) can be uniquely defined in terms of multi-perspective flows associated with ordered sets of activities. A natural benefit of this second view of processes is that 'requirements thinking' is decoupled from 'thinking about system solutions'. Indeed, systems engineers often think it is natural to separate out models of 'problems' from models of 'solutions'. Such a separation can be key to good process and systems engineering practice, as it is known to facilitate reasoning, such as about the performance of different candidate human and technical resource systems as they realize a common set of activities, tasks or jobs (thereby enabling choice between alternative resource configurations); and about using a specific resource to realize one or more sets of activities, tasks and jobs (thereby enabling analysis and prediction about relative performances of alternative process configurations).

1.2 *Definition of terms*

This paper is mainly aligned with the second (namely 'systems') thread of thinking about processes. It describes an enhanced way of modelling networks of processes deployed by MEs. The enhanced modelling approach was conceived to facilitate the life-cycle engineering of multiple, dependent ME processes, including so-called Business Processes. Therefore, before describing the purpose of the enhanced modelling approach and illustrating its use, it is necessary to define explicitly the terminology used. The intention is that the definitions can be readily accepted and understood by relevant user, researcher and developer communities.

Use of the terms *process logic* and *process model* will mean 'some abstraction (or modelled representation) of flows associated with an ordered set of activities'. The two terms will be used interchangeably. The former will be used to convey the notion of order or flow. The latter will imply a capability to use/reuse abstract understandings about (activity, information, control and possibly material, product and value) flows that are explicitly encoded by a model: so as to understand better, make predictions about or make engineering decisions in relation to process requirements.

The term *Business Process* will mean 'a real (or actual) ME process and its embedded process logic that is resourced by an appropriate set of human and technical resource elements'. Such a Business Process will add value to inputs to that process, but in so doing will consume resources (and hence incur costs) during Business Process execution and during Business Process engineering and management. Some Business Processes of MEs regularly repeat their execution, such as processes used to make, assemble and deliver similar products in quantity to one or many customers. Other Business Processes deployed to realize special engineering projects, specialist infrastructural support and strategy realization may seldom be repeated during the lifetime of their host ME; and should their execution be repeated they may need to be redesigned and customized (e.g. in terms of their process logic and/or their use of resource systems) each time they execute. In general, where Business Processes repeat, frequently opportunity will arise to develop them on a continuing basis, possibly optimizing, standardizing and physically distributing their process logic and the resource systems they deploy.

From the foregoing, it is evident that when referring to processes, the term's *lifetime* and *life phases* must be used with caution. For example, a specific instance of an executing ME Business Process will typically have a finite timeframe ranging between minutes to years. Such a single instance of an executing Business Process may itself involve distinctive life phases. However, often within MEs when the terms life time and life phase are used in relation to a Business Process there is an inference that there will be many (possibly very large numbers of) repetitive executions of that Business Process during its useful lifetime; and as a consequence opportunity will arise to (re)engineer that Business Process, so that new or improved versions of it can be realized to enhance ME performance. Hence, commonly the lifetime of a Business Process will be greater (possibly much greater) than that of a specific executing instance of it. It follows that the term life phase is used to describe stages of engineering development of a Business Process, as well as stages of execution of a single instance of a Business Process.

By inference, the process logic embedded into a given Business Process (or some executing instance of it) is of a logical, rather than physical, nature. This is normally different from the nature of human and technical resource system elements used to execute, manage and engineer a Business Process; which is likely to be some combination of physical and logical entities. Because of its logical nature, and because it is often implemented using software and related data entities, commonly process logic will be relatively easy to change. Having said that, if process logic is poorly designed or ill-defined (e.g. if it is embedded in an unspecified way into a physical resource system element such as an ERP or CAD/CAM system, a production machine or machine operator or supervisor) it may be very difficult and costly to change.

2. Implied need to model Business Processes

It follows that in general the capture and reuse of a semantically rich model of a Business Process will be rather more complex than simply capturing and reusing a model of the process logic deployed. This paper considers aspects of the additional complexity involved and explains that in general a well-defined Business Process Model may need to incorporate: (1) a model of the ME context in which the Business Process is to be deployed, (2) models of process logics (that are or could be) used, (3) characteristic models of resource systems (that are or could be) used and (4) models of work patterns that modelled Business Processes (will or could) need to realize within specified time and cost constraints.

2.1 *Derivative model of Business Process (re)engineering*

Normally any ME (re)design, and associated Business Process (Re)Engineering projects, will inherit an 'as is' network of dependent Business Processes that realizes existing products for customers, generates values for stakeholders; and (optionally) innovatively develops new products. Also, normally over various timeframes ongoing change will have previously been made to: the process logics (embedded into that network), the resource systems used to underpin process execution, and certain dependencies between Business Processes of the network. Such changes may have been a response to external influences like customer requirements change, change in competitor behaviours and change in environmental legislation. Alternatively they may have been deemed necessary because of internal (to the ME) decisions, such as: to outsource process segments to business partners or other companies; to introduce new or rationalized products; to improve selected processes, resource systems and associated production methods, etc. In all such change cases though, the present authors posit that necessary Business Process change will require similar life stages characterized by the model of Business Process Engineering shown in figure 1.

In the model proposed, it is presumed that typically the *Specify Change* life phase will begin with (or have been preceded by) the capture of 'as is' models of the process logic and resource systems currently used by the Business Process (or Business Processes) of concern. With these as is' models in mind, persons responsible for specifying needed process changes will interpret the change requirements and determine implied requirements for new process logics, new resource system designs, new work assignments, and so forth. In so doing they will create candidate 'to be' models of process logics, resource systems, etc that reflect the nature of the recommended Business Process Improvements. The *Specify Change* life phase may or may not incorporate an analysis of value streams and costs in relation to workflows through the modelled segments of Business Processes. Model capture during this life phase may or not be formally represented and be stored in computer executable forms, but normally it will be informed by specific process experts (including process owners, actors and users) and by historical data capture during other life phases (particularly the *Monitor and Control Business Process Execution* life phase).

During the (*Re*)*Design* life phase alternative outcomes and ways of achieving Business Process change should be analysed, with the purpose of detailing the design of possible new activity, information, material and control flows and of specifying

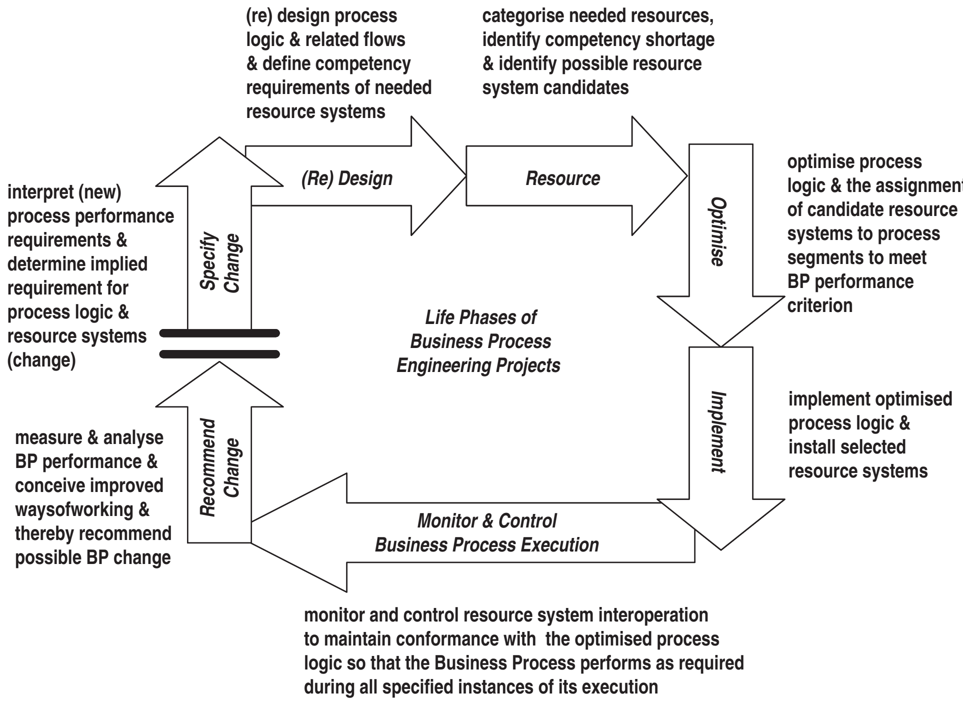


Figure 1. Proposed model of business process engineering.

needed functional competencies of resource systems to achieve those flows. During the *Resource* life phase, resource deficiencies (in terms of competency, capacity, flexibility and costs) need to be explicitly identified so as to inform the selection of new resource system components and ways of organizing selected resources. Typically here it is assumed that MEs may ultimately need to purchase technical systems and hire and train human resources so that they possess the structures (including procedures and methods) and abilities required to achieve 'to be' candidate process-oriented designs.

The purpose of the *Optimize* life phase is to analyse and predict dynamic behaviours of ME Business Processes when they are subject to historical (previous 'as is') and predicted 'to be' patterns of work. The aim of so doing is to quantitatively predict and validate the impact of possible decisions made to: deploy alternative process logics; assign responsibilities of given candidate resource systems to specific process segments and their workloads; purchase, install and train new resource systems, etc. Having chosen between candidate designs the *Implement* life phase will involve the installation of new resource systems; the reorganization of material, product and information flows; the configuration of IT support systems; training for process actors, etc.

During the '*Monitor and Control Business Process Execution*' life phase needed patterns of work will be realized via an interoperating set of human and technical resource systems. This should be achieved in conformance with the process logic defined, so as to coordinate and control the actual flows of activities, information, materials and products through the Business Process segments of concern, whilst achieving inter-working with other Business Processes in the ME's process network.

Over time (and commonly the repetitive execution of many instances of a Business Processes) the purpose of the '*Recommend Change*' life phase will be to identify potential performance enhancements. This in turn will lead to potential Business Process improvement opportunities and the identification of new process and resource system designs in respect of new patterns of work. Thereby, the process-engineering life cycle can continue.

2.2 *Implied requirement for a multi-process modelling capability*

It follows that MEs can be considered to comprise: a primary network of Business Processes (defined by their process logics and realized by assigned resource systems) that interoperate to satisfy current and possible future customer and stakeholder needs.

Typically because of (1) financial, people and technical resource constraints, and (2) difficulties involved in creating a 'big picture' about possible ME futures which can be shared by all relevant ME personnel, common best practice in manufacturing industries is to design and engineer change to a primary Business Process network in a piecemeal fashion. Consequently, multiple process engineering projects may be current at any point in time to address (short-, mid- and long-term) requirements for change arising from within and without the ME. In general, although each project can be expected to pass through similar life stages (figure 1), they will have specific but likely overlapping scopes, durations and concerns.

It follows, therefore, that MEs also require a secondary network of 'Pseudo-Business Processes' that need to interoperate to manage ME operations, tactics and strategies and as appropriate to engineer change to the primary and secondary Business Process networks throughout the useful life of the ME. Because it may be more difficult to quantify values and costs associated with such a secondary network, its constituent processes will be referred to as 'Pseudo Business Processes'.

The competitiveness of any ME will depend heavily upon characteristics of its primary and secondary Business Process networks. Those characteristics will depend upon embedded process logics (including methods, procedures and systems), competencies, capacities, flexibilities and costs, and will be manifest in the typical behaviours they demonstrate, and the ease which they can be brought to bear on changing patterns of work. Bearing this observation in mind the authors observed that timely and effective (and, therefore, competitive) ME behaviours can be induced via timely, effective and competitive design and change engineering decision making, which in turn necessitates the use of sufficiently semantically rich models of the ME's primary and secondary Business Process networks. This will be the case whether those models can be explicitly represented and executed in a computer or rather more conventionally exist in the heads of relevant ME personnel.

In general, therefore, during the lifetime of any ME its Business Processes and Pseudo Business Processes need to be reused, developed and changed. Consequently, there is a common need for high-quality modelling methods with capabilities that facilitate the capture, deployment, development and reuse of semantically rich models of Business Processes (and segments of Business Processes) which appropriately encode characteristics of specific ME Business Process networks in support of network design and change. This paper reports on progress made by the authors and their research collaborators towards meeting this need; where the authors have identified the following generic modelling requirements which will be exemplified in subsequent sections of this paper:

- Any Business (or Pseudo Business) Process of an ME needs to be modelled in terms of its (1) process logic, (2) candidate human and technical resources (and their (functional and behavioural) abilities and availabilities), (3) patterns of work that can be overlaid onto process logics, and (4) dependencies with other Business Processes in a specific ME.
- Business (and Pseudo Business) Process Models of MEs need to be captured, formally documented and computer exercised in reusable forms so as to quantify their abilities to meet job and work pattern requirements, and changing requirements of process engineering projects, whilst satisfying ME and environmental constraints.
- Change capable process logic (and hence synchronization, control and monitoring code), that is coherent with developed models of Business Processes, needs to be readily and explicitly embedded into actual process network configurations. Thereby, explicit models of synchronization and control for a configuration of ME processes, and their causal and temporal relationships with selected interoperating resource systems, can explicitly be developed and computer-executed so that collective and systemic working can lead to specified ME process behaviours and goal attainment that matches specific environmental requirements and constraints.

This paper reports mainly on progress made with respect to the first and second points. In so doing, it explains how it delivers new knowledge about using unified modelling concepts.

3. Status of enterprise modelling in support of Business Process engineering

The literature describes a number of modelling architectures and frameworks designed to support aspects of enterprise engineering. Well-known and industrially proven examples include: IDEF (US Air Force 1981), GRAI/GIM (Chen and Doumeingts 1996), Purdue (Williams 1992), CIMOSA (ESPIRIT-CIMOSA Standards 1993), IEM (Mertins and Joschem 1998), ARIS (Scheer 1998), RPM (Monfared *et al.* 2002) and MPM (Chatha *et al.* 2003). For more than a decade researchers in the MSI Research Institute at Loughborough University have monitored and categorized modelling capabilities provided by these and other enterprise modelling approaches (Weston 1998). Observations from one such review are summarized in table 1. This contrasts and compares modelling capabilities embedded into CIMOSA, RPM, IDEF3 and IEM enterprise modelling approaches. The purpose of this particular comparison was to illustrate the extent to which current public domain modelling concepts can underpin the generic modelling requirements described in section 2.2, under the first three headings.

Table 1. Modelling requirements identified (in section 2.2) provided by a selection of existing enterprise modelling approaches.

Organization design requirements	CIMOSA	RPM	IDEF3	IEM
Need to model multi-process networks and explicitly enforce process, system and work pattern decomposition principles	CIMOSA provides a fairly comprehensive, but incomplete, set of decomposition principles. Domains under study are decomposed into subdomains that have domain processes, Business Processes etc. The 'correctness' of decompositions depends upon the reality and upon a modeller's understanding and experience of CIMOSA principles. CIMOSA can represent multiple processes and some types of dependencies between them but it lacks some formalisms and is particularly limited with respect to capturing time dependencies between process elements	RPM facilitates the application of CIMOSA concepts with respect to end-to-end BPs of an organization. Therefore, it inherits the strengths and weaknesses of CIMOSA	IDEF3 is a process description language not a modelling architecture or framework. It captures process knowledge and represents this graphically via defined constructs. It explicitly defines any decomposition principles	IEM is essentially a process modelling language. It can be used to create so-called 'Function Models' and 'Information Models'. It uses object-oriented principles to define object-classes and decompose them into subclasses and objects. It does not explicitly specify decomposition principles and does enable the creation of organization models

Need to create models that support the life cycle engineering of Business Processes	CIMOSA provides principles for decomposing processes into subprocesses and systems into subsystems that can facilitate their subsequent integration. But its capture of inter- and intra-process dependencies is limited. For process resourcing, CIMOSA concepts support a mechanistic approach where EAs have elemental functional operations with assigned functional entities. CIMOSA provides limited concepts to optimize process behaviours and resource assignments. It does assert that models need to be computer executed via an infrastructure. It provides some process state modelling constructs but these are limited with respect to dependencies between process and resource system behaviours and resource system synchronization and control	RPM approach provides graphical modelling constructs that operationalize CIMOSA's process and system modelling constructs. It can capture limited data about DPs, BPs, EAs, and their resources and represent them along a time line in order to estimate one-off process lead-times. This can usefully support some aspects of process design and change, but is limited with respect to process optimization	IDEF3 only supports aspects of process design by enabling representations of resources, related data and their operation sequences in an organization	IEM supports process design, resourcing and analysis stages. Processes are modelled using 'function model view' modelling constructs, while resources are modelled via 'information model view' constructs. Once relevant process information is captured, processes can be analysed and evaluated with respect to time and cost criteria and then executed. IEM provides a rather mechanistic and inflexible approach to resourcing. Aspects of team working, run-time operation and control are not catered for

(*continued*)

Table 1. Continued.

Organization design requirements	CIMOSA	RPM	IDEF3	IEM
Need for a generic process modelling language that can generate semantically rich process specifications	CIMOSA provides an extensive set of modelling concepts, modelling templates, modelling viewpoints, levels and life stages. But it does not provide explicit modelling formalisms in which can be executed by simulation tools. CIMOSA leaves it to the modeller to choose his own way of using the modelling constructs defined	RPM systemizes use of its graphical modelling templates. It does not formally create computer executable ME process models. However, indirectly it facilitates resource system design and implementation description that provide a visual picture of the ME under study. The RPM method also recommends use of ISO information and software description languages during resource system design. But like CIMOSA it lends limited support for modelling process and system behaviours	IDEF3 provides a fairly rich set of modelling constructs to describe processes and associated resources in terms of their object views. However, organization structure and process life cycle concepts are not included	IEM inherits some formalisms from SADT/IDEF0. It represents enterprise entities as object views within three classes namely: product, resource and order. It lacks concepts in relation to organization structure and aspects of process run-time
Need for explicit methods to engineer Business Processes	CIMOSA modelling methods define Requirements Definition, Design Specification, Implementation Description, Operation and Maintenance stages of enterprise modelling. Because of its limited support for behavioural modelling it offers little to facilitate process optimization and analysis and prediction of model behaviours	RPM operationalizes Requirements Definition and Design Specification stages of the CIMOSA methodology	IDEF3 specifies a method for developing process descriptions, with a limited focus	IEM modelling method includes stages of system delimitation, model development, model evaluation and use, and model update. But it provides very limited business process life cycle engineering concepts

Need for an explicit framework to connect modelling concepts	CIMOSA explicitly defines a modelling framework, including four views: function, information, organization and resource. However, these views are considered to be insufficient when developing semantically rich models of process networks and particularly how those processes can realize alternative patterns of work	RPM employs CIMOSA framework concepts to develop CIMOSA conformant models of an enterprise	No modelling framework is explicitly defined	IEM has two modelling views: 'function model view' and 'information model view' which IEM consider are sufficient to capture aspects of enterprise design and working
Need to handle exceptions to standard process model specification and execution	CIMOSA raises the need for exception handling at process run-time. It defines some exception types and ways in which they can be handled but those types are insufficient enough to realize organization change in a structured way	Alternative configurations of EAs and BPs can be modelled	No concepts provided	No concepts provided
Need for modelling formalisms and constructs that support coordination and control amongst resource systems	No concepts of substance are provided	RPM implicitly specifies the use of very limited coordination and control mechanisms	No concepts of substance provided	No concepts of substance provided

From table 1, the following conclusions can be drawn:

- All of modelling approaches reviewed are limited in respect of enabling:
  - Coherent sets of process and resource system models to be reused during all life stages of Business Process engineering projects (as described by figure 1).
  - 'Work pattern' models (characterizing (causal and time) -dependent relationships between material, information, knowledge, control and exception flows) to be coherently mapped onto different configurations of process and resource system models; so as to facilitate prediction and decision making about the performance of alternative Business Process networks and about alternative ways of organizing work (e.g. into small or large batches, into make-to-stock, make-to-order supply chains, etc.).
- Different enterprise engineering approaches have different strengths and weaknesses with respect to the various stages involved in engineering Business Processes, i.e. they have complementarities. It follows that opportunities exist to draw out and combine their concepts, methods, etc, with those provided by best-in-class simulation and workflow technologies into an enhanced Business Process modelling approach.

Had this comparison of enterprise modelling approaches been extended to cover all public domain approaches, the authors believe that very similar conclusions would have been reached.

Many modelling approaches are under development, both within the enterprise modelling research community and in various other modelling communities (such as within vendor and research communities creating and developing ontologies, simulation modelling tools and workflow modelling tools). It follows that there are many other modelling languages, techniques and tools, not normally categorized under the enterprise-modelling banner. Evidently, these other modelling communities offer complementary modelling facilities that potentially can enable aspects of Business Process engineering. For example, various simulation modelling tools can usefully model process, resource system and work pattern behaviours; but the enterprise modeller would require their use to be appropriately integrated with that of a well-defined enterprise engineering approach so that the conditions under which they execute and the results they generate can be interpreted with respect to their intended context of use. Similarly, software engineering methods, languages and tools can be deployed to implement and change those Business Processes (and their assigned resource systems) defined and optimized via enterprise modellers. Workflow management systems are one class of software engineering tool that can naturally implement and change required aspects of specified process logics, so as to realize resource system coordination and control in a change capable manner.

Numerous proprietary simulation packages have been used in industry to facilitate focused aspects of Business Process engineering. This paper will not attempt to review and analyse their capabilities. However, it is appropriate to point out that Bahrami *et al.* (1998) considered the scope of use of contemporary simulation modelling techniques and identified a gap between the industrial need for simulation models that support the daily operation of businesses and present day capabilities of proprietary simulation packages. They argue that in order to reap advantages of simulation modelling, and to gain adequate return on process modelling investment, simulation systems need to be properly integrated into their context of use. Key to the satisfaction of this need, Bahrami *et al.* suggest that an enterprise wide architecture for Business Process simulation is required. Other relevant literature indicates that to date simulation modelling in support of Business Process engineering has been centred mainly on process (re)design and analysis (Bhaskar *et al.* 1994, Gladwin and Tumay 1994). The published literature does not explicitly show how simulation modelling can be used to support: the management and operation of Business Processes; nor the engineering of their underlying human and technical resource systems; nor the planning, allocation and control of work patterns through Business Processes and their underlying resource systems.

4. Enriched multi-process modelling (E-MPM) environment

Experience gained from developing MPM and using it to engineer Business Processes (Chatha *et al.* 2003), coupled with an observed need to meet the modelling requirements specified in section 2.2, led the authors to develop an Enriched Multi-Process Modelling (E-MPM) approach. The principles of E-MPM and an illustration of its use are described herein for the first time in the public domain. E-MPM was conceived as an enhancement of MPM in as much that it was required to develop and facilitate the reuse of semantically enriched models of Business Process networks. When specifying the required capabilities of E-MPM it was decided that its environment for modelling should comprise the following:

- Enriched set of multi-process modelling constructs that can be operationalized within a context defined by an E-MPM Framework; such that these constructs more naturally support process simulation and process enactment when compared with the MPM Framework earlier conceived.
- E-MPM Method that structures multi-process modelling along similar but improved lines relative to its predecessor MPM method; except that it is designed to structure the use of E-MPM modelling constructs rather than MPM ones.
- E-MPM Environment that comprises a specific instance of the E-MPM Framework, E-MPM Method and a selection of proprietary process modelling, simulation and enactment tools.

It followed that the E-MPM Framework was designed so that it retained a number of well-proven modelling concepts previously defined by CIMOSA. However, new complementary concepts needed to be conceived and incorporated into E-MPM that more naturally enable enriched and coherent process, simulation and workflow models to be created and executed by selected model enactment tools. The E-MPM Framework so specified is represented conceptually in figure 2.

Previously when developing static (i.e. relatively enduring) and dynamic (i.e. time dependent in the modelled timeframe) models using the MPM approach it was observed that the CIMOSA modelling framework (which provides the baseline modelling concepts for MPM) lacks sufficient modelling concepts to capture and represent sufficient time dependent (dynamic) attributes of an enterprise. Also, it was observed that MPM and its adopted CIMOSA modelling constructs lack

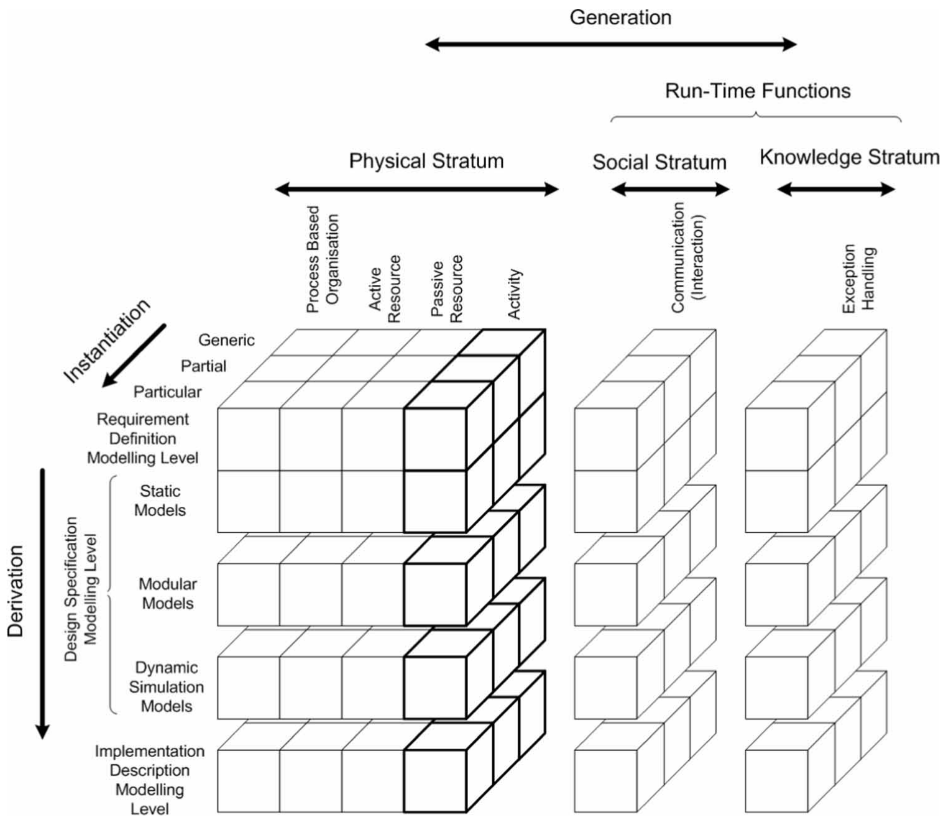


Figure 2. Enriched multi-process modelling framework.

explicit means of representing and supporting the use of other important enterprise engineering concepts, such as 'change capability', 'modularization' and 'collaboration'. This observation provided the prime motivation for devising and adding new modelling concepts that have an ability to explicitly encode selected: collaboration concerns; exception types and their handling; aspects of process modularization; and developmental aspects of dynamic models. The full set of E-MPM modelling concepts is described by Ajaefobi (2004) and Chatha (2004). However, a significant number of founding CIMOSA concepts were retained, although in some cases minor amendments were made to enable them to be used consistently in conjunction with the new concepts. All new and amended concepts were organized in relation to pre-existing specifications of the CIMOSA modelling framework. This enabled the scope, and capabilities of the E-MPM Framework to be defined, relative to an ISO standard.

The E-MPM Framework has three dimensions (similar to the CIMOSA modelling framework): a 'generation', 'instantiation' and 'derivation' dimension. E-MPM's instantiation dimension closely mirrors that of the CIMOSA instantiation dimension. However, the 'generation' dimension is split into three strata that represent reality, where the strata chosen are akin to aspects of 'human beings': a 'physical body', 'intellect and knowledge' and 'self' (Al-Hujweri/

Nicholson 1976). Authors such as Schael (1998) have conceived (manufacturing) organizations to be socio-technical systems. However, the present authors have investigated new ways of modelling (manufacturing) organizations as socio-technical systems with an ability to use and produce knowledge. Therefore, the three strata of the 'generation' dimension are physical stratum, a knowledge stratum and a social stratum. The physical stratum captures aspects related to physically building an organization. The knowledge stratum captures aspects related to the knowledge used and produced by or for an organization. This includes tacit knowledge as well as explicit knowledge. This may also encompass procedures for handling change. Whilst a social stratum captures aspects related to social behaviour and the social environment of the organization. In the current version of the E-MPM Framework, the social stratum is centred on coordination, collaboration and communication concepts and principles. However, currently the present authors and their research colleagues are also studying and applying in industry ways of modelling developmental and behavioural aspects of human systems (comprising structured sets of individuals, work group and teams). Each of these three strata of an organization is considered to be 'open' in the sense that the E-MPM Framework is eclectic, being designed to accommodate the introduction of additional modelling concepts. Modelling concepts incorporated into the three strata of reality are used collectively to structure and represent different modelling perspectives when seeking to study, design, develop and change an organization.

Returning to the physical stratum of the E-MPM Framework, a number of enhancements were made in comparison to the CIMOSA modelling framework. In this study, it is first assumed that most MEs can be modelled as a primary network of Business Processes, which is designed and changed by a secondary Pseudo-Business Process network. Therefore, it is presumed that other organizational perspectives of a modelled ME can be usefully modelled in relation to a process-oriented organizational view. Consequently, the 'function' view of the CIMOSA framework was explicitly replaced by an 'activity' view. In the E-MPM approach to modelling, activity execution explicitly requires active resources, that have capabilities to do (CIMOSA conformant) functional operations, so as to carry out those activities. Also, it is presumed that activities will normally require passive resources on which functional operations are either carried out to produce outputs or used or consulted when carrying out activities. These modified and additional concepts were designed to facilitate mapping between static enterprise models described using sets of graphical modelling templates into dynamic models that can be executed via simulators and workflow modellers. The derivation dimension encodes and represents requirements of systems during their lifetime. Notable differences in this dimension (compared with the CIMOSA framework) are concepts provided to create semantically rich static process models; modularize processes; and to create dynamic models of systems.

The full set of modelling concepts comprising the E-MPM Framework provide modelling capabilities that do the following:

- Support the decomposition and capture of semantically rich descriptions of processes and dependencies between processes.
- Enable selected segments of semantically rich process descriptions to be transformed readily into a computer executable form that can be run either

in a stand alone mode or as an integral part of actual process logic being designed, resourced and controlled.

- Naturally enforce a structured way of linking aspects and life phases of 'process models' to related aspects and life phases of candidate 'models of systems' (i.e. organized collections of models of human and technical system elements) that are or could be used to resource modelled processes. This structure was designed to enable transformation, change, reconfiguration, extension, scalability and general reuse of models and segments of models; enable process and system designers to use 'guides' and 'constructs' to create models of processes in a modular fashion, thereby enabling change capable processes to be specified and developed based on the reuse of process modules. (The term 'guide' is used here to indicate the provision of some exemplar (or reference) model, method or rule, which can guide design, process resourcing and control activities specified and/or carried out by process designers and developers. The term 'construct' is used to indicate that a description or modelling mechanism is provided.)
- 'Guide' and 'construct' the use of suitable coordination theory, so as (a) to lend time-based structures to groupings of activities involved in the design, resourcing and control of (multiple) complex processes, and (2) to structure communications among organized sets of resources used to realize complex processes.
- Offer a generic approach to handling exceptions that may interrupt the normal execution of a process. Also, to provide mechanisms to handle different types of exceptions.

Based on the concepts developed and incorporated into the E-MPM framework, an E-MPM method was developed for enterprise modelling (table 2). For detailed descriptions of E-MPM, see Ajaefobi (2004) and Chatha (2004). Figure 3 illustrates common model transformations enabled by E-MPM.

The E-MPM method conceptualizes an organization as a system of three classes of process working in parallel in different time frames. Business Processes belonging to each class of process are identified and developed in accordance with the E-MPM method. The method uses modelling concepts of the E-MPM framework to develop process and resource system models. Like its predecessor, the E-MPM method leads to the generation of three kinds of model: static, simulation and workflow. These models are successively generated when following the E-MPM method stage by stage. The E-MPM method makes use of a 'Resource Selection Method' which was conceived and developed primarily to facilitate initial resource selection based upon explicitly defined functional and performance requirements of specific Business Processes at various levels of granularity.

5. Use of the E-MPM method

This section illustrates use of E-MPM with respect to a simple application. The chosen application is simple in the sense that the Business Process Engineering activity described required only the use of a relatively small subset of the complete set of E-MPM modelling concepts.

Table 2. Enriched multi-process modelling method.

	Outline description of modelling activities needed at each main step of the modelling method	Method and concepts used to 'structure' modelling activities and multiple process representations	Modelling techniques and tools deployed to represent and analyse modelled entities and their interrelationships
Stage 1: Elicit 'as is' process data from engineering partners	Elicit and record multiple understandings about current Business Processes deployed by the engineering partners, with the aim of developing a unified set of process representations that collectively form a static pool of enterprise knowledge that can be reused for various purposes	Developed approach to documenting alternative views of multiple Business Processes; held either within the heads of people responsible for different process segments or previously recorded in company documents. Structured interviews (which constitute an integral part of the approach) are organized with reference to the need to develop enhanced-CIMOSA, E-MPM conformant static and dynamic models	Various paper based sketches of E-MPM conformant 'domain processes', 'Business Processes' and 'enterprise activities' are developed to facilitate knowledge elicitation and multi-process documenta tion, leading to the development of static and dynamic models
Stage 2: Create and validate 'static views' (or representations) of 'AS-IS' processes	Reuse of elicited data to populate and validate multiple 'static views' of 'AS-IS' Business Processes that collectively and coherently provide a 'semantically rich picture' of relatively enduring enterprise entities and their interrelationships that can be reused by different enterprise personnel in support of their various roles	Static views captured and populated in conformance with enhanced-CIMOSA E-MPM diagramming templates and models needed to encode 'enterprise requirements'. Thus fragmented process views, at multiple levels of abstraction are organized into 'context', 'interaction', 'structure' and 'process' modelling templates pertaining to both partnership enterprises and individual partner businesses. Individual and collective validity of the views is rechecked with appropriate personnel	A structured approach to the use of a combined PowerPoint (general-purpose presentation software) and VISIO was developed to facilitate the generation of graphical (non-computer executable) representations of 'AS-IS' static model views, based on the use E-MPM modelling constructs. Use for this purpose of various specialist commercial tools (such as FIRST STEP, MO^2GO and METIS) was considered but not adopted

(*continued*)

Table 2. Continued.

	Outline description of modelling activities needed at each main step of the modelling method	Method and concepts used to 'structure' modelling activities and multiple process representations	Modelling techniques and tools deployed to represent and analyse modelled entities and their interrelationships
Stage 3: Develop and validate dynamic models pertaining to focused aspects of 'AS-IS' processes	Selected aspects of the static representations of 'AS-IS' processes are recoded into computer executable models with capability to simulate process operation and behaviours from some perspective and thereby provide new insights into 'AS-IS' process design, process resourcing and process operation. Initial dynamic model analysis and development is focused on model validation with subsequent analysis on identifying possible constraints arising from 'AS-IS' practice	Various general CIMOSA-based modelling concepts (pertaining to 'derivation', 'generation' and 'instantiation') were adopted in E-MPM and used to focus and structure dynamic model generation. However, use of these concepts and associated E-MPM decomposition principles needed to be translated into an alternative set of modelling concepts which can be practically implemented using a selected dynamic systems modelling tool	Various modelling studies have, for different purposes, generated alternative dynamic models using the *iThink* modelling tool, by recoding selected entities and entity relationships previously coded by the static base data. This yields computer executable models that simulate and display metricated dynamic behaviours in various programmable and interactive forms
Stage 4: Create static views of possible 'TO BE' processes	Reuses of the elicited data to develop static views of 'TO BE' Business Processes that collectively, coherently and agreed with enterprise personnel provide a 'semantically rich picture' of relatively enduring enterprise entities and their interrelationships that can be reused by different enterprise personnel in support of their various roles	Static views captured and populated in conformance with E-MPM diagramming templates for static models needed to encode 'enterprise requirements'. Thus fragmented process views, at multiple levels of abstraction are organized into 'context', 'interaction', 'structure' and 'process' modelling templates pertaining to both partnership enterprises and individual partner businesses. Models are agreed on with appropriate personnel in the enterprise	A structured approach to the use of a combined PowerPoint (general purpose presentation software) and VISIO was developed to facilitate the generation of graphical (non-computer executable) representations of 'AS-IS' static model views, based on the use E-MPM modelling constructs

Stage 5: Develop and validate dynamic models of focused aspects of possible 'TO-BE' processes	Based on knowledge of 'TO-BE' process properties (static), new business process scenarios are developed and are run under simulation. This provides metricated analysis of alternative: process designs; attributions of resources to process elements; and process operations	Use of E-MPM concepts help structure 'TO-BE' scenario generation. Use of enterprise activity and active and passive resource concepts help structure process resourcing activity. These and new concepts needed to be mapped onto modelling concepts and constructs made available by the selected dynamic systems modelling tool	Causal loop diagramming techniques and the *iThink* systems dynamic tool are used to 'visualize' and 'simulate' causal effects and the operation of various candidate 'TO-BE' scenarios. This enables conceptual thinking and focused simulation of possible 'TO-BE' behaviours and metrictated performance measurement made relative to 'AS-IS' benchmarks
Stage 6: Modularizing 'TO-BE' processes	Creates modules of enterprise activities based on dependencies they have among themselves within a process class and between two process classes thus realizing intra- and inter-process modules of enterprise working	Information contained in Static views of TO-BE processes was reused to identify process modules using E-MPM module identification method	E-MPM module identification method was deployed to identify process modules using Excel Spreadsheet as a tool to support concepts
Stage 7: Focused deployment and use of static and dynamic process models to control actual workflows	One important potential use of 'AS-IS' and 'TO-BE' static and dynamic process models is to manage and control workflows. At this stage of the modelling method, selected model fragments (previously captured and validated) are recoded so that they can be executed (in a suitable workflow tool). This allows computer executable models to be linked to the actual process and its resource entities	E-MPM decomposition principles, particularly its active resource, passive resource modelling concepts and adopted modelling concepts (from CIMOSA) instantiation, enterprise activity, functional entity, information object and enterprise event are used to partially structure the reuse of previously coded process knowledge into recoded forms (namely control flows and data flows) that need to be enacted by the set of modelling constructs provided by the selected workflow tool	The *iFlow* workflow management tool was selected to operationalize focused workflow aspects of the 'AS-IS' and 'TO-BE' process models previously captured, validated and analysed

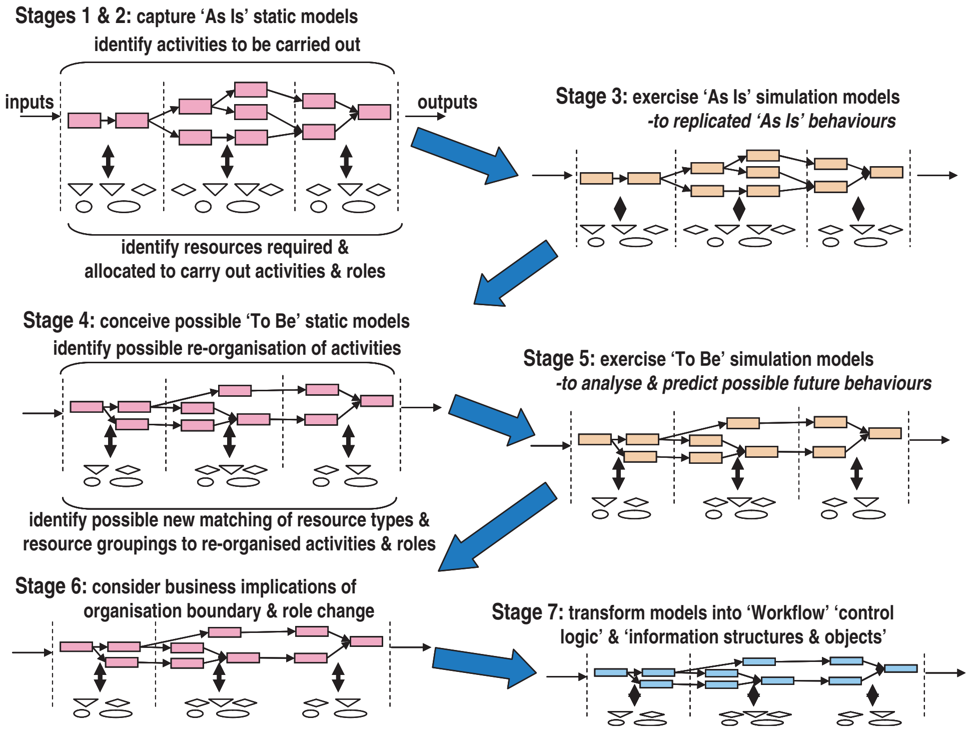


Figure 3. Common model transformations enabled by E-MPM.

5.1 *Static models*

When applying the E-MPM method, initially the following general modelling steps are recommended:

- Interview sessions with process owners in the ME under study should identify and initiate analysis of: the primary activity flows needed to 'obtain product orders' from ME customers; 'realize product orders' in conformance with customer requirements; and to 'manage order generation and order fulfilment'. During interview sessions E-MPM modellers should also gain general understandings about the full network of Business Processes and Pseudo Business Processes used by the ME to: engineer new products and services; provide infrastructural support for direct value generating processes; and determine and realize changes in strategic intent. The process understandings generated should illustrate process outcomes, cycle times, etc. Also, identified and analysed should be key causal and temporal activity flows of the ME. Further interview discussion should be centred on identifying and characterizing process-related concerns of process owners.
- Having gained an initial understanding of the overall network of Business Processes and Pseudo Business Processes used by the ME, specific process data is elicited and marshalled. Data elicitation is achieved in an organized and tabular form so that graphical modelling templates can be populated

by E-MPM modellers. Here general modelling principles of E-MPM (many of which are inherited from CIMOSA) are applied by deploying Visio^{TM} and PowerPoint graphical modelling tools to create an Enterprise Model (EM) which encodes relatively enduring characteristics of the 'as is' processes used by the ME under study.

The 'as is' EM so created constitutes a formal decomposition of the ME processes studied. That decomposition comprises (causally and temporally) dependent process segments (and their elemental activities) using decomposition formalism specified originally by CIMOSA. This requires the capture of information about starting events and end events of process elements. It is also necessary to elicit and represent information about 'active resources' (i.e. human and technical resources that can directly realize activities) required to carry out process elements, and about the passive-used and passive-processed resources that need to be transformed into products or need to be used to support those transformations. To enable semantic enrichment of Enterprise Models captured using E-MPM, new modelling formalisms were defined with respect to resource types, such that they complement previously defined CIMOSA modelling formalisms. The importance of this modelling enhancement was as follows.

Like CIMOSA, E-MPM makes use of 'Context Diagram', 'Interaction Diagram' and 'Structure Diagram' modelling formalisms. However, it replaces the use of CIMOSA 'Activity Diagrams' with E-MPM 'Process Diagrams' which were developed by the present authors to facilitate the transformation of Enterprise Models into coherent simulation and workflow models.

'Context Diagrams' are used to define the scope of Enterprise Models and to organize process models into interrelated CIMOSA-conformant and non-CIMOSA conformant domains, the former being domains of concern that are modelled in detail. They are decomposed as required into more detailed (lower-level) 'Context Diagrams', so as to model reality more completely within the domains. A typical domain might be a business unit, department or cell of the modelled ME. E-MPM modellers determine so-called domain processes that contribute to the specific network of ME processes being modelled. Normally execution of the domain processes identified will be well decoupled from the execution of other domain processes, in the sense that well-defined interactions between modelled domain processes occur and can be characterized in terms of event and material, information and other resource interchanges. Domains are also characterized in terms of their objectives and owners. Interactions between domain processes are explicitly captured by E-MPM modellers using 'Interaction Diagrams'. Those interactions are normally modelled in terms of the exchange of information, human resource and/or physical resources where such an exchange is triggered by specified events. Domain processes are typically decomposed into subdomain processes comprising CIMOSA conformant Business Processes and enterprise activities. Hence, the CIMOSA decomposition rule that a domain process may be decomposed into Business Processes and enterprise activities is deployed to (1) break down the EM into 'manageable chunks' and, later, (2) structure and enable understandings about the integrated working of the ME as a holistic unit. Specifics of the way in which domain process are decomposed into Business Processes and enterprise activities, characterizes the way that activity flows occur (individually and collectively) within a domain under study. Interactions amongst ‘Business Processes’ are formally captured by the E-MPM modeller by creating ‘sub-Interaction Diagrams’. Business Processes and enterprise activities belonging to a domain process should, therefore, collectively fulfil its purpose and objectives, and thereby realize its deliverables. CIMOSA ‘Business Processes’ are similar to domain processes in concept. However, the prime difference being that domain processes can be triggered by an event which impacts on its parent domain, whereas Business Processes need to be triggered in conformance with the defined process logic of its parent domain process. Business process specifications also require a well-defined ending status which again is typically defined by the parent domain process logic. Enterprise activities constitute ‘atomic’ units of activity to be considered by the E-MPM modeller. Enterprise activities exist to transform inputs into outputs and they require active resources (i.e. human, machine and IT system) and passive resources (i.e. material, data, information) to realize their purpose.

Also, in conformance with CIMOSA modelling conventions, E-MPM modellers use Structure Diagrams to define and organize explicitly Business Processes and enterprise activities that constitute a domain process. In various industry case studies, Structure Diagrams were attributed usefully and formally relatively enduring (or static) organizational relationships that couple process elements. However, the combined use of CIMOSA Structure Diagrams and CIMOSA Activity Diagrams was observed to be limited, if enterprise modelling is viewed as being a first step (of decomposing and formally defining characteristics of a specific ME) which individually leads to subsequent secondary steps; centred on creating more focused simulation and workflow models which can be computer-executed so as to analyse and predict the relative performances of different combined pairs of (process logic) and (human and technical resource system) when subjected to historical and possible future patterns of workload. This observed deficiency and the desires of the authors to facilitate dynamic (time dependent) modelling of specific (real and very complex) case study MEs was the prime motivation for enabling the use of ‘E-MPM process diagrams’ as an alternative to ‘CIMOSA Activity Diagrams’.

E-MPM process diagrams were conceived to define explicitly precedence links amongst Business Processes and enterprise activities of domain processes and their relationships with active and passive resources. The E-MPM modeller creates specific process diagrams using a well-defined set of modelling constructs which are particularized within a modelling template by case data. The additional process semantics encoded in this way facilitated model transformations between enterprise models and related simulation and workflow models derived to a significant extent from semantic information encoded by process diagrams.

Figure 4 is included to help visualize how E-MPM modelling constructs can be used to create process diagrams. The particular process segment illustrated is used, in conjunction with many other causally and temporally dependent process segments, to design, implement and change car engine assembly plants around the world. Uses of this illustrative process diagram will be considered in the next subsection.

5.2 *Resource selection method*

Having used E-MPM diagramming templates to capture relatively enduring properties of a number of specific ME process networks, it was observed by the

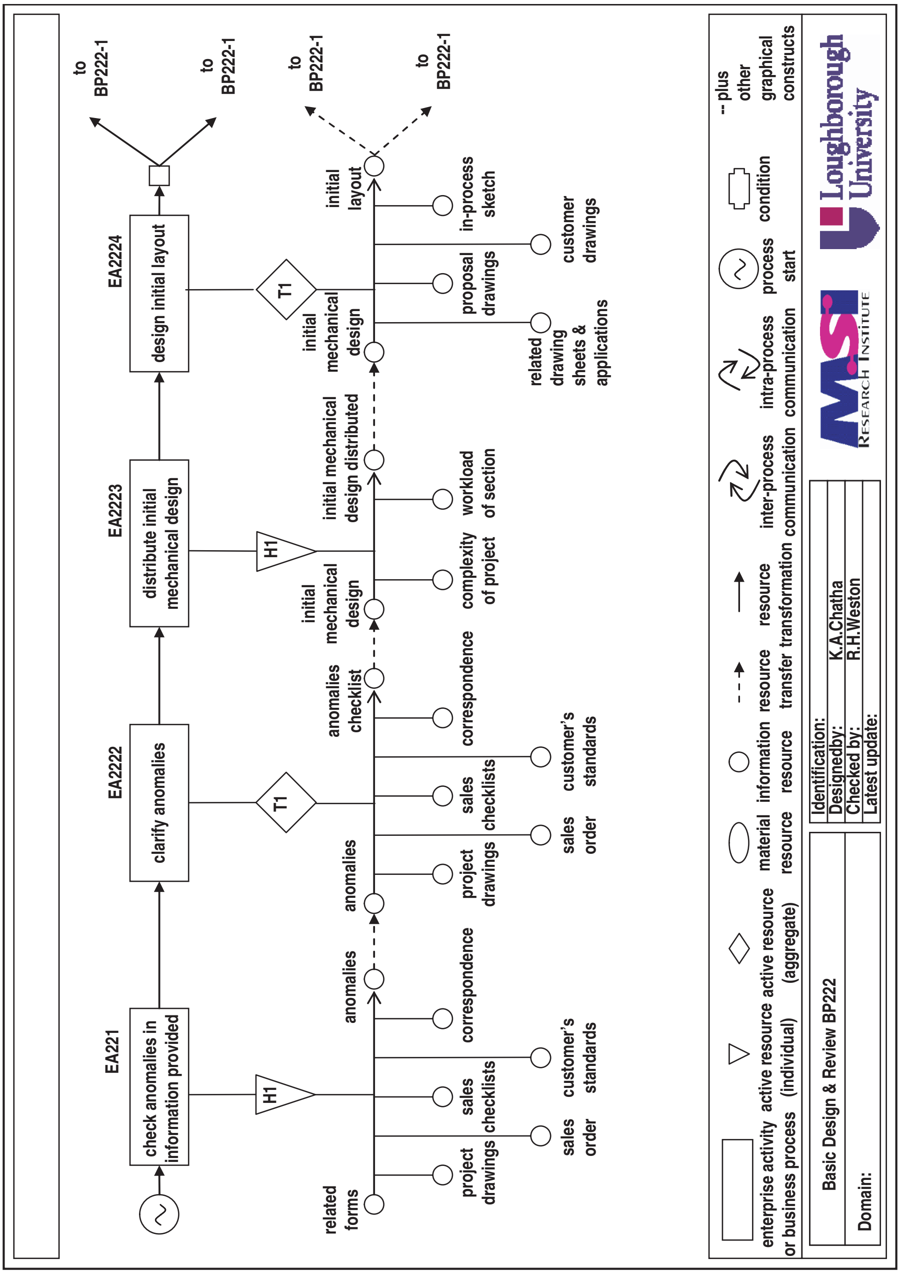


Figure 4. Example of a static model created using E-MPM activity modelling formalisms.

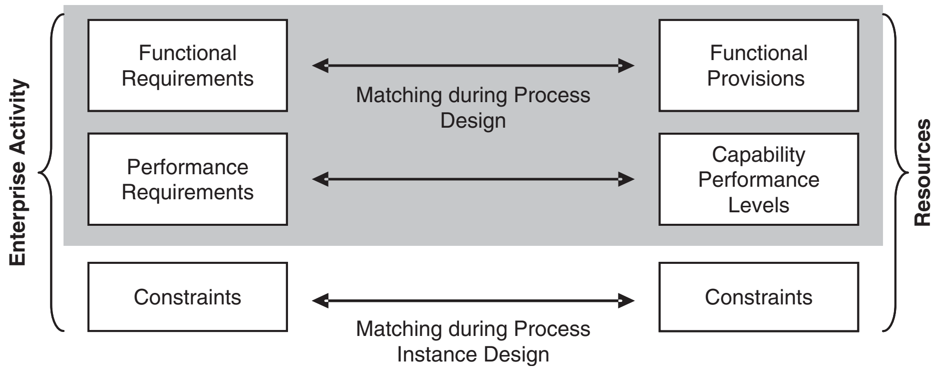


Figure 5. Matching between enterprise activities and resources.

authors that a new 'role based' resource selection method could be defined and used to select resources with capabilities needed to carry out organized groupings of enterprise activities. During process modelling, specific enterprise activity requirements of case study MEs are described in terms of their process logic. This defines precedence relationships, information and other interchanges, etc. Similarly using E-MPM modelling formalisms required resource capabilities that can be defined in terms of functional abilities they need to possess, the performance levels with which they need to fulfil those functions and other run-time constraints. Hence, central to a new resource selection method can be a process of finding viable candidate human and technical resources that can realize the needed capabilities identified by E-MPM defined process logics. Once a match is made between enterprise activity requirements and (potential) resource provisions in an organizational subsystem, appropriate resources can be 'requisitioned' and allocated to activities. Such a matching between enterprise activity requirements and resource provisions can naturally be carried out in two steps: (1) at process design time and (2) at process instantiation time (figure 5). At process design time (required and possessed), functionalities and performances are matched. Whilst (time-dependent) constraints are matched at process instantiation times. Therefore, E-MPM can provide the basis of an explicit role based resource selection method which can be deployed to determine those resources that can successfully carry out activities based on functional and performance requirements. Whereas simulation modelling can be used predominantly to match temporal constraints.

A number of resource selection methods have been investigated by the authors. One such method was operationalized using Excel spreadsheets (figure 6). The functional and performance requirements of enterprise activities shown in the example process of figure 4 were generated and validated by case study company personnel. Also, potential resource capabilities were identified and formally captured by interviewing human resources and reviewing equipment documentation. A comparison was made between activity requirements and resource provisions and based on this comparison resources were given ratings (figure 6). Based on the ratings specified, resources that have highest ratings are allocated to activities.

Functional Requirements	Capability Level
Function - 1	1
Function - 2	3
Function - 3	2
Function - 4	4
Function - 5	2
Function - 6	2
Function - 7	4
Function - 8	5
Function - 9	3
Function - 10	5
Function - 11	1
Function - 12	2
Function - 13	1
Function - 14	2
Function - 15	1

Functions Available	Capability Level									
	AR-1	AR-2	AR-3	AR-4	AR-5	AR-6	AR-7	AR-8	AR-9	AR-10
Function - 1	1	2	2	1	5	1	3	3	4	4
Function - 2	4	1	1	2	2	2	3	2	2	4
Function - 3	2	2	4	3	4	4	3	5	1	5
Function - 4	3	4	3	4	3	5	2	4	4	2
Function - 5	5	5	3	2	2	3	1	1	2	3
Function - 6	2	3	3	1	2	3	2	2	1	1
Function - 7	1	2	5	3	2	4	3	3	4	1
Function - 8	2	5	5	1	2	2	1	1	2	2
Function - 9	5	1	2	2	3	3	2	4	1	5
Function - 10	3	3	2	1	4	1	3	5	3	4
Function - 11	4	3	4	4	5	1	1	1	5	3
Function - 12	2	4	1	2	3	3	2	2	2	2
Function - 13	1	2	3	3	5	2	4	3	1	1
Function - 14	1	1	2	1	4	1	5	1	1	5
Function - 15	3	5	4	2	2	1	2	2	5	1

Functions Available	Differences in Performance Level									
	AR-1	AR-2	AR-3	AR-4	AR-5	AR-6	AR-7	AR-8	AR-9	AR-10
Function - 1	0	1	1	0	4	0	2	2	3	3
Function - 2	1	–2	–2	–1	–1	–1	0	–1	–1	1
Function - 3	0	0	2	1	2	2	1	3	–1	3
Function - 4	–1	0	–1	0	–1	1	–2	0	0	–2
Function - 5	3	3	1	0	0	1	–1	–1	0	1
Function - 6	0	1	1	–1	0	1	0	0	–1	–1
Function - 7	–3	–2	1	–1	–2	0	–1	–1	0	–3
Function - 8	–3	0	0	–4	–3	–3	–4	–4	–3	–3
Function - 9	2	–2	–1	–1	0	0	–1	1	–2	2
Function - 10	–2	–2	–3	–4	–1	–4	–2	0	–2	–1
Function - 11	3	2	3	3	4	0	0	0	4	2
Function - 12	0	2	–1	0	1	1	0	0	0	0
Function - 13	3	1	2	2	4	1	3	2	0	0
Function - 14	–1	–1	0	–1	2	–1	3	–1	–1	3
Function - 15	2	4	3	1	1	0	1	1	4	0

Cummulative Shortcomings, Over Capabilities, and Matched Capabilities										
	AR-1	AR-2	AR-3	AR-4	AR-5	AR-6	AR-7	AR-8	AR-9	AR-10
Cummulative Shortcomings	–10	–9	–8	–13	–8	–9	–11	–8	–11	–10
Cummulative Over Capabilities	11	14	14	7	18	7	10	9	11	15
Number of Equal Capabilities	5	3	2	4	3	5	4	5	5	3
Ratings	4	7	9	1	10	6	2	8	3	5

Figure 6. Example application of resource selection method.

5.3 *Simulation modelling*

It was observed that computer executable models of processes resourced by alternative candidate human and technical systems are commonly needed when designing and changing MEs. This observation was based on the reasoning that static models alone do not provide qualitative means of exercising 'what if' thinking, and nor do they directly encode certain real time working concerns, such as about how individuals or dependent processes might alternatively behave in response to changes in process inputs, process flows, operating conditions and so forth. Hence, E-MPM was conceived as an approach to ME modelling which led to the development and reuse of combined enterprise, simulation and workflow models. Here it was also observed that different kinds of simulation model could support different life phases of ME processes. This helped in establishing the scope of simulation in the context of E-MPM modelling (table 3). Subsequent development and case study use of E-MPM derived simulation models by the authors has proven effective in quantifying and predicting process behaviours in support of ME process (re)design, process resourcing, process optimization and process monitoring and control. During process (re)design simulation modelling supports an analysis of AS-IS process behaviour, and the improved understandings developed have helped identify desired ME configurations and work pattern loadings, by computers

Table 3. Comparative scope of enterprise modelling and simulation modelling in support of the life cycle engineering of ME processes.

Life cycle engineering phases	Enterprise modelling	Simulation modelling
Specification	Static models for capturing AS-IS Business Processes	–
(Re)design	Static models to identify problems with respect to the AS-IS process logics, such as unnecessary wastes	AS-IS Simulation Models can replicate AS-IS Business Process behaviours and suggest TO-BE scenarios for improvement
Resource	Static methods help classify resource system requirements, in terms of needed competencies and capacities	Feasible Resource Simulation Models can help determine the types and numbers of resources needed
Optimize	–	Feasible Resource Simulation Models can help optimize Business Processes subject to process lead-time, cost and value generation criteria
Implement	–	–
Operate	–	–
Monitor and control	–	Progress Monitoring Simulation Models can facilitate monitoring of the progress of Business Processes
Improve	–	Finalized Simulation Models can help predict possible implications of minor changes to Business Processes

exercising different combinations of process logics and resource systems and quantifying impacts of design decisions in relation to possible future TO-BE scenarios. Simulation models can help modellers and process owners to analyse and predict changes in process performances, e.g. in terms of lead-times and costs. During the process optimization stages of projects, Business Process lead-times, resource requirements, value generation and cost consumption can be analysed and improved. Once a feasible Business Process has been developed and is used in the field, simulation models can help to monitor the progress of operating Business Processes to help ensure that necessary management, maintenance and development actions are taken. When working successfully simulated process, resource system and work pattern models can act as a virtual knowledge base about real Business Processes, leading to improved opportunity to make relatively minor Business Process Improvements on a continuing basis. Here, suggested changes in the virtual environment can be trialled and likely outcomes assessed before those changes are adopted in the field.

It was observed that significant benefit could accrue if simulation models are systematically (and possibly semi-automatically) generated from static process diagrams of the type described in section 6.1. Therefore, the authors sought to derive formal mappings between (1) generic process model building blocks and (2) equivalent *iThink* model building blocks. (Because of limited research resources, during initial E-MPM conception and development, simulation modelling was targeted at the use of the *iThink* modelling tool (www.hps-inc.com). Previous experience of *iThink* was found to enable simulation modelling at different levels of abstraction in support of various life phases of Business Processes. Later research, not reported in this paper, has targeted simulation modelling on other commercial discrete event simulators.) This required a detailed understanding of *iThink* model building blocks. Also, it was necessary to describe formally transformations between modelling constructs that facilitate *iThink* model generation from E-MPM process diagrams. Transforming static process models into dynamic simulation models was found (1) to require the modeller to expend significant periods of time on understanding commonalities and differences between concepts underlying the two sets of modelling constructs involved and (2) to find ways of mapping between these constructs, structuring simulation models appropriately and populating simulation models with specific case information not encoded by the process diagrams involved. This was observed to require the development of an alternative process model structure that can be executed by the specific simulation tool (subject to its model representation and execution capabilities) and to compensate for any information loss during this process. It was observed but not scientifically proven that should modelling tools become available, to transform readily and rapidly static enterprise models into simulation models without significant structural change or information loss, then better and faster Business Process Engineering will result.

Consider once more the example segment of a Business Process shown in figure 4. As explained in section 6.1, this 'Basic Design and Review Process BP222' is currently used (by an engineering company) in conjunction with many dependent Business Process segments to engineer manufacturing facilities. An *iThink* simulation model of BP222 was created to investigate alternative ways of resourcing the process logic described by figure 4; appendix 1 illustrates the simulation model created for this purpose. To quantify effects of using different resources on the lead-time of different EAs (e.g. the 'Check Anomalies' enterprise activity), and to enable selection of an appropriate resource (system) from among candidates; suitable human resource systems were observed with respect to the real Business Process and were subsequently categorized with respect to their potential to realize one or more of four competency classes: C1–4. Competency attributes associated with those classes were defined (Ajaefobi 2004) as follows:

- C1: Competency to execute some defined set of general operational activities based on already specified articulated methods, procedures and order of operation.
- C2: Competency to understand, interpret and translate concepts, designs, plans, methods, procedures linked to a specific scenario and to apply them when solving practical problems.
- C3: Competency required to translate abstract concepts into those tangible realities (through design, design analysis, process plan development, methodology specifications, development of operational plans and procedures, etc.) needed to realize products and services.
- C4: Competency needed to set goals, define and articulate missions, policies and principles for an organization to motivate, mobilize, harness and channel the available but scarce resources towards achieving specified goals.

Discussion with the case company also highlighted that specific people possessing those competencies would vary in their ability (or desire) to perform. Hence, three levels of performance (L1–3) were conceived which were considered to be sufficient to model different performance levels that individuals with different competencies exhibit when carrying out specified enterprise activities. Here performance ratings were derived by multiplying assigned ratings for: autonomy, output quality, flexibility and experience ratings assigned to individuals. Numerical values were assigned to these factors. When these numerical values were multiplied together, the product was used as a quantitative performance rating for a particular class and level. Similarly, when creating the simulation models different performance ratings can be aligned to different paces at which a job may need to be carried out. This information is useful because if the work content of an enterprise activity is known, the time taken by a particular class and level of human resource to carry out that enterprise activity can be calculated using the formula:

$$\text{Time Taken (Class, Levels)} = \frac{\text{Work\_Contents (Class, Levels)}}{\text{Pace (Class, Levels)}}.$$

For example, if the work content of an enterprise activity is 10 units, and the pace of individuals belonging to C1 levels L1–3 are, respectively, 1.25, 2.5 and 5 units, then the time taken by individuals belonging to C1 levels L1–3 will be 8, 4 and 2 units, respectively. It should be kept in mind that the intention when conducting E-MPM modelling in this case was not to identify those factors that define the performance of an individual belonging to a particular class and level. Here only logic is defined so that if a performance rating is known and a pace can be rated, then the time can be ascertained for each class and level of individual.

When values are assigned to different variables of this enterprise-activity model, the modeller can realize a number of beneficial results. From amongst these results,

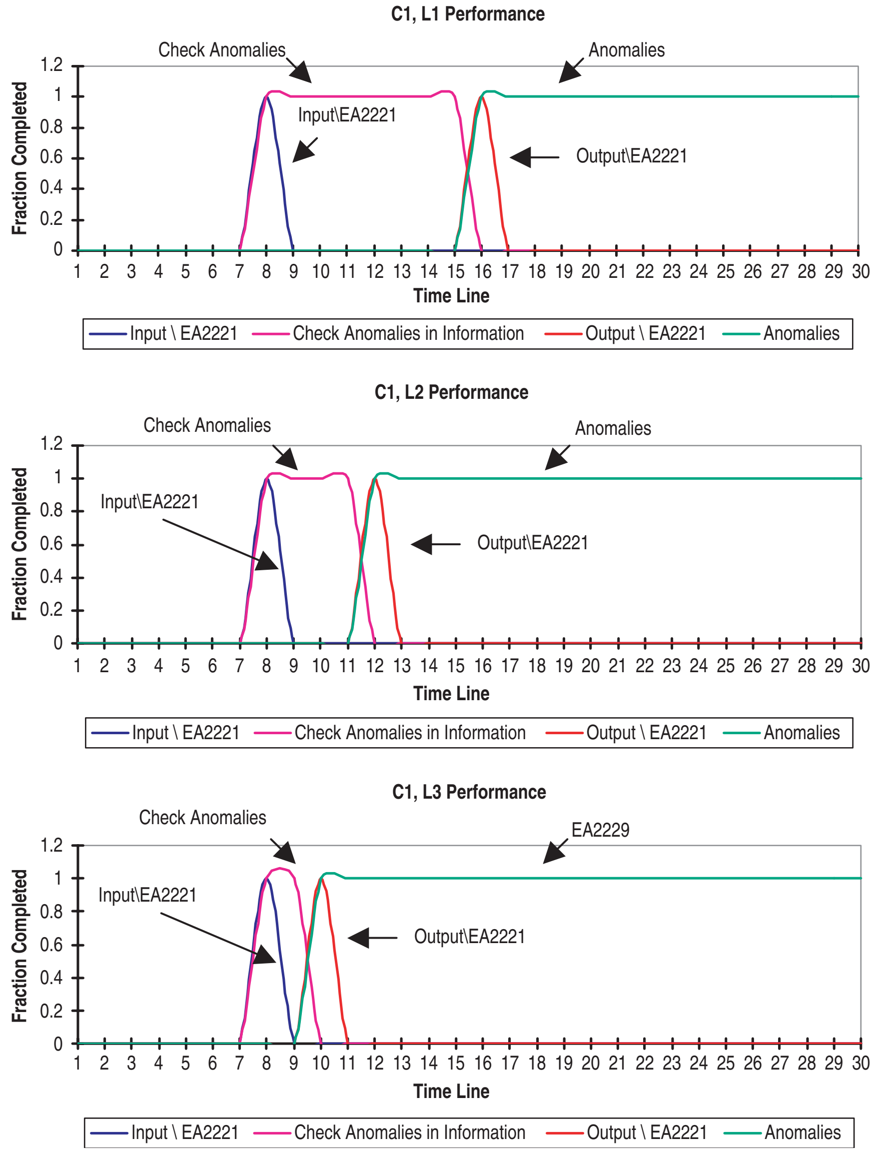


Figure 7. Performance achieved by different levels within the same competency class.

figure 7 compares the performance of individuals with C1 competency that have different performance attributes. For the same EA, a person with performance level L1 takes 8 units of time, while a person with L2 and L3 levels will take 4 and 2 units of time, respectively. This developed charting technique has proven particularly useful when predicting 'activity start and completion times' and the 'time taken' by active resources, and when calculating the resultant effect on the overall process time line (i.e. process lead-times). The approach provides opportunities for process designers to select from amongst classes and levels of human resource that can feasibly (time-based) carry out enterprise activities.

By repeatedly following these steps to create interconnected models of EAs that run in an *iThink* simulation environment, many different resource models have been created and their operation simulated. This has enabled lead-time predictions to be made about a number of Business Processes used by the vendor of car engine assembly production lines.

For the complete 'Basic Design and Review Process (BP222)' an *iThink* simulation model (time based) was created and some of the output graphs produced by the simulation model are included in this paper to illustrate the assistance given to a process designer (in terms of suggesting information and activity structures) during the selection of resources, and when developing process structures, taking into consideration specific time constraints.

Suppose the process designer needs to choose from among a number of C1 active resources. For this purpose, four graphs can be generated to contrast and compare the feasibility of alternative resources (figure 8). The top graph informs the designer about standard completion times of the process (and its sub processes and enterprise activities). The graph second from top informs the designer about the performance of persons with C1, L1 attributes and, therefore, about those enterprise activities or Business Process segments he/she can complete in a given timeframe. The third graph provides relative information for a C1, L2 person; while the fourth graph provides relative information for C1, L3 individuals. Now the second graph from top shows that resource of capabilities C1, L1 can perform only one activity, i.e. EA2221. The third graph from top shows that resource with capabilities C1, L2 can perform activities EA2221, EA2222, EA2223, EA2224, and sub-Business Processes BP222-1 and BP222-2. Whereas the fourth graph from top shows that resources with capabilities C1, L3 can perform all the activities and sub-Business Processes in this process thread. The distance along the timeline in each graph shows how long resources belonging to different capabilities will take to carry out specific activities. Hence, a process designer can choose resources that satisfy designated time constraints. For example, if the process needs to be completed in shortest time possible, then all resources belonging to C1, L3 can be allocated to the process. However, allocating all C1, L3 resource types to a process may result into higher process costs. For this reason, the model was further enriched by taking into consideration time and cost based feasibility criteria. However, the enriched model has not been reproduced here because of space limitations of the paper. In their research, the present authors have shown that by using a combined time- and cost-based feasibility simulation model the process designer can optimize Business Processes in terms of their execution times and resource costs.

Once feasible resources have been selected and a Business Process design has been finalized and delivered, the process designer can produce and use a Progress Monitoring Model, such as the example model shown in appendix 2. When actual field values are inserted in this model usable results can be obtained. To monitor progress, the process designer is presented with a display indicating the overall resource requirements in the executing Business Process, in the form shown in figure 9. Such a graph quantifies the active resources required as and when they are required. Now when the process starts and each active resource becomes

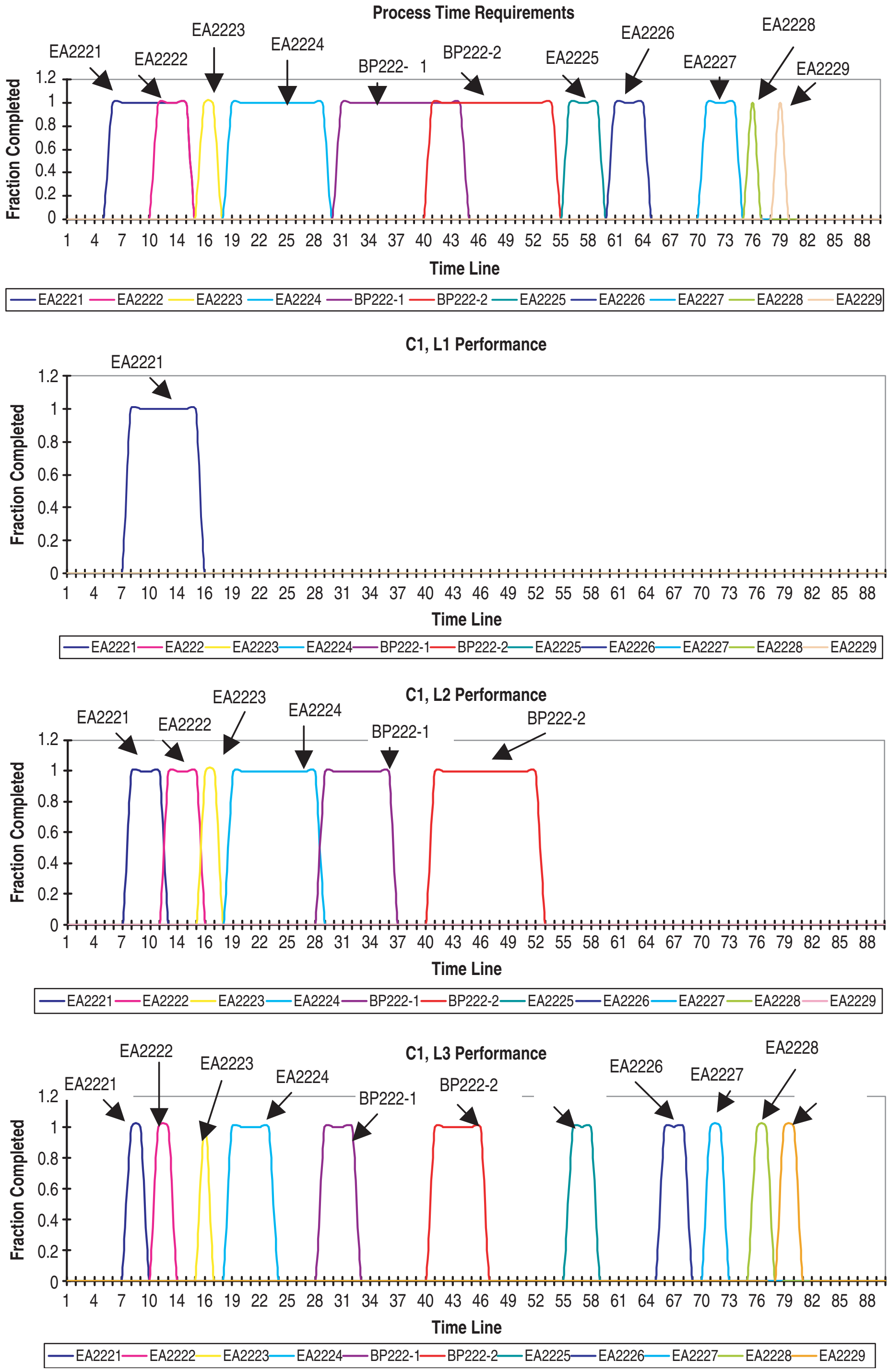


Figure 8. Time requirements and resource performances.

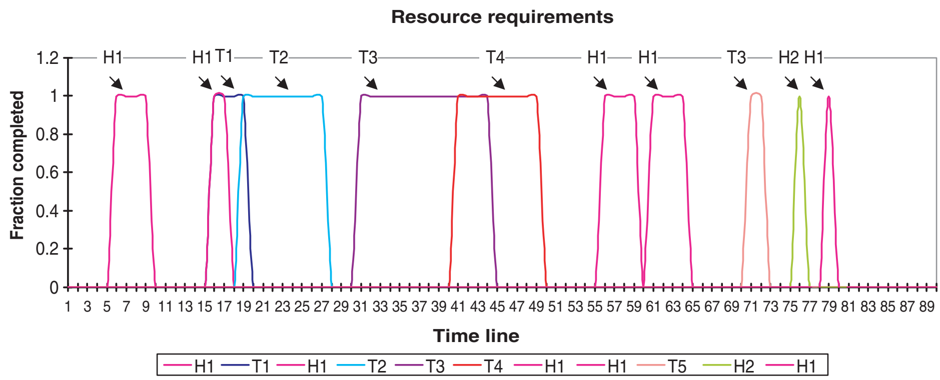


Figure 9. Active resource requirements for an example process.

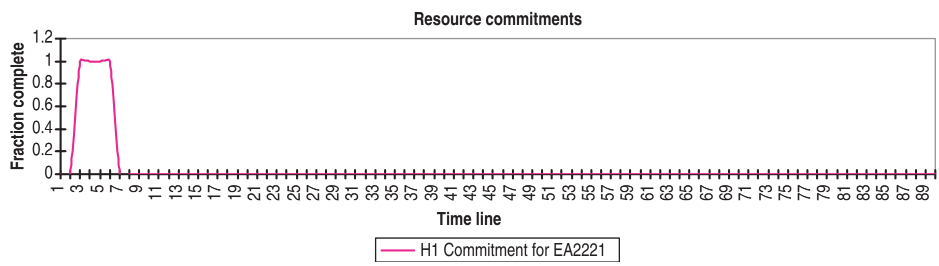


Figure 10. Arrival of H1 at time = 2.

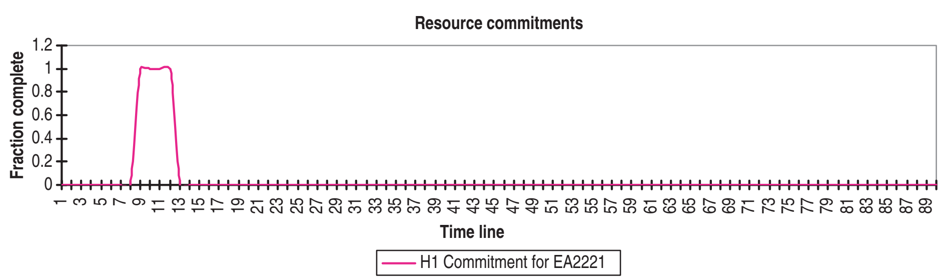


Figure 11. Arrival of H1 at time = 8.

available, the process designer can insert actual starting time in the model used to monitor the progress of the specific Business Process. For example, if H1 arrives at time = 2, the process designer will insert this value in the 'time available/lower limit', and will then run the simulation. The resultant output for the first activity can take the form shown in figure 10. And if H1 arrives at time = 8, the activity will be completed at times shown in figure 11.

It can be concluded from these results that simulation modelling derived from a parent enterprise model can contribute lifecycle engineering support to Business Processes deployed by specific manufacturing enterprises. Special reference is made in this paper to the provision of analytical support for process resourcing, process optimization and process monitoring and control. However, the combined use of enterprise and simulation models can also lend support to all life phases of Business Processes identified in figure 1.

5.4 *Workflow models*

During the development of E-MPM (and its MPM predecessor), the prime concern was to help systemize and realize the specification, management and control of actual Business Processes used for strategic, tactical and operational purposes in organizations. However, it was understood that research and development efforts worldwide had created workflow systems that can overlay 'controls' onto operating instances of Business Processes. For example, appropriate use of workflow systems was known to be able to help reduce overly long resource system design and build lead-times, and impacts of late change to resource system designs. Similarly workflow systems can be developed and workflow instances can run at a strategic level to help coordinate and control business planning, and strategy making processes in and across organizations. Hence, the authors decided to enhance further E-MPM to facilitate the generation of context-dependent workflow models. At a seventh stage of E-MPM modelling, CIMOSA concepts (related to model instantiation) were used to lend structure to the capture and description of workflow models that can be enacted by an 'off the shelf' workflow management tool, namely the *i-Flow*™ tool.

Once a specific process segment has been designed and resourced (and approved by process owners) workflow models can be generated that will facilitate coordination and control of the real Business Process in the field. Existing workflow technology has capabilities to coordinate the operation of resources by placing control over their working. Figure 12 shows an example workflow model created by transforming the process diagram shown in figure 5 into an equivalent model that can be executed by the commercial *iFlow* tool.

6. Discussion

Previous subsections described the development and application of different types of model that can be used during different life phases of Business Process Engineering projects. It is recommended that process design and feasible resourcing models are developed by process designers, and once a measure of optimization has been achieved with respect to the selection and attribution of resource systems, the generated simulation model is delivered to process actors involved in actually running the process segment(s) involved. Similarly, process progress monitoring models developed by process designers can be delivered to process supervisors to enable them to input values interactively during process run-time in order to monitor and enact change to the progress of the Business Process concerned. During Business Process run-time, this will provide useful information to the process supervisor,

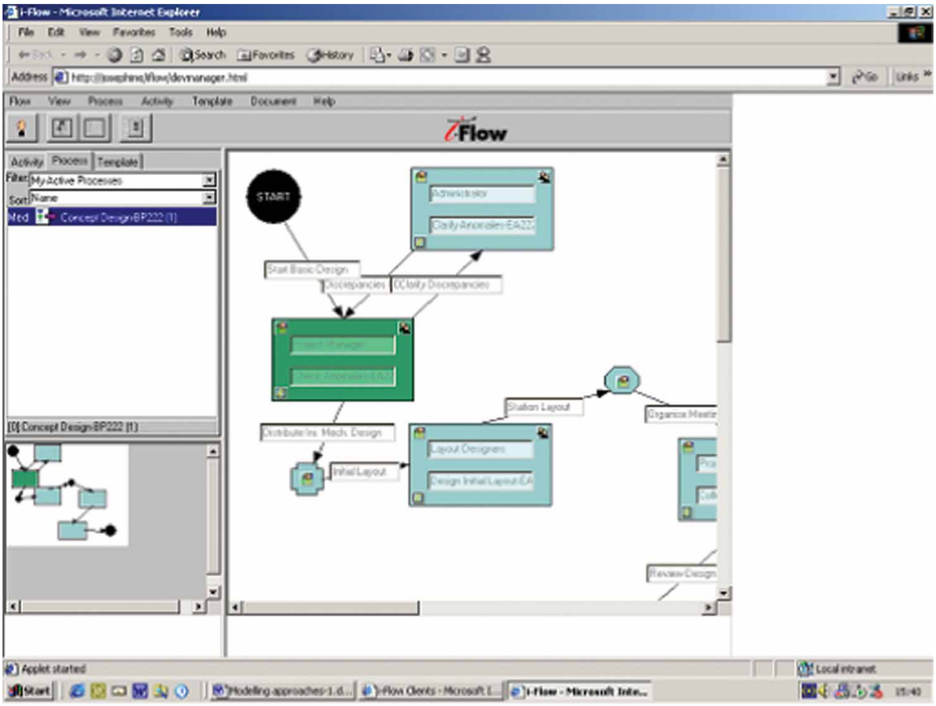


Figure 12. Example workflow model developed in *i-Flow*.

regarding Business Process completion times or potential bottlenecks. If process supervisors think that a Business Process is not going to complete within a defined process deadline, they can make changes to allocated resources so that task realization can be accelerated or otherwise process supervisors may divide the task between resource groups.

The case study E-MPM models described in this paper do not cover all life cycle engineering requirements of ME processes. However, they do illustrate key, in context, enterprise and simulation modelling that can facilitate important aspects of BPR and BPI projects. In this respect, the paper advances the literature in its field. Common ME Business Process and Pseudo Business Process interactions amongst different process actors (including process designers, process supervisors and process participants), reveals that valuable support is provided that allows actors with differing organizational roles and responsibilities to work coherently and interactively, despite their different time frames of concern. This capability arises primarily because the model forms they use are derived from a common enterprise model. Achieving mappings from static models to simulation models was observed to involve complex processes, requiring significant knowledge of simulation tools and expertise in mapping phenomenon. It also requires restructuring of models and compensation for information loss. In some situations, it may be fruitful and feasible to autogenerate simulation models from a 'common' enterprise knowledge base, such as that coded by E-MPM's static modelling templates. Modules of simulation models can be incorporated into libraries, which can be attached to basic simulation models designed for different purposes, having been mapped automatically from static models. This kind of approach has been observed to reduce significantly the man-hours required to develop different purposeful simulation models from a common contextual model.

This paper adds to the knowledge of enterprise modelling discipline by introducing an E-MPM approach that consists of three parts (1) an E-MPM method for re-engineering ME processes, (2) an E-MPM modelling framework that builds upon and extends the state of the art CIMOSA modelling framework by organizing the use of complementary modelling concepts related to complex manufacturing enterprises, and (3) an E-MPM environment that brings together a number of public domain software tools that support the practical application of these concepts. Moreover, this paper characterizes key aspects of Business Processes deployed by MEs, defines common life phases and shows how E-MPM can lend analytical and operational support for some of these phases which is over and above support previously described by the enterprise engineering literature. Many concepts embedded into the E-MPM approach are equally applicable to Business Processes deployed by service and manufacturing organizations. For example, a number of E-MPM concepts have been tested when redesigning Student Admission Process of Pan-American University (Worley *et al*. 2005).

The present paper also illustrates generic examples of how enterprise modelling, simulation modelling and workflow modelling can play different but important complementary roles during Business Process Engineering projects. Information flows to and fro among these tools should lead to better process designs and more rapid and holistic realization of Business Process change. In principle, it can lead to virtual prototyping of organizations and should help predict viable organizational futures when faced with uncertain environmental factors.

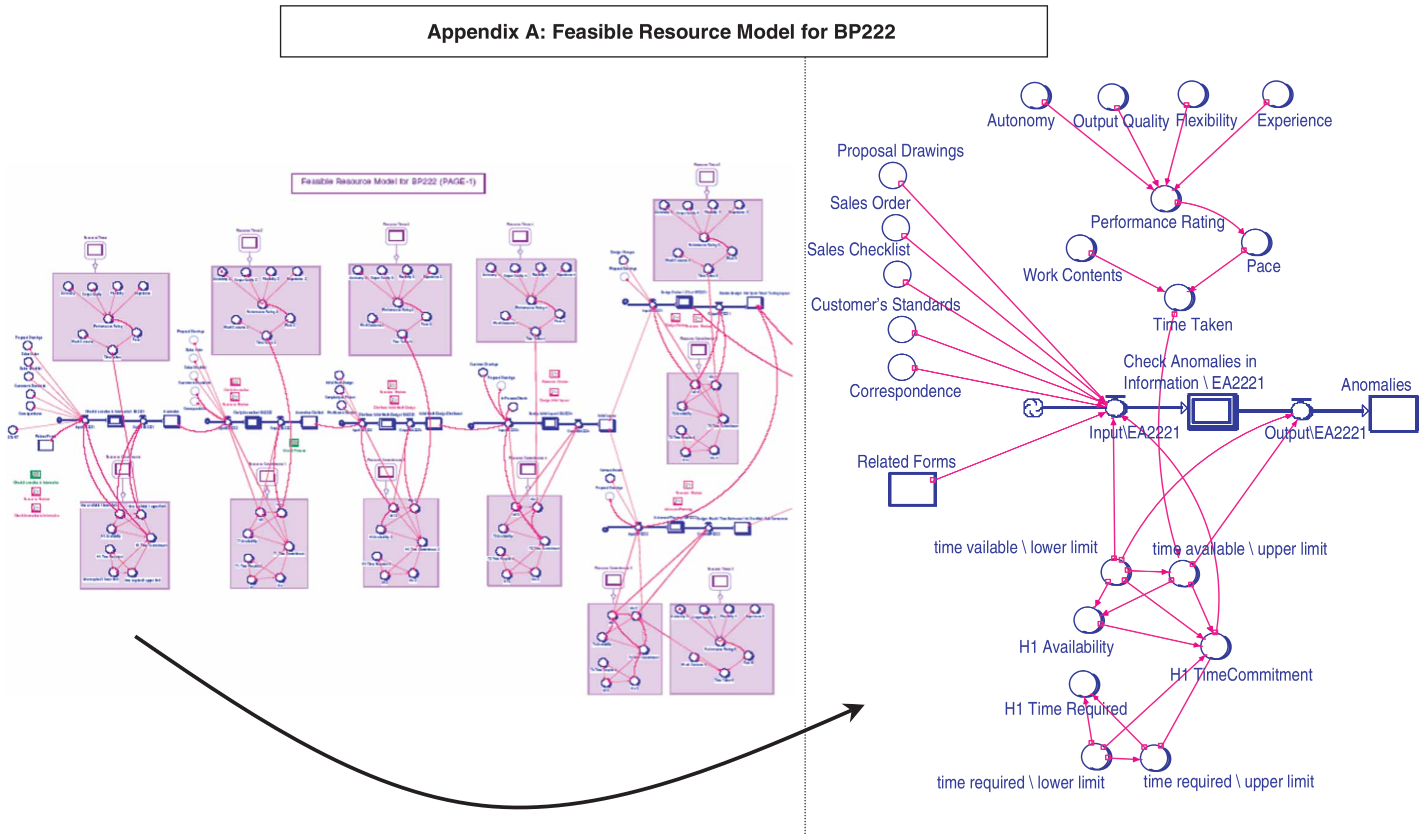
7. Observed strength and weakness of E-MPM

E-MPM combines the use of selected enterprise modelling, simulation modelling and workflow modelling techniques in a coherent, albeit unique, way. That combination of techniques has proven to possess synergistic capabilities that satisfy the three generic modelling requirements listed in section 2.2. Further, in a number of real industrial cases involving both large and small MEs, E-MPM has successfully been used to support all life phases of Business Processes depicted by figure 1. In these respects, the application of E-MPM reported in this paper represents an advance in current Business Process Engineering best practice. In this paper, though it has only been possible to illustrate life cycle engineering benefits realized in respect of one segment of a Business Process currently deployed by a large ME.

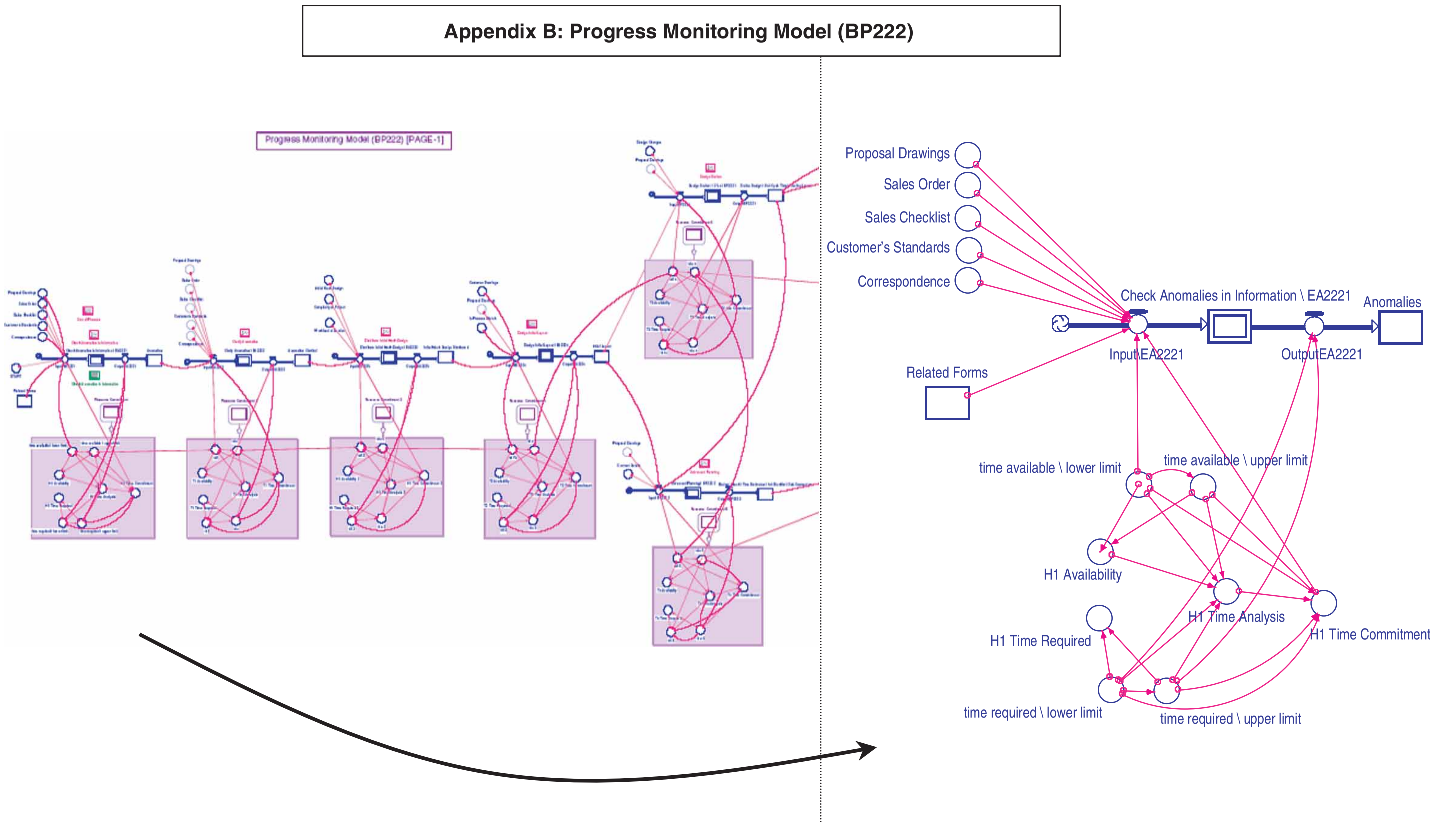
Significant new research is required to evaluate formally the strengths and weaknesses of the full set of modelling concepts embedded into E-MPM. It is understood that when developing and applying E-MPM rather pragmatic decisions needed to be taken. For example, the choice of CIMOSA enterprise modelling concepts, *iThink* and Simul8 simulators and *iFlow* workflow management software were not formally justified. It follows that other technology choices might have proven more effective. More reasoned decisions were made when conceiving modelling concepts to interconnect chosen technologies. Here existing and new modelling ideas related to 'modularization', 'roles', 'competencies', 'capabilities', 'capacities', 'units of work', 'elements of work' and 'dynamic producer units' have been studied, developed and adopted. Ongoing PhD studies are seeking to quantify (generic and domain specific) benefits that these connecting concepts might deliver. During E-MPM conception, development and application, new understandings have been gained about mapping processes involved when moving between Enterprise Modelling, Simulation Modelling and Workflow Modelling environments. But further research is needed before the underlying phenomenon is well understood and can be effectively disseminated, so that suitable mapping tools can be devised.

A concluding observation of the authors is that it is almost certainly impractical to create a single modelling tool with all needed E-MPM capabilities embedded into it. Both conceptual and technical factors constrain tool development and application. Consequently, it is probably that a more complex, single modelling tool would inherit a greater set of constraints. Consequently, the authors believe that a better way forward is to define and evaluate use of an ontology designed to facilitate interoperation between sets of modelling tools that collectively provide domain specific life-cycle engineering support for various Business Process owners, developers and actors. Such an ontology should ensure uniformity of 'model structures'. Future developments of this type can build upon those connecting modelling concepts described in this paper.

Appendix 1: Feasible resource model for BP222



Appendix 2: Progress monitoring model (BP222)



References

Ajaefobi, J.O., Human systems modelling in support of enhanced process realisation. PhD thesis, Loughborough University, 2004.

Al-Hujweri, Al-Jullabi, Uthman, A.B., *Kashf Al-Mahjub*, translated by R.A. Nicholson as *Kashf Al-Mahjub of Al Hujweri: The Oldest Persian Treatise on Sufism*, 1976 (Gibb Memorial Trust, Lowe & Brydone).

Bahrami, A., Sadowski, D. and Bahrami, S., Enterprise architecture for business process simulation, in *Proceedings of 31st Conference on Winter Simulation*, December 13–18 1998, pp. 1409–1414, Washington D.C. (IEEE Computer Society Press: Los Alamitos, CA).

Chatha, K.A., Multi-process modelling approach to complex organisation design. PhD thesis, Loughborough University, 2004.

Chatha, K.A., Weston, R.H. and Monfared, R.P., An approach to modelling dependencies linking engineering processes. *Proc. Inst. Mech. Eng. B: J. Eng. Manuf.*, 2003, **217**, 669–687.

Chen, D. and Doumeingts, G., The GRAI-GIM reference model, architecture and methodology. In *Architectures for Enterprise Integration*, edited by P. Bernus, L. Nemes, and T.J. Williams, pp. 103–126, 1996 (Chapman & Hall/IFAC/IFIP: London).

Davenport, T.H., *Process Innovation — Reengineering Work through Information Technology*, 1993 (Harvard Business School Press: Boston, MA).

ESPIRIT-CIMOSA Standards, *CIMOSA*: *Open System Architecture for CIM*, 1993 (Springer: Berlin).

Gladwin, B. and Tumay, J., Modelling business processes with simulation tools, in *Proceedings of 26th Conference on Winter Simulation*, 11–14 December 1994, pp. 114–121, Orlando, Florida (Society for Computer Simulation International: San Diego, CA).

Hammer, M. and Champy, J., *Reengineering the Corporation*, 1993 (Harper Business: New York, NY).

Mertins, K. and Jochem, R., Integrated enterprise modelling: reference architecture and methodology. In *Handbook of Life Cycle Engineering: Concepts, Models, Technologies*, edited by A. Molina, A. Kusiaka, and J. Sanchez, 1998 (Kluwer: Berlin).

Monfared, R.P., West, A.A., Harrison, R. and Weston, R. H., An implementation of the Business Process modelling approach in the automotive industry. *Proc. Instit. Mech. Eng. B: J. Eng. Manuf.*, 2002, **216**, 1413–1428.

Schael, T., *Workflow Management Systems for Process Organisations*, 1998 (Springer: Berlin).

Scheer, A.W., *ARIS — Business Process Frameworks*, 1998 (Springer: Berlin).

Tayur, S., Ganeshar, R. and Magazine, M., *Quantitative Models for Supply Chain Management*, 1999 (Kluwer: Berlin).

Weston, R.H., A comparison of the capabilities of software tools designed to support the rapid prototyping of flexible and extendible manufacturing systems. *Int. J. Prod. Res.*, 1998, **36**, 291–312.

Williams, T.J., *The Purdue Enterprise Reference Architecture*, 1992 (Research Triangle Park, NC: Instrument Society of North America).

Womak, J., Jones, D. and Ross, D., *The Machine that Changed the World*, 1990 (Rawson Associates).

Worley, J.H., Chatha, K.A., Geneste, L., Weston, R.H., Aguirre, O. and Grabot, B., Implementation and optimisation of ERP systems: a better integration of processes, roles, knowledge and user competences. *Comput. Ind.*, 2005, **56**, 620–638.