SIMULATION BASED ORGANIZATIONAL CHANGE IN MULTIPLE PRODUCT ASSEMBLY SYSTEMS

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During the last few decades, Manufacturing Enterprises (ME) have been facing increasingly volatile market conditions due to changes such as globalisation, reduced product lifetimes and increased competition. Simulation modeling (SM) has been widely deployed to help MEs optimise their operations by assessing uncertainties and possible future organizational behaviours. This paper reports ongoing research study which is developing and testing the use of a unified set of SM concepts within the context of Enterprise Modelling (EM) to facilitate process oriented organizational change related to the planning and control of ME's operations. Case study research findings are described which focus on optimizing multi-product flows through assembly shop resources available to a furniture making SME based in UK.

1. INTRODUCTION

Typically, Manufacturing Enterprises (MEs) change and improve their processes continuously during their lifetime in order to remain competitive in a highly volatile market. The ways in which MEs operate and add value to process inputs including material, information and knowledge can be defined in the form of 'a process network' (Weston 2004). Process network change can take the form of: (1) modifications to the order of activities within one or more process threads (2) modifications to the resource assignment made available to one or more segments of process threads (human and technical systems) and (3) modifications to product variety, volumes and mixes that flow through process threads. Enterprise modelling (EM) facilitates (collective and individual) reasoning about the multi-perspective aspects of process oriented organisation design and change by providing a systematic approach and suitable mechanisms for modelling business processes.

The authors recognise that current EM approaches focus on encoding relatively enduring entities, and structures linking entities. However as the complexity of enterprise models (EMs) must remain within manageable bounds, generally they do not provide sufficient support for capturing dynamic characteristics of process networks and this has limited business improvement projects. In addition EMs do not facilitate solution generation in the sense that they lack necessary mechanism for future prediction by visualisation and relative quantification of possible alternative ME designs; such as by exercising differently configured resource systems when they are subjected to changing workloads. The research emphasis in this paper concerns a generalised attempt to develop a set of concepts for realising synergistic use of EM and simulation modelling (SM) techniques. The research concepts developed have been applied and tested within a number of small and large MEs. This paper considers the combined use of EM and SM to achieve improvements to the process network of a furniture making SME based in UK. The initial findings related to 'machining processes' of the case study organisation are previously reported in the literature (Rahimifard and Weston, 2006). This paper complements the original paper, and describes follow-on research related to another part of the case study process network, namely downstream 'assembly processes'.

2. BACKGROUND

Manufacturing enterprises in general comprise extremely complex systems of processes and resource systems that need to be 'loaded' by product flows that vary over time. Simulation modelling provides modellers with capability to replicate ME's product flows and related causal and temporal relationships between process, resource and product variables lead to a replication of real behaviours. In general alternative product (volume and mix) flows can directly be input into models of 'as is' processes used by the ME, in order to verify that the models behave as the real ME behaves. However, it is known that in order for SM to be practical modelling abstraction needs to be suitably limited given the scope of the problem tackled; so as to overcome the modelling complexity without compromising the model validity.

The authors observe that EM can provide an explicit and holistic description of 'elemental building blocks' and in-depth understandings of ME and its environmental context. Consequently EMs can define a context for building feasible simulation models so that in principle the additional modelling complexity generated when developing any SM can be reduced by focusing on self-contained meaningful process segments defined by the EM. Therefore, the authors argue that a combined use of EMs and SMs can significantly improve modelling in support of process oriented organisational change through replicating and predicting the reality well. Within this combined use of EM and SM the modeller can encode possible 'could be' or future 'to be' product flows and other modified dynamic aspects by achieving a systematic reuse of SM fragments informed by the EM so that the impact of alternate business (and manufacturing) strategies, policies, rules and dependencies can be predicted prior to the need for expensive and time-consuming real changes. This provides the modeller with an approach to creating simulation models (SMs) more rapidly and effectively. It will also enhance change recommendations as the specific context in which the organisation needs to operate can be fully incorporated in the simulation experiments and subsequent analysis of simulation results.

This paper reports on findings from ongoing EPSRC funded research entitled "Study of the Interplay between Role Dynamics and Organisational Performance". In this research project, a methodology has been being developed to systematically decompose relatively enduring aspects of ME's processes and resource systems into a specific set of interoperating processes and resource systems using best-in-class EM techniques. It is also aimed at facilitating detailed specification and design of the needed changes to ME process and resource systems, by re-encoding selected segments of static ME models into dynamic models so as to understand their time-based behaviours, via the adoption of suitable performance measures within the specific context described by the static models (i.e. EMs). Subsequently selected structures and parameters encoded by the static and dynamic models can be transformed into a tertiary model form which can be enacted by best-in-class workflow management technology in order to facilitate improved specification, design and implementation of planning and control structures within specific MEs. The remainder of this paper reports on a systematic reuse of fragments of an enterprise model in such a way that simulation models help structure decision making about organisation change within a case study company.

3. STATIC MODEL GENERATION

The case study company (referred to by the pseudonym ‘Woodlands’) in which the research concepts applied is a UK based pine wood furniture manufacturing SME with 50 employees. The Woodlands company’s product portfolio includes over 300 different designs of tables, cabinets, wardrobes, beds and other miscellaneous furniture items and its customers are the furniture retailers. The production processes involve complex routings of cutting and shaping operations of furniture parts in the machine shop, assembling of furniture parts in two ‘specialist’ assembly areas corresponding to different product families, and spraying and painting the furniture items with the desired colour and finish as defined by the customer order specification. The company operates in a make-to-order fashion. Over the last few years, the production lead time has increased significantly from 4 weeks to 8 weeks between the receipt of order and customer delivery due to the recent withdrawal of a major competitor from the market. Thus, Woodlands management decided to investigate organisational change, so as to cater for the increased demand without making significant investments in new human and technical production resources.

Following a detailed discussions with directors and other senior managers, Woodlands’ enterprise modelling techniques were used to decompose, document and understand the company’s current process network. The baseline EM technique selected was Computer Integrated Manufacturing Open Systems Architecture (CIMOSA) (ESPIRIT-CIMOSA Standards 1993) since previous experience of the authors and their colleagues and the literature review had shown this to be a powerful yet fairly easy-to-interpret (by non-modellers) public domain EM approach. Four types of CIMOSA diagramming templates, namely ‘context diagrams’, ‘interaction diagrams’, ‘structure diagrams’ and ‘activity diagrams’ were utilised to capture coherent sets of static models that collectively represent the process network (Rahimifard and Weston, 2006).

Following discussion with knowledge holders in the company, the Woodlands’ process network was decomposed into three main end-to-end process threads namely ‘Strategy Making and Realising Process’, ‘New Product Engineering

Process', 'Make and Deliver Furniture to (aggregated) Order Process'. This high level process decomposition was also determined with reference to the general ME process classification published by Salvendy (1992). This paper focuses on results of modelling part of the 'make and deliver furniture to (aggregated) order' process thread in WOODLANDS which has two primary process segments, namely so called 'business management' and 'produce and deliver furniture' processes: which loosely correspond to the 'obtain an order' and 'fulfil an order' process types defined by Pandya *et al.* (1997). The part of the ongoing research that is reported in the remainder of this paper concerns the produce and deliver furniture process. The produce and deliver furniture process is defined as the collection of manufacturing activities that starts with the receipt of a production order and realised all needed furniture parts and final assembled items, until finished furniture is delivered to customers. It was observed that this process thread was one of the main contributors of 'as is' lead time of 8 weeks. Hence because the objective of the organisational improvement and change consideration was to reduce lead times, improvement in the make-span of this segment was expected to directly reduce the overall lead time.

The main business processes (BPs) of Woodlands produce and deliver furniture process comprised *make furniture to order, spraying and finishing, package and delivery, support production and finally manage and maintain production process segments*. Relationships between these process segments were shown in Figure 1 using a CIMOSA 'Structure Diagram'. Each of these business processes were detailed with knowledge elicited from relevant Woodlands personnel and by populating a number of CIMOSA activity diagram templates of the type presented in (Rahimifard and Weston, 2006) with that knowledge. This documented relevant transformations of inputs into outputs using necessary resources. Therefore, activity diagrams were found to be of particular significance in establishing a link between static models and simulation models.

The EM exercise was proven to be effective by allowing key aspects of the company's current processes and their structural dependencies to be formally documented; thereby collating and externalising key knowledge collectively possessed by various knowledge holder employees of the Woodlands company. The approach also enabled both the modeller and the company personnel with the development of new understandings about the scope and focus of the company's current approach to making furniture. However, it was observed that, in order to specify process improvement opportunities, additional knowledge is also needed about related (temporal) dynamic properties of processes such as time dependent flows of control, material, product, value addition and cost.

4. MODELLING OF DYNAMIC ASPECTS

In general, a large numbers of instances of interactions occur between product elements, process elements and their underpinning resource elements within the process network of any ME. These system dynamics can be modelled using existing simulation techniques and tools, and the build up of queues, stochastic events, breakdowns or absences of resource can be replicated and uncertainties can be assessed. Complexity inherited within the context of the process network used by

MEs makes it practical to explicitly visualise and specify necessary changes to improve ME processes. Thus, SM provides a better understanding about 'as-is' system behaviours that can lead to more effective 'to-be' design alternatives for ME change by visualising the whole process within a given period of time.

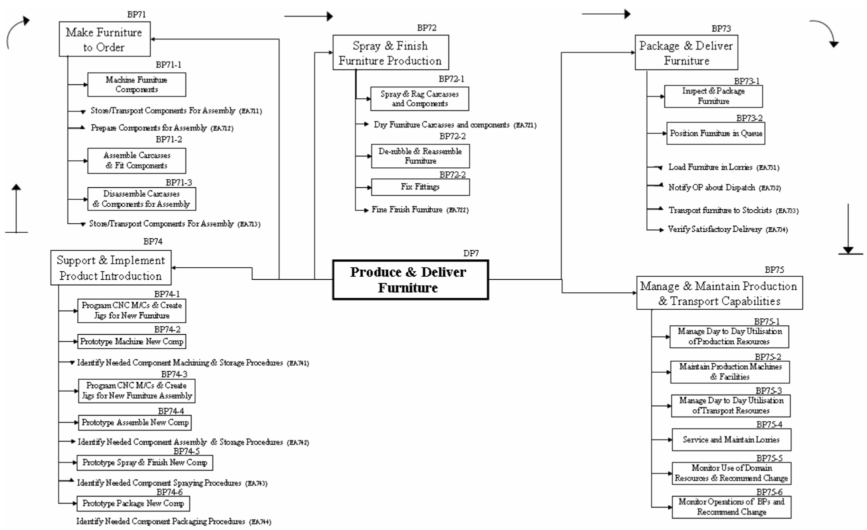

Figure 1 **-** Structure Diagram for Produce and Deliver Furniture Process.

Bearing this in mind, selected segments of the static models of Woodlands's process network were transformed into simulation models to facilitate ME change specification. The SM study reported in the remainder of this paper is based on the assumption that by systematically following a decomposition process, in this case informed by static models defined by EM, essentially separable process segments can be described which then can be usefully modelled in greater detail. A discrete event simulation tool, namely 'Simul8' (Simul8 Cooperation 2000) was used to encode both relatively enduring and dynamic characteristics of the assembly process segment some properties of which had already been identified through EM. The main purpose of SM was to investigate lead time improvement opportunities by placing alternative product loads on the assembly process segment.

The static CIMOSA enterprise models were found to partly capture data required for building the simulation model. The EM was found to naturally encode the sequence of activities required for processing and aspects of material and information flows. Additional data collection for more specific and/or time related information was also organised by deploying the framework provided by the static models. The resulting user interface to the simulation model for Woodlands' assembly process is illustrated by Figure 2. Following model validation, tests were conducted to understand in detail the 'as-is' behaviour of assembly processes of Woodlands. As indicated earlier, twice weekly production order list is released to the Assembly Shop. Each production order list defines the types and quantities of furniture items which need to be assembled during a given run which on average needs to be 2-5 working days. Item types and quantities are largely determined by chance because each run comprises those items randomly ordered in a given 4 weeks time slice by a specific group of customers who share a UK location to which a delivery van will travel. Once a particular production order has been determined and released, shop supervisors seek to maximise work throughput by assigning the assembly jobs to appropriate operators in appropriate batches. This 'as-is' approach to scheduling and dispatching workloads has proven effective but is known to give rise to significant variations in throughput for different assembly runs. Consequent swings occur in assembly shop behaviours from near state of panic to slow paced working.

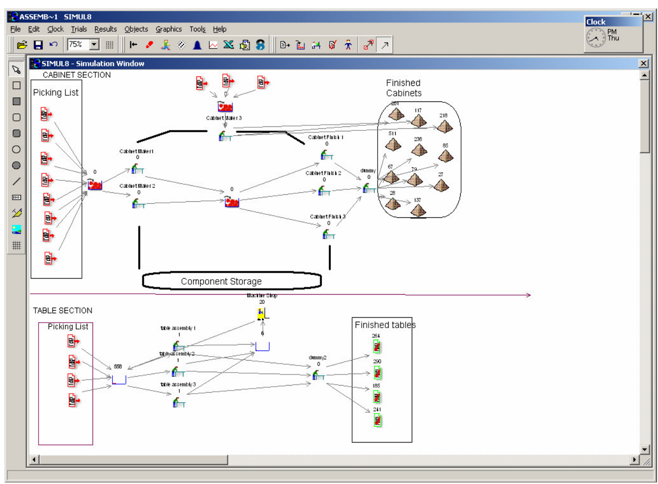

Figure 2 - Simulation model of Woodlands' assembly process in Simul8.

To enable replication of 'as-is' assembly shop behaviours historical patterns of work load were studied. Determining historical work patterns proved to be a non-trivial exercise because that data was not easily manipulated into the form required as input to the 'as-is' assembly shop simulation model. It was found to be necessary because of the very large number of furniture items and parts involved to simplify matters by consolidating items and parts into a similar product groups. Figure 3 illustrates the example 'as-is' simulation results and very significant variations in lead times of different job runs. This tallied closely with the actual variations within that shop. These 'as-is' behaviours were subsequently used as a benchmark against which alternative assembly work organisation policies could be compared. An intended use of the simulation model created was to suggest possible alternative policies and rules for creating production order list and particularly to observe the impact of suggested changes on process lead times. The as-is simulation model not only formed benchmark behaviours but also provided tactical insights to the modeller to devise alternative product loads by indicating the bottleneck resources and alternative routes. Furthermore, it enabled visualisation of possible outcomes arising from the suggested changes in the way the production order list is generated and released. For example one interesting line of enquiry centred on the assumption that the delivery van constraint on production scheduling could be released. Here, for example, it was assumed that some or all customer deliveries could be outsourced to a competent external agency. By releasing this constraint, rather than waiting for up to 4 weeks to define and release each production order list various alternative scheduling rules could be applied to (1) release production order lists earlier and (2) seek to optimise the design of each production order list from the viewpoint of minimising processing lead time.

	group 1	group 2	group 3	group 4	group 5	group 6	group 7
min	27.6	48.4	73.3	83.2	68.6	75.8	69.2
max	198.4	240.4	267.1	247.0	666.4	560.3	589.2
average	67.2	90.0	93.5	107.9	241.1	225.7	226.3

Figure 3 **-** Lead time (in mins) of product groups based upon a set of historical production runs.

With these kinds of opportunities in mind, the authors are currently quantifying the benefits and costs of various possible future scheduling and releasing policies that Woodlands could adopt. Figure 4 illustrates some early results when seeking to group historical patterns of ordered furniture items over one and two week periods with a view to minimise set up times. By comparing Figure 3 and 4 it is evident that for all product types significant lead-time savings could be realised without any need for additional investment in (human or technical) assembly system resources.

	group 1	group 2	group 3	group 4	group 5	group 6	group 7
min	27.6	48.4	73.3	83.2	68.6	75.8	69.2
max	104.6	127.4	145.3	103.6	177.9	162.7	154.0
average	28.8	49.9	74.6	84.2	79.8	91.0	82.8

Figure 4 - Lead time (in mins) of product groups based upon a set of reorganised production runs.

5. OBSERVATIONS AND DISCUSSIONS

This paper describes early results of a part of an ongoing industry-based case study research that is seeking ways to facilitate rapid, effective and systemic design and change in complex organisations by gaining synergy from an integrated use of enterprise modelling and simulation modelling techniques.

The CIMOSA diagramming templates implemented a process-oriented, hierarchical decomposition technique to create a rich knowledge base about the current ME and its environment prior to decision making about future organisation design and change. However, it was observed that because the resultant models were static in nature it was not possible to replicate or predict the possible outcomes of the proposed changes to the design of the ME. Initial investigations using simulation modelling related to possible organisational changes in Woodlands aimed at reduction in manufacturing lead time. Different manufacturing policies were incorporated into separate simulation models of well decoupled process segments comprising Woodlands' 'Produce and Deliver Furniture' process. The company is currently considering alternative ways of organising workflows and resources in respect of both individual and collective process segments. For example, supported by the authors EM and SM studies, they are investigating use of a new set of production strategies. At present, the authors and their colleagues are investigating means of realising interoperability between the assembly simulation model with SM of other process segments that are also being modelled by the authors' colleagues. As Woodlands operate a make-to-order policy, before they can realise significant benefits from increased throughput and lead time improvements in one production shop the company must achieve similar throughput improvements in other related shops. The 'as-is' activity diagrams of Woodlands encoded by the EM provide some key details of the various activity flows and their relatively enduring dependencies for consolidated product groups. This provides a big picture of how the performance of one process segment can impact on other process segments. To develop the use of this picture from a dynamic systems (temporal) viewpoint the causal impacts of one production shop on the other production shops was modelled using causal loops. The collective understandings documented by the EM and the casual loops have fed into the authors' current thinking and combined SM experimentation with a view to selecting improved schedules and workflow control policies that balance the future throughput as defined by the new forms of production order list through Woodlands' machining, assembly, painting and finishing shops. Early results indicate that significant savings predicted in the assembly shop need not be compromised by other shops. Thereby in principle the use of the combined SMs predicts that by making policy changes as opposed to cost investments in resources, Woodlands can increase its competitiveness significantly.

In conclusion, the integrated use of EM and simulation modelling shows great promise in providing ways of facilitating a holistic static and dynamic picture to facilitate organisational change. The use of EM provides simulation modeller with broad based company understandings that bear in mind the specific context in which the organisation will need to operate. It has been found that collectively EM and SM provides a sound basis for managing and enacting change through structuring decision making about organisation change, analysing the impact of alternative change scenarios and presenting a better visualisation of the possible competitive futures.

6. REFERENCES

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