Business-process modelling and simulation for manufacturing management: A practical way forward

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Abstract Many companies are taking a process view as a result of business-process re-engineering exercises, statutory compliance (e.g. Securities and Futures Authority), reaction to market forces (e.g. to achieve accreditation under ISO9001:2000 or BS5750) and the promotion of integrated computer and information systems (e.g. computer integrated manufacture). This means questioning the way in which companies operate and has implications for management. Business process modelling (BPM) and business-process simulation (BPS) help to facilitate process thinking. BPM provides management with a static structured approach to business improvement, providing a “holistic” perspective on how the business operates, and provides a means of documenting the business processes while BPS allows management to study the dynamics of the business and consider the effects of changes without risk. There are a number of BPM and BPS methodologies, approaches and tools available, each of which may be applicable to different circumstances. This paper briefly reviews the diverse literature in relation to manufacturing management. Evidence from the literature indicates that few tools are available for supporting manufacturing-business-process-management and that, except for a few small-scale processes, BPS implementations in manufacturing have had limited success. This paper identifies the reasons for this and suggests a practical way forward until hardware and software limitations are overcome.

1. Introduction
Business-process re-engineering (BPR) advocates, for example (Heslop, 1995), have proposed that business structures based on traditional functional areas (e.g. sales, finance, production, etc.) are now outdated and suggest that businesses be organised according to the processes employed. For an overview of BPR see O’Brien (1995). These processes are concerned primarily with how things are done and not necessarily with what is done (Davenport, 1993). The
goal of BPR is the elimination of the functional boundaries that are said to suppress action and initiative within traditionally-organised companies. Typically, four stages are identified in conducting a BPR exercise:

1. identify the process to be re-engineered;
2. map (i.e. model) the processes;
3. measure using a diagnostic team; and
4. improve the process using a project approach (Williams, 1994).

This concept has been extended by Ashareyi et al. (1998) who applied system dynamics to low-level processes in organisations.

In addition to reviewing the traditional structure of business, traditional measures of business performance (e.g. return on investment, cash flow, earnings per share) are also being questioned due to the short-term view taken by many speculators. As a result other performance measures have been proposed, for example, market value added (MVA) and economic value added (EVA), which take a longer-term view of company performance (Lynn, 1996). Performance measures for the internal running of organisations and traditional cost accountancy and its performance metrics have also been brought into question, (Fry et al., 1994) and (Kaplan and Norton, 1996), and it has been advocated that all manufacturing measures should be time based (Owen, 1993). Over 100 different business performance measures have appeared in the literature (White, 1996).

The complexity of many business systems, particularly in manufacturing, combined with the fact that man possesses only bounded rationality, makes it virtually impossible to comprehend a system in its entirety. The reductionist approach takes the view that all phenomena can be broken down into sub-systems while the holistic fraternity, claims that systems can only be understood as indivisible wholes. In either case it is not possible to experiment with real live systems to understand their behaviour or to attempt improvement and hence models need to be developed which take a process view and where necessary incorporate a variety of business performance measures.

In general, models are either static (i.e. “as is”) or dynamic (e.g. “what if”). Dynamic models are always more complex than their static counterparts, but the information obtained is invariably richer and both are of equal importance, for example, the “as is” model can be used as a benchmark against which “what if” scenarios can be evaluated. In sections 2 and 3, both static and dynamic process modelling methodologies for supporting manufacturing management are reviewed, as are the current tools available and the ways in which they have been integrated to support manufacturing business decisions. A number of common issues and themes that reoccur in implementations of business-process modelling (BPM) and business-process simulation (BPS) are identified in section 4 and the limitations of current methodologies are
presented in section 5. Section 6 proposes a possible way forward for model builders of manufacturing management support systems.

2. Process modelling methodologies and tools
Process modelling methodologies originated from systems analysis to provide a graphical description of business activities. The value of process modelling is well documented, noted for illustrating the big picture, and as a vehicle for development and communication (Williams, 1994). Several different structured approaches for processes modelling have been identified (see, for example, Colquhoun, 1996; Wu, 1994), including:

- structured analysis design technique (SADT) (Ross and Schoman, 1977);
- icam definition (IDEF) (USAf, 1981);
- structured system analysis design methodology (SSADM) (Longworth and Nicholls, 1986);
- Jackson systems design (JSD) (Jackson, 1983);
- structured systems analysis (SSA) (Gane and Sarson, 1979);
- Group de Recherche en Automatisation Integrere (GRAI) (Domeingts, 1985);
- soft system methodology (SSM) (Checkland, 1984);
- data flow diagrams (DFD) (DeMarco, 1979);
- concept mapping (CM) (Neely and Byrne, 1992);
- unified modelling language (UML) (Fowler and Scott, 1997); and
- architecture for integrated information systems (ARIS) (Scheer, 1998).

The IDEF series (IDEF0, IDEF1, IDEF1X, IDEF-TD, IDEF2, IDEF3) appear to be the most favoured in manufacturing. For example, the use of IDEF to aid BPR can be found in Bradley et al. (1995) and Kusiak et al. (1994) and the use of IDEF to design a job shop can be found in Gong and Lin (1994).

Concept maps were originally devised as instructional and evolutionary tools (Neely and Byrne, 1992), but their use has become more widespread as a knowledge elicitation method within commercial organisations (Zaff and McNeese, 1991; McFarren in Wolf et al., 1991) while UML has yet to become established.

GRAI integrated methodology (GIM) is a combination of several static business mapping techniques making use of GRAI grids and nets. It employs entity relationship diagrams (ERDs) and network models taken from SSADM (Vernadat, 1996; Domeingts et al., 2001) and uses IDEF0 for operational modelling.

ARIS takes a functional perspective using event drive process chains (EPCs) balanced by an organisational or resource perspective; uses an organisational chart for modelling human resources. It employs a network topology map for
IT systems and uses ERDs for data perspective at the requirements level (Vernadat, 1996; O'Sullivan, 1994).

Although not a modelling framework, Purdue enterprise reference architecture (PERA) is a detailed method for introducing computer integrated manufacture (CIM) and has been integrated into the generalised enterprise reference architecture and methodology (GERAM), which is a revision of the computer integrated manufacturing methodology open systems architecture (CIMOSA). Essentially, CIMOSA synthesises the ideas of IDEF, GIM and ARIS (Vernadat, 1996; Kosanke and Zelm, 1999; Berio and Vernadat, 1999) while GERAM has taken CIMOSA from being a reference architecture to a full scale methodology which can be used for implementing software, CIM, etc. The GERAM methodology is based on a framework that focuses on the implementation process, moving from requirements to design, rather than explicitly considering the model structures themselves. For example, it does not explain how models designed for different decision levels (strategic, tactical, operational) can be integrated.

CASE tools (Fisher, 1991) have eliminated, or at least substantially reduced, many design and development problems that occur with large software projects by allowing the software designer to concentrate on the architecture of the system rather than the actual implementation (coding). A primary goal of CASE technology is the separation of the design process from the implementation process. While each CASE tool is slightly different, they all have components that allow the analysts/designer to enter diagrams via a GUI, include a data dictionary for textual definitions on the diagram, include an encyclopaedia to hold development paths and data, store process data (usually in a relational database) and generate output reports. In theory every system and process within an organisation could be modelled with one or several relational databases. Criteria for CASE tool selection for systems analysts and designers can be found in Mair (1993) and directions for CASE are discussed in Spurr and Layzell (1992). Some tools allow the use of a “metamodel” (or framework) which defines the “objects” within the model and the “relationships” between those objects. Model data can be related to both the objects themselves and also the relationships through the use of object oriented programming (OOP) as in the UML. Following the popularity of BPR a number of propriety BPR CASE tools have emerged based on IDEF including: IDEFone, DesignIDEF and System Architect BPR. While Enterprise Modeller is an object oriented, repository-based modelling tool using a generic but highly customisable modelling method. An appraisal of most process modelling tools can be found in Process Product Watch (Enix Consulting, n.d.).

The major drawback of most of these traditional process-modelling approaches and tools is that they attempt to represent a dynamic system with a two-dimensional “static” image.
3. Dynamic modelling methodologies and tools

Dynamic modelling methodologies include Petri nets, system dynamics, workflow modelling and simulation. Although basic Petri nets (Reisig, 1985) are a static approach, they have been used as reference models and for transforming static process models into simulation models (Meta Software Corporation Design, 1992). A methodology for system control using Petri nets has been proposed in Boucher and Jaffai (1990), an application use of Petri nets for BPR can be found in Van der Aalst and van Heh (1996), while the integration of Petri nets in workflow management software is described in Krotzsc et al. (1999). Timed Petri nets (Donatelli, 1999), although offering dynamic modelling, are cumbersome and limited in their application and have been preferred as reference methods in the design of simulation models (Van der Aalst and van Heh, 1996).

System dynamics (Forrester, 1992; Randers, 1992) require the formulation of sophisticated differential equations, which require specific solution procedures and therefore rely on detailed modelling and analysis skills. Due to the need for sophisticated modelling and analysis skills few commercial off the shelf (COTS) packages for Petri nets and system dynamics exist and would be incomprehensible to most managers or users in manufacturing.

Although many workflow management systems (WFMS) are available as COTS packages (Jablonski and Bussler, 1996), few would be of use for manufacturing management. Perhaps the most popular and most mature form of WFMS is SAP R/3 BWF, which has been found to suffer from significant implementation problems particularly in transforming business processes into workflow models (Joos et al., 1997).

Simulation is a well-established methodology that has received great attention in the literature, has a widespread application base in manufacturing and offers, at least in theory, to be an attractive approach to supporting manufacturing management. There is a wealth of literature on the subject and most offer guidelines for undertaking a simulation study (e.g. Law and Kelton, 1991; Pidd, 1988; Von Uthman and Becker, 1999). Although “continuous” simulation has been used in conjunction with computer-aided design (CAD) systems, for example, in the modelling of vehicle suspension systems, it is discrete-event simulation (DES) that has been adopted for the majority of studies in manufacturing. In manufacturing, the state variables change at discrete points in time so there is no need to model the plant as a continuous process. Furthermore because DES can provide statistics related to time it is perfectly suited to incorporating many of the recently proposed performance measures. In conducting a simulation study in a manufacturing environment, specific issues need to be addressed (Carrie, 1992). For example, is an aggregate model required to examine output from a plant and departments or a disaggregated model that details the total processes down to the individual actions on a machine set-up (Thomas and Davies, 1996; Thompson, 1994).
The development of simulation tools has followed the developments in computers and in the early days of computing, simulations were programmed in machine code and then in generic programming languages such as FORTRAN and more recently C++. Many specific simulation languages or simulators have also been developed including GPSS, Simscript, GASP, SLAM, AweSim, Siman, Simul8, Taylor III, Automod, Witness, Promodel, Processmodel and, more recently, Service-Model, SimProcess, ProcessCharter, Bonapart, iThink and Extend+BPR. The most favoured simulation tools in manufacturing appear to be Automod, Witness, Promodel, Processmodel while Service-Model, SimProcess, iThink and Extend+BPR appear to be favoured for process modelling and BPR. Some of the most recent simulators also claim to generate simulation models from static modelling methodologies using automatic code generation. A comparison of generic languages and simulators can be found in (McHaney, 1991) while strategies for selecting simulation packages based on costs, application and personnel can be found in Law and McComas (1992), Mott and Tumay (1992) and Norman (1994).

There are numerous examples of simulation studies in manufacturing spanning some 30-40 years, mirroring the developments of computer technology and some typical cases can be found in (Dewhurst, 1990). Several more recent studies have employed simulation for evaluating and investigating the application of production methodologies and tools. For example, Chan and Smith (1993), Lovell (1992) and Wu (1994) investigate just in time (JIT) (Meta Software Corporation Design, 1992), Schafer and Meredith (1993) consider cellular manufacturing, and Schian and Morrison (1992), Yenradee (1994) and Yavuz and Satir (1995) consider optimised production technology (OPT). The most popular applications are in the comparison and evaluation of scheduling rules (see, for example, Byrne and Jackson, 1994; Neely and Byrne, 1992; Thiel et al., 1999). Most practical applications in manufacturing have been for the design of systems and plants and in justifying their financial viability (see, for example, Crowley et al., 1994; Farhadi, 1994; Muller et al., 1999). Further examples of the general acceptance of simulation in manufacturing can be found in Ardhaljian and Fahner (1991), Hwoke and Nelson (1993), Koelsch (1992) and Mabroak (1996).

4. Studies in BPS
The limitations of static models have been known for sometime and recognised by systems analysts and designers for over a decade. Indeed, Bravoco and Yadav (1985), recognised that dynamic modelling should be an integral component of any systems study. However, it is only recently that dynamic modelling, in particular simulation, has been considered an essential component of process modelling and the term “business-process simulation” has been coined (Scholz-Reiter et al., 1999). Several attempts have been made to integrate static and simulation modelling with different degrees of success.
An IDEF model of an entire manufacturing company to study the effects of alternative “what if” scenarios (e.g. make or buy decisions) to facilitate BPR can be found in Steels (1995). An approach, which incorporated dynamic information into IDEF0 models for rough-cut simulation can be found in Wang et al. (1993), while the use of IDEF3 as a front-end for the design of simulation models is considered in Plia and Carrie (1995). None of these studies formally integrated the static and dynamic tools employed.

An early attempt at developing an integrated modelling tool for manufacturing was proposed in Stark (1989) where industrial engineering flowcharting techniques were combined with a discrete event simulator. The user (engineer) entered simulation data via a graphical interface, rather than by explicit coding, using CAD techniques to construct a manufacturing process flowchart. While the system attracted some interest in the late 1980s, the interface was too slow and cumbersome and no commercial release of the software was made. However, it was recognised that the idea of interfacing a simple flowchart style graphical input to powerful simulation software showed considerable potential.

More recently studies in manufacturing have focussed on integrating COTS packages. An attempt to integrate Enterprise Modeller and Witness through the use of macros in a project sponsored by BiT and AT&T is described in Heslop (1995). The results were favourable during development and experimentation but several problems were encountered. From a technical viewpoint, the major problem was the time taken to enter code into Witness and the excessive time required to run models and compile results. Although the accuracy of the data transfer linkage between the two tools was shown to work, it proved fragile and prone to failure and minor changes to the model demanded the reworking of the linking macros, which was both time consuming and error prone. From a purely commercial perspective, the project was aborted through lack of industrial interest and support and it was concluded that Witness was not the ideal partner for the Enterprise Modeller tool. Furthermore, as model creation in Enterprise Modeller and Witness are complex tasks they both require a high degree of different technical and programming skills beyond those that would normally be found even in well-resourced manufacturing companies. An attempt to link the output from System Architect to provide input to Promodel through Microsoft Access and Lotus spreadsheets is reported in Burns (1999). However, although output from System Architect could be linked to an Access database it was found too difficult to link Access to Promodel. Instead of employing a static modelling tool an approach, in which Microsoft Access was used to store IDEF static models and Visual Basic was used to link Excel to control Witness for simulating SME manufacturing environments, was successfully demonstrated in Rogers (1999) and Rogers and Barber (1998). A similar, but untried and
untested, approach using a groupware-based toolbox integrated through Lotus Notes can be found in Bastian and Scholz-Reiter (1999).

Event driven process process chains (EPCs) are a step towards simulation modelling and are employed in ARIS. However, some problems in handling multiple flow entities have been found in implementing ARIS for strategic planning (Pritchard, 2001) and no successful applications in manufacturing have been reported in the literature.

Some software houses have also attempted the integration of static and simulation modelling tools. For example, ProModel Corporation (PROMODEL Corporation, 1996) released ProcessModel in 1996, which employed the Micrografx ABC Flowchart package with drop down menus to allow easy and logical entry of relevant system data to the ProModel discrete event simulation engine. An application of ProcessModel in which a company’s bill of materials (BOM) was used to provide legacy data for the models can be found in Burns (1999). Many high-end enterprise resource packages (ERP) such as Baan or SAP, have in-built process modelling capability and are said to be “dynamic” because they not only permit an organisation to be modelled but can automatically configure the ERP system.

Limited successes have been reported in other (non-manufacturing) sectors. A successful deployment of BPS tools in a limited BPR exercise in the telecommunications industry was reported in Lee and Elcan (1996) and a similar successful study in assessing the value of e-commerce is reported in Giaglis et al. (1998). However, implementation problems occurred with ProcessCharter in larger study of the co-operation between a pharmaceuticals company and local distributor (Giaglis, 1999). The problems highlighted in this latter study were similar to those described in Heslop (1995) and included a mismatch between data requirements and data handling between the static flowchart model and the simulation model, the need for user involvement and training to ensure success and the lack of interface mechanisms between different modelling tools, particularly simulators. Further support for some applications and a discussion of integrating information systems and process modelling can be found in Henderson (2000). In particular, Eatoek et al. (2000) point to the difficulties of integrating BPR and computer network simulations (CNS) which are being addressed through the EPSRC ASSES-IT project.

5. Limitations of the current methodologies
Many process improvement methodologies consider only single processes and allow improvements to that one process, but do not consider the effect of the changes on other processes within the business. It may be that improvements to the studied process may have a detrimental impact on the business as a whole. To be absolutely sure that process improvements benefit the business, then the entire business should be modelled and evaluated. It follows that a holistic model of the entire business should be the ultimate objective. The
results of studies show that when applied to small and discrete manufacturing processes, integrating static and dynamic modelling methodologies works extremely well. However, there are questions surrounding the application to large interrelated manufacturing processes and ultimately an entire manufacturing system. Static modelling tools are capable of building large models of complex systems but they cannot deal with the additional complexity imposed by the temporal perspective. Conversely, dynamic tools are not sufficiently scalable (due to hardware and software limitations) to allow the creation of large business models. Furthermore, when small individual process models are joined into a large hierarchical construct, the resultant model quickly becomes too big to run effectively.

Many existing tools are incompatible or require significant programming and software engineering skills beyond those normally found in most companies. Recent attempts have been made to integrate system dynamics and the balanced score card (BSC) (see Bontis, 1999). However, there are limitations on the number of perspectives allowed in the BSC (currently only four compared to the nine used by most researchers) and the already mentioned inherent complexities of system dynamics limit its adoption by practitioners.

An earlier observation was that business wide holistic models are best created within a static repository-type modelling tool while for smaller scale end-to-end processes, discrete event simulation models could be built. It follows that the creation of process models usually requires detailed knowledge of more than one modelling tool. Skills of this type are not usually available within many manufacturing companies. Companies that do possess a process modelling capability will rarely have more than one modelling tool and since they are not usually used on a day-to-day basis, the skills of the people who work with the models is frequently not maintained. Furthermore, as tools and techniques improve, so it is increasingly difficult for personnel to keep up to date.

6. A practical way forward
Until the hardware and software limitations are addressed we propose an approach and procedure based on interfacing large-scale static business models with selective small-scale dynamic process models.

Realistically a complete holistic static model may not be achievable in a single project due to time and budgetary constraints and should be regarded as an ongoing objective. With each successive process review or improvement project, relevant pieces of a holistic business model could be identified and placed into the holistic model. In this way, over a period of time, a holistic model could be developed to cover the entire scope of the business. Once completed, a holistic model could be validated by running performance reports that could be compared to actual business performance. Once validated, these performance figures from the model would become the “as-is” performance figures against
which future improvements could be measured. This holistic model would need updating each time a change was undertaken in the business.

If companies cannot justify or afford the commitment to such detailed modelling work, maintenance, training and periodic updating it may best to consider subcontracting out to specialists. Where process models are created in house, the department responsible for their creation is often the quality assurance (QA) department. Process models are useful for process training and education and also for accreditation with quality standards such as ISO9001:2000. Thus a QA department may be the appropriate host for the management of modelling tools or purchasing responsibility.

Once the holistic “static” model has been constructed the following procedure, illustrated in Figure 1 and described in greater detail below, could be adopted.

The holistic business model would consist of many interrelated business processes and while the overall objective is to improve the performance of the business, this may only be achieved by improving individual processes identified by management. Processes targeted for improvement should be set performance target improvement project objectives identified by a multi-functional improvement team created to undertake the improvement project.

Having identified a target process it could be extracted from the holistic business model for further detailed analysis and improvement. Providing that the holistic business model had been correctly created in a suitable modelling environment, it should be easy to highlight the target process as end-to-end threads within the organisational hierarchy and then copy it to a separate process diagram for further analysis. The threads cross traditional functional boundaries and some software allows for extracting process threads to process diagrams (e.g. Enterprise Modeller). When the end-to-end process thread has been extracted from the holistic model, it can be translated into a simulation tool. It would be ideal if the static holistic modelling tool possessed a simulation facility, as this would allow a seamless process thread extraction and dynamic analysis. The process-modelling exercises could be completed by an in-house specialist group, or they might be subcontracted out to a specialist process improvement contractor.

When the static and dynamic process models for the target process, become available, they should be presented to the improvement team. A professional process improvement facilitator may be desirable to avoid one or more individuals or functional areas exerting pressure on the outcome. Brainstorming sessions should encourage the creation conventional and radical improvement ideas and it may be appropriate if the improvement team had previously undertaken some training in formal process improvement methods. Deliverables from the brainstorming sessions would include methods and metrics used to measure process performance and possible process improvement ideas to be taken forward for further analysis and appraisal by
Figure 1. Procedure for selective modelling
the process modelling specialists or subcontractors. Simulation models of the end-to-end process would be used to evaluate the ideas generated during the brainstorming session. The results of the process simulation exercises together with previously identified performance metrics would be formally reported back to the improvement team and an agreement reached on the ideas to be reflected in new process designs.

These new process designs, along with the performance figures (e.g. as activity times, resource requirements and costs) should be re-entered into a new version of the holistic business model. This model would then reflect a “to-be” view of the whole business. The performance reports for the holistic business model could then be obtained and compared with the “as-is” performance figures. Given that the costs of implementing a given improvement could be estimated then a relatively simple cost benefit analysis could then be undertaken to decide on whether or not to proceed with a particular process improvement project.

7. Conclusions
Existing software tools, although significantly advanced over the last decade, are still limited in breadth and depth. Even the so-called integrated tools are as yet unable to deal with the full complexities of a manufacturing operation, due to limitations on the number of entities and difficulties with importing model data from external sources (e.g. legacy systems and other tools).

The end-user requirements need to be fully taken into consideration by software designers and management of manufacturing companies need to be aware of the total costs (including staff time) involved for hardware and software purchase, development and implementation, hardware and software maintenance, regular training, and model updating.

As with any tool (static or dynamic) it is essential that careful consideration be given to selection. Clearly, the primary consideration is that the method and tool(s) selected meets the requirements of the modeller, to represent the structural and behavioural characteristics of the object system accurately. Other criteria which may also play a part in the final selection of a modelling tool, include: hardware and software support and availability; model capacity; ease of use; technical support; documentation; training; licensing restrictions; cost (purchase, development, maintenance, etc.), and analyst familiarity.

Until the hardware and software limitations are addressed we propose a cost effective approach and procedure based on interfacing large-scale static business models with selective small-scale dynamic process models for manufacturing enterprises.

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