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Developing simulation components for supply chain modeling

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Abstract

Modeling supply chains is a pre-requisite for any supply chain improvement initiative. However, modeling supply chains is generally a complex and time consuming task. One way of working around this issue is to have re-usable pre-defined components that represent typical activities in supply chains. The paper presents the application of this principle to the modeling of e-business processes and analyses how the approach can be extended to supply chains. A new methodological approach is presented for the development of static (templates) and dynamic (components) re-usable simulation models. The research contributes to the knowledge of components and re-use theory in simulation and gives practitioners mapping guidelines and offers a way of breaking the barrier for the use of simulation

1. Introduction

Supply chain systems are generally complex and have a large number of interrelations between different processes and actors, commonly located in different organizations. New information systems designed to help supply chain management allow the expansion of these interrelations and links. As companies move from traditional processes to e-enabled processes the performance of these processes will change. Modelling, simulation in particular, has the necessary attributes to assess the changes in performance over time under typical operating conditions to allow process designers to understand the overall impact of the changes they are about to introduce.

The work by Lambert and Cooper (1998) and other models such as SCOR (2007) on developing generic process models has helped create a greater awareness of process thinking and provided a starting point to develop new processes. New processes can be mapped out and then the detail of each activity developed. Whether a process is ‘traditional’ or e-enabled, the series of steps could be very similar and therefore it is mainly the behaviour of these activities rather than their overall structure that is most influential the overall performance. Therefore static, diagrammatic analysis of processes is a starting point but does not give insight into the expected performance.

Modelling, and in particular simulation, is a technique that can be used to represent processes and model their behaviour under typical, everyday conditions to assess performance. Simulation is able to represent the detail of process steps and provide results on utilisation, cost, lead-time, work-in-progress, etc. It is worth noting that the latter metrics listed are dynamic metrics that can only be judged by simulation techniques that model the passage of time. The use of simulation is therefore well suited to modelling and assessing the performance of e-business processes.

This paper introduces e-business and supply chain e-process modelling. It argues that modelling e-processes by selecting pre-defined components from a library will allow e-business processes to be modelled and analysed quickly and effectively. The use of e-business simulation components will be demonstrated through a case study. The contribution of this paper is the development and application of the concept of e-business simulation components to e-business processes and how this can be extended to the supply chain.

2. Review of supply chain modelling

2.1 Introduction to e-business

E-business and e-commerce have been defined in different ways, sometimes conflicting or incomplete. Here, e-commerce has been defined as “the buying and selling of goods and services via electronic mediums such as the Internet” (Bontis and De Castro, 2000). Although the definition is rather simplistic, it encompasses the essence of electronic commerce transactions: goods or services being interchanged using an electronic interface e-business, on the other hand, is defined as “the transformation of key business processes through the use of Internet technologies” (Chaffey,(2002). There are different levels of application of e-business, from the internal sharing of information, to the customer interface or a wider supply chain application involving a network of companies. E-business is now usually referred as being comprised of applications such as e-commerce, Business Intelligence (BI), Customer Relationship Management (CRM), Supply Chain Management (SCM) and Enterprise Resource Planning (ERP) amongst others (Strauss and Frost, (2001).

As can be appreciated from the previous definitions, e-business presents a more complex scenario than solely e-commerce, having the potential of affecting a greater number of internal operations in a business. The complex situations that could derive from the application of e-business must be analysed and understood before going ahead with such projects. New technologies have failed because not enough analysis of the effects of such implementations was carried out before starting the project (Larsen and Myers, 1999; Hlupic and Robinson, 1998).

Fryer (2001) identifies the characteristics of the market in an electronic commerce environment: more erratic and difficult to predict demand, last-second orders and expectation of overnight fulfilment, a removal of the slack that traditional processes have between operations and the uncertainty to back-end supply chain members about order fluctuations, reducing their responsiveness. This is particularly apparent in the Order Fulfilment processes and other processes in the operate classification. It has been stated by Porter (2001) that “the internet has created some new industries… however, its greater impact has been to enable the reconfiguration of existing industries that had been constrained by high costs for communicating, gathering information or accomplishing transactions”.

2.2 Business Process Simulation

The whole area of Business Process Simulation (BPS) has received attention from the research community, some of which are focused on e-business simulation or modelling. For example, Chen et al. (2006) present an analysis of critical factors for the implementation of web services. They propose a simulation analysis to analyse the combination of these factors, although their approach is more akin to Monte Carlo simulation than a true, dynamic Discrete Event Simulation (DES). Madhusudan and Son (2005) describe an analysis of web services and "a simulation-based framework to guide scheduling of composite service execution". They present a DES approach, which is focused on the electronic transactions within the web services, rather than on the business process in which these web services are used.

In the area of business process modelling (although not necessarily simulation modelling), Shen et al. (2004) present a methodology for business process modelling based on a combination of IDEF0, IDEF3 and DFD models. However, these models are static and not focused on e-business. Doerner et al (2006) describe the application of Petri Nets and stochastic branch-and-bound techniques for the analysis of workflow systems. They conclude that "modelling and evaluation techniques are becoming essential features of workflow systems … [which] keep any potential losses low by identifying critical sub-processes and evaluate appropriate measures". Greasley (2006) presents the application of DES to the modelling of business processes in the service sector. He highlights "the ability of simulation to proof new designs was seen as particularly important in a government agency where past failures of information technology investments had contributed to a more risk-averse approach to their implementation".

Gans et al. (2005) present the use of simulation for "database-centric business process management" and describe is based on agent-based, rather than DES, modelling. Caridi et al. (2004) introduce a case study of the use of DES for the analysis of e-procurement options in a pharmaceutical company. They conclude, "the application of BPS techniques provides a guide for a rational study of the AS-IS processes and can give interesting insights for the assessment of TO-BE ones". As with many other simulation studies reported in the literature, they present a single case study without extracting generalisable simulation constructs from the cases. Likewise, Sharp (2006) depicts a model that is related to sourcing decisions in e-commerce. The method proposed is a combination of Simple Multi-Attribute Rating Technique (SMART) methods, EFQM and other TQM methods. According to Sharp (2006), "the method proposed adopts a standard model for every business process with a very restricted number of inputs and outputs." That is, simplifications of business processes are used to model the different sourcing options. This is an approach that has value for the analysis of static configurations and risk analysis, but which does not cover the dynamic behaviour of the system. Lastly, Melao and Pidd (2006) present the development of a component library for business process simulation in a proprietary simulator (BPSim++). The components developed for this application detailed and represent individual activities, rather than a collection of activities that represents a sub-process.

3. Templates for modelling e-business processes

Another area in which emerging literature is to be found is the development of templates for business process modelling. Some of these developments are in the area of general modelling, with some reports focusing on simulation. Andersson et al. (2005) present goal-oriented high-level processes and propose using patterns to develop these processes. Danesh and Kock (2005) present initial evidence that implies that "using communication flow methodologies in the analysis stage should significantly help the design and the development processes". This communication flow methodology presented in their paper is akin to the simulation perspective of modelling. Nurcan et al. (2005) present a static modelling approach that uses the concept of re-usable components at the strategic level. However, some of the maps presented are at the operational level and incorporate a type of specialisation as described by Malone et al (1999), with the difference that all the specialisations are included in one map and do not constitute different components as it is in the case of Malone and the MIT business process repository (MIT, 2007).

From Table 1, reported supply chain applications can be grouped in terms of the business process affected by e-business. For example, Tatsiopulous et al (2002) and Ngai et al (2003) deal with sales management. An analysis of commonalities in the processes can lead to the discovery of patterns in the sales process.

Author	**Modelling Approach**	**Case Study**	**E-business application analysed.**	**Business Processes affected**	**Performance measures**
Tatsiopoulos et al (Tatsiopoulos et al., 2002)	GRAI Grid, IDEF-0/ IDEF-3 ABC costing	Garment manufacturer	e-commerce	Order receiving (manage customer order)	Lead time Cost
Gunasekaran et al (2002)	---	---	A variety of applications.	A Variety of processes	--
Ngai et al (2003)	Flowcharting	Mineral water manufacturer	Web-based workflow	Order fulfilment (Sales management)	Efficiency Cost

Table 1. Modelling of e-business applications specific to supply chain.

Figure 1 presents such an example for the purchasing process. These patterns can then be re-used within simulation to facilitate the analysis of sales processes in other case studies. The advantages are to have guidelines of how processes change when e-business is involved and to have pre-built sales processes that can then be customised for the specific needs of the case under study.

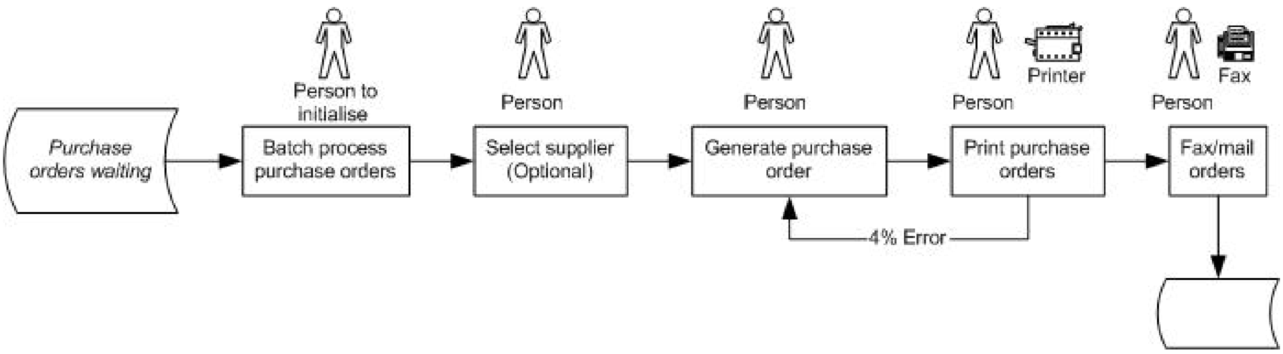


Figure 1 Example of template for e-purchase order process

4. Development of simulation components

This paper has introduced the e-business concept and the ability to model such business processes using simulation. By examining published and new cases of e-business processes it is possible to identify commonalities in the processes, capture these commonalities as generic e-business processes in the form of 'templates'. Ultimately these generic e-business process templates can be reused within simulation software to support assessment of the operational performance. This section examines reuse and identifies a means by which the generic elements of e-business processes can be captured as templates and these templates then implemented in simulation software as 'components' for rapid modelling and assessment of new e-business processes.

4.1 Reuse in systems engineering

The reuse concept has been proposed in the software engineering arena as a way to make the software creation process speedier. A number of authors have described what reuse entails: for example, Duskink and van Karwijk (1995) define reuse as "all activities aiming at reusing previously constructed artefacts within the process of (software) development". On the other hand, Reese and Wyatt (1987) define reuse as "the isolation, selection, maintenance and utilisation of existing software artefacts in the development of new systems". These authors identify McIlroy as the one who originally coined the term more than thirty years ago. Since then, the reuse concept has been extended to other disciplines such as design (e.g. Smith, 2002) knowledge management (Oussalah, 2002), modelling and design of manufacturing systems (Chandra et al., 2005) and simulation in general (Pidd, 2002; Aronson and Bose, 1999; Mclean and Shao, 2003). Most of the arguments for reuse are based on the premise that

> "…building models of all types is an expensive process as it takes a considerable amount of time and effort to analyse and understand the systems and processes that form an essential part of the operation of an enterprise" (Chandra et al., 2005).

Accordingly, some of the arguments for reuse are:

- Reusing an existing design in a new application as an obvious way of reducing effort and risk (Chandra et al., 2005).
- If in building new models, existent solutions can be reused, the construction of this new system will be more likely to be in time (Dusink and van Katwijk, 1995).
- If a single existent solution is used more often, it is likely that the quality of the solution will improve.
- Each new simulation case study performed today probably repeats at least some work previously done by others … hence, the development of standard templates for different types of case studies would be a step in the right direction to minimise the duplication of work (Mclean and Shao, 2003).
- Individual case studies should be able to be used as modular building blocks and templates to solve more complex manufacturing problems (Mclean and Shao, 2003).
- Reusability provides not only software productivity and quality, but also provides flexibility to meet changing simulation requirements (Aronson and Bose, 1999). The demand for such

flexibility can be met by developing simulation applications by composing reusable pieces accessed from a reuse repository.

- Simulation systems are excellent candidates for component reuse since model development, validation and verification costs are high. Composition offers opportunities for large savings in simulation development (Aronson and Bose, 1999).

In summary, it can be argued that reuse takes advantage of existing structured knowledge and applies it to new problems, making problem solving process faster, more productive, more flexible and theoretically of better quality.

4.2 Component-based reuse in simulation

Although the reuse concept has been applied to software engineering for almost thirty years, its application to simulation is somewhat more recent. Ball & Love (1995) describe object oriented techniques for manufacturing simulation in which objects or 'components' are reused. Pidd (2002) describes a "very non-linear" spectrum for software reuse. It presents four types of software reuse: Code scavenging, Function reuse, Component reuse and Full model reuse. It additionally presents two different horizontal axes: Frequency and Complexity. It is argued that reuse is more likely to occur in code scavenging than on full models, while complexity runs in the opposite direction, making reuse of full models a far more complex task than that of code or function reuse, see Figure 2.

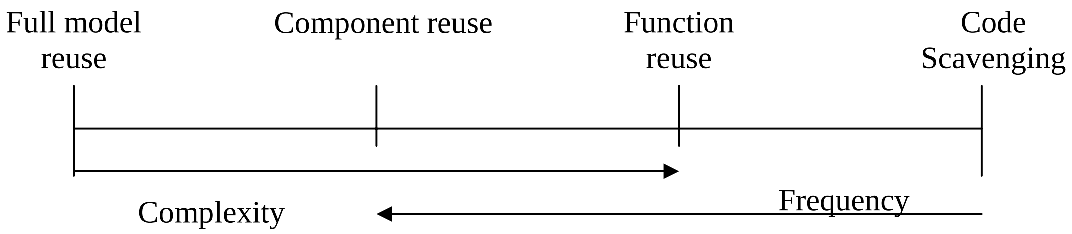


Figure 2. Reuse spectrum (Source: Pidd, 2002)

Using Pidd's classification, we can argue that the area for exploring reuse that has not been completely exploited and that has potential to inform knowledge and contribute to practice is that of component reuse. Code scavenging and function reuse have been extensively used in the past, while full model reuse is rare and it is very difficult to find two contextual settings in which a whole model could be reused. It is then in the area of components that the potential for reuse can be realised. Using components as modules, a simulation model can then be assembled as if it was a jigsaw. A number of conditions must be present for this assembly to take place: a defined set of rules, an interface specification, documentation, and processes for reuse.

Different analyses of potential applications of the use of components in simulation have been presented for general simulations (Pidd, 2002; Onggo et al., 2006; Pidd et al., 1999) and for military applications (Kasputis and Ng, 2000; Davis et al., 2000). Some applications have been developed using XML-specified components (Röhl and Uhrmacher, 2006). However, as can be seen, the number of reported applications is not extensive, an indication of the developing nature of the field.

It is then in the light of generating a better understanding of how component re-use can be applied to computer simulation that a number of e-business simulation components are developed and their application studied. The next section will describe the developing process for these components.

4.3 Generic e-Business Components

The use of generic static frameworks for mapping the differences between traditional and e-enabled business processes does not capture the full extent of the differences, since these differences are usually perceived in the behaviour, rather than in the structure of the processes. It has also been argued that dynamic analysis, such as simulation, is necessary if such changes in behaviour are to be fully understood. However, one of the problems with such dynamic modelling is that is usually more time consuming than static analysis tools.

This brings us to the question of how to improve the effectiveness of simulation modelling of e-business and its effect on business processes. As explained earlier, one approach is that of using pre-built simulation elements (or components) that encompass a number of entities that represent e-business activities. These components provide a unique set of functionalities that can be used as building blocks in creating multiple simulation models, thereby allowing new models to be assembled, rather than being built from scratch. The questions that arise are: *Are there any benefits in using traditional generic process maps as a starting point for building more dynamic models? Can patterns be identified that characterise the e-business processes of manufacturing companies?*

The initial thought behind these questions was to build complete processes (e.g. Generate order) that then could be "called" from a simulation library and that could "generate" the whole simulation model or at least the corresponding part, e.g. Generate Order with all its activities and sub-activities (22 in total in Childe et al.'s (1994) model). This approach was in line with the Full Model reuse type proposed by Pidd (2002). However, as explained before, generic process maps have difficulty in capturing the differences between traditional and e-enabled processes. Additionally, it was demonstrated that actual business processes do not conform rigidly to the structure and hierarchies imposed by these generic process maps. Hence, the approach of having such wide process components would bring little aid in building models faster, since the amount of customisation (time and skill) required could exceed that required to build a model from scratch.

4.4 Component development

It has been established that building all-encompassing e-business process models to aid building simulation models is unsuitable. An alternative for the full model reuse approach is that of component reuse. The approach followed to address this was to identify groups of activities that are generic enough to be used in a wide range of applications but at a sufficiently low level to avoid imposing pre-determined hierarchies on processes. The idea is similar to concept of modularity. Such components can be then be "plugged" into simulation models as required (e.g. instead of having the Generate Order process with all its sub-activities, one would be able to choose from "Order arrives by telephone" or "Order arrives via the Internet" or a combination of both, see Figure 3). The development of these components was based on the observations from the authors' case studies and generic process maps. An example of a component that resulted from this process is shown in Figure 3.

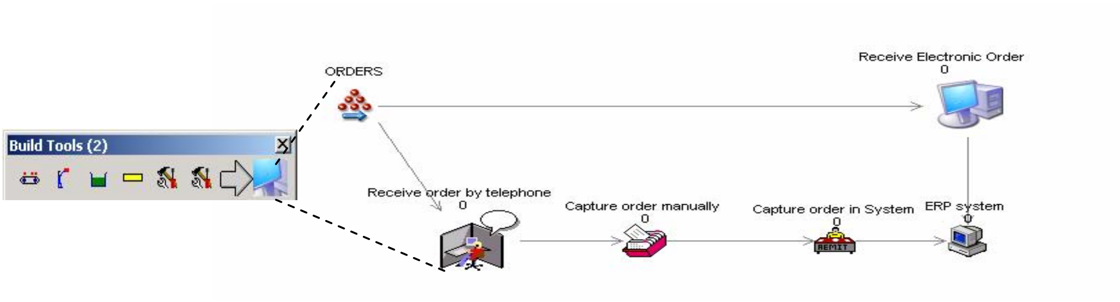
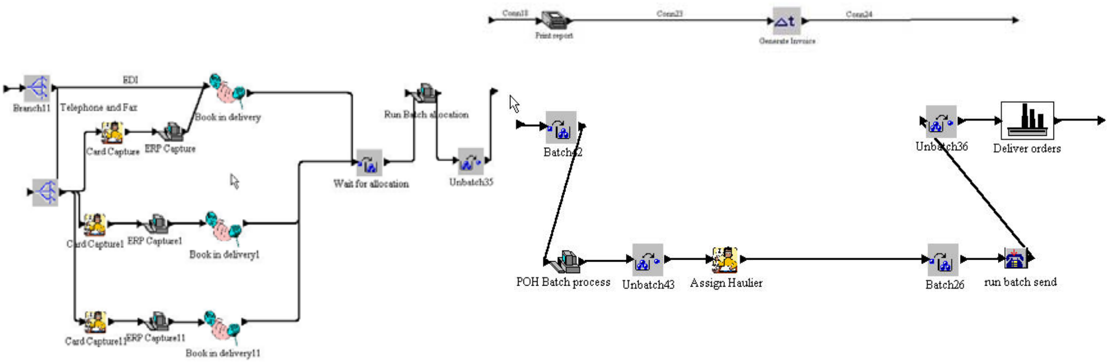
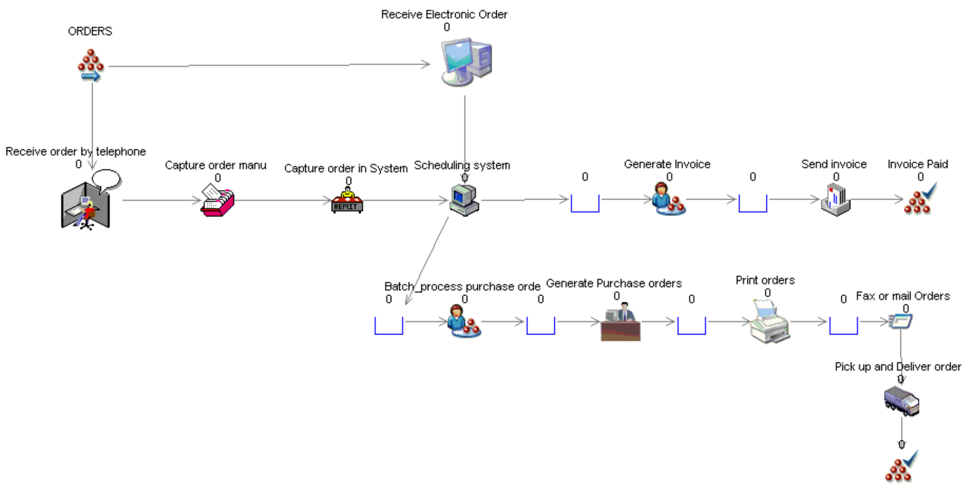


Figure 3. Combined order taking (manual and electronic) reusable simulation component

In order to validate the components, a pattern-matching logic approach was followed, in which "such logic compares an empirically based pattern with a predicted one (or several alternative predictions)" (Trochim, 1989). In order to test the usability of these components, a number of tests are conducted. First, the building of simulation models from current case studies. Figure 4 shows a comparison between (a) a model built from scratch and (b) a model built with the components (the model is presented without further customisation). As can be seen, the models are similar, although some modifications are needed in order to reflect the actual process (for example, increasing the number of operators receiving order from one to three).



a) created from scratch



b) created with components (without further customisation)

Figure 4. Comparison of simulation models

As mentioned before, the components are "progressively tested". That is, they are built from initial case studies and tested in later cases, each case validating the pertinent components and serving as source for the development of new components, which in turn are validated in the next case.

For each of the case studies, the typical pattern followed can be described as follows (lead times indicated in brackets):

- Access negotiation. Liaison with managers and process owners (2-3 weeks).
- Initial interviews with process owners (2 weeks).
- Pre-application questionnaire to document and refine objectives.
- Interviews with process owners and process workers. Process definition and mapping. Document times, resource requirements, work-in-progress and decision points. This stage also involved spending some days following the process and timing the activities as a way of validating the information gained from the process owners and operators (overall 3 weeks).
- Formal mapping of processes in process software (usually MS Visio).
- Process validation. With process owners and workers (1 week).
- Development of AS-IS simulation model.
- Simulation model validation. With process owners and workers for (1 week).
- Development of TO-BE (e-business) simulation model (1 week).
- Experimentation and option comparison. This step included deriving the timing for the new processes in conjunction with the process owners (1 week).
- Meeting with managers, process owners and process workers to present results.
- Report writing and final documentation (1 week).

4.5 Components developed

The component development followed the path explained in Table 2. Each component was derived from a case study (either primary or secondary) and tested in the next case. Primary case studies are indicated by the name 'NameCo' where the 'Name' indicates the type of industry the case belongs to. Secondary cases are indicated by the author reference.

Component	Derived from	Case(s) tested on
Combined order taking (Figure 3)	WaterCo	LabelCo, BottlingCo.
e-Purchasing	WaterCo.	PharmaCo, BottlingCo.
Order processing	LabelCo.	Tatsiopoulos et al, Shen et al.
High level manufacturing	IEE	LabelCo, WindowCo,
Invoicing/ e-invoicing	WaterCo.	LabelCo, MotorCo.
Receiving	VirtualCo.	BottlingCo
Enquiry Management	LabelCo.	BottlingCo
Configure order	Pharma	Tastsiopoulos
Quote handling	LabelCo	BottlingCo, Cheng et al.
Shipping	Pharma	VirtualCo
Supplier selection	Tatsiopoulos	Shen et al.
e-Replenishment	MotorCo.	

Table 2. Component development and testing

The components that have been developed in this research are an extension of the simulator concept. In the early stages of simulation development, the way of carrying out simulation was to write programming code in either a programming language or a simulation language. This has evolved to the current Visual Interactive Simulators, which allow the use of predefined elements to be dragged onto the screen to build a simulation model. The components are built on the concept of simulator and the assumptions that people have about these systems (e.g. visual, drag and drop, menu-driven model building). By extending the scope of the elements available to the user, the components are an easy next step in the functionality that simulators provide, without requiring a big change of paradigm in the simulation user's frame of mind.

5. Case study of component application

The previous section has described in detail the rationale, approach and outcomes of the development of simulation components for modelling of e-business processes within an enterprise. This section will focus on the application of a sub-set of these components to a supply chain case and the results that were generated.

5.1 MotorCo case study

The case study is of an automotive company (MotorCo) and relates to schedule sharing with a supplier. It draws on different components for the analysis of sending orders from the company to one of its suppliers. The process was identified, objectives set, process mapped, simulation model developed based on selecting and modifying components from the e-business library and the results of the model run analysed.

The outcome of the application of components to the analysis of this case was twofold. First, it illustrated the extendibility of the component concept beyond the boundaries of a single enterprise and into the realms of supply chain. Second, it illustrated the use of components in which a more complex logic is involved. Figure 5 presents the component developed Simul8.

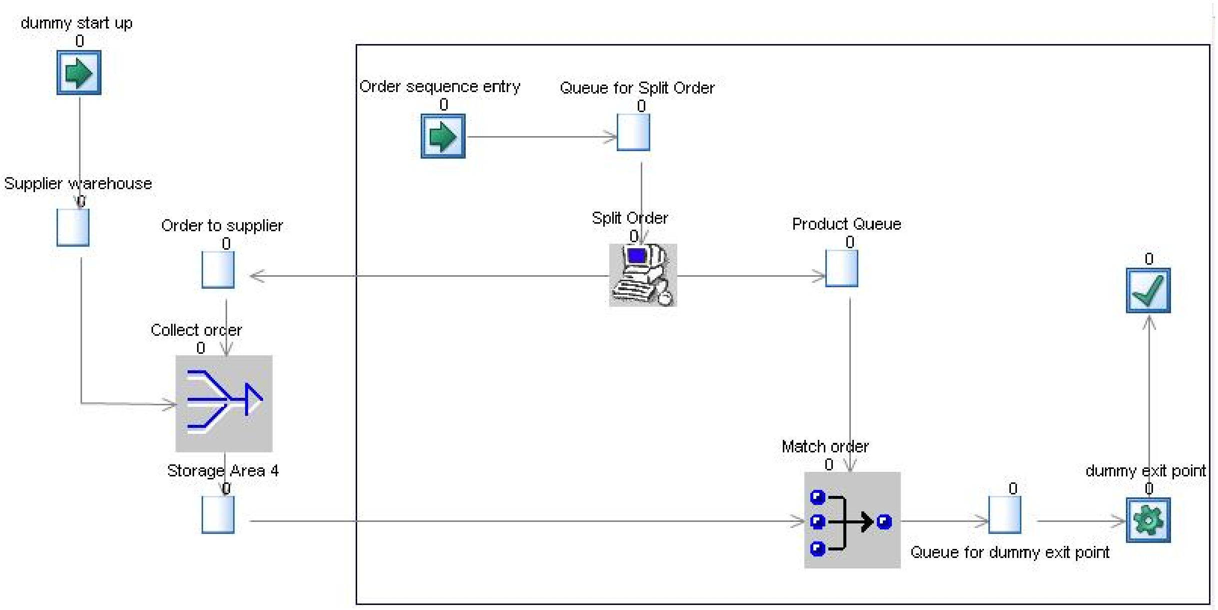


Figure 5. Schedule sharing component

The logic used in this component is one of the most complex of the components created. The OEM (MotorCo) activities are represented inside the rectangle shown in Figure 5. Orders are dispatched to the shop floor using the order sequence entry. Products with different characteristics can be manufactured in this component. For example, cars with different seat colour. Dialogues are used to ask the user how many different products and the proportion of those products. Based on this information, a distribution is created which drives the order sequence entry. Products move through the system until they reach the Split Order point. Here the product continues through the system, but an order is generated and sent to the supplier. This order inherits the characteristics of the original product and looks for a match in the supplier's warehouse. For example, if a car requires brown leather seats, this order to the supplier is for brown leather seats. Once the supplier matches the order, the material is sent to the OEM, where is matched with the specific car that required it. This component can be split to include intermediate activities (e.g. the actual manufacturing of the supplies in case of a Make-to-Order process).

This component can be used to explore the implementation of collaborative planning and forecasting and compare the performance of such system with the traditional ordering methods (for example, sending one order at the end of each day, or using one-month forecasts). Table 3 presents a comparison of two such scenarios averaged over 10 simulation runs.

Simulation Object	**Performance Measure**	**Average (Daily ordering)**	**Average (Electronic ordering)**
Parts assembled	Number Completed	1064.2	1201
	Average Time in System	816.0	614.5
Match order	Working %	88.7	99.9
	Waiting %	11.3	0.1
Product Queue	Average Queuing Time	814.6	613.0
Order to supplier	Average Queuing Time	270	0
Supplier warehouse	Average Queuing Time	910.9	640.9

Table 3. Comparison for MotorCo case (times in minutes)

5.2 Review of case study

The initial use of these components has shown that they can reduce the model building time and help guide the simulation build regarding relationships between activities and routing of products and information. However, the tasks of data collection and model population remain time-consuming activities. Nonetheless, the overall building time is reduced, thereby reducing the cost of modelling and allowing the non-specialist to build simulation models that otherwise would be restricted to those with simulation experience. This will have implications for e-business decision-making, as it will allow the e-business user or analyst to create models without having to have a specialist at hand. Having the opportunity to "plug" different components to the model, different scenarios can be readily created and modified.

One of the main contributions of the components is to guide the creation of e-processes, especially when it is not clear what the business process will look like or how it will behave dynamically. Using the practices from previous e-business applications (e.g. internet sales process in a make to order environment) can help to visualise alternative processes.

From early use of these components, it can be predicted that the use of such components will help the use of simulation as an evaluating tool for e-business process analysis and design. Insights into the limitations of the usability of such components were also gained. It is thought that the biggest value of such components is to be gained when building large models. This, however, does not preclude their use in small processes, characteristic of SMEs, where it is unlikely to have a simulation expert. One concern is that the use of such components could become prescriptive or encourage laziness from the modeler when customizing, accepting what the component proposes and not what the actual process is. Additionally, the components must be well documented and clearly explained for ease of use.

Overall, the use of case studies allowed the testing of the applicability of the components in scenarios which are different to the cases the components were created from. The resulting models were able to discern between the traditional and the e-business enabled option. From a simulation point of view, this exercises helped prove the generalisability of the simulation component approach and gave some indication about the usability and utility (See Platts, 1993) of the components, providing insights into how the components are used and the value of having these components to model the implementation of e-business and the changes it brings to the business processes in the organisation. The cases also illustrated that the components are a good guide for e-business processes, however, they must be customised to suit the particular application.

Future work will be carried out to develop supply chain components based on best practices (e.g. Vendor Managed Inventory, VMI). Supply chain models are generally large and complex and it is our belief that having “plug-and-play” components will allow a better analysis of the implications of implementing these strategies.

7. Concluding remarks

The increasing dynamic nature of companies adopting e-business has made it more difficult to analyse the effect of decisions across the wider business. Modelling the business processes is a step towards a better analysis of such decisions. This paper has argued that existing generic process models do not cover the full range of options that e-business brings to manufacturing companies, the approach proposed by the MIT (MIT, 2007) being the closest to this goal.

Moreover, it was argued that process models alone cannot fully analyse the effect that e-business has on the business processes and that a dynamic analysis tools such a simulation is needed. The development of simulation process components as a way to reduce the modelling time was introduced and it is proposed that, by using these components for the detailed model building, more time can be devoted to the data collection, experimentation and analysis phases. The use of such components acts as a way of addressing deficiencies in the existing process models. However, in order to be useful, these components have to be well documented and care must be taken to avoid using the components as de-facto processes and ensure that they are customised to the individual processes of the case under analysis.

Previous work (Albores et al., 2005) had demonstrated the use of e-business process elements in a single enterprise. This paper extends this work to a supply chain application and demonstrates applicability of these simulation components across more than one enterprise. The contribution of the paper lies in the development of components and the demonstration of their practical application in the analysis of e-business processes.

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